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Stratigraphic Palynology of the Lake Menindee region, Northwest Murray Basin, New South Wales

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ABSTRACT. A number of shallow bores in the marginal marine region of the northwest part of the Murray Basin have yielded pollen and dinoflagellates in the lower dark grey-black clays. The upper red-brown-yellow sediments, showing signs of weathering, are barren.

The bores of this area correlate best with the late Oligocene - early Miocene sequence in the Oakvale bore (Truswell *et al.*, 1985) which is also in the northwest part of the basin. The assemblages may be placed in the upper part of the *P. tuberculatus* Zone (Stover and Partridge, 1973) and conclusive evidence for the latest early to mid Miocene *T. bellus* Zone has not been found.

Dinoflagellates found in many of the bores are reported here.

The spore-pollen palynology of this northwest part shows some differences when compared with the eastern margin of the basin. These differences are consistent with the hypothesis of a climatic gradient parallel to that of today, i.e. drier in the northwest, controlling geographic variation in the vegetation of the time.

INTRODUCTION

The bores reported here were sunk by Mines Administration Pty Ltd. Samples and bore data were subsequently acquired by the Department of Water Resources (formerly the Water Resources Commission of New South Wales). These bores are situated close to the margin of the Murray Basin, in the northwest sector. The area was subject to marine influence in the mid Tertiary (Fig. 1).

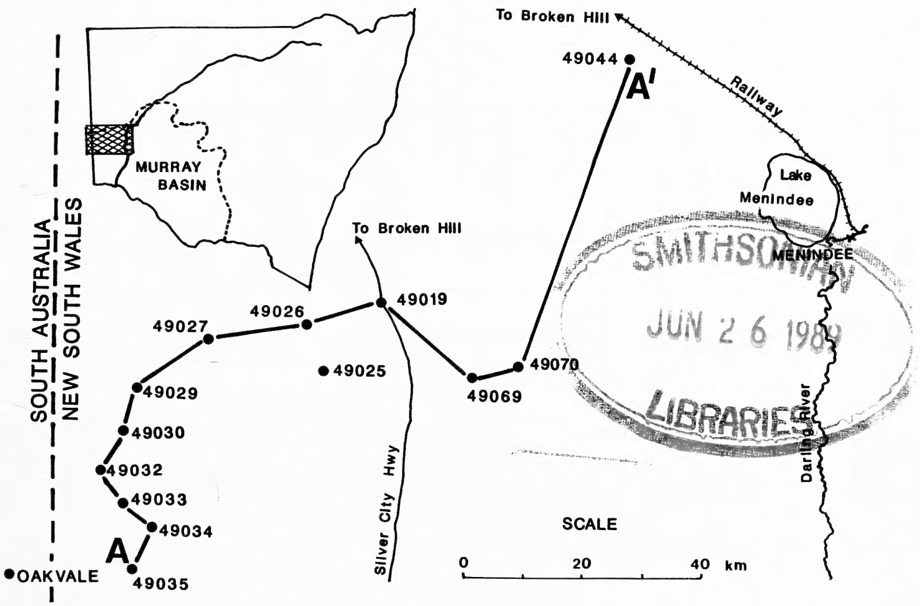

Fig. 1 Locality map

GEOLOGY

The stratigraphic units described by Lawrence (1975) for Victoria are applied to the units encountered here and are as follows:

1. The Olney Formation consists of dark grey carbonaceous clays, lignite layers and sand lenses. In the eastern part of the Murray Basin, the basal part of the Olney Formation is late Eocene and it extends into the Miocene. Here, only the upper portion is present.

2. The Geera Clay is predominantly olive grey to dark grey clay or silt. The darker clays resemble the carbonaceous clays of the Olney Formation, but the colour is due to iron minerals and very little carbon is present. Glauconite and pyrite are the dominant iron minerals. The Geera Clay was deposited in marginal marine environments (Lawrence, 1975) and is probably early to mid Miocene in age.

3. The Calival Sand, overlying the Olney Formation, consists of coarse sand and fine gravel with minor bands of carbonaceous clays. It is thought to be late Miocene to Pliocene in age.

4. The Shepparton Formation, the uppermost unit, is characterised by polymict sand and variegated clays, with yellow and brown the dominant colours.

The lithologic logs of all bores show a distinct dark grey clay unit, sometimes with small lignite layers (Fig. 2). Pyrite is common throughout and shell fragments are recorded from some of them. The relationship of the Olney Formation and Geera Clay is uncertain and in this area, close to the limits of the marine transgression, it may be complex. Over most of its extent, the Olney Formation is non marine but here a number of the assemblages from the dark grey clays contain dinoflagellates. For these reasons, there is little purpose in the identification of these two units in the bores.

Only the basal dark grey clays have yielded palynomorphs. The upper part of each bore is brownish, reddish, yellowish and grey, with signs of

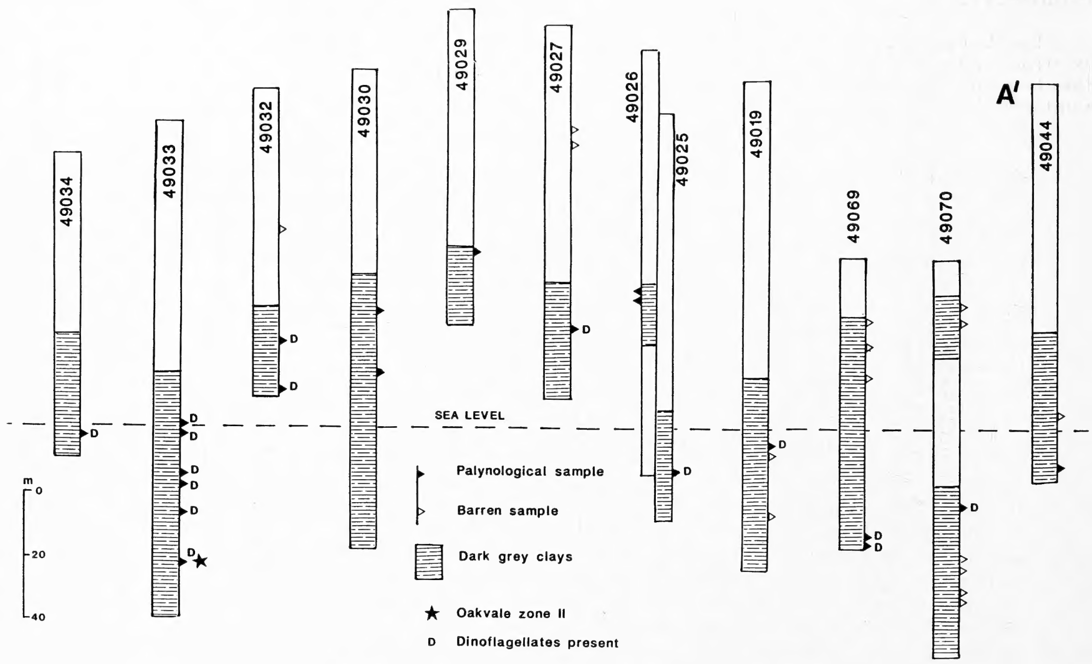

Fig. 2 Cross section A-A. Oakvale zone II is marked and all other assemblages may be placed in Oakvale zone I. (See text for further explanation. All of the assemblages containing dinoflagellates are shown and the best ones are presented in Table 2.

weathering. These sediments have not yielded pollen.

PALYNOLOGY

Table 1 presents the identifications of spores and pollen from some of the bores. The assemblages are all generally similar over the area and sections considered here.

Diagnostic species of the latest early to mid Miocene *T. bellus* Zone (Stover and Partridge, 1973) have not been found in these assemblages, except for *Tubulifloridites antipodica* and *Polypodiaceoisporites tumulatus*. Although the former species may not appear until the mid Miocene in the Gippsland Basin (Stover and Partridge, 1973), there are some Oligocene records (Muller, 1981). Moreover, it belongs to the family Compositae and species of this family are common in the vegetation of this region so that modern contamination is a possibility. Fresh modern contaminants are readily distinguished in palynological preparations but it is questionable whether old pollen, which had been in the soil for some considerable time, could be distinguished from fossils. Truswell *et al.* (1985) do not record *T. antipodica* from the Oakvale corehole, and as most of the samples here are cuttings, this adds further doubt about the source of *T. antipodica*. There is only one record of *P. tumulus*.

Collectively, this dubious and meagre evidence is considered insufficient to indicate the *T. bellus* Zone. (Problems of identification of this zone are discussed further, below). For these reasons, these assemblages are placed in the upper part of the *P. tuberculatus* Zone of late Oligocene to early Miocene age.

Fig. 3 presents the quantitative aspects of the assemblages in bore 49033, the bore with the best sequence. There are many features in common with the Oakvale bore (Truswell *et al.*, 1985). The high content of the *brassii* type of *Nothofagus* in the basal 136m level of bore 49033 is similar to Oakvale Zone II of late Oligocene age. The sequence from 120m to 92m, with a high Myrtaceae content and relatively little *Nothofagus* is similar to Oakvale Zone II of late Oligocene - early Miocene age. A relatively high content of *Araucariacites* (120m to 108m) is similar to Oakvale Zone II also. A higher content of Cyperaceae (108m to 92m, bore 49033) is seen towards the top of Oakvale bore, but in the latter, this occurs within the *T. bellus* Zone.

The basal level of bore 49033 is the only assemblage with a high *Nothofagus* content and thus equivalent to Oakvale Zone II. All of the other assemblages recovered from the bores of this area have the higher Myrtaceae content hence are equivalent to Oakvale Zone I or the upper portion of the *P. tuberculatus* Zone.

Truswell *et al.* (1985) have tentatively identifed the *T. bellus* Zone in the Oakvale bore. In the basal part of this zone, recognition of the zone relies on the diagnostic species, *Triporopollenites bellus* Partridge in Stover and

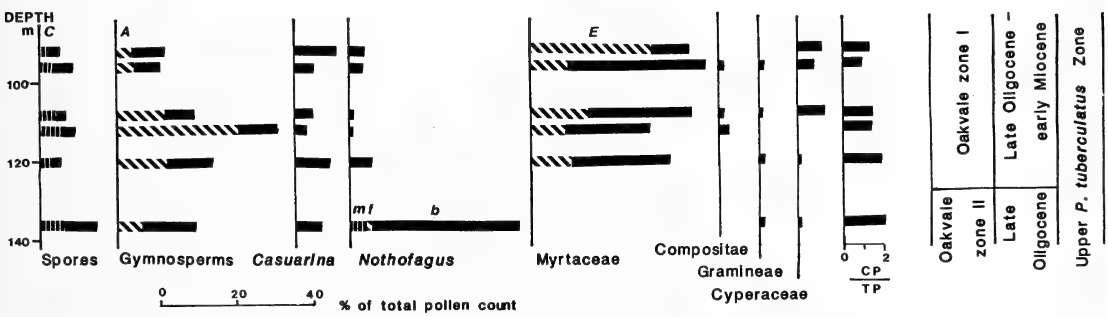

Fig. 3 The spore-pollen assemblages of bore 49033. CP/TP is the ratio of carbonised particles to total spore-pollen counts. The cross-hatched parts of species bars are:

A, *Araucariacites australis*.. C, *Cyathea paleospara*. E, the eucalypt pollen type. mf, the *menziesii-fusca* pollen types. b, the *brassii* pollen type.

Partridge (1973). A second diagnostic species, *Symplocoipollenites austellus* Partridge in Stover and Partridge (1973), is found higher in the sequence. These diagnostic species have not been found in the bores of this study.

The ratio of carbonised particles to spore/pollen count is shown in Fig. 3 also. These low ratios are consistent with late Oligocene to early Miocene strata in a bore in the northeastern part of the Murray Basin (Martin, 1987).

PHYTOPLANKTON

The dinoflagellates and algae identified are listed in Table 2. Where there are sufficient numbers to count more than 120 specimens, percentages are presented. With low numbers of dinoflagellates, the most common species may be shown on Table 2. A trace occurrence of dinoflagellates in other bores is shown on Fig. 2.

Spiniferites ramosus is the most common and abundant dinoflagellate. *Dapsilidinium pseudocolligerum, Glaphyrocysta* sp., *Hystrichokolpoma* spp. and *Operculodinium centrocarpum* are sometimes abundant. These dinoflagellate assemblages are generally consistent with those reported for Oakvale by Truswell *et al.* (1985).

Pediastrum and "*Zygnema* - type" are fresh water algae and their presence is inconsistant with dinoflagellates which are found in brackish to marine water. Non-marine algae are present in Oakvale also and Truswell *et al.* (1985) attribute their presence to drainage from lakes and swamps in the hinterland.

DISCUSSION

The spore pollen palynology of these bores correlate best with the late Oligocene to early Miocene sequence in the Oakvale bore (Truswell *et al.*, 1985) which is situated in the northwest part of the basin also. Conclusive evidence of the latest early to mid Miocene *T. bellus* Zone has not been found, but this zone has been tentatively identified in Oakvale.

The *T. bellus* Zone in the Murray Basin is somewhat problematic. Identification relies on a few diagnostic species which are not common. Quantitatively, the assemblages are very similar to the underlying upper part of the *P. tuberculatus* Zone. However, when the *T. bellus* Zone of the Murray Basin is compared with that of the Gippsland Basin, there are considerable quantitative differences. It the latter, *Nothofagus* is abundant and Myrtaceae relatively uncommon (Luly *et al.*, 1980). Consequently, data which may be used for correlations between the two basins is limited. As the *T. bellus* Zone was deposited in the latest early to mid Miocene (Partridge, 1975), at a time of high sea level, (Loutit and Kennett, 1981), its presence may be expected. That so few assemblages of the *T. bellus* Zone have been found in the Murray Basin (Martin, 1984a; 1984b) may result from subsequent erosion during the late Miocene low sea level. As well, some assemblages may have been destroyed by deep weathering of the sediments. These factors are additional to the problems of identification.

Comparison of equivalent late Oligocene to early Miocene strata in the northwest and on the eastern margin shows lower *Nothofagus*, higher Myrtaceae and higher *Araucariacites* in the northwest (Martin, 1986). These differences are consistent with a climatic gradient, drier in the northwest. In the late Oligocene, when *Nothofagus* was abundant, it is estimated that precipitation was about or above 1800mm, and in the early Miocene, when Myrtaceae became abundant, the precipitation decreased to about 1500mm, in the northeast part of the basin (Martin, 1987). However the low ratios of carbonised particles when compared with the ratios of the late Miocene to Pliocene (Martin, 1987) indicate that there was no well-marked dry season and burning had not become an integral part of the environment in the early Miocene of the northwest Murray Basin.

ACKNOWLEDGEMENTS

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REFERENCES

Bujak, J.P., Downie, C., Eaton, G.L. and Williams, G.L., 1980. Taxonomy of some Eocene dinoflagellate cysts from southern England. *In* Bujak, J.P., Downie, C., Eaton, G.L. and Williams, G.L., eds. *Dinoflagellate cysts and acritarchs from the Eocene of southern England.* Palaeontological Association, Special Papers in Palaeontology, 24, 26-36.

Cookson, I.C., 1953. Records of the occurrence of *Botryococcus braunii*, *Pediastrum* and the Hystrichosphaerideae in Cainozoic deposits of Australia. *Memoirs of the National Museum, Melbourne* 18, 107-123.

Cookson, I.C. and Pike, K.M., 1954. The fossil occurrence of *Phyllocladus* and two other Podocarpaceous types in Australia. *Australian Journal of Botany* 1, 60-68.

Germeraad, P.H., Hopping. C.A. and Muller, J., 1968. Palynology of Tertiary sediments from tropical areas. *Review of Palaeobotany and Palynology* 6, 189-348.

Lawrence, C.R., 1975. Hydrodynamics and hydrochemistry of the southern Murray Basin. *Geological Survey of Victoria, Memoir* 30, 1-139.

Lentin, J.K. and Williams, G.L., 1977. Fossil dinoflagellates. Index to genera and species. *Bedford Institute of Oceanography, Report Series* B1-R-77.

Loutit, T.S. and Kennett, J.P. 1981. Australian Cenozoic sedimentary cycles, global sea level changes and the deep sea sedimentary record. *Oceanol. Acta S.P. Proceedings 26th International Geological Congress*, Geology of Continental Margins Symposium, Paris July 7-17, 1980, 45-63

Luly, J., Sluiter, I.R. and Kershaw, A.P., 1980. Pollen studies of Tertiary brown coals. Preliminary analysis of lithotypes within the Latrobe Valley, Victoria. *Monash Publications in Geography,* 23, 1-78.

Martin, H.A., 1973. The Palynology of some Tertiary Pleistocene deposits, Lachlan River Valley, New South Wales. *Australian Journal of Botany, Supplementary Series* 6, 1-57.

Martin, H.A., 1974. The identification of some Tertiary pollen belonging to the Family Euphorbiaceae. *Australian Journal of Botany.* 22, 271-291.

Martin, H.A., 1984a. The stratigraphic palynology of the Murray Basin in New South Wales. II The Murrumbidgee area. *Proceedings of the Royal Society of New South Wales* 117, 35-44.

Martin, H.A. 1984b. The stratigraphic palynology of the Murray Basin in New South Wales. III The Lachlan area. *Proceedings of the Royal Society of New South Wales* 117, 45-51.

Martin, H.A., 1986. Tertiary stratigraphy, vegetation and climate of the Murray Basin in New South Wales. *Proceedings of the Royal Society of New South Wales* 119, 43-53.

Martin H.A., 1987. Cainozoic history of the vegetation and climate of the Lachlan River Region, New South Wales. *Journal and Proceedings of the Linnean Society of New South Wales*, 109, 213-257.

Mildenhall, D.C. and Crosbie, Y.M., 1979. Some porate pollen from the upper Tertiary of New Zealand. *New Zealand Journal of Geology and Geophysics* 22, 499-508.

Muller, J., 1981. Fossil pollen records of extant angiosperms *Botanical Review* 47, 1-142.

Partridge, A.D., 1975. Late Neogene spore-pollen zonation. In *Symposium on Bass Strait Geology*. Victorian Branch, Geological Society of Australia, Meeting Nov. 20 1975 (Unpubl.)

Stover, L.E. and Evitt, W.R., 1978. Analysis of pre-Pleistocene organic walled dinoflagellates. *Stanford University Publications, Geological Sciences* 15, 1-300.

Stover, L.E. and Partridge, A.D. 1973. Tertiary and Late Cretaceous spores and pollen from the Gippsland Basin, southeastern Australia. *Proceedings of the Royal Society of Victoria* 85, 237-286.

Truswell, E.M., Sluiter, I.R. and Harris, W.K., 1985. Palynology of the Oligocene-Miocene sequence in the Oakvale-1 corehole, western Murray Basin, South Australia. *Bureau of Mineral Resources Journal of Geology and Geophysics* 9, 267-295.

Van Geel, B. and Van der Hammen, T, 1978. Zygnemataceae in the Quaternary Colombian sediments. *Review of Palaeobotany and Palynology*. 25, 377-392.

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TABLE 1

SPORES AND POLLEN IN SELECTED BORES

References: 1, Martin, 1973. 2, Stover and Partridge, 1973. 3, Cookson and Pike, 1954. 4, Germeraad *et al.*, 1968. 5, Mildenhall and Crosbie, 1979. 6, Martin, 1974. 7, Truswell *et al.*, 1985.

The species content is given in percentage of a total spore-pollen count of more than 120. +, species observed but not present in the sub-sample counted.

SPECIES	Bore, depth (m) 49033, 91-94	" 94-97	" 107-110	" 110-113	" 119-122	" 134-137	49026, 73-76	" 76-79	49069, 84	" 88
SPORES										
Baculatisporites disconformis 2					0.6			+		
Cingulatisporites bifurcatus 1					0.6				0.7	
Cyathea paleospora 1	3.2	3.8	5.0	6.5	3.2	8.3	2.2	0.7	3.6	1.8
Deltoidospora inconspicua 1		1.5		0.7		2.5	3.7	2.7		
Dictyophyllidites concavus 1		0.7	+			1.7			+	0.6
Gleichenia circinidites 1		1.5		0.7	+	+	+		+	+
Laevigatosporites ovatus 1	0.8	1.5	0.8		1.3	0.8	2.2	2.7		0.6
Matonisporites ornamentalis 2									0.7	0.6
Polypodiaceoisporites tumulatus 2								+		
Polypodiidites sp. 1										0.6
Rouseisporites sp. 1	1.6	+	1.7		+			+		
Rugulatisporites mallatus 2							+	+		+
cf *Todisporites* sp. 1				0.7						
TOTAL SPORES	5.6	9.0	7.5	8.6	5.8	15.0	8.1	6.1	5.1	4.7
GYMNOSPERM POLLEN										
Araucariacites australis 1	4.0	4.5	12.5	31.9	12.9	6.7	2.9	6.1	8.7	11.3
Cupressaceae 1	3.2	1.5	1.7	1.4	5.2	1.7	5.1	3.4	7.3	7.1
Dacrydium florinii 1	0.8		1.7	+	2.6	0.8	0.7	4.1	1.4	1.2
Microcachryidites antarcticus 1						+			0.7	
Phyllocladidites mawsonii 2						0.8		+		
P. palaeogenicus 3					0.6	+			+	
Podocarpus (Dacrycarpus) australiensis 1	0.8		1.7	2.2	0.6	2.5	+	0.7		
Podocarpus elliptica 1	4.0	5.3	2.5	5.8	2.6	7.5	+	4.8	5.1	3.0
TOTAL GYMNOSPERMS	12.9	11.2	20.0	41.3	24.5	20.0	8.8	19.0	23.3	22.5

ANGIOSPERM POLLEN										
Acacia myriosporites 1							+			
Banksieaeidites elongatus 1						+				
Chenopodipollis chenopodiaceoides 7								+		
Cupanieidites orthoteichus 1						+				
Cyperaceae 1 (*Cyperaceaepollis* spp. 7)	6.4		7.5		0.6	0.8	5.9	12.9		1.8
Dilwynites granulatus 2						1.7			1.4	7.1
Echiperiporites cf *E. estelae* 4								+		
Ericipites cf *E. scabratus* 1							+			+
Graminidites media 1		1.5	1.7		1.9	1.7			1.4	
Haloragacidites harrisii 2 (=*Casuarina* 1)	10.4	4.5	4.2	3.6	8.4	6.7	6.6	4.8	0.7	8.9
Liliacidites sp.					0.6	0.8				0.6
Malvacipollis subtilis 2	+		0.8		+		0.7	+	1.4	0.6
Milfordia homeopunctata 2					0.6					
M. hypolaenoides 1						0.8				
Myrtaceidites eucalyptoides 1	31.4	10.5	14.0	6.5	10.3		6.6	2.7	8.7	11.2
M. mesonesus 1					0.6					
M. parvus 1	0.8	8.3	5.0	2.9	9.0		5.9	4.8	10.9	4.7
Myrtaceae unidentified	8.1	25.5	22.5	22.5	15.5		10.3	9.5	13.1	8.9
TOTAL MYRTACEAE	40.3	44.4	41.7	31.9	35.5		22.8	17.0	32.8	24.8
Nothofagidites asperus 2						4.2		0.7		1.2
N. brachyspinulosus 2									0.7	
N. emarcidus 2	4.0	3.8	0.8	0.7	5.8	26.7	5.9	8.1	16.7	5.9
N. falcatus 2	+					5.0			1.4	
N. flemingii 2						0.8		+		
N. vansteenisii 2	+					6.7	0.7	2.0		
TOTAL *NOTHOFAGUS*	4.0	3.8	0.8	0.7	5.8	43.3	6.6	10.9	19.0	7.1
Periporopollenites demarcatus 2								+		
Polycolpites reticulatus 2								+		
Polyorificites oblatus 1 (=*Heliciporites astrus* 2)	0.8						1.5	0.7	+	
Proteacidites ivanhoensis 1					+	+	+		+	0.6
cf *P. pseudomoides* 2		0.7								
P. subscabratus 1				0.7		+	0.7	+		0.6
Proteacidites spp. unidentified				0.7	+	0.7		+		+
Quintina psilatispora 1			0.8		1.9			1.4	2.2	
Sparganiaceaepollenites barungenesis 1	1.6	2.2	0.8	0.7		0.8	1.5	0.7		
S. sphericus 5	4.8	6.0			1.3		12.5	4.1		
Stephanocolpites oblatus 1	0.8									
Tricoloporopollenites cooksonii 1								+		
T. endobalteus 6								0.7	+	
T. ivanhoensis 1		0.7		0.7		0.8	4.4	2.0		
T. substriatus 1	0.8		0.8				0.7	0.7		3.5
Tubulifloridites antipodica 1			0.8	2.2						
Unidentified tricolpate/tricolporates	11.3	10.5	10.0	7.4	10.3	5.0	17.6	17.0	9.5	17.8

TABLE 2

PHYTOPLANKTON IN SELECTED ASSEMBLAGES

References: 1, Bujak *et al.*, 1980. 2, Lentin and Williams, 1977. 3, Stover and Evitt, 1978. 4, Truswell *et al.*, 1985. 5, Cookson, 1953. 6, Van Geel and van der Hammen, 1978.

The species content is given in percentage of a total dinoflagellate count of 120 or more. Where 120 specimens could not be found, + indicates presence and C the most common species.

Bore, depth (m)	49033, 91-94	" 94-97	" 107-110	" 110-113	" 119-122	" 134-137	49027, 91-94	49019, 110-113	49069, 84	" 88	49070, 76
? *Adanatosphaeridium* sp. 2		+			+			0.8	0.7	3.5	0.7
Apteodinium australiense 2		+	+		+				0.7		
Dapsilidinium pseudocolligerum 1										12.9	0.7
Glaphyrocysta sp. 3								40.9	0.7	0.7	40.8
Hystrichokolpoma rigaudiae 2						+		9.8	0.7		
H. stellata 4			+			0.6	+	10.6	9.0	9.0	0.7
Hystrichosphaeropsis sp. 2									+	1.4	
Impagidinium sp. 3										0.7	
Lingulodinium machaerophorum 2				+	+			0.8	3.0	5.6	0.7
Operculodinium centrocarpum 2	+		+	+	+	62.7	+	1.6	0.7	16.6	
Pentadinium laticinctum									0.7		
P. taeniagerum 2			C								0.7
Polysphaeridium zoharyi 1			+	+					4.5	5.4	1.4
Spiniferites ramosus 2	+	+	+	+	C	32.7	+	27.9	63.1	27.0	47.9
S. ramosus ssp. *granomembranaceous*									6.7	0.7	
Spiniferites sp.								0.8			
Spiniferites group			+		+	0.6		4.9	9.0	7.0	2.8
Systematophora placacantha 2			+		+	2.6	C			0.7	
Unidentified						0.6		1.6		7.0	
Dinoflagellate/pollen ratio	0.01	0.02	0.04	0.01	0.02	0.15	0.04	0.35	0.08	0.20	0.36
Botryococcus colonies 5/pollen ratio						0.02		+	0.10	+	0.01
Pediastrum 5/pollen ratio		0.02	0.03		0.07	0.06	0.01	+			
"*Zygnema* - type" 6	+										

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Cainozoic Morphology of the Inner Continental Shelf near Sydney, N.S.W.

A.D. Albani, J.W. Tayton, P.C. Rickwood, A.D. Gordon, J.G. Hoffman

ABSTRACT

The bedrock morphology of the inner continental shelf near Sydney has been recognised from detailed shallow seismic and side scan sonar surveys. It has been possible to ascertain the nature and seaward extent of the pre-existing fluvial drainage patterns which have been concealed by the rise of sea level that resulted in the present day coastline. Most of major channels cannot be traced below -120 m but the Hawkesbury River channel persists to -200 m, indicating a pre-Pleistocene erosional phase. The morphology of unusual sand bodies is described and, in addition, an analysis of the economic potential of this area for building and beach nourishment sands has been made from the distribution of the unconsolidated sediment cover.

The results are presented as a series of maps showing the Pleistocene drainages and bedrock contours.

INTRODUCTION.

The inner continental shelf off Sydney has been investigated to a distance roughly 5-6 km from the shore (Fig.1), in order to determine the nature of its morphology, to map the sediment cover and to extend our previous estuarine studies - Albani & Johnson (1974), Johnson et al. (1977), Albani et al. (1978) and Albani et al. (1983).

Ringis (1972) and Davies (1975, 1979) reported on a broad investigation of the N.S.W. continental shelf but no detail of the bedrock morphology was presented. Other marine studies in the vicinity of Sydney [Law (1975), Ringis (1975), Caldwell Connell (1976), Andrews (1978a,b, 1979)] were of a very specialized and restricted nature so that little was added to the understanding of the overall morphology of the inner shelf.

Various investigations of the bedrock morphology of the estuaries (Phipps and Emerson, 1968; Albani et al. 1973; Albani and Johnson, 1974; Johnson and Albani, 1975; Johnson et al. 1977; Albani et al. 1978; Albani et al. 1983) have shown that most of the drowned river valleys have a typical dendritic fluvial pattern and reach to -110 m below sea level (b.s.l.) at the present day entrances. The present study commenced at such locations and sought to trace these drainage patterns onto the shelf. A small part of our data has already been incorporated into the paper by Roy (1983).

METHODOLOGY

The techniques used for the measurements reported here are conventional and brief descriptions suffice.

Seismic data was acquired using a capacitor discharge spark energy source, with a maximum stored energy of 400 joules. The multi-point source unit was towed 10 m behind the survey vessel, at a depth of approximately 0.5 m. Reflected energy was received by a single channel hydrophone array consisting of twelve individual hydrophones spaced over a distance of 6 m. The centre of the array was located 50 m from the vessel. After filtering the amplified signal was plotted on an analogue section plotter, together with navigational information.

Side scan records were obtained with a Klein 521 system utilizing a 100 kHz towfish for broad scale mapping and a 500 kHz towfish for high resolution bedform information. Typically, the broad scale mapping was carried out using a slope range of 150 m either side of the track. The survey lines were run at approximately 5 knots, approximately 200 m apart and, where possible, the tow height above bottom was maintained at between 10% and 15% of the scan width. The 500 kHz detailed bedform information was obtained using a scan width of 50 m with a spacing of 100 m and with a vessel speed of 0.5 knots. The side scan records featured a non-filtered signal dis-

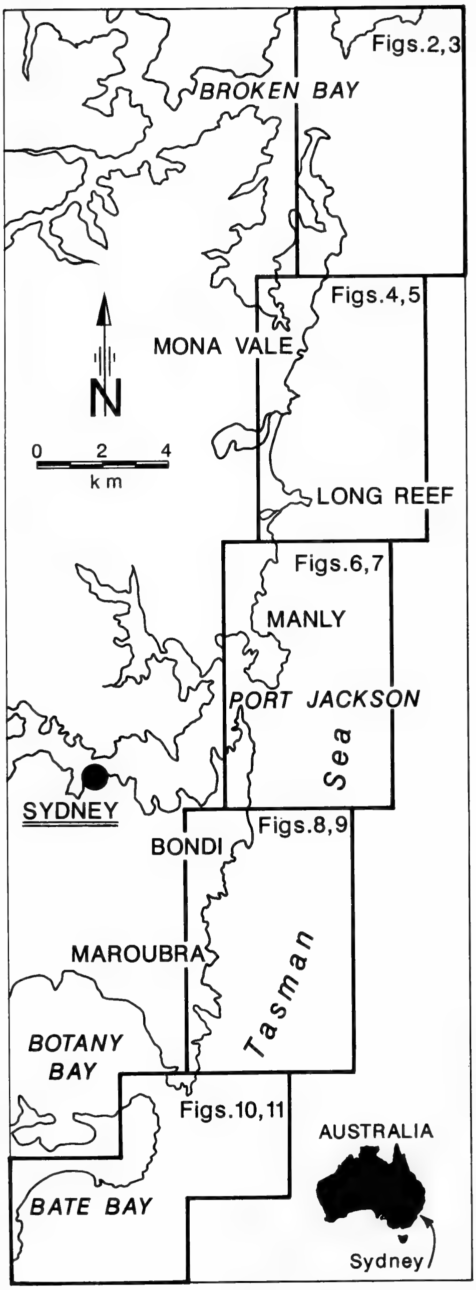

Fig. 1 - Locality map. The numbers in each inset refer to the figure numbers in this paper.

played on a wet paper process recorder. The image distortions resulting from vessel movement and slope range were removed numerically during the analysis phase. Towfish lay back corrections were calculated from winch and side scan data.

The side scan data was supplemented with precision depth information supplied by a dual frequency (30 kHz and 210 kHz) Atlas Deso 20 fathometer. Side scan and fathometer records were automatically fix marked at 30 second intervals by a central processor unit. Digital sounding records were written to tape every 10 seconds along with the positional data. Verification and ground truthing of side scan records was obtained using diver observations, video equipment RCV's, seabed cameras and some 650 seabed surface samples (Gordon and Hoffman, in press 1).

All the traverses were controlled by precise position fixing using a Motorola Mark III 16 channel Miniranger system. The locations of the shore-based repeater stations were surveyed by theodolite; the distances obtained from the on-board master console were transferred to the data processing unit. As the ship's position fixing antenna and the various data collection sensors differ in position, corrections to both the seismic and side scan surveys were made to obtain the exact location of the records. During the seismic survey, an Apple II+ computer was used to calculate position coordinates (A.M.G. grid based) and the ship's track was plotted using a Watanabe Digi-Plot (Model WX4671) (Figs. 2, 4, 6, 8 and 10).

Real time position data was utilized to correct the ship's track thus compensating for the wind wave and current induced drift.

For the side scan survey the Miniranger microwave unit was linked to a Motorola Data processor, plotter and magnetic tape storage unit. This system included a bridge mounted navigational package which enabled pre-programmed courses to be followed and was necessitated by the closeness of track spacing required for the side scan coverage. Navigational position and corrections were updated every 2 seconds. Track plots for the over 5,000 km of side scan runs are to be presented in Gordon and Hoffman (in press 2).

A proton precession magnetometer was also operated, with the sensor towed 60 m behind the vessel. Total magnetic field values, recorded with a precision of ±1nT, allowed the recognition of the many igneous features, mainly dykes, intruded into the bedrock. However, the results obtained have little relevance to the present discussion and, therefore, will be presented elsewhere.

BEDROCK TOPOGRAPHY

The results of our measurements are presented here in map form (Figs. 2 - 11) except where particular features warrant separate discussion. The surface topography and bedrock outcrop presented on the figures are mainly based on the side scan and fathometer interpretations and the sub-bottom bedrock topography was interpreted from the seismic data.

The bedrock morphology of the inner shelf off Sydney is dominated by four major drainage paths. In the north, the Hawkesbury River Valley is a broad asymmetric structure with a steep southern wall (Fig. 3). In contrast, the valleys of the Port Jackson, Botany and Cooks-Georges-Port Hacking Rivers are best described as narrow symmetric gorges (Figs. 7, 9, and 11).

The termination depths of these drainage systems are of considerable importance in evaluating the geological development of the area. Most buried river channels become unrecognizable at a depth of -110 to -120 m when the valley floor becomes broad and loses identity. However, the area north of Long Reef Point (Figs. 3 and 5) is linked with the river valley system of the Hawkesbury River, and is exceptional in that it is traceable to depths in excess of -200 m (Fig. 3). At a distance of 25 km from shore this major channel loses its fluvial character at a depth greater than -250 m.

The S1 acoustic reflector horizon, as defined by Davies (1979), has been found within the drainage system towards its terminal extremity. Thus the cutting of this river valley preceded the development of S1 which Davies (1979, p 10) suggested to be of early to middle Pliocene age.

If the sediments below are of the same age as those found in the Little Bay area (Partridge et al., 1978), i.e. lower Miocene, then the erosional phase resulting in the in this drainage system may possibly be related to the early Oligocene low sea level stand (Vail et al., 1977b; Loutit et al., 1981).

Investigations on the age of several interfaces, cropping out on the outer shelf, being presently conducted, will be able to clarify this point.

The area south of Long Reef (Figs. 7, 9 and 11) was drained in a southerly direction mainly by the "ancient" Parramatta River, Botany River and the combined Cooks-Georges-Port Hacking Rivers (Albani et al., 1976; Johnson & al., 1977). The most conspicuous feature of this part of the inner shelf is the southward extension of North Head (at the entrance to Port Jackson - Fig. 7) which forms a dissected plateau extending to a position east-north-east of Ben Buckler where the ancient Bondi River joins the Parramatta River (Fig. 9). The southern end of this plateau is marked by an outlying miniature plateau (A on Fig. 7 and 9) at depths shallower than -70 m and is similar to one on the northern extremity of Jibbon Head (B on Fig. 11) near Cronulla.

SEABED FEATURES

Overall features

The area mapped is predominantly comprised of the inner shelf which Davies (1979) regarded as extending to depths of -60 m. In some places we observed a pronounced steepening of slope at -70 m and would make that the lower boundary. Only a small part of the middle shelf occurs in this area but it is sufficient for us to regard it as being from -70 to -120 m whereas Davies had limits of -60 and -130 m. The -120 m boundary is chosen because most ancient river channels become obscure at this level and it seems to be of considerable morphological significance.

Davies (1979, p 13) noted that many terraces exist on the middle zone; but we found only one in the area mapped and that is east of Malabar between -80 and -90 m b.s.l. This is the second most frequently observed terrace as seen by Davies (1979, fig. 17) in his regional study.

The innermost part of most of the shelf is a seabed formed from bare bedrock. However, north of Little Head, bedrock outcrop is rare (Fig. 2) except close inshore off Barranjoey and off Bouddi National Park where a major reef exists. To the north of Sydney Harbour (Port Jackson) (Figs. 2, 4 and 6) the shelf is generally rocky up to 5 km offshore tapering northwards to 3 km offshore of Little Head (Fig. 2); this rocky area is incised with partially infilled river valleys.

South of Sydney Harbour this zone is narrow, generally extending less than 1 km offshore (Fig. 6, 8 and 10). Between South Head and Malabar the bedrock again crops out a further 2 km seaward (Fig. 6 and 8) but the intervening zone and shelf to the south of Malabar features sediment bodies of varying thickness (Fig. 10).

Below a water depth of 60 to 80 m the bedrock throughout the study area becomes generally covered by unconsolidated sediment of varying thickness.

Sand bodies

A number of convex upward sand bodies (Field and Roy, 1984; Gordon and Hoffman,1985 and unpublished reports by Hudson, 1985 and Roy 1985), cross shelf sand ridges and mid shelf sand bodies with rythmic asymmetric morphology have been identified in the area south of Sydney Harbour at depths of -30 to -70 m. These rest on a gently sloping bedrock surface (1°) and at a distance of 1 to 3 km offshore; it is significant that these sand bodies occur in areas lacking pronounced offshore drainage and/or south of rocky ridges that reduce longshore drift (Albani and Johnson, 1974; Field and Roy, 1985).

Three main types can be recognized which we

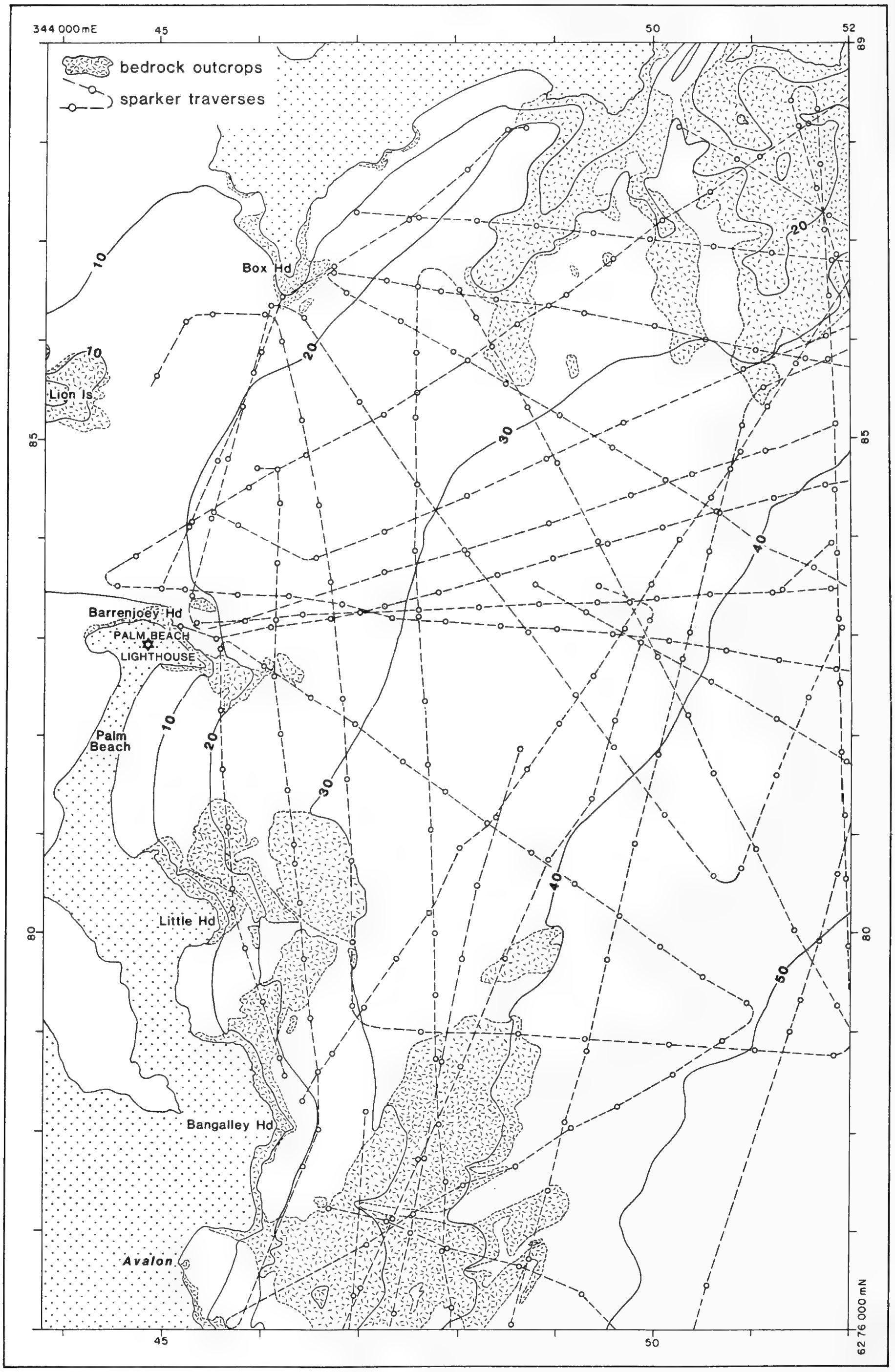

Fig. 2 - Bathymetry (in metres b.s.l.); sparker traverses and bedrock outcrops from Box Head to Avalon.

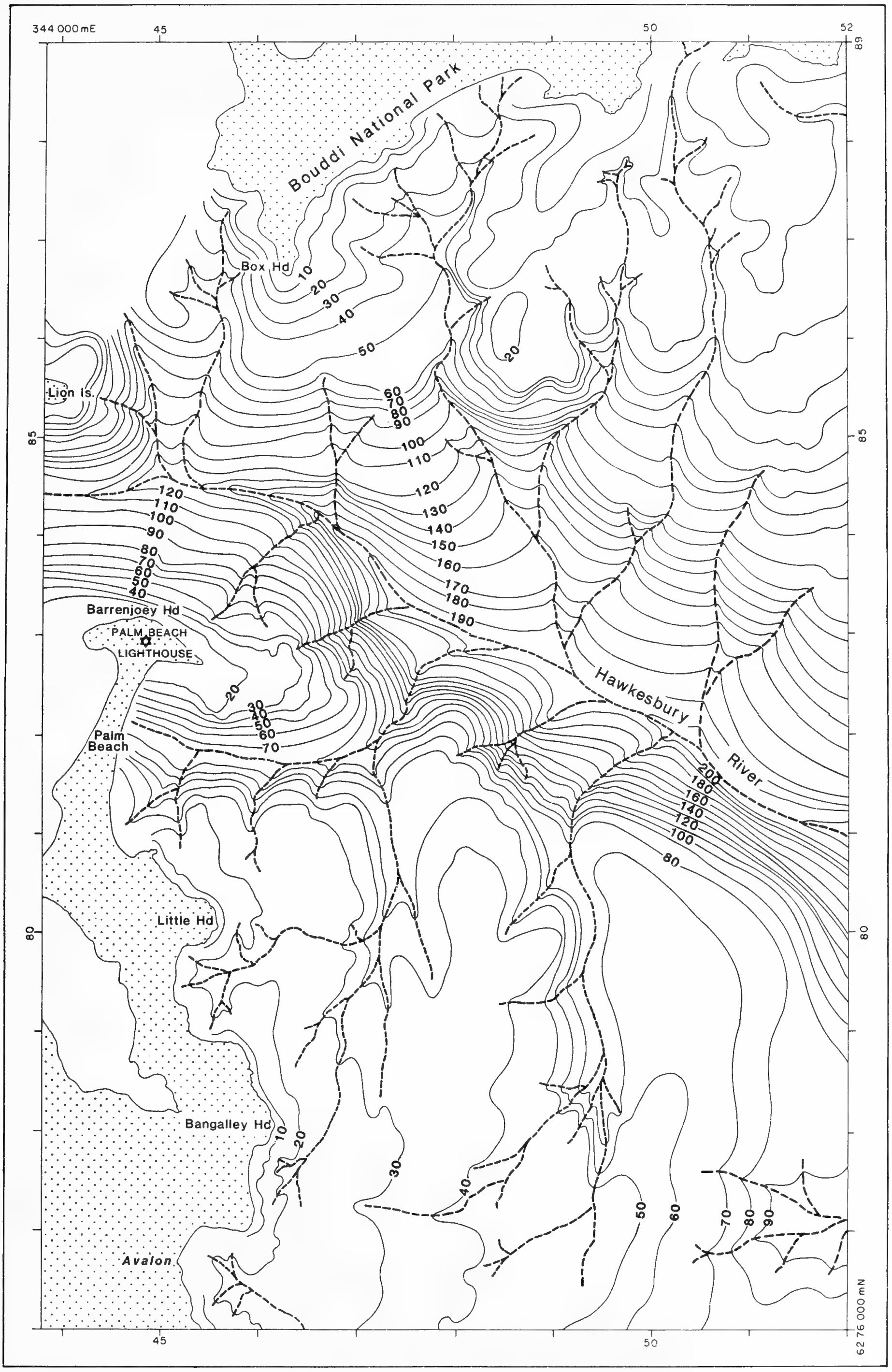

Fig. 3 - Bedrock contours (in metres b.s.l.) from Box Head to Avalon.

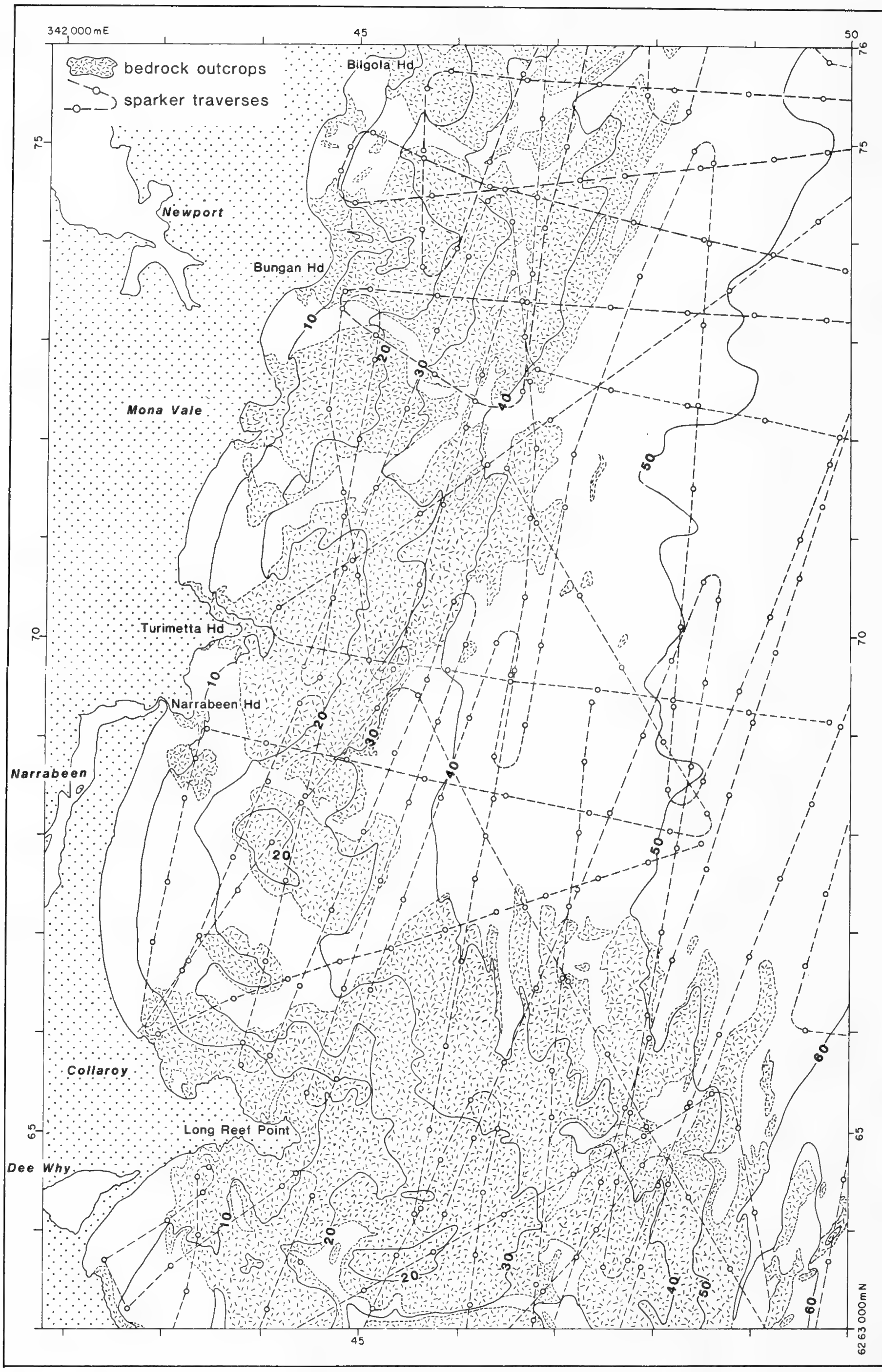

Fig. 4 - Bathymetry (in metres b.s.l.); sparker traverses and bedrock outcrops from Bilgola Head to Long Reef Point.

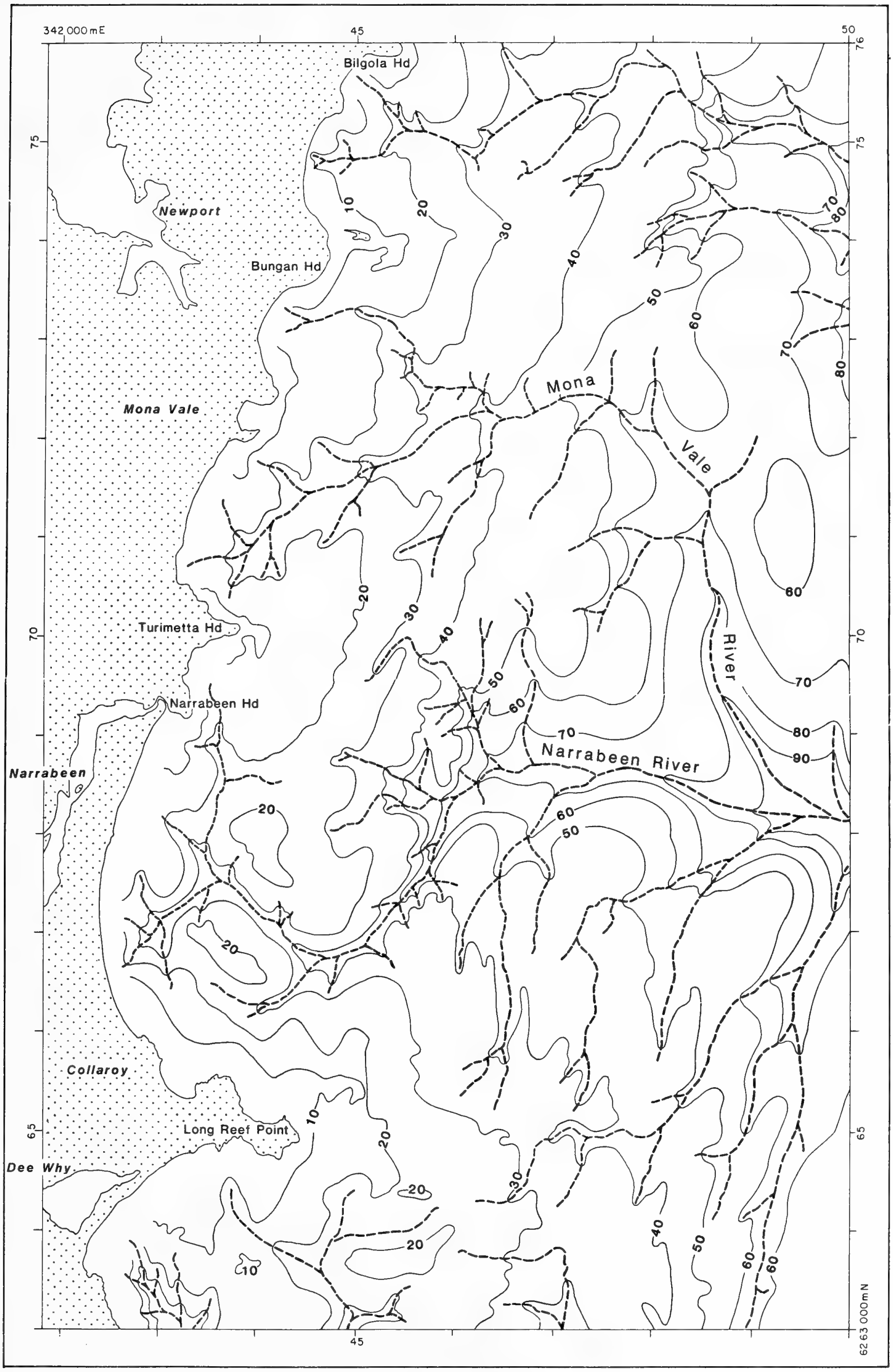

Fig. 5 - Bedrock contours (in metres b.s.l.) from Bilgola Head to Long Reef Point.

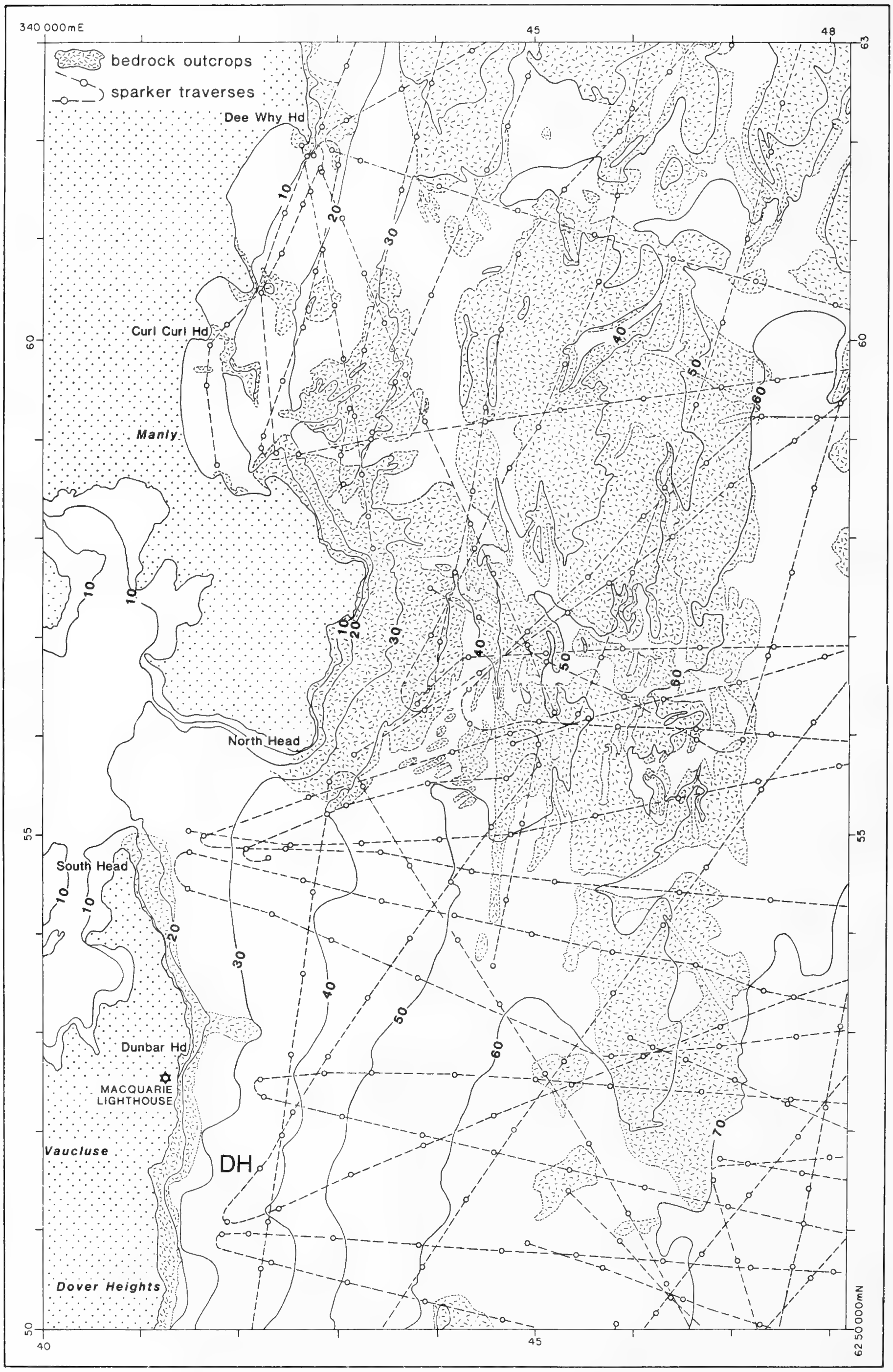

Fig. 6 - Bathymetry (in metres b.s.l.); sparker traverses and bedrock outcrops from Dee Why Head to Dover Heights. DH, location of the seismic record (Fig.12).

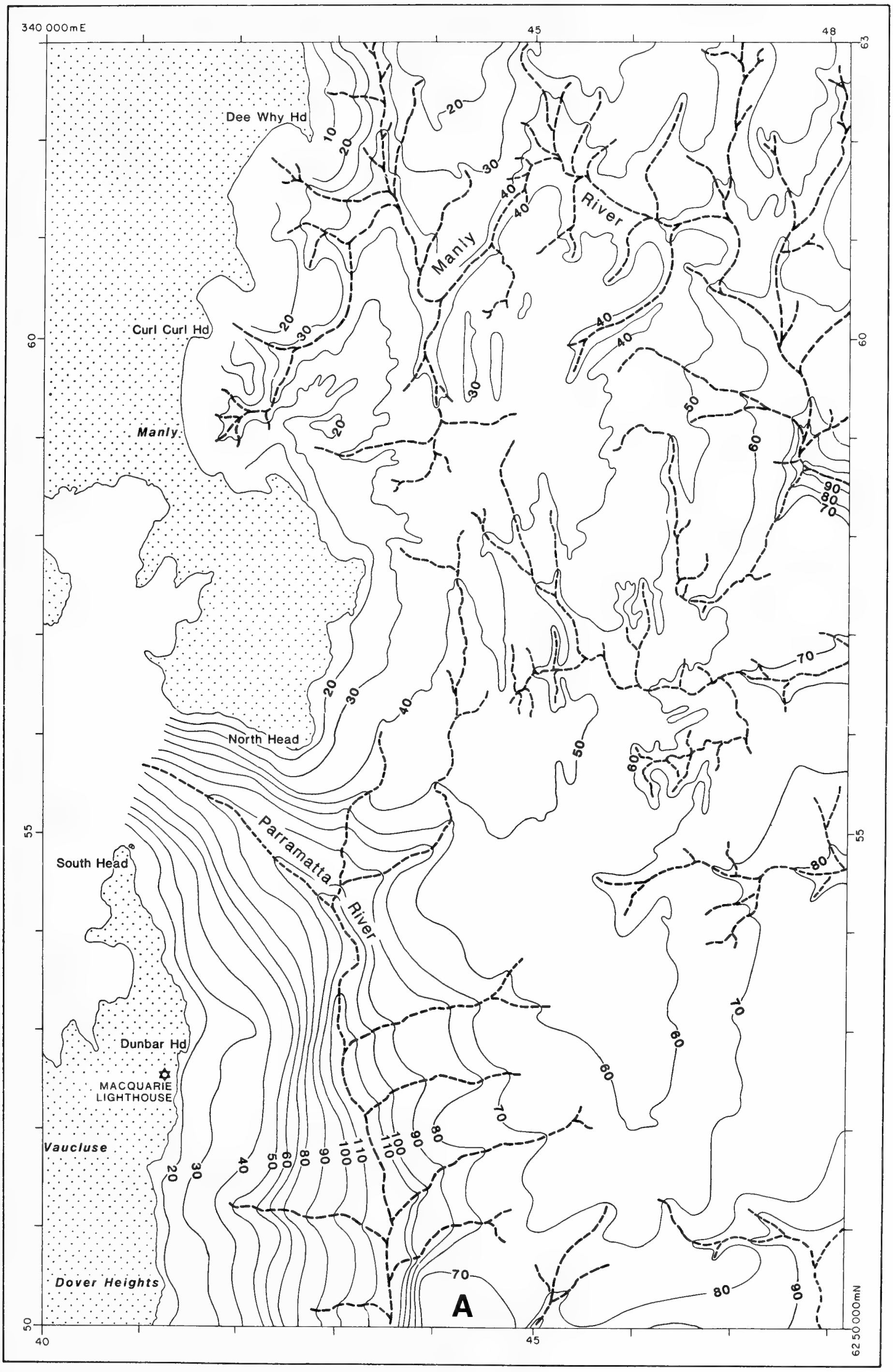

Fig. 7 - Bedrock contours (in metres b.s.l.) from Dee Why Head to Dover Heights.

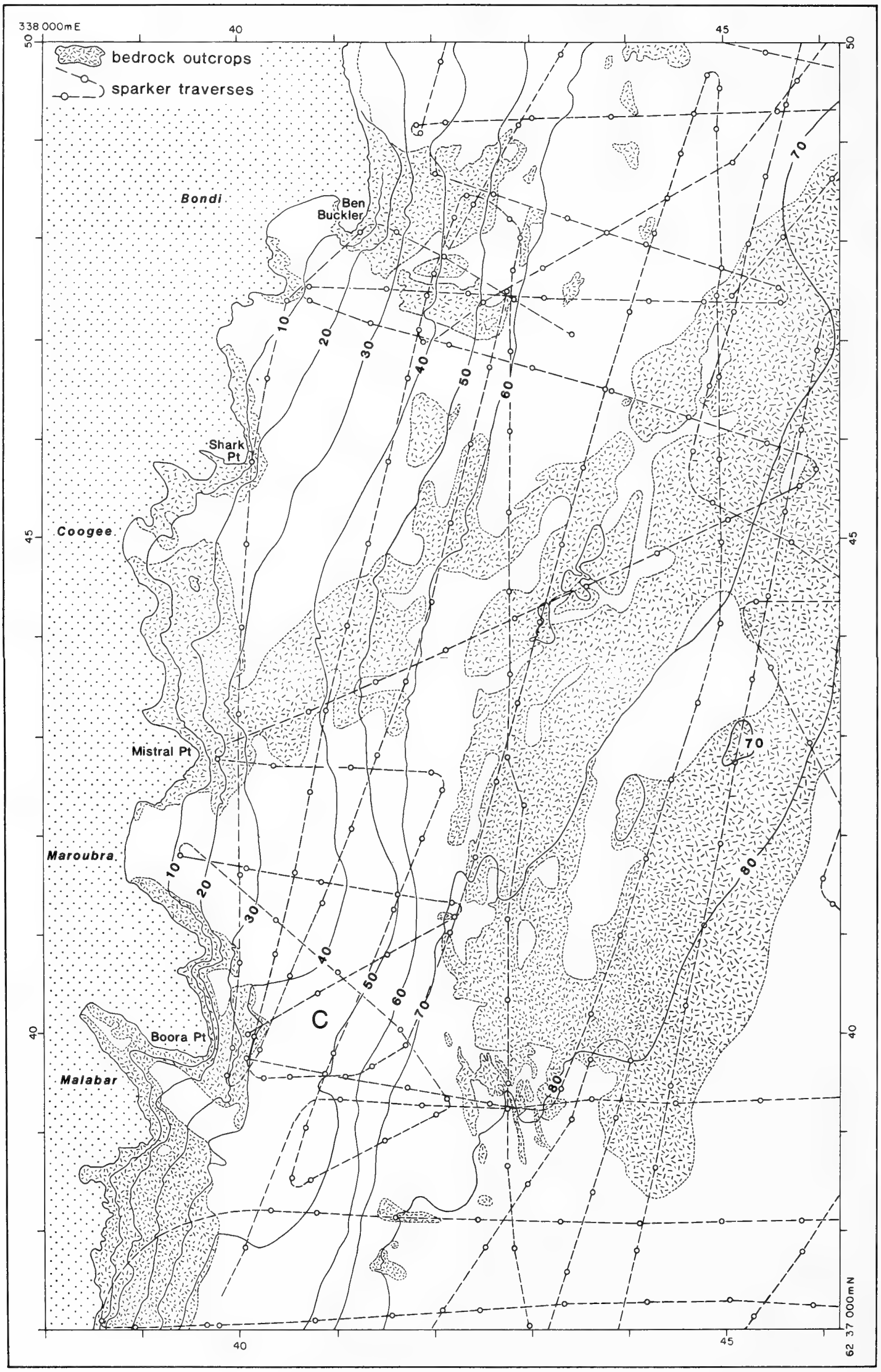

Fig. 8 - Bathymetry (in metres b.s.l.); sparker traverses and bedrock outcrops from Bondi to Malabar. C, location of the Maroubra sand ribbon (Figs.12, 13).

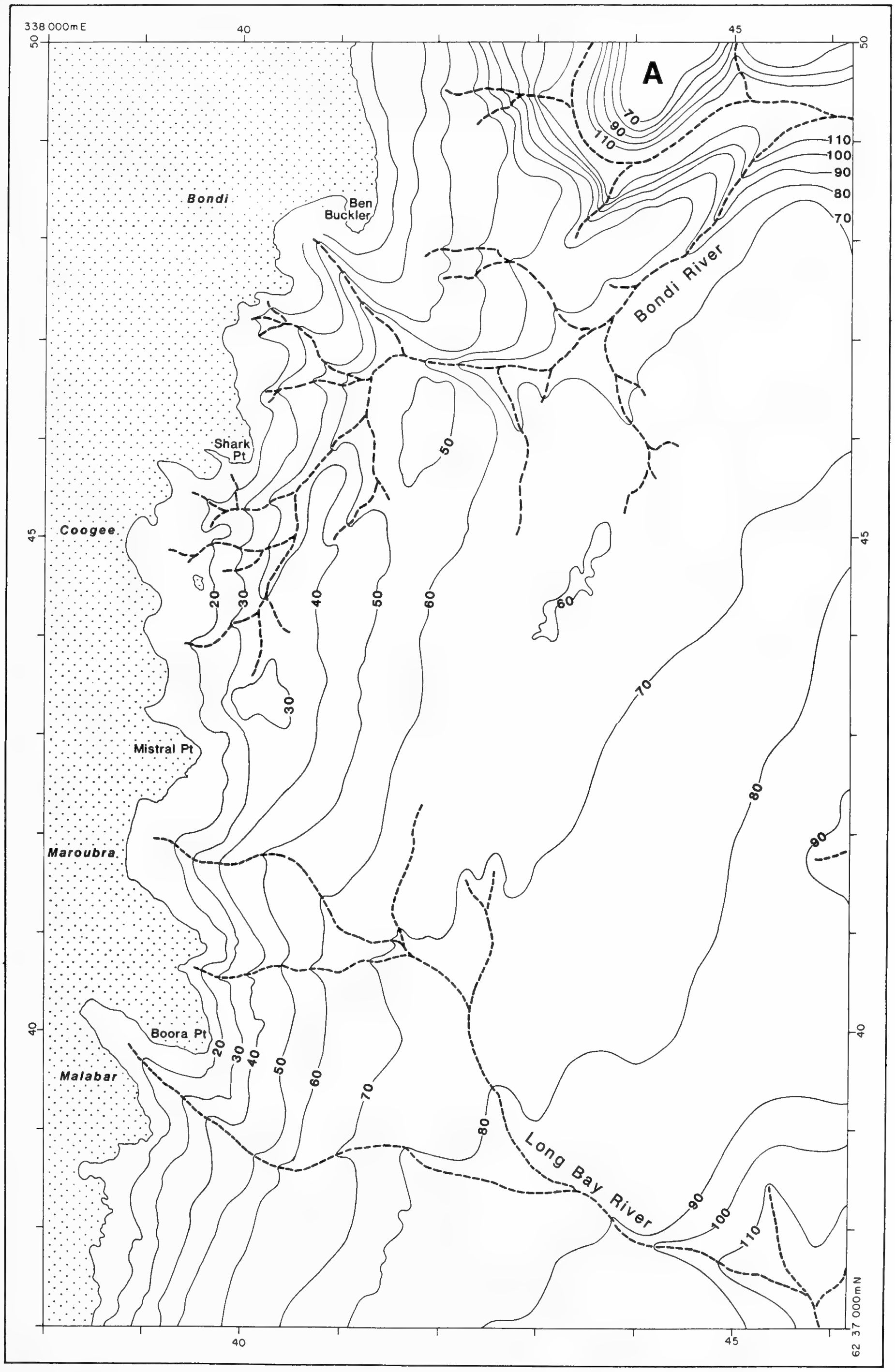

Fig. 9 - Bedrock contours (in metres b.s.l.) from Bondi to Malabar.

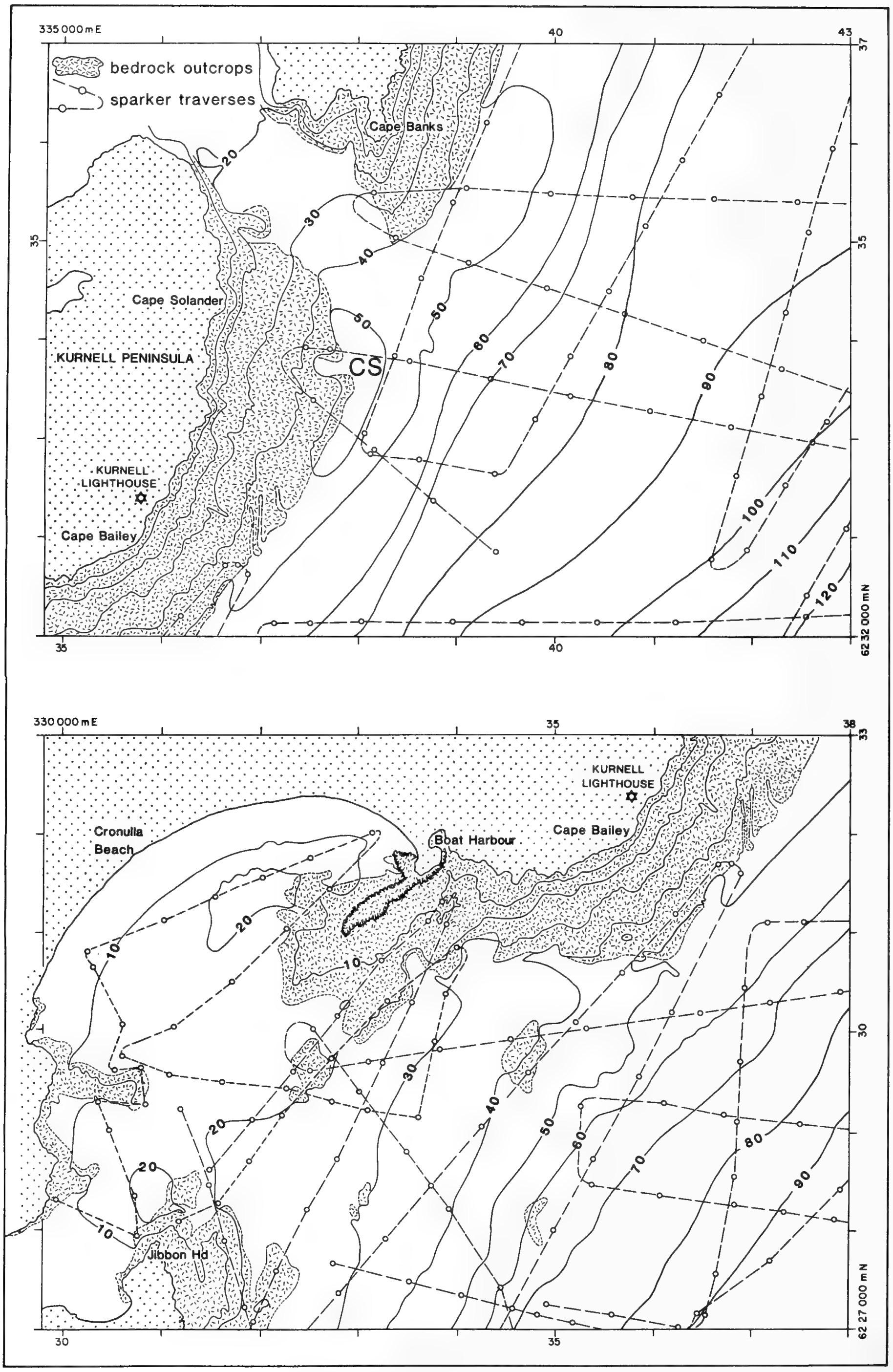

Fig. 10 - Bathymetry (in metres b.s.l.); sparker traverses and bedrock outcrops from Cape Banks to Jibbon Head. CS, location of seismic record (Fig.12).

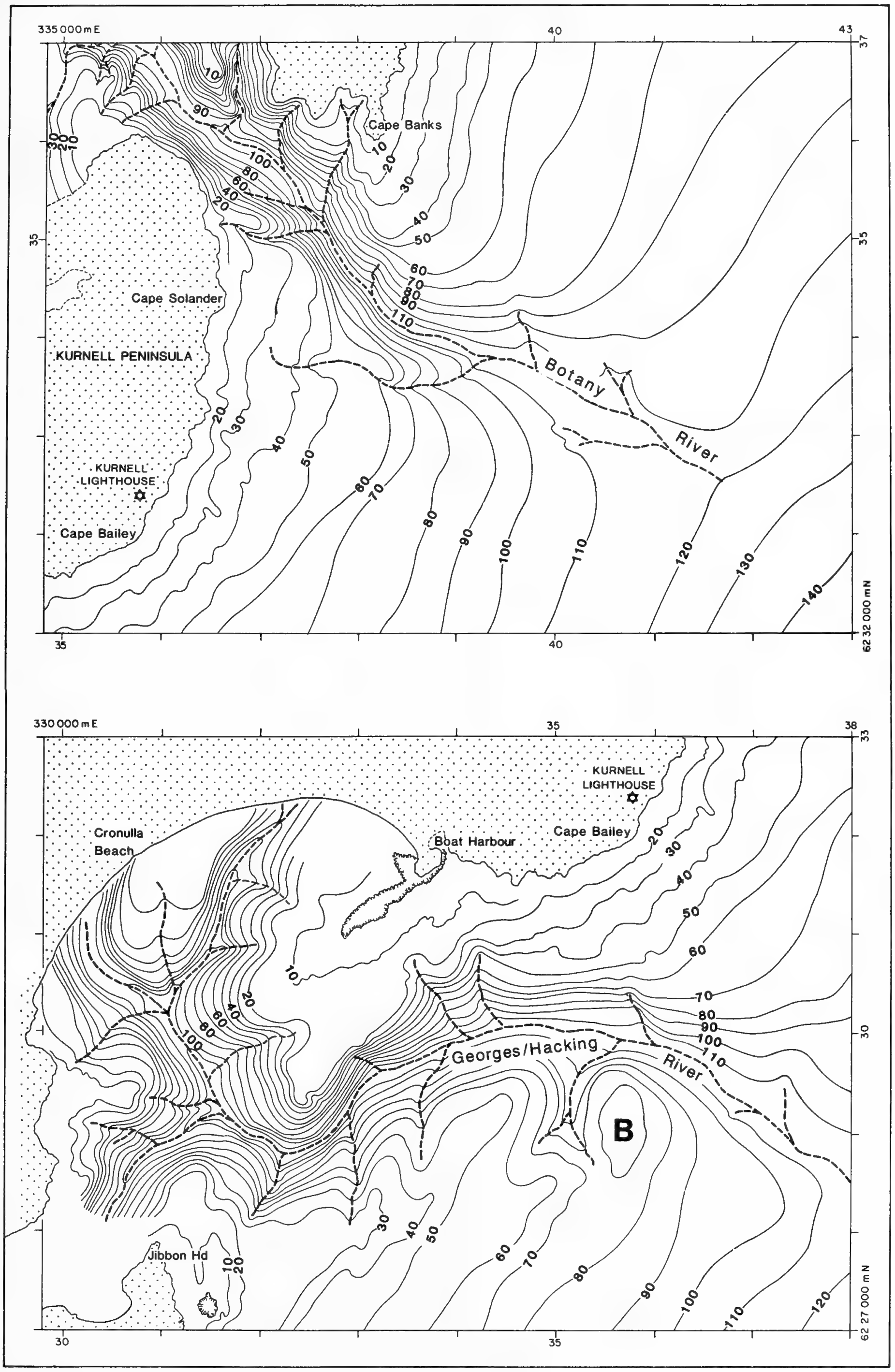

Fig. 11 - Bedrock contours (in metres b.s.l.) from Cape Banks to Jibbon Head.

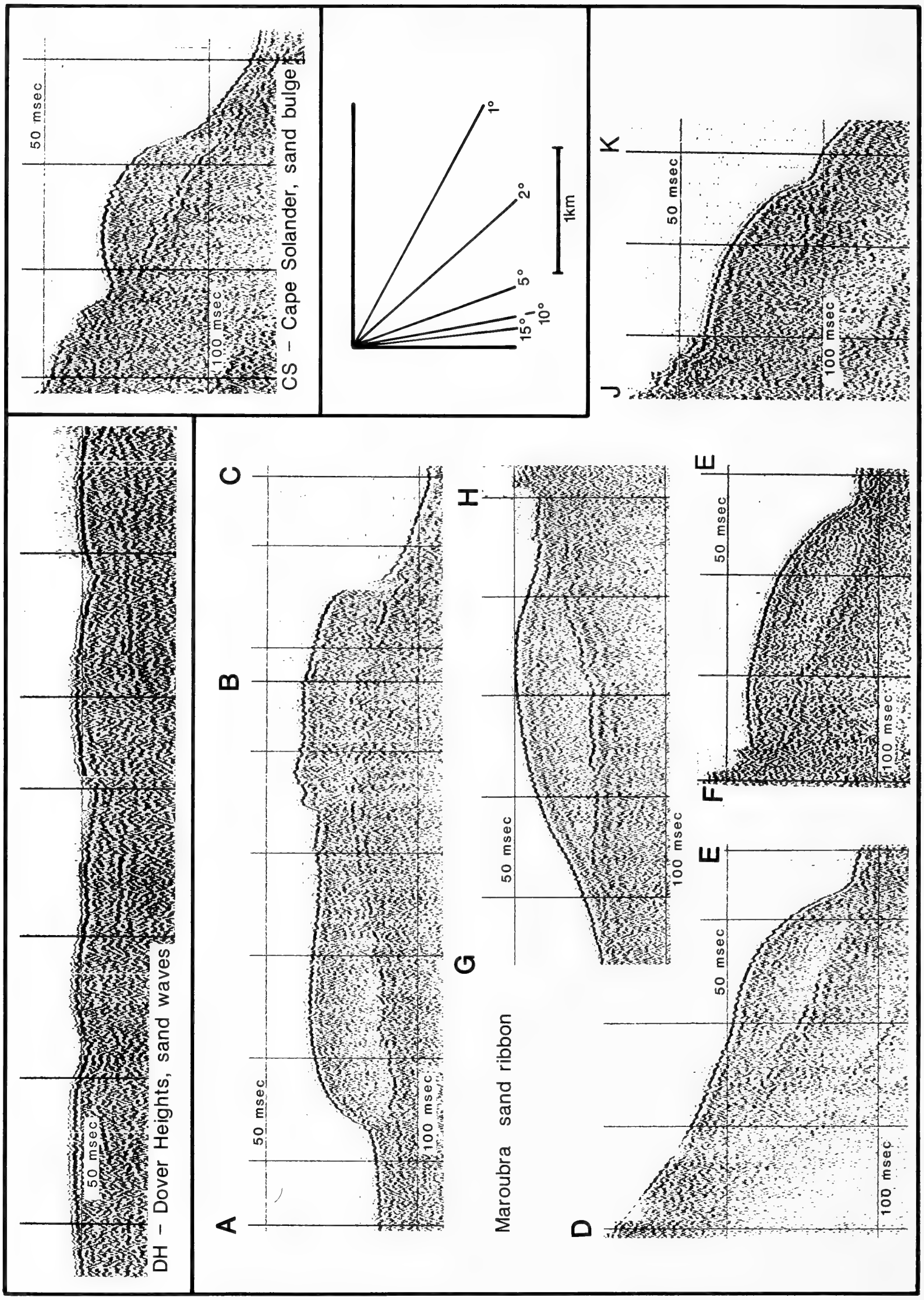

Fig. 12 - Seismic records of the sand bodies; for location see Figs. 6,9,10 and 13

have called sand waves, sand ribbons and sand bulges. Absence of acoustic reflectors within them indicates that these bodies of unconsolidated sand have insignificant internal structure.

Several asymmetric sand waves are located east of Dover Heights (DH on Fig. 7) and aligned at right angles to the shore; they occur north of the survey tracks indicated by Field and Roy (1985, fig. 3). These sand waves have a wavelength of about 1 km and an amplitude which may reach 6 m; their troughs are relatively narrow (Fig. 12).

The most conspicuous sand ribbon occurs 1.5 km offshore southeast of Maroubra (C on Fig. 8) in water depths between 40 and 70 m, was investigated in detail.

It is elongate sub-parallel to the coast with a length of 7 km and a width of about 2 km. The marginal terminations have slopes of 6°-7° in marked contrast to the bedrock surface that slopes less than 1° which, in this area, is without any strongly incised drainage. This sand ribbon is generally 15 m thick; an isopach map (Fig. 13) shows the presence of three high points at which thicknesses are 22 m (off Maroubra), 20 m (near Malabar) and 26 m (at Cape Banks). The seismic records (Fig. 12) reveal very little internal sedimentary structure. This ribbon has been cored by the N.S.W. Department of Mineral Resources and material was made available to us. Shallow water foraminifera, recovered from a number of samples from the above cores, all have well preserved tests which indicate a depositional environment of relatively low energy.

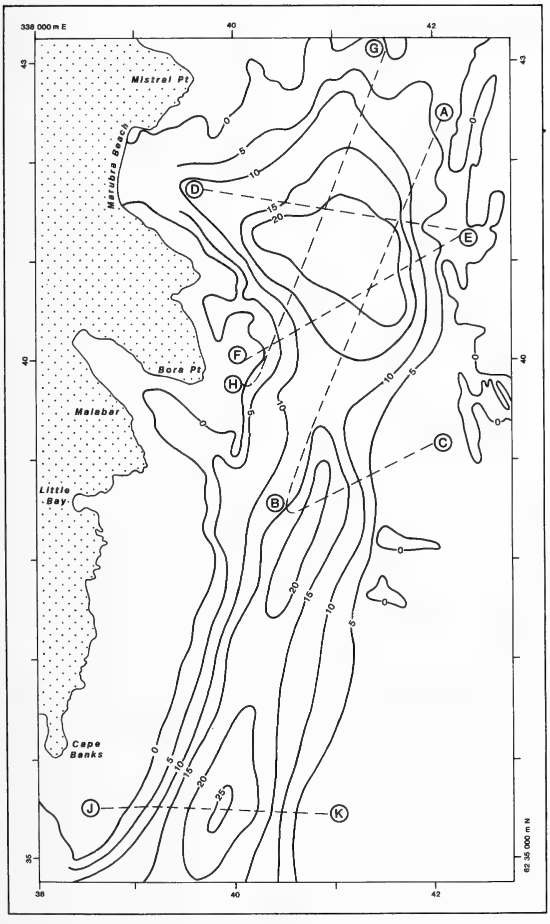

Fig. 13 - Isopach map of the Maroubra sand ribbon.

The most evident sand bulge exists 1.5 km off Cape Solander (CS on Fig. 11). It is roughly circular in plan with a diameter of about 1.5 km and a thickness of 20 m (Fig. 12) so that it resembles the high areas of the Maroubra sand ribbon.

These sand bodies tend not to show any evidence of significant internal structure; they appear to be slowly migrating northward (Fig. 14), and do not show any direct relationship with sand bodies on shore.

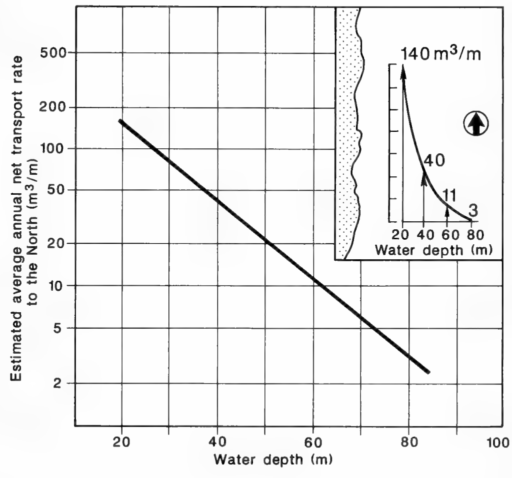

Fig. 14 - Sediment transport rates across the inner shelf (after Gordon and Hoffman, 1985).

From the seismic profiles and the foraminiferal content a possible process for the formation of these sand bodies is presented, and graphically shown in figure 15.

During the last low sea level (c.20,000 yBP) (Phase 1) beaches existed eastwards of the present day coastline. As the sea level rose some westward redistribution of unconsolidated material is likely to have occurred mainly under the influence of waves generated bottom currents (Phase 2). In some places well developed cliffs would have hindered this westward redistribution and wherever the coastal morphology prevented the development of extensive beaches, sand would have piled up (Phase 3) only to be totally summersed during the final sea level rise (Phase 4) (8,000-6,000 yBP). Waves and wave generated bottom currents are considered to subsequently erode the topmost landward portion of the sand body, redepositing it as a seaward prograding front (Phase 5). Offshore drainage from the submerging landmass would have separated the various sand bodies and controlled their longitudinal length and hence their shape.

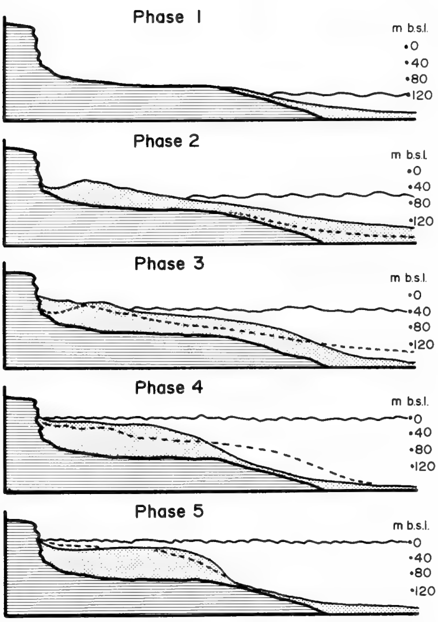

Fig. 15 - Diagramatic representation of the formation of sand bodies.

ECONOMIC POTENTIAL

The extensive outcrop of bedrock throughout the inner portion of the shelf, within the range of depth of mining by dredging, rather drastically reduces the potential of this area as a source of sand. Limited occurrences of sand suitable for marine aggregate and/or beach nourishment occur as infill of the various drainages, and are closely related to the present day beaches. Any extraction of these minor deposits would probably affect the stability of the related beaches which, in many instances, are already in an impoverished state.

Only in a few areas could sand mining be contemplated, subject to suitability of the material, an adequate hydrodynamic assessment, and a careful design of the dredge path. The most economically viable location, within the study area, include the large sediment infill region seaward of Broken Bay entrance (Fig. 2), the sediment features between South Head and Bondi (DH, Fig. 6) and the sand body south of Maroubra (Fig. 13). The Maroubra sand body, for instance, contains about 300 million tonnes of unconsolidated sediment, twice the total amount required by the Sydney market from now to the year 2000 (N.S.W. Department of Environment and Planning, 1981).

CONCLUSIONS

Many sea level fluctuations occurred during the Pleistocene Period and sediment eroded from the valley floor during the phase of low sea level, was deposited by the coastal streams at their mouths and on the adjacent inner shelf region. At the next rise of sea level this material was then redistributed by tidal and wave action back into the drowned river valleys. However each drop in sea level did not result in the total removal of such unconsolidated material from the newly reactivated river valleys (Albani, 1980, 1981); only part of it was involved in the process.

With the Holocene sea level rise the sediments on the drowned coastal plain underwent extensive reworking under the action of waves and currents. Some of this material remained on the new inner shelf region, whilst a significant portion was moved landward to infill the newly created drowned river valleys, bays and estuaries.

Along the Sydney coastline, the largest sediment infill occurred where the bedrock morphology formed large funnel-shaped traps: Bate Bay, Port Jackson, Broken Bay. The seismic records from these infilled valleys show the presence of coastal onlap sedimentary structures typical of a mobile tidal delta (Mitchum, 1977; Vail et al., 1977a). Landward mobility of present day sediment in Port Hacking (P.W.D., 1986), Broken Bay (Albani et al., 1974) and most of the other estuaries, is evidence of this process.

To the north of Sydney Harbour the inner shelf is mainly characterized by extensive outcrops of gently sloping bedrock, incised with valleys which are now partially infilled with unconsolidated coastal sediments.

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The authors are greatly indebted to Mr. Roy N. Foster who assisted the whole project by making available his vessel *T.S.M.V. Sieglinde.* His skill as skipper and his intimate knowledge of the coastal waters has been invaluable for the success of the surveys. We also gratefully acknowledge the assistance of Mr. K.S. Gibbons for the collection of the seismic and magnetic data.

This project has mainly been financed by the N.S.W. Public Works Department. A few of the seismic lines used were obtained during the overall major study of the outer shelf, sponsored by the Australian Research Grant Scheme, which has been completed and is being prepared for publication.

REFERENCES

Albani, A.D., Carter, A.N. and Johnson, B.D., 1973. The bedrock topography of Jervis Bay, New South Wales. *In* OCEANOGRAPHY OF THE SOUTH PACIFIC, pp. 179-184. Fraser, R. (Ed.). New Zealand National Commission for UNESCO, Wellington.

Albani, A.D., and Johnson, B.D., 1974. The bedrock topography and origin of Broken Bay, N.S.W. *Journal of the geological Society of Australia, 21,* 209-214.

Albani, A.D., Rickwood, P.C., Johnson, B.D., McGrath, C.A. and Tayton, J.W., 1978. A GEOLOGICAL INVESTIGATION OF THE SEABOARD AREA OF THE SUTHERLAND SHIRE. Unisearch Ltd., Sydney, 143 pp.

Albani, A.D., 1980. Pleistocene foraminifera from Botany Bay, New South Wales. *Alcheringa, 5,* 147-160.

Albani, A.D., 1981. Sedimentary environments and Pleistocene chronology of the Botany Basin, N.S.W., Australia. *Geo-marine Letters, 1,* 163-167.

Albani, A.D., Rickwood, P.C., J.W. and Johnson, B.D., Tayton,1976. THE ANCIENT RIVER SYSTEMS OF BOTANY BAY. Sutherland Shire Studies no.8, 4 pp.

Albani, A.D., Rickwood, P.C., Tayton, J.W. and Johnson, B.D., 1983. Some Geological aspects of the Port Hacking Estuary. pp.17-21. *In* SYNTHESIS AND MODELLING OF INTERMITTENT ESTUARIES. CUFF, W.R. and TOMCZAK, M. (Ed.), Springer-Verlag, New York.

Andrews, H.E., 1978a. Marine geophysical survey off Turrimetta Head, Warriwood, for Metropolitan Water, Sewerage and Drainage Board. *Geological Survey Reports, G.S.* 1978/341.

Andrews, H.E., 1978b. Marine geophysical surveys off North Head for Metropolitan Water, Sewerage and Drainage Board. *Geological Survey Reports, G.S.* 1978/018.

Andrews, H.E., 1979. Marine geophysical surveys off Bondi and Malabar for Metropolitan Water, Sewerage and Drainage Board. *Geological Survey Reports, G.S.* 1979/324

Caldwell Connell Engineers, 1976. REPORT ON SUBMARINE OUTFALL STUDIES, METROPOLITAN WATER, SEWERAGE AND DRAINAGE BOARD. Sydney, 237 pp.

Davies, P.J., 1975. Shallow seismic structure of the continental shelf, southeast Australia. *Journal of the Geological Society of Australia, 22,* 345-359.

Davies, P.J., 1979. Marine geology of the continental shelf off southeast Australia. *Bureau of Mineral Resources, Bulletin 195.*

Field, M.E. and Roy, P.S., 1984. Offshore transport and sand body formation: evidence from a steep high energy shoreface, southeastern Australia. *Journal of Sedimentary Petrology, 54,* 1292-1302.

Gordon, A.D. and Hoffman, J.G., 1985. Sediment features and processes of the Sydney continental shelf. *Public Works Department technical Memo 85/2.*

Gordon, A.D. and Hoffman, J.G., 1988, Seabed Studies - Bondi and Malabar. *N.S.W. Public Works Department* (In press 1).

Gordon, A.D. and Hoffman, J.G., 1988, Sydney Coastal Study. *N.S.W. Public Works Department* (In press 2).

Hudson, J.P., 1985. Geology and depositional history of late Quaternary marine sediments on the south Sydney inner continental shelf, southeastern Australia. *Coastal Studies Unit Technical Report 85/2,* Department of Geography, University of Sydney. (Unpubl.)

Johnson, B.D. and Albani, A.D., 1975. Bedrock topography in Northern Jervis Bay. *Journal & Proceedings of the Royal Society of N.S.W., 108,* 12-15.

Johnson, B.D., Albani, A.D., Rickwood, P.C. and Tayton, J.W., 1977. The bedrock topography of the Botany Basin, New South Wales. *Journal of the Geological Society of Australia, 24,* 403-408.

Law, D., 1975. Aspects of continental shelf marine geology between North Head and Garie Beach. *B.Sc. (Hons) Thesis. University of Sydney.* (Unpubl.)

Loutit, T.S. and Kennett, J.P., 1981. Australian Cenozoic sedimentary cycles, global sea level changes and the deep sea sedimentary record. *Oceanology Acta, Proceedings 26th International Geological Congress, Geology of Continental Margins Symposium, Paris, July 1980,* 45-63

Mitchum, R.M., 1977. Seismic stratigraphy and Global Changes of Sea Level, Part 11: Glossary of Terms used in Seismic Stratigraphy, *in* SEISMIC STRATIGRAPHY - APPLICATIONS TO HYDROCARBON EXPLORATION, pp. 205-212.
Payton, C.E. (Ed) American Association of Petroleum Geologists, Mem. 26, Tulsa.

N.S.W. Department of Environment and Planning, 1981. Sydney's Extractive Industries, Regional Environmental Study.

Partridge, A.D., Benson, J.M. and Bell, D., 1978. Unwrapping Little Bay. *Abstract Twelfth Symposium "Advance in the Study of the Sydney basin", Newcastle 1978,* 19-20.

Phipps, C.V.G. and Emerson, D.W., 1968. Seismic profiling studies in the lower section of Port Jackson. *Australian Journal of Science, 31,* 190-191.

Public Works Department, N.S.W., 1986. PORT HACKING MARINE DELTA. MANAGEMENT OPTIONS. Sydney.

Ringis, J., 1975. Marine Geophysical Surveys off North Head, Bondi and Malabar for the Metropolitan Water Sewerage & Drainage Board. *Geological Survey Reports, G.S.* 1975/176.

Ringis, J., 1972. The structure and history of the Tasman Sea and the southeast Australian margin. *Ph. D. Thesis, Univ. New South Wales.* (Unpubl.)

Roy, P.S., 1983. Quaternary Geology. pp 41-91 *in* Herbert, C. (Ed.), *Geology of the Sydney 1:100,000 sheet, 9130.* Geological Survey of New South Wales. Department of Mineral Resources, 225 pp.

Roy, P.S., 1985. Marine sand bodies on the south Sydney shelf, S.E. Australia. *Coastal Studies Unit Technical Report 85/1,* Department of Geography, University of Sydney. (Unpubl.)

Vail, P.R., Mitchum, R.M. and Thompson, S., 1977b. Seismic stratigraphy and Global Changes of Sea Level, Part 4: Global Cycles of Relative Changes of Sea Level, *in* SEISMIC STRATIGRAPHY - APPLICATIONS TO HYDROCARBON EXPLORATION, pp. 83-97
Payton, C.E. (Ed) American Association of Petroleum Geologists, Mem. 26, Tulsa.

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Volatile Leaf Oils of Six Northern Australian Broad-Leaved Melaleucas

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ABSTRACT. The volatile leaf oils of six northern Australian broad-leaved *Melaleuca* species *viz. M. arcana, M. lasiandra, M. stenostachya, M. cajuputi* subsp. *"platyphylla"* (Cape York), *M. cajuputi* subsp. *"cajuputi"* (Northern Territory), *M. dealbata,* and *M. nervosa,* were analysed by gas chromatography and gc/ms. The species can be divided roughly into two groups on the basis of their oil composition. The oils of the first four taxa consist mainly of monoterpenoids while those of the latter three consist mainly of sesquiterpenoids.

INTRODUCTION

The genus *Melaleuca* consists of about 200 species which mainly occur in Australia although the distribution of some, e.g. *M. nervosa* (Lindley) Cheel extends to Papua New Guinea. Species range in size from small trees in arid zones, e.g. *M. suberosa* (Schau.) C. Gardiner, to tall trees, e.g. *M. cajuputi* Powell, in the wet tropical zones of Australia. The leaves of adult trees vary in size from small and inconspicuous in species like *M. nanophylla* Carrick to large and very "eucalypt like" in *M. dealbata* S.T. Blake.

Several species of melaleuca are harvested commercially for their essential oils. *M. alternifolia* Cheel is harvested in wild stands and small commercial plantations in norther N.S.W. In New Caledonia, *M. quinquenervia* (Cav) S.T. Blake is harvested to extract oil, marketed under the name "Niaouli", while in Indonesia a small industry in Bali is based on cultivated stands of *M. cajuputi.*

As a continuation of our interest in the oil of tropical melaleucas (Brophy et al., 1987; Brophy and Lassak, 1988), this paper focusses on six broad-leaved *Melaleuca* species of tropical Australia such as *M. cajuputi* and its allies. These six broad-leaved melaleucas occur naturally in the tropical parts of northern Australia. Their taxonomy was revised by Blake (1968) and later by Byrnes (1984, 1985, 1986). A review of their taxonomy is continuing (Barlow, pers. comm., 1987) with emphasis on determining their phylogenetic relationships. These species range from shruby trees to large trees and occur in seasonally waterlogged areas, e.g. *M. dealbata,* or along streams, e.g. *M. cajuputi.* Barlow (pers. comm., 1987) has suggested that the Queensland and Northern Territory material of *M. cajuputi* represents two discrete subpecies, *viz.* subsp. *"platyphylla"* and subsp. *"cajuputi"* respectively.

EXPERIMENTAL

Collection of plant material and isolation of volatile oils

Air dried leaves and terminal branchlets were collected from one and two year old trees grown from known seedlots in Queensland Department of Forestry/Australian Centre for International Agricultural Research (ACIAR) field trials at Gympie, Qld. Leaves were steam distilled with cohobation as previously described (Lassak, 1979) for seven hours to yield colourless oils. Species, seedlot numbers and origin information are as follows: *M. arcana* S.T. Blake, S14866, NNE of Tozers Gap, Qld and S14876, NW of Cooktown, Qld; *M. lasiandra* F. Muell., S13752, Rabbit Flat and S13751, Vaughan Springs, N.T.; *M. stenostachya* S.T. Blake, S14149, Mareeba; *M. cajuputi*, S14550, SE of Daintree, Qld and S14878, N of Mossman, Qld; *M. dealbata*, S11935, near Humpty Doo, N.T.; *M. nervosa*, S13440, Lake Buchanan, Qld. Oil was also obtained from adult leaves of *M. cajuputi* growing in the Adelaide River plains, N.T. Voucher botanical material of original seedlots are lodged at the Division of Forestry and Forest Products, CSIRO. Seedlot numbers and seed were supplied by the Australian Tree Seed Centre.

Identification of components

Analytical gas chromatography (glc) was carried out on a Shimadzu GC6 AMP gas chromatograph. A SCOT column of SP 1000 [85m x 0.5mm] which was programmed from 65°C to 225°C at 3°C/min was used with helium carrier gas. For combined gc/ms the gas chromatograph was connected to an AEI MS12 mass spectrometer through an all glass straight split interface. The mass spectrometer was operated at 70 eV ionising voltage and 8000V accelerating voltage with an ion source at 200°C. Glc conditions were the same as for the analytical glc. Spectra were acquired every six seconds and processed by a VG Display Digispec data system. Glc integrations were performed on a Milton Roy C1-10 electronic integrator.

Compounds were identified by their identical glc retention time to known compounds and comparison of their mass spectra with either known compounds or published spectra (Stenhagen et al., 1974; Heller and Milne, 1978, 1980, 1983).

RESULTS AND DISCUSSION

Table 1 lists the components found in each of the species examined and the yield of oil obtained. The data indicate that the species can be divided roughly into two groups according to their oil composition, *viz.* those species whose oils are mainly monoterpenoid and those whose oils are mainly sesquiterpenoid. Species in the first group include *Melaleuca arcana, M. lasiandra, M. stenostachya* and *M. cajuputi* from the Cape York region of Queensland (subsp. *"platyphylla"*). Species in the second group include *M. dealbata, M. nervosa* and a sample of *M. cajuputi* from the Adelaide River plains in the Northern Territory (subsp. *"cajuputi"*).

Species in Group 1

M. arcana

The oil from this species had a quite pleasant aroma and contained mainly α-pinene and 1,8-cineole with the former compound being the larger component. These two compounds usually accounted for more than 50% weight of the oil. Accompanying these two compounds were smaller amounts of the usual monoterpene hydrocarbons. There were small amounts (usually <5%) of the monoterpene alcohols terpinen-4-ol and α-terpineol and trace amounts of other cyclic and alicyclic monoterpene alcohols. The sesquiterpenes accounted for only about 10% of the weight of oil. The principal components were germacrene-D, α-amorphene, bicyclogermacrene and δ-cadinene. Some sesquiterpene alcohols were detected, the most abundant being α-cadinol at about 1%. Components accounting for approx. 1% of the oil remain unidentified. They were mostly sesquiterpenes.

The yield of oil from Tozers Gap, Qld material was about 1% and this was considerably greater than that of the oil from leaves obtained from Cooktown. This latter batch of trees contained practically no oil, though its composition (with the exception of α-farnesene present in this sample only) was similar to that of the Tozers Gap material.

M. lasiandra

The oil was rich in monoterpenes and the principal components were α- and β-pinene and limonene which accounted for about 70% of the oil. There were only very small quantities of the monoterpene alcohols, with α-terpineol being the principal member. A significant amount of benzaldehyde was detected in the oil no doubt due to the decomposition of mandelonitrile during the steam distillation. Sesquiterpene alcohols were more abundant than the hydrocarbons with α-, β- and γ-eudesmols, together with globulol, being the principal alcohols. The major sesquiterpene hydrocarbons were caryophyllene, aromadendrene and viridiflorene. Sesquiterpenes at most totalled less than 15% of the oil.

M. stenostachya

The leaves yielded 1.5% oil and the major compounds were 1,8-cineole (53%) and α-pinene (24%). There were much smaller amounts of β-pinene and limonene as the next most abundant monoterpenes. Of the monoterpene alcohols only α-terpineol at 2% was of any consequence. Altogether monoterpenes accounted for over 90% of the oil. Small amounts of sesquiterpenes were present with caryophyllene, at about 6% by far the largest component. There were small quantities (each <0.7%) of humulene, globulol, spathulenol and a compound which, from its mass spectrum, was assumed to be a caryophyllene alcohol. About 1% of the oil was due to components (mostly sesquiterpenes) which remain unidentified.

M. cajuputi subsp. *"platyphylla"*

The oil of *M. cajuputi* subsp. *"platyphylla"* from two sources, *viz.* south east of Daintree and north of Mossman, was monoterpenoid in character. α-Pinene, at about 65% was by far the largest component, the next most abundant monoterpene being 1,8-cineole (at 1.2-3%). The monoterpene alcohols were present, but only in somewhat larger than trace quantities. The remainder of the oil of *M. cajuputi* subsp. *"platyphylla"* consisted of sesquiterpenes with caryophyllene and humulene being the major components. There were small but significant amounts of α- and β-selinene present in this oil, as well as small quantities of globulol, viridiflorol and spathulenol. The yield of oil varied from 0.1% to 1%. Altogether components accounting for about 2.5% of the oil remain unidentified. These were sesquiterpenes.

Species in Group 2

M. cajuputi subsp. *"cajuputi"*

The oil obtained from *M. cajuputi* subsp. *"cajuputi"* originating from Adelaide River plains, N.T. contained almost exclusively sesquiterpenes. Of these α- and β-selinene accounted for over 40% of the oil. There were smaller amounts of caryophyllene, aromadendrene, α-bulnesene and alloaromadendrene accounting for about 15% of the oil as well as numerous other sesquiterpene hydrocarbons in <0.5% amounts. The sesquiterpene alcohols were dominated by spathulenol (10%) and there were smaller amounts of globulol and viridiflorol. Another unidentified compound, $C_{15}H_{24}O$ (4%), was also present. Once again there were numerous oxygenated sesquiterpenes present in amounts of <0.5%.

M. dealbata

This species yielded a complex oil containing about 1% monoterpenes, the major members being 1,8-cineole and α-terpineol. The remainder of the oil consisted of sesquiterpenes with caryophyllene, at 34%, being by far the major component. Other sesquiterpene hydrocarbons present included aromadendrene, α-bulnesene, alloaromadendrene, humulene, viridiflorene, α- and β-selinene and calamanene. All of these compounds were present in 1-4% amounts. The oxygenated sesquiterpenes were caryophyllene oxide and globulol, accounting for 11% of the oil. There were also smaller amounts of viridiflorol, spathulenol T-cadinol and T-muurolol, and a trace amount of farnesol. All told 17% of the oil consisted of compounds, mostly oxygenated sesquiterpenes in small amounts, which could not be identified. The yield of oil from this species was 0.1%. No trace was found of the previously reported tetraketone leptospermone (Lassak and Southwell, 1977).

M. nervosa

The oil obtained (in 0.1% yield) from *M. nervosa* contained about 2% monoterpenes, the major contributor being limonene (1%) with smaller amounts of camphene and terpinen-4-ol. The remaining 98% of the oil was a complex mixture of sesquiterpenes. The major sesquiterpene hydrocarbon was caryophyllene (18%) with lesser amounts of aromadendrene, alloaromadendrene and calamanene and trace amounts of humulene, viridiflorene, α- and β-selinene and α-copaene. The oxygenated sesquiterpene components were dominated by spathulenol in up to 40% in one tree. There were smaller quantities of caryophyllene oxide, globulol and viridiflorol. About 24% of the complex mixture of sesquiterpenes, the majority of which were present in <0.5% amounts, remains unidentified.

SUMMARY

All the species in Group 1, which contain predominantly monoterpenic oils, are qualitatively similar, with α-pinene being in all cases (except *M. stenostachya*) the major compound. Limonene, β-pinene and 1,8-cineole were also major compounds with this latter compound being the major component in *M. stenostachya*. While the monoterpene alcohols were present in all samples they were very minor components. The related sesquiterpene alcohols, globulol, viridiflorol and spathulenol were present in each of these oils but in small quantity. Because of the high α-pinene in these oils they had a pleasant perfume though with yields in the range of 0.1%-1.5% it may be difficult to find any commercial interest in them.

For the species in Group 2, the oil from both *M. dealbata* and *M. nervosa* was qualitatively and quantitatively similar with caryophyllene being the major component. Spathulenol was the major sesquiterpene alcohol in each case but the poor overall oil yield (~0.1%) does not make this a viable source of this component which is much better obtained from *Eucalyptus spathulata*

Barlow (pers., 1987) recognises three subspecies of *M. cajuputi*, two of which occur in Australia and a third one (subsp. *"c"*) from Asia. The last subspecies presumably produces the oil "cajuput" (rich in 1,8-cineole) obtained from this area. The two subspecies represented in this paper differ markedly in their oil contents, with *M. cajuputi* subsp. *"platyphylla"* (from Daintree, Qld) being very rich in monoterpenes and containing up to 72% of α-pinene. The other subsp. *"cajuputi"* (from Adelaide River plains, N.T.) contained only sesquiterpenes with α- and β-selinene being the major components.

REFERENCES

Blake, S.T., 1968. A revision of *Melaleuca leucadendron* and its allies (Myrtaceae). *Contributions from the Queensland Herbarium*. No. 1. 114 pp.

Bowyer, R.C. and Jefferies, P.R., 1962. New sources and synthesis of torquatone. *Australian Journal of Chemistry, 15,* 145-150.

Bowyer, R.C. and Jefferies, P.R., 1963. Structure of spathulenol. *Chemistry and Industry,* 1245-1246.

Brophy, J.J. and Lassak, E.V., 1988. The leaf oil of *Melaleuca leucadendra*, L. *Flavour and Fragrence Journal,* in press.

Brophy, J.J., Lassak, E.V. and Boland, D.J., 1987. Volatile leaf oils of the two subspecies of *Melaleuca acacioides*. *Journal and Proceedings of the Royal Society of New South Wales, 120,* 135-139.

Byrnes, N.B., 1984. A revision of *Melaleuca* L. (Myrtaceae) in northern and eastern Australia, 1. *Austrobaileya, 1,* 65-76.

Byrnes, N.B., 1985. A revision of *Melaleuca* L. (Myrtaceae) in northern and eastern Australia, 2. *Austrobaileya, 2,* 131-146.

Byrnes, N.B., 1986. A revision of *Melaleuca* L. (Myrtaceae) in northern and eastern Australia, 3. *Austrobaileya, 3,* 254-273.

Heller, S.R. and Milne, G.W.A., 1978, 1980, 1983. *EPNA/NIH MASS SPECTRAL DATA BASE*, U.S. Government Printing Office, Washington D.C.

Lassak, E.V. and Southwell, I.A., 1977. Essential oils isolates from the Australian flora. *International Flavours and Food Additives*, 126-132.

Lassak, E.V., 1979. The volatile leaf oils of three species of *Melaleuca*. *Journal and Proceedings of the Royal Society of New South Wales*, *112*, 143-145.

Stenhagen, E., Abrahamsson, S. and McLafferty, F.W., 1974. *REGISTRY OF MASS SPECTRAL DATA*, 2nd Edn., Wiley, New York.

TABLE 1

VOLATILES IDENTIFIED IN THE SIX *MELALEUCA* SPECIES

COMPOUND	*M. arcana* %	*M. lasiandra* %	*M. dealbata* %	*M. stenostachya* %	*M. nervosa* %	*M. cajuputi* (subsp. *platyphylla*) %	*M. cajupti* (subsp. *cajuputi*) %
α-pinene	33-50	30-34		24.3		61-72	
α-fenchene	0.01	0.01				0.01	
camphene	0.08	0.10		0.02	0.3	0.1-0.2	
β-pinene	1.9	12.8		1.3	0.01	1.2	
sabinene	0.3-6.9			0.01	0.01	0.01-0.1	
Δ-3-carene		0.4-0.9					
myrcene	1.1-1.4	0.1-0.3		0.4	0.01	0.01	
α-phellandrene	0.3-0.9			0.01		0.05	
α-terpinene	3.2-4.2			0.1		0.2	
limonene	5.5-7.1	27-35	0.2	4.2	1.0	1.1	
1,8-cineole	1.1-38.4	0.9-1.2	0.7	52.7	0.01	0.2-3.2	
β-phellandrene	0.01	.01-0.1					
β-trans-ocimene		0.6	0.01				
γ-terpinene	6.3-10.9	0.01-0.1		0.5		1.0	
p-cymene	1.5-5.4	0.1	0.01	0.1	0.01	0.4-0.5	
terpinolene	1.3-1.9	0.3		0.2		0.5-0.9	
α,p-dimethylstyrene	0.1-.03	0.01				0.01-0.1	
cis-linalool oxide		0.01					
trans-linalool oxide		0.01					
campholinic aldehyde		0.01					
α-cubebene	0.01		0.05		0.01	0.01	
citronellal	0.01-0.6						
δ-elemene		0.05			0.01		
α-copaene	0.30	0.01			0.5	0.01	
benzaldehyde	0.01	1.0-7.0	0.01	0.1			
linalool		0.01			0.1		
trans-menth-2-en-1-ol	0.01-0.1			0.01			
β-copaene	0.5						
β-bourbonene	0.2-0.5				0.01		
terpinen-4-ol	2.3-7.3	0.02	0.01	0.3	0.1	0.1-0.1	
caryophyllene	0.7-0.9	0.4-3.2	33.8	5.6	17.6	7.4-10.2	2.3
aromadendrene	0.13	0.1-0.7	3.5	0.1	2.4	1.5-1.9	7.3
α-bulnesene		0.1-0.2	0.5		0.01	0.01.0.1	1.9
cis-menth-2-en-1-ol	0.5			0.01			
allo-aromadendrene		0.1-0.4	2.4	0.1	3.9	0.2-0.3	1.5
δ-terpineol				0.01		0.01	
citronellol	0.21						
humulene	0.3-0.4	.01-0.3	1.3	0.7	0.5	4.0-6.6	0.5
α-terpineol	1.0-2.2	1.1-1.9	0.5	2.0		0.7	
viridiflorene	0.17	0.6-0.8	1.5		0.2	0.01-0.3	
germacrene D	0.4-2.0						1.1
α-amporphene..tent..	0.01-0.5						

α-gurjunene			0.3			0.1-0.2	
β-selinene			1.1		0.2	2.3	14.2
α-selinene			1.3		0.7	2.2	26.7
bicyclogermacrene	0.01-0.5			0.02			
α-bisaboline			0.1	0.04			
α-muurolene					0.01		
δ-cadinene	1.1-3.7	0.2			0.01	0.01	
γ-cadinene						0.01	
β-bisabolene		0.2-0.4					
myrtenol					0.3-0.4		
α-farnesene	2.5						
cadina-1,4-diene	0.04						
calamanene	0.06		2.9	0.01	1.7	0.01	0.01
methyl eugenol	0.01						
neral	0.12						
geranial	0.01						
calacorene	0.01	0.01		0.01		0.01	
p-cymen-8-ol		0.01					
palustrol		0.01	0.1		0.3		
eugenol	0.01					0.4	
caryophyllene oxide		0.4-0.7	6.7	0.4	7.4	0.1-0.4	
a caryophyllene alcohol		0.1-6.1					
globulol	0.1-0.4	4.0-6.0	4.5	0.6	4.1	0.5-1.0	1.3
viridiflorol		0.1-0.7	1.0	0.03	3.8	0.1-0.3	0.9
spathulenol	0.5-0.7	0.1-0.5	14.4	0.3	19.6-40	0.2-0.5	9.1
cubenol							0.5
T-cadinol	0.1-0.3		1.6				
T-muurolol	0.1-0.8		1.5				
γ-eudesmol		0.7-3.3					
α-eudesmol		1.1-6.6					
β-eudesmol		0.9-4.4					
α-cadinol	0.1-0.9						
farnesol			0.4				
unknown terpenes (%)	1.1	1.4	17	1	12	2.5	30
Yield % (dry weight)	.01-1.0	.3-1.3	0.1	1.4-1.7	0.1-0.2	0.1-1.1	0.70

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Lasers in Surgery and Medicine

M. A. Stubbs-Race

From time to time we learn (usually) from the Press that a certain hospital or clinic has just purchased a Nuclear Magnetic Resonance facility; a Laser; a Lithotripter or perhaps a Computerised Tomographic Scanner. Frequently these machines become news because they are the result of a collection for charity or a gift from a benefactor. Even governments buy them at times!

Everyone endorses the idea of installing such and such a machine, but frequently we seldom understand exactly what today's highly sophisticated instruments actually do or how they are used to help cure a patient. In this talk I shall be describing a small selection of lasers, the way in which they are used and how they contribute to the cure or relief of sick patients. This is not a study of the design or development of lasers, but rather a layman's view of how and why lasers have entered into medical use.

Whilst there is now a bewildering array of lasers being manufactured by a even greater number of companies, there are only five or six designs in common use in surgery and medicine. Obviously a number of new developments are experimental to varying degrees, but tonight we are only concerned with the established instruments which may now be found in the operating theatres of most major hospitals.

Theodore Maiman, a physicist working with the Hughes Aircraft Company (U.S.A.), first brought the laser into being in 1960. Between the years 1960 and 1970 development was slow but sound engineering was laying foundations for this entirely new invention. During this early period of development the laser was often unkindly described as an invention looking for a use. Uses for lasers are now indeed manifold and no less so in the diverse fields of medicine.

From about 1970 onwards commercial manufacture of lasers of many kinds got under way as more industrial and medical uses became apparent. The United States of America, Israel and West Germany had manufacturers with special interests in this particular branch of physics. The United States of America had something of a lead because very large and very costly crystals are needed for solid state lasers. Government funded research establishments were in a better position to produce such crystals, therefore early manufacturers were organisations with defence budgets or were partially owned by the government.

Ophthalmologists were the first practioners to realize the potential of lasers, since for many years they had used a beam of high intensity light to perform work within the human eye. The source of light used was originally incandescent tungsten and later quartz-halogen followed by xenon arc through filters. These light sources naturally produce a lot of heat causing undesireable effects in many procedures. Because heat or infra-red energy has wavelengths very close to visible light, it is most difficult to filter out or eliminate. To be suddenly landed with a generator of pure light, of one colour, of high intensity and yet with little or no heat certainly appeared as the "Excalibur" of ophthalmic surgery. It is as a result of ophthalmic use that lasers has expanded into most medical and surgical specialties.

Lasers generate electro-magnetic energy ranging from short-wave ultra-violet through the visible spectrum to the far infra-red. It is these longer wavelengths that are in current use for medicine, although new developments are showing additional uses for shorter wavelengths, especially if applied in pulses rather than as a continuous beam. What happens when a laser beam strikes biological tissue varies greatly, depending upon wavelength, power and duration of exposure. Some effects are very difficult to understand and doctors have to be satisfied with a final result; for the time being at least. Other effects like cutting and coagulating are more obvious in use, particularly as there appears to be no danger of overdosing as in the case with ionising radiations like gamma or X-rays.

Similar types of emmission with regard to wavelength may have quite different results when incident on tissue. For example, the very long wavelength of a carbon dioxide laser has little penetrating effect beyond a few tenths of a millimeter. At one tenth this wavelength, the Neodymium Yttrium Aluminium Garnet (Nd-YAG) laser can penetrate up to six millimeters and still perform useful work. The work of course is entirely different.

The tissue effect which is easiest to understand is that produced by long-wavelength lasers. It produces, in somewhat unprofessional terms, cooking on a microscopic scale! What happens when we warm up flesh? That is if we consider infra-red energy for the moment.

(i) up to 50°C, warming of tissue improves capilliary circulation.

* Presidential Address delivered before the Royal Society of New South Wales on 1st April, 1987.

(ii) around 65°C, protein denaturation occurs.
(iii) between 70°C and 100°C the now dead tissue dries out.
(iv) beyond 100°C the dried tissue shrinks and temperature rises rapidly causing the tissue to become charred and vanish as smoke.

Each of these temperature domains can be usefully employed in some treatment or other. Each effect is put to good use by the doctor according to his needs.

The shorter wavelengths of lasers produce quite different effects, the mechanisms of which are not (yet) fully understood, however the therapeutic results are. Low-power lasers have proved to be quite exceptional in their curative roles and the same wavelength may be used in totally different ways according to application. The helium-neon (HeNe) red laser may promote wound healing, be a substitute needle for acupuncture, kill off certain kinds of cancer cells or can be used for the relief of chronic pain. I trust you can now see that just about every kind of laser has its preferred application, and that while some areas of use may be common to two or more wavelengths, no one laser can serve all of the clinicians' requirements.

Let's turn to specific laser types, and start with the one which has been in common use for the longest time: the Carbon Dioxide gas laser. Carbon Dioxide (CO_2) produces a beam in the far infra-red spectrum at 106,000 Ångström. This is a medium power laser of between forty and sixty watts for most work, but the long wavelength creates a major problem. No commonly available material is transparent to it. This means that the entire generating assembly must be aimed at the target, or an elaborate assemblage of reflectors built to guide the beam to the operation site. Last year, however it was announced that an Israeli company had developed a flexible light guide for this laser, but at a very high cost. The CO_2 laser beam cannot penetrate the skin because its energy is strongly absorbed at the surface with little or no scattering. All the energy is dissipated at the surface resulting in a high temperature rise causing the tissue to burn instantly. To many specialists this effect is extremely useful and has contributed to the popularity of this particular laser. It is this laser we call the 'Light Scalpel'. When the beam is focussed to a spot of less than one millimeter it cuts like a knife, leaving a reasonably clean cut which does not bleed, provided vessels larger than about one millimeter have not been traversed. The carbon dioxide laser is very popular for use in micro-surgery where it is coupled to an operating microscope and micromanipulator. In this form it is used by ear-nose-and throat-and neurosurgical specialists. For gynaecology, the laser is linked with other instruments which control the track of the beam as it is most frequently used for tissue ablation. The Nd-YAG laser is also an infra-red generator, not far removed from visible red light. This laser is a solid state device in which the beam of energy is generated within a garnet rod. The name originates from the initials of the elements used in the doping of the garnet during manufacture; viz, neodymium and yttrium. The laser is best described as a coagulating laser, although it is capable of cutting under certain circumstances. The beam wavelength is 10,640 Ångström (1064nm). High power is necessary because of losses due to back-scattering of the incident beam, and absorption within tissue. Nd-YAG lasers range from forty to one hundred and twenty watts in common use. The beam is readily transmitted through quartz or glass with little attenuation. Transmission losses mostly occur at optical interfaces of quartz/air or air/quartz, in other words when the beam enters or leaves an optical system. With the aid of specially developed light-guides the Nd-YAG laser can be used in all fields of classical endoscopy, ie, for the staunching of acutely bleeding ulcers in the gastro-intestinal tract having acquired special significance. In fact, this laser probably has the widest range of use of any clinical laser, it can serve just about any specialty in some way or other. This beam is less strongly absorbed than that of the CO_2, and so can penetrate much deeper. Optical scattering manifests itself strongly and promotes uniform distribution within the tissue resulting in a clearly defined volume coagulation together with an outstanding haemostatic effect. Due to its thermal penetration, the Nd/YAG laser is suitable as a coagulator in places where the aim is thermal destruction without the removal of tissue and little mechanical damage to the tissue surface. By simple variation of output power and or spot size, the depth of homogenous coagulation can be predetermined to reach from 0.2mm to over 5mm. The subsequently deeper penetration in comparison with other laser systems demands the use of high powers. The deep penetration and correspondingly wide damage zone of typically more than 5mm also make it possible to seal up blood vessels several millimeters in diameter. The advantages of the Nd-YAG laser in endoscopy are directly apparent because the possibilities of surgical intervention in body cavities without open surgery are extremely restricted with other methods.

In neurosurgery the Nd-YAG laser offers an additional aid to conventional tumour preparation, particularly in cases where the size of the tumour, its high blood content or its localisation give rise to working difficulties. In oral surgery the use of lasers has been successful in combatting various bleeding disorders. This is of particular significance for the treatment of patients suffering from haemophilia. In gastroenterology, conventional surgical methods in the event of acute gastric or gastro-intestinal haemorrhage lead to mortality rates of up to 60%. This is because operations of this kind normally have to be performed on an emergency basis, often under shock conditions, perhaps without adequate preparation time. By using a Nd-YAG laser such haemorrhage can be sealed off endoscopically directly following localisation. Laser coagulation cannot eliminate the cause of this occurrence of haemorrhage, but once the bleeding is stopped, planned surgical interventions can take place. In urology, both in endoscopic and external use the laser is able to replace known locally applied techniques, such as electro-coagulation. Dissemination of tumour cells by opening of the vessels or through manipulation of the tumour may be prevented by contactless application of the laser beam.

Argon lasers produce a visible beam of blue-green light at 4765 Ångström and are again transmittable through quartz or glass fibres. This laser was earlier used as a coagulating instrument with operating powers of between 20 and 30 watts. However, since blue-green light is strongly absorbed by melanine and haemoglobin, tissue penetration is limited to about 2mm only. Argon lasers are still used in dermatology and ophthalmology but have largely been superceded by the Nd-YAG laser. Currently produced Argon lasers are frequently combined with Krypton lasers to serve wider applications in ophthalmic use. In dermatology the shallow penetration is preferred especially where treatment of 'port-wine stains' is indicated. In this procedure the aim is to reduce both the intensity of colour as well as the roughness of the skin surface which usually accompanies this disorder.

Krypton, the yellow-red laser is best for transmission through clear tissue, and again in ophthalmic use, useful in retinal coagulation near the macula. The Krypton laser can be more efficient and safer than its sister beam provided by the argon laser.

Helium-Neon (He-Ne) lasers are probably the most common form of laser seen in every day use. This laser is used as a pointer at lectures, a measuring beam for surveyors, a needle for the acupuncturist and recently caused a surprise for its many different uses in medicine. Helium-neon has a wavelength of 6323 Ångströms in the visible part of the spectrum, and is very close to the wavelength for optimum transmission through vascular tissue. Typically these lasers run up to about 2mW with 5mW as the maximum power used, but with such good tissue transparency penetration can exceed 10mm. HeNe lasers appear to have no contra-indications in medical use and no overdose limit. They are certainly thought to be the safest of all lasers.

Here we have the case of a laser beam which can be used for several quite different purposes. In wound healing, it has been found that when the margins of a wound or sore are illuminated with HeNe laser light healing times can be reduced by as much as 40%. It is thought that tissue growth is accelerated by increased collogen production caused by the beam. The exact process is not fully understood. This same illumination has been found to be valuable in the relief of chronic pain. Several papers concerning this issue were presented at last year's meeting of laser specialists in Jerusalem. Yet another widely different use for the HeNe lasers is to be found in Photo-Dynamic therapy or PDT as it is commonly known. In this procedure certain cancer cells can be selectively destroyed by a photochemical effect within the cell. This experimental procedure relates to the detection and treatment of certain types of cancer. Initiation of treatment is by means of injection of a photo-active benign dye known as haematoporphorin derivative or HPD. After a short time, the HPD dye is either retained or collected by the malignant cells. When these cells are illuminated with red laser light, a photochemical reaction commences to produce toxic substances from within the cell causing it eventually to die. Photodynamic therapy is a relatively new area of research and currently being pursued by major hospitals in both Sydney and Melbourne.

Copper and gold vapour lasers have been developed which produce beams in the visible part of the spectrum, and are capable of producing more power than equivalent gas lasers. Metal vapour lasers are being used to replace argon and krypton lasers as well as adding service to photo-dynamic therapy research.

As we have seen lasers produce only one working wavelength, suitable for certain limited procedures. The ideal laser as far as the doctor is concerned, would be one that can be tuned to whatever wavelength is required for the job on hand. This ideal seems still a long way off. However, a small step in that direction has been taken with the development of the tunable dye laser. These lasers produce light in the visible spectrum and are indeed tunable over a very limited range. Dyes are injected into the beam of an argon laser and changes of colour occur according to variations of dye used. These lasers are necessarily restricted in power but are being developed with medical uses in mind.

With so many uses in medicine, the laser turns out to be a variety of instruments with a common name. Lasers generate their working beams in a gas discharge, in a solid rod or in a liquid medium. Even rye whisky has been found to be suitable as a laser medium, which may at least add some pleasure for the bio-medical engineer. If a laser could be made to vary its wavelength, more hospitals could afford to own them. For example, the Nd-YAG laser apart from producing a beam wavelength of 10,640Å, can also produce a longer wavelength beam at 13,180 Angström, with powers up to thirty watts. Unfortunately, the device cannot be switched between the two whilst in use.

Returning to the field of ophthalmology, it should perhaps be said that these specialists use just about every type of laser, depending for which part of the eye it is required. Ophthalmologists were the first medical practitioners to use lasers. It has been said in order to predict to-morrow's medical lasers, we should look over the shoulder of today's ophthalmologists.

Lasers are becoming standard equipment in most major hospitals around the world, and many surgical procedures now indicate their preferred use. Lasers are now very much common place instruments used for surgery and medicine.

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Doctoral Thesis Abstract (The University of Sydney): Studies in the Bioactivation of Chemical Carcinogens: Role of *in vitro* Cell Mutagenesis

A. M. Bonin

There are many compounds in the environment, particularly pollutants such as polycyclic aromatic hydrocarbons (PAH) and closely related polycyclic azaaromatics (PAA), which cause cancer in mammals as well as man. These cancers are believed to result from a series of steps which commences with bioactivation of these compounds to reactive intermediate metabolites, followed by reaction of the activated metabolites with critical cellular molecules such as DNA. Such intermediates are termed "genotoxic" and their affinity for the genetic material of cells is exploited in a number of "short-term" assays which have been developed for their rapid detection, employing the induction of mutations as the end point.

The in vitro metabolic activation system employed in mutagenicity assays has long been considered a serious limitation because of the inherent inability to simulate in vivo metabolism. One aspect of this thesis describes a study of inducing agents on the mixed function oxidase (MFO) system which metabolises foreign molecules (xenobiotics) such as the PAH and PAA.

Induction of the MFO in rat liver by the suspect carcinogen, DDT, resulted in a different profile of mutagenic metabolites compared with the standard inducing agent, Aroclor 1254, as determined by both mutagenic and metabolic data. DDT-induced liver MFO enzymes failed, however, to activate the inducing agent itself to a mutagenic intermediate in bacteria (Salmonella/mutagenicity assay).

Furthermore, guinea pig liver microsomes induced by 3-methylcholanthrene (MC) were superior to Aroclor rat liver microsomes in activating all carcinogenic PAH and PAA substances tested to mutagens. The weak carcinogen, benz[c]acridine, was also mutagenic, but only when activated by this preparation.

Another aspect of this thesis reports on a study of the efficacy of mutagenesis assays using bacteria and cultured mammalian (V79) cells in the elucidation of the metabolic pathway whereby two specific PAA, 7MBAC (7-methylbenz[c]acridine) and DBAJAC (dibenz[a,j]acridine) are activated to their ultimate reactive intermediates. Mutagenicity results of synthetic metabolites obtained in both assays implicate bay region diol epoxide formation as a major bioactivation pathway for these compounds, consistent with the bay region theory of carcinogenicity which has been proposed for PAH generally.

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Doctoral Thesis Abstract (The University of Sydney): Crystal Growth and Aerodynamics of Drug Particles

HAK-KIM CHAN

Solid forms of three therapeutic agents were studied for crystal habit modifications and/or aerodynamic properties with the aim to improve the therapeutic efficiency in direct pulmonary administration.

Firstly, cromoglycic acid (CA), characterized by physical and chemical methods, was prepared in forms of elongated fibrous particles suitable for inhalation. The fibres have a geometric standard deviation (σ_g) = 1.88 and a mass median aerodynamic diameter (MMAD) = 0.65µm which is in the respirable range. As compared to the currently used sodium cromoglycate, CA has a much lower aqueous solubility which thus minimizes the hygroscopic growth of the drug particles and favours the pulmonary deposition that may offer a therapeutic advantage. Theoretical calculations of the aerodynamic diameters indicate that the calculated MMAD and σ_g assuming a perpendicular flight orientation of the fibres are in reasonable agreement with the values obtained by cascade impactor.

Secondly, three solid forms of methotrexate (MTX), a widely used chemotherapeutic agent, were found and characterized: tetragonal crystals from hot water crystallization; the original powder with a lower degree of crystallinity from the manufacturer, and an amorphous powder from methanol. Single crystals were prepared with size sufficiently large for the structure to be solved by X-ray diffraction. The results show that conformation of MTX molecules in the crystal is a potential energy minimum and is similar to the proposed structure of dihydrofolate bound to dihydrofolate reductase (DHFR). These results are in disagreement with theoretical studies which suggested that the bound forms of MTX were highly strained, and are therefore of importance to those attempting to design new inhibitor of DHFR. Subsequent habit modification of MTX crystals using various crystallization conditions revealed a similar rounding effect on crystal habit by different additives. The results suggest that rounding of drug particle may be possible simply by using additives during crystallization. This might be useful pharmaceutically for preparing spherical particles to improve the handling and processing characteristics of crystalline solids.

Lastly, mechanistic studies of the formation of 2 distinct crystal habits of hexamethylmelamine (HMM) in different solvents revealed that growth of compact crystals in both polar and non-polar solvents is controlled by volume diffusion. Formation of needle crystals on fast evaporation from polar solvents is the result of diffusion controlled growth along the [0001] direction and surface controlled growth along the [1100] direction. Discrepancies were found between the α-values and the observed growth rates, which may be attributed to volume diffusion. Solute-solvent interactions in solutions are found to be very weak and no statistically predominant stereospecific interaction can be identified as responsible for the habit modifications in different solvents. A solvate of HMM-hexafluorobenzene was also identified.

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Doctoral Thesis Abstract (The University of Sydney): Kinetic Aspects of Calcium Metabolism in Forage Fed Sheep

JEREMY STORER CHRISP

Calcium kinetics in forage fed sheep were investigated by an isotopic dilution technique in three trials. The data from the two lactation and one growth trials were analysed by compartmental analysis using the SAAM program (Simulation Analysis and Modelling). During early lactation (trial one) calcium metabolism was determined in Poll dorset ewes consuming either fresh ryegrass-white clover (Dry Matter Digestibility: DMD = 71% and calcium content: Ca = 5.48 mg/g DM) or greenfeed oats (DMD = 69% and Ca = 3.79 mg/g DM). The importance of supplementary protein to the metabolism of calcium in ewes consuming clover swards was also investigated and further examined in trial two. In the third trial, net faecal endogenous loss of calcium was estimated in Romney wether hoggets consuming either fresh herbage (DMD = 73% & Ca = 12.1 mg/g DM) or a conserved forage (DMD = 57% & Ca = 6.41 mg/g DM). These latter diets were selected to provide variation in the amount of indigestible matter and calcium passing through the gastrointestinal tract.

In the first lactation trial, protein supplementation (100 g/d/head of protected casein per os.) served to increase milk production by up to 24% and changed the rates of calcium transport. The gastrointestinal calcium absorption rate increased (mean +/- s.e.m.: 51.8 +/- 15.3 v 75.4 +/- 4.4 mg/d/kg LW for control & protein groups, respectively) as did skeletal calcium accretion (41.7 +/- 3.8 v 48.6 +/- 5.3 mg/d/kg LW, respectively). Skeletal resorption decreased (66.9 +/- 14.4 v 59.9 +/- 8.6 mg/d/kg LW, respectively) and the overall calcium balance improved (-25.2 +/- 17.2 v -11.5 +/- 4.2 mg/d/kg LW, respectively). In the second lactation trial, unprotected casein was infused (100 g/d/head abomasally) and milk production was balanced between control and supplemented groups offered a similar ryegrass-white clover herbage (DMD = 78% and Ca = 6.47 mg/d DM). Protein supplementation consistently altered the rates of calcium transport in both these trials but not to a significant extent. This was despite a significant improvement in nitrogen balance. Possible reasons for this include: the preference of supplementary casein for energy metabolism rather than for bone matrix synthesis, the suitability of casein as a source of amino acid for this synthesis, or alternatively, that bone mineral losses are inevitable during early lactation.

The availability of dietary calcium from the greenfeed oats was lower than that from the ryegrass-white clover (17 v 19%, respectively). This was unexpected both because of the lower calcium content of the oats and also the high requirement for calcium which resulted from high levels of milk production. All availability values obtained were much lower than the current Agricultural Research Councils value of 68%. The term, availability, was discussed as to its meaning and value.

Net faecal endogenous loss of calcium varied with dry matter intake in the wethers (19.6 to 53.6 mg/d/kg LW). When data from all the three trials were combined, the best predictor of endogenous loss was faecal calcium output. A distinction was made between the parameter of net faecal endogenous loss as opposed to a gastrointestinal secretion of calcium and the relationship between these two identities was also examined.

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Doctoral Thesis Abstract (The University of Sydney): Observations of Alfven Waves in a Tokamak Plasma

A. B. Murphy

In order to heat a tokamak plasma to the temperatures required for thermonuclear fusion to occur, a source of energy additional to the ohmic heating due to the current flowing through the plasma will almost certainly be required. Radiofrequency heating through the excitation of Alfvén waves is a possible means of providing this power.

The thesis is predominately concerned with an experimental investigation of the excitation and propagation of Alfvén waves in a tokamak plasma, and in particular the potential application of Alfvén waves to the heating of a fusion plasma.

A general introduction to the Alfvén wave heating scheme and its theoretical basis is given. A detailed discussion of the effect of a low density edge plasma (which is normally present in a tokamak) on the compressional Alfvén wave dispersion relation is presented.

The TORTUS tokamak, and the radiofrequency apparatus and procedures employed in the experiments, are described in detail. The construction of the antennas used, and their properties in the absence of a plasma, are discussed.

Experimental investigations of the plasma loading of a large number of antenna configurations are presented. It is demonstrated that the anomalously large resistive and inductive loading of some antenna configurations is due to the connection of extra current paths by the plasma. The dependence of antenna loading on antenna configuration and excitation frequency, and plasma parameters, is discussed.

Measurements of the poloidal and radial distribution of the magnetic fields associated with the waves excited by a Faraday shielded antenna, oriented in a poloidal plane of the tokamak, are presented. It is shown that the antenna directly couples to the torsional Alfvén wave, which propagates along magnetic field lines in the edge plasma. The antenna excitation frequency and plasma electron density dependence of this undesirable coupling is investigated. Means of minimising the coupling are suggested.

Coupling of energy from the antenna to Alfvén resonance surfaces well inside the central plasma (as required for Alfvén wave heating) is also observed, through significant wave field enhancement at the theoretically predicted radii. Experiments utilising a phased array of three toroidally spaced antennas indicate that energy is coupled to the Alfvén resonance surfaces through excitation of the surface branch of the compressional Alfvén wave. A significant proportion of the total wave energy is shown to be coupled to surfaces well inside the central plasma, which is a result favourable to the prospects of the Alfvén wave heating scheme.

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Annual Report of Council for the Year Ended 31st March, 1988

MEETINGS

Nine general monthly meetings and the annual general meeting were held during the year. The average attendance was 27 (range 15 to 52). Abstracts of the addresses were published in the Newsletter. The meetings were held at the Lilac Room, the Australian Museum.

The 44th Clarke Memorial Lecture for 1987 was delivered by Associate Professor J.J. Veevers of the School of Earth Sciences, Macquarie University, on Wednesday, 5th August, 1987, at Macquarie University. The title of the Lecture was "Earth History of the South-east Indian Ocean and the conjugate margins of Australia and Antarctica".

Eleven meetings of Council were held at the Society's Office, 134 Herring Road, North Ryde. The average attendance was 10.

PUBLICATIONS

The Journal and Proceedings, Volume 120 Parts 1 and 2 were published in September, 1987, incorporating the inaugural Poggendorff Memorial Lecture 1986, and four papers delivered at the 25th Anniversary of the New England Branch on 24th March, 1986. Parts 3 and 4 of Volume 120 are in press and include the Annual Report of Council for 1987. Council again thanks the voluntary referees who assessed papers for publication. The assistance of Miss H. Basden in processing the printing is gratefully acknowledged.

Nine issues of the Newsletter were published. Council is most grateful to the authors of short articles, which are much appreciated by members.

MEMBERSHIP

The membership of the Society at 31st March, 1988, was:

Honorary Members	14
Life Members	28
Ordinary Members	267
Absentee Members	10
Associate Members	21
Total	340

During the year the deaths were announced with regret of the following members:

George Henry Briggs (1919), Life Member, died 24.7.87;
Henry Arthur James Donegan (1928), Life Member, died 1.10.87;
David Gordon Drummond (1975), died 20.11.87;
Henry James Emmerton (1940), died 27.2.1987;
Ivor Vickery Newman (1932), Life Member, died 5.5.87.

AWARDS

The following awards were made for 1987:

Clarke Medal: Dr. Antony James Underwood
Cook Medal: Dr. Phillip Garth Law
The Society Medal: Dr. George Studley Gibbons
Edgeworth David Medal: Dr. Andrew Cockburn
Archibald D. Olle Prize: Dr. S.J. Riley and Mr. H.M. Henry.

SUMMER SCHOOL

A most successful Summer School on "Environmental Issues" was held from 11th to 15th January, 1988, at Macquarie University. It was attended by 24 students and 15 speakers took part. The Summer School was organised on the Society's behalf by Mrs. M. Krysko. The Society's appreciation is extended to Mrs. Krysko and to Council members who assisted her. Council also wishes to thank the speakers, and the National Acoustics Laboratory, Chatswood, and MWS & DB Laboratory, West Ryde, where half-day excursions were held. The School was opened by the Hon. Bob Carr, and students were welcomed to the University by the Vice-Chancellor, Professor D. Yerbury.

LIBRARY

Acquisitions by gift and exchange continued as heretofore, the overseas and some Australian material being lodged in the Royal Society Collection, Dixson Library, University of New England and other Australian material being lodged in the Society's office at North Ryde. The cataloguing of the Collection at Armidale is nearing completion and it is hoped that a printed catalogue can be produced early in 1988. The Council thanks Mr. K. Schmude, University Librarian, for his care and concern in ensuring the smooth operation of the Collection.

Mrs. Grace Proctor has continued to supervise the North Ryde collection and to liaise with Mr. Schmude and other New England librarians when necessary. The Council is very grateful to Mrs. Proctor for her continuing voluntary assistance and for a substantial donation to the Dixson Library to establish a special endowment fund for the growth and preservation of Special Collections, particularly the Royal Society Collection.

NEW ENGLAND BRANCH

The New England Branch held four very well attended meetings during the year 1987/88. They were:

8 May: Dr. D.O. Zimmerman, Managing Director (Aust.) Uranerz:

"Multiple Land Use: Examples from mining in Germany and Australia.

22 May: Dr. John Daw, Anglo-Australian Telescope: "Supernovae".

22 September: Dr. F. Sampson, Reader in Botany, Victoria University, Wellington: "Pollen Grains of Flowering Plants".

15 March: Professor R.D. Davies, President of the Royal Astronomical Society: "Astronomy, Ancient and Modern".

FINANCE

The accounts for 1987 show a deficit from operations of $1181, an increase of $226 over the previous year's result. The principal contributor to the 1987 result was an unavoidable decrease in interest income of $1877. A detailed analysis of other significant contributing factors shows that the implied cost of writing-off unfinancial members ($500), and reduction in publication sales ($300) were not sufficiently outweighed by savings on general, publication and secretarial expenses ($1800).

The net assets of the Society at the end of 1987 were $131,000, down $1500. They were principally represented by interest-bearing, Trustee-Act-authorised, investments of $121,000 (up $700). No significant new investments were possible during the year, but your Honorary Treasurer and Council retain the object of building as substantial a secure investment base as possible. The Society receives no Government grants and must stand on its own feet financially.

The professional assistance of Mr. A.M. Puttock, F.C.A., in the conduct of the Society's finances is again acknowledged with gratitude.

ABSTRACT OF PROCEEDINGS

The 120th Annual General Meeting and nine General Monthly Meetings were held during 1987. The August and September General Monthly Meetings were held at Macquarie University; the other meetings were held in the in the Lilac Room of the Australian Museum. Abstracts are given below.

APRIL 1

983rd General Monthly Meeting. Location: Australian Museum. The President, Mr. M.A. Stubbs-Race, was in the Chair, and 20 members and visitors were present. Colleen Ann Drew was elected to membership.

The death of Mr. Harry A.T. Scholer on 6.12.86 was announced with regret.

120th Annual General Meeting. Followed the 983rd General Monthly Meeting. The Annual Report of Council and the Annual Financial Report were adopted.

The following awards for 1986 were announced: Walter Burfitt Prize: Professor Brian Norman Figgis; Clarke Medal (Geology): Associate Professor David Ian Groves; The Society Medal: Professor Sydney Charles Haydon; and the Edgeworth David Medal: Dr. Peter Gavin Hall and Dr. Leslie David Field.

Messrs. Wylie and Puttock, Chartered Accountants, were elected Auditors for 1987.

The following Office-Bearers were elected for 1987/88:

President:	Dr. F.L. Sutherland
Vice-Presidents:	Mr. M.A. Stubbs-Race
	Professor J.H. Loxton
	Dr. R.S. Bhathal
	Professor R.L. Stanton
	Dr. R.S. Vagg
Hon. Secretaries:	Dr. D.J. Swaine
	Mrs. M. Krysko v. Tryst
Hon. Treasurer:	Dr. A.A. Day
Hon. Librarian:	Miss P.M. Callaghan

Members of Council: Mr. H.S. Hancock, Professor R.M. MacLeod, Mr. R.A.L. Osborne, Mr. T.J. Sinclair, Mr. M.L. Stubbs-Race, Mr. J.A. Welch and Associate Professor D.E. Winch.

The retiring President, Mr. M.A. Stubbs-Race, delivered his Presidential Address entitled "Lasers in Surgery and Medicine".

The incoming President, Dr. F.L. Sutherland, proposed a vote of thanks.

MAY 6

984th General Monthly Meeting. Location: The Australian Museum. The President, Dr. F.L. Sutherland, was in the Chair, and 18 members and visitors were present. Dr. Jeremy Storer Chrisp was elected to membership.

The Society's Medal for 1986 was presented to Professor S.C. Haydon.

Papers read by title only: K. Campbell: "Evolution Evolving"; R.H. Crozier: "Selection, Adaption and Evolution"; G. Miklos: "Molecular, Facts and Evolutionary Theory"; and D.P. Craig: "Science: the private and the public face".

The death was announced of Mr. Henry James Emmerton (27.2.87).

A talk on "Genetic Fingerprinting" was given by Dr. Michael Denton of the Department of Clinical Chemistry, Prince of Wales Hospital.

JUNE 3

985th General Monthly Meeting. Location: The Australian Museum. In the absence of the President, Dr. D.J. Swaine, was in the Chair, and 22 members and visitors were present. Ian Terence Graham was elected to membership.

The Clarke Medal (in geology) for 1986 was presented to Associate Professor D.I. Groves of the University of Western Australia.

The death was announced of Life Member, Dr. Ivor Vickery Newman, on 5 May, 1987.

A talk on "The Macleays and the Macleay Museum" was given by Dr. Woody Horning, Curator of Invertebrates and Research Fellow at the Macleay Museum, University of Sydney.

JULY 1

986th General Monthly Meeting was replaced by a Members' Evening at the Australian Museum. It was attended by more than 40 members and friends. After an introductory converzatione over refreshments, Dr. Robyn Williams from the Australian Broadcasting Commission Science Unit, gave a short talk. The talk was followed by a tour of the Planet of Minerals Gallery. The Society then joined a joint gathering of the Australian Museum Society and Australian Conservation Foundation to hear Dr. Williams speak on "Facing up to the Future".

AUGUST 5

987th General Monthly Meeting. Location: Theatre T2, Building E7B, Macquarie University. The President, Dr. F.L. Sutherland, was in the Chair, and 52 members and visitors were present.

The death was announced with regret of Life Member, Dr. George Henry Briggs, 24 July, 1987.

Papers read by title only: J.J. Brophy, E.V. Lassak and D.J. Boland: "Volatile Leaf Oils of two Sub-Species of *Melaleuca acadioides* F. Muell."; E.G. Akpokodje: "The Mineralogical Relationships between Some Arid Zone Soils and their Underlying Bedrocks at Fowlers Gap Station, N.S.W., Australia".

The Walter Burfitt Prize for 1986 was presented to Professor B.N. Figgis of the University of Western Australia.

Associate Professor J.J. Veevers delivered the 44th Clarke Memorial Lecture entitled "Earth History of the South East Indian Ocean and the conjugate margins of Australia and Antarctica".

SEPTEMBER 2

988th General Monthly Meeting. Location: Theatre T2, Building E7B, Macquarie University. The President, Dr. F.L. Sutherland, was in the Chair, and 27 members and visitors were present.

Papers read by title only: H.A. Martin: 'Stratigraphic Palynology of the Lake Menindee Region, North-West Murray Basin, N.S.W."; J.J. Veevers: "Earth History of the Southeast Indian Ocean and the Conjugate Margins of Australia and Antarctica"; H.M. Henry: ""Mellong Plateau, Central N.S.W.: An anomalous landform"; S.J. Riley and H.M. Henry: "A geophysical survey of Couloul and Mellong Creek Valley Fills: Implications for Valley Development in Sandstone Terrain".

Dr. Alan Vaughan, Senior Lecturer in Physics at Macquarie University, gave a talk on "Recent Developments in Astronomy". After the meeting members and friends were invited to inspect the Macquarie University Observatory at the sportsground.

OCTOBER 7

989th General Monthly Meeting. Location: The Australian Museum. The President, Dr. F.L. Sutherland, was in the Chair, and 17 members and visitors were present. Christopher David Kimpton and Patricia May Porritt were elected to membership.

The death of Mr. Henry Arthur James (Harry) Donegan on October 1, 1988, was announced with regret.

Papers read by title only: J.A. Dulhunty, E. Middlemost and R. Beck: "Potassium-Argon Ages, Petrology and Geochemistry of some Mesozoic Igneous Rocks in Northeastern N.S.W."; M.B. Katz: Analysis of a Small-Scale Fault at Bingi-Bingi, NSW, and Speculations on its Relationship to a Large-Scale Transform Fault of the Tasman Sea".

A talk entitled "The Catastrophe of Coma. A Way Out" was given by Dr. E.A. Freeman, Director of the Brain Injury Therapy Centre, Eastwood.

NOVEMBER 4

990th General Monthly Meeting. Location: The Australian Museum. The President, Dr. F.L. Sutherland, was in the Chair, and 33 members and visitors were present.

A forum on "Astrology" was held with the following three speakers: Mr. David Ellyard, ABC Quantum program, Dr. P. Slezek, School of History and Philosophy of Science, University of N.S.W., and Mr. John Clarke, Sydney Astrology Centre, Chippendale.

DECEMBER 2

991st General Monthly Meeting. Location: The Australian Museum. The President, Dr. F.L. Sutherland, was in the Chair, and 15 members and visitors were present.

The death was announced of Dr. David Gordon Drummond on November 20, 1988.

Mr. Vaughan Evans of the Australian Association for Maritime History gave a talk entitled "Man is Not Lost", a history of navigation instruments from 15th to 18th Century.

AUDITORS REPORT

In our opinion:

(a) the attached accounts, set out on pages 2 to 10 which have been prepared under the historical costs convention, are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society at 31st December 1987 and of the results of the Society for the year ended on that date; and

(b) the accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provisions of those Rules

WYLIE & PUTTOCK
Chartered Accountants.

By ALAN M. PUTTOCK
Registered under the Public Accountants Registration Act, 1945 as amended.

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET as at 31st December 1987

	RESERVES		
7310.57	**Library Reserve (note 2(a))**		7310.57
5709.22	**LIBRARY FUND (note 2(b))**		6676.36
21202.75	**TRUST FUNDS (note 3)**		19565.24
98422.34	**ACCUMULATED FUNDS**		97560.31
132644.88	**TOTAL RESERVES AND FUNDS**		131112.48
	Represented by:		
	CURRENT ASSETS		
400.00	Petty Cash Imprest	195.20	
3059.50	Debtors for Subscriptions 1707.95		
3059.50	Less Provision For Doubtful Debts 1707.95		
6962.65	Other Debtors & Prepayments	8351.78	
8125.89	Cash at Bank	2979.80	
15488.54			11526.78
	Less: CURRENT LIABILITIES		
16220.00	Sundry Creditors & Accruals	14230.58	
27.37	Life Members Subscriptions - Current Portion	35.37	
79.63	Membership Subscriptions Paid in Advance	36.70	
1473.23	Subcriptions to Journal Paid in Advance	1562.82	
17800.23			15865.47
2311.69	NET CURRENT LIABILITIES		4338.69
	Add: FIXED ASSETS		
1101.66	Furniture, Office Equipment, etc.- at cost less Depreciation	986.66	
13600.00	Library - 1936 Valuation (note 4)	13600.00	
10.00	Pictures - at cost less Depreciation	10.00	
14711.66			14596.66
12399.97			10257.97
	Add: INVESTMENTS		
5400.00	Commonwealth Bonds & Inscribed Stock	5400.00	
100000.00	Loans on Mortgage	100000.00	
15000.00	Interest Bearing Deposits	15698.73	
120400.00			121098.73
132799.97			131356.70
	Less: NON-CURRENT LIABILITIES		
155.09	**Life Members Subscriptions - Non-Current Portion**		244.22
132644.88	**NET ASSETS**		131112.48

F.L. SUTHERLAND President

A.A. DAY Honorary Treasurer

STATEMENT OF ACCUMULATED FUNDS
For the Year Ended 31st December 1987

1986			1987
(954.58)	OPERATING DEFICIT for year		(1180.57)
1044.36	Donations & Interest to Library Fund		1285.68
1497.18	Transfer from Library Fund		318.54
97879.74	Accumulated Funds - Beginning of Year		98422.34
99466.70	AVAILABLE FOR APPROPRIATION		98845.99
1044.36	Transfer to Library Fund	1285.68	
1044.36			1285.68
98422.34	ACCUMULATED FUNDS Current Year		97560.31

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1987

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1987. Unless otherwise stated, such accounting policies were also adopted in the preceding year

(a) Basis of Accounting

The accounts have been prepared on the basis of historical costs

(b) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

Furniture	7.50%
Office Equipment	15.00%

2. MOVEMENTS IN PROVISIONS AND RESERVES

(a) Library Reserve

1986			1987
7310.57	Balance at 1st January		7310.57
7310.57			7310.57
0.00	Transfer to Accumulated Funds	0.00	
7310.57	Balance at 31st December		7310.57

(b) Library Fund

1986			1987
6162.04	Balance at 1st January		5709.22
1044.36	Add Donations and bank interest		1285.68
7206.40			6994.90
297.18	Less Library purchases and expenses	318.54	
1200.00	Transfer to general fund re costs exchange jnls for library	0.00	
1497.18			318.54
5709.22	Balance at 31st December		6676.36

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1987

3. TRUST FUNDS

	Clarke Memorial Fund - Capital			
5000.00	Balance at 1st January	5000.00		
5000.00	Balance at 31st December		5000.00	
	Clarke Memorial Fund - Revenue			
841.54	Revenue Income for Period	745.70		
348.02	Less Expenditure for Period	1074.46		
493.52		(328.76)		
(89.08)	Balance at 1st January	404.44		
404.44	Balance at 31st December		75.68	
5404.44				5075.68
	Walter Burfitt Prize Fund - Capital			
3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	
	Walter Burfitt Prize Fund - Revenue			
504.92	Revenue Income for Period	447.42		
112.36	Less Expenditure for Period	680.15		
392.56		(232.73)		
2440.93	Balance at 1st January	2833.49		
2833.49	Balance at 31st December		2600.76	
5833.49				5600.76
	Liversidge Bequest Fund - Capital			
3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	
	Liversidge Bequest Fund - Revenue			
504.92	Revenue Income for Period	447.42		
960.85	Less Expenditure for Period	520.00		
(455.93)		(72.58)		
1512.58	Balance at 1st January	1056.65		
1056.65	Balance at 31st December		984.07	
4056.65				3984.07

	Olle Bequest Fund - Capital			
4000.00	Balance at 1st January	4000.00		
4000.00	Balance at 31st December		4000.00	
	Olle Bequest Fund - Revenue			
673.23	Revenue Income for Period	596.56		
4.84	Less Expenditure for Period	1600.00		
668.39		(1003.44)		
1239.78	Balance at 1st January	1908.17		
1908.17	Balance at 31st December		904.73	
5908.17				4904.73
21202.75	**Total Trust Funds**			19565.24

4. LIBRARY

During the 1983 year the Society gifted the serials collection component of the library to the University of New England. The Society has retained that section of the library which is of historical significance. At the 31st December, 1987 a current valuation of the library had not yet been obtained.

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31st December 1987

	INCOME			
	Membership Subscriptions			
7379.30	- Ordinary			6852.30
	Membership Subscriptions			
27.37	- Life Members			35.37
75.00	Application Fees			25.20
----------				----------
7481.67				6912.87
	Subscriptions and			
	Contributions to Journal			
6613.58	Publication Costs			12080.91
----------				----------
	Total Membership and			
14095.25	Journal Income			18993.78
17372.48	Interest Received			15495.38
234.00	Sale of Reprints			30.00
59.55	Sale of Back Numbers			39.20
	Sale of Other			
103.00	Publications			20.00
154.46	Summer School Surplus			392.22
52.87	Annual Dinner Surplus			0.00
75.00	Other Income			157.80
----------				----------
32146.61				35128.38
	Less:EXPENSES			
1200.00	Accountancy Fees		1500.00	
600.00	Audit Fees		750.00	
	Bank Charges & Government			
24.50	Duties		29.95	
150.00	Branches of the Society		200.00	
128.00	Depreciation		115.00	
198.20	Entertainment Expenses		143.25	
66.01	Insurance		65.44	
	Journal Publication and Distribution Costs			
14063.40	Printing	17700.16		
1200.00	Wrapping & Postage	2600.14		
----------		----------		
15263.40			20300.30	
297.18	Library Expenses		318.54	
184.05	Miscellaneous Expenses		168.80	
120.00	Monthly Meeting Expenses		200.18	
	Newsletter Printing &			
2431.32	Distribution		1825.37	
475.52	Postage		418.92	
	Printing & Stationery -			
635.07	General		358.13	
	Provision for Doubtful			
1218.40	Debts		31.45	
2000.00	Rent		2000.00	
183.10	Repairs & Maintenance		322.50	
7691.87	Salaries		7327.47	
234.57	Telephone		233.65	
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33101.19				36308.95
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954.58	DEFICIT for the year			1180.57
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STATEMENT OF SOURCE AND APPLICATION OF FUNDS
For the Year Ended 31st December 1987

	SOURCE OF FUNDS		
	Donations and interest to		
1044.36	library fund		1285.68
2524.61	Trust fund income		2237.10
	Reduction in working		
4488.15	funds		3378.55
	Life Membership		
0.00	Subscriptions		132.50
----------			----------
8057.12			7033.83
==========			==========
	APPLICATION OF FUNDS		
	Operating deficit for the		
954.58	year	1180.57	
	Less:		
	Items not involving the outlay		
	of funds in the current period:		
	Depreciation of fixed		
128.00	assets	115.00	
	Provision for doubtful		
511.90	debts	(1351.55)	
----------		----------	
	Funds applied to		
314.68	operations		2417.12
	Reclassification of life		
	members subscriptions in		
27.37	advance		43.37
6289.00	Increase in investments		698.73
1426.07	Trust fund expenses		3874.61
----------			----------
8057.12			7033.83
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Awards

THE JAMES COOK MEDAL

PHILLIP GARTH LAW

Dr. Phillip Garth Law, AO, CBE, MSc, D.App.Sci.(Hons.), FAA, FTS, FAIP, is a graduate of the University of Melbourne, where he also lectured in the Physics Department. His research on cosmic rays was furthered by voyages to Japan and Antarctica. He was Director of the Antarctic Division in the Department of External Affairs and Leader of the Australian National Antarctic Research Expeditions from 1949 to 1966. From 1966 to 1977 he was executive vice-president of the Victoria Institute of Colleges and later became president of the Victorian Institute of Marine Sciences. His forthright views often state the sound commonsense that many others feel, but do not express.

Dr. Law made 28 journeys to Antarctica and took part in mapping 6500km of coastline. J. Chester has stated recently that "Never again would ANARE or Australia's Antarctic involvement be as influenced by one individual". His accomplishments may well exceed those of Scott, Shackleton and Mawson. He has done more than any other person to ensure that Antarctica remains a special place, an immense natural reserve open to all nations, yet protected from undue exploitation. In view of James Cook's forays into Antarctica, it is surely fitting that the James Cook Medal is being awarded to an eminent polar explorer, Dr. Phillip Law, who has also made significant contributions to education.

D.J. Swaine

CLARKE MEDAL

ANTONY JAMES UNDERWOOD

Dr. Antony James Underwood, B.Sc. (Hons.), Ph.D., D.Sc. (Bristol), FIB, FAIB, is an outstanding marine zoologist and leading experimental scientist in Australia. He commenced post-doctoral studies on experimental intertidal ecological research at the University of Sydney in 1972. He pioneered such studies in Australia with his work on the ecology of New South Wales coastal marine invertebrates. His intellectual and practical skills allowed him to design manipulative experiments on animals in their natural habitat. As a result, his studies attracted considerable post-graduate student support, making the fauna of shallow-water ecosystems in New South Wales among the best studied and understood in the world. Dr. Underwood's work has shown the ecological processes on New South Wales shores are uniquely different from those studied in other parts of the world. This has gained him world recognition in the ecological based literature.

Besides the academic side of his work, the results have been recognized in development of procedures of management and conservation of natural resources. He has extended the work on teaching side to run courses for the public in Seashore Ecology. This has raised general awareness of the need for better understanding of the New South Wales shorelines.

The high quality and innovative aspects of his work have been recognized recently with the awarding of a D.Sc. and election to fellowship of the Institute of Biology in the United Kingdom in 1985 - and election as a fellow of the Australian Institute of Biology in 1986. He presently occupies the position of both Reader in Experimental Ecology and Director, Institute of Marine Ecology at the University of Sydney. He is a member of many professional societies in Australia and overseas and serves on the editorial boards of international journals.

He has participated in many conferences, research seminars and invited lectures around the world. He has nearly sixty research papers and contributions published in the literature with his co-workers, including ten general reviews of related ecological fields.

The award for the Clarke Medal for 1987 is a fitting reqard for Dr. Underwood's outstanding achievements in Australian marine zoology.

F.L. Sutherland

THE SOCIETY'S MEDAL

GEORGE STUDLEY GIBBONS

The Society's Medal for contributions to the progress of the Society and to Science is awarded to Dr. George Studley Gibbons, MSc, PhD. Dr. Gibbons graduated BSc from the University of Sydney and PhD from the University of N.S.W. After Several years at the Geological Survey of N.S.W., he joined the New South Wales Institute of Technology. As Head of the Department of Geology there, he developed a well-integrated and respected department. A feature of his approach was his time spent as a visiting scientist in industry and academia, thereby gaining real insight into diverse aspects of geology. Dr. Gibbons has always appreciated the nexus between field and laboratory studies, as is shown by his research in mineralogy, mineral resources and the conservation of building materials.

George Gibbons joined the Society in 1966, became President in 1980 and Vice-President in 1981. Since 1981 he has been the Society's delegate to the Council of Heritage Organizations (NSW). In 1986 he was appointed Assistant Director of the Geological Survey of N.S.W., where he is currently responsible for the North-east and Far West Regions and for the Specialist Services Section. Dr. Gibbons' contributions to the Society and to Earth Sciences make him a worthy recipient of the Society's Medal.

D.J. Swaine

THE EDGEWORTH DAVID MEDAL

ANDREW COCKBURN

Dr. Andrew Cockburn, MSc, PhD, is a graduate of Monash University, where he received several undergraduate and postgraduate awards. His postdoctoral studies were supported by a CSIRO Studentship and a prestigious Queen Elizabeth II Fellowship. Apart from a year at the University of California, Berkeley, his research has been carried out in Australia. In 1984, he was appointed to the staff of the Department of Zoology at the Australian National University.

Dr. Cockburn's research is of a very high quality. He has put forward new perceptions about interrelationships between small mammals of heathlands and woodlands of eastern Australia. Another outcome of his research is the testing of some present ideas in evolutionary ecology. Current work on the small marsupial *Antechinus stuartii* is generating new ideas in general ecological theory and providing crucial tests of older theories. His approach is to do field work based on theory. In other words, he plans detailed field work to test hypotheses, not the usual approach of ecologists.

Dr. Cockburn has already published 2 books and about 30 papers. In his latest book he "attempts to forge a synthesis between the discipline of behavioural ecology and what is known of the social behaviour and population dynamics of cyclic populations of vertebrates", surely an important aspect of modern ecology. In his teaching, Dr. Cockburn shows the "same critical faculty, the same penetrating insight and the same integrative capacity" that is a feature of his research. Dr. Cockburn has established an international reputation for sound research in a field weighed down with untested theories. The Edgeworth David Medal is for distinguished research by a scientist under 35 years of age. Clearly, Dr. Cockburn is an outstanding scientist in the field of evolutionary ecology and is of the calibre that makes him a worthy recipient of the Edgeworth David Medal.

D.J. Swaine

ARCHIBALD D. OLLE PRIZE

The Archibald D. Ollé Prize is for excellence in an original scientific paper contributed by a member of the Society to the Society's Journal and Proceedings. The Prize is awarded to Dr. S.J. Riley and Mr. H.M. Henry, Macquarie University, for their paper entitled "A Geophysical Survey of Culoul and Mellong Creeks Valley Fills: Implications for Valley Development in Sandstone Terrain", published in the Journal and Proceedings, Volume 120 Parts 3/4.

Dr. S.J. Riley, who is a Senior Lecturer in the School of Earth Sciences, Macquarie University, has always been interested in aspects of Earth surface processes as they relate to water. He has worked in a variety of environments with a number of different organisations and persons. He has studied erosion processes in forested areas, hillslope hydrology in forested and agricultural areas, the alluvial stratigraphy and geomorphic history of rivers in western N.S.W., secular changes in the hydrology and morphology of river systems, and the hydrology and erosion characteristics of roads and freeways. He has published more than 30 papers and has organised several conferences. His association with Mr. Henry began in 1974 and has continued over the years with their common interests in river systems. The paper was based on a research project which started about 10 years ago. Because Mr. Henry was still active in his law firm he pursued his studies part-time, and graduated from Macquarie University's School of Earth Sciences in 1972 with a BA. He has published two other papers in the Journal and Proceedings.

Biographical Memoirs

HENRY ARTHUR JAMES DONEGAN

(1902-1987)

Henry Arthur James ("Harry") Donegan, who died on October 1st, 1987, at the age of 85, was a member and active supporter of the Royal Society of N.S.W. for 59 years. He was elected to membership of the Society in October 1928, and was made a Life Member in 1964.

Mr. Donegan served on the Council of the Society for 13 years, holding the offices of Honorary Treasurer from 1952 to 1957, Vice President 1958-59 and President in 1960. He was awarded the Society's Medal for 1966 for "meritorious contributions in the fields of mining and mine safety" and for his services to the Society.

A brilliant scientist, Mr. Donegan spent all his working life in the N.S.W. Department of Mines. He joined the Department as a clerk and after 47 years service, retired as Chief Analyst. His contributions to his field of work, study, research and development are summarized in the citation for the Society's Medal in 1966:

> ".... Mr. Donegan was the first in Australasia to investigate coal and oil shales by low temperature carbonization, to determine the explosibility of coal and shale, mine dusts and other dusts; to test self-contained breathing apparatus used in mine work; to investigate and recommend use and conditions of diesel locomotives in underground mines; to determine ash fusion points of Australian and New Zealand coals, and to thoroughly appraise the oil shale seam at Glen Davis."

Mr. Donegan was the author of many departmental publications and reports, and many articles in technical journals both in Australia and Great Britain, thus ensuring that his valuable contributions to mining and chemical sciences were well documented.

The dedication and enthusiasm which was evident in Mr. Donegan's professional life was found also in his recreational and social life.

Throughout his life he maintained a love of, and loyalty to the Scout Movement which he joined in Grafton in 1915. In 1928, he formed the Ramsgate Group, where he was Scout Leader for many years, and later a District Commissioner. He was named an Honorary Commissioner when he retired from active involvement in 1955. He was awarded scouting's highest honour, the silver acorn in 1983. Mr. Donegan also held scouting's highest honour for bravery for his part in the rescue of a shark-attack victim in 1944. Both he and a Cronulla life-saver who assisted in the rescue were awarded the Royal Humane Society's silver medal.

Mr. Donegan was born in England in 1902 and came to Australia in 1910. In his youth he rowed for Leichhardt Rowing Club. He was also a foundation member of Ramsgate Swimming Club, and a vice president of St. George Soccer Club.

He held a Master of Science degree, and had almost completed his thesis for a Ph.D. when he died. He was made a Member of the Order of Australia (AM) in 1975.

The Society proudly salutes the memory of friend and colleague Harry Donegan - a fine intellect, a brave man and a true philanthropist.

Mr. Donegan is survived by his wife, his son Brian, of Newcastle, and daughters Barbara (Mrs. Hardy) of Oatley West and Marion (Mrs. Delaney), of Coffs Harbour.

B. Hardy

GEORGE HENRY BRIGGS

(1893-1987)

George Henry Briggs, a Life Member of the Royal Society of N.S.W. and a member since 1919, died on July 24, 1987 at the age of 94. He was the Society's longest surviving member and was, for all those years, a strong supporter of the Society. His membership of the Society was proposed by three very eminent scientists of their day, Professor J.A. Pollock, O.U. Vonwiller and Sir Edgeworth David. During his life, Briggs made several substantial donations to the Society's Library Fund and he left a Bequest to the Society in his Will.

In 1979, while recounting something of his personal and professional life, Briggs remarked:

> "Looking back on my career, I have probably seen the most rapid rate of development" (of science) "in all time. When I was a boy, there were no aeroplanes, radioactivity had not been discovered, we knew little about the nature of the universe in which we live and we are finding out more about this universe at a greater rate than ever."

This is indeed true and Briggs himself made very significant contributions to the development of physics in Australia, particularly in the fields of precise physical measurement and in his studies in radioactivity. He played a leading role in the provision of physical units and standards of measurement for the nation through the National Standards Laboratory and in the organisation of physicsts through the establishment of their own professional Institute. He may be reagarded as one of the founding fathers of modern physics in Australia.

Born in Sydney on March 23, 1893, he was the only child of William Briggs of Halifax, Yorkshire and of Hanna (nee Bennett) of Surrey, England. His childhood was spent at Concord, Sydney and his secondary schooling at Fort Street High School, Patersham, incidentally with N.A. Esserman and H.V. Evatt with both of whom he was closely associated in later life.

On matriculation, Briggs entered Sydney University in the Faculty of Engineering but transferred to Science in his third year. He graduated B.Sc. with Honours in Physics and Mathematics in 1916, and, continuing in the Physics Department under Professor J.A. Pollock, he was appointed Lecturer in 1918. His early research, at the suggestion of Associate Professor E.M. Wellish (Applied Mathematics) was concerned with radioactivity and this remained Briggs' main research interest until he left the University in 1939 to become Officer-in-Charge of the Physics Section of the C.S.I.R. National Standards Laboratory.

His principal concern, for which he was awarded his D.Sc. by Sydney University in 1937, was the measurement of the absolute velocities of alpha particles from the products of radioactive decay.

He was granted leave of absence from the University to study at the Cavendish Laboratory, Cambridge (Emmanuel College) in 1925 where he worked on a problem suggested by Rutherford on the nature of the charge of the alpha particle as it passed through gases. The laboratory in which he did this work was, in fact, next to Rutherford's own laboratory. There is no doubt that Rutherford's influence on Briggs was very considerable. These were the golden years of the Cavendish with such notables as J.J. Thompson (the electron), Chadwick (the neutron), C.T.R. Wilson (cloud chamber), Blackett (cosmic rays), Kapitza (high magnetic fields) and Oliphant making their mark.

After two years at Cambridge, Briggs gained his Ph.D. and returned to the University of Sydney, where in 1928 he was appointed Associate Professor.

It was my privilege to work with him in 1933-35. While Briggs was measuring the absolute velocities of alpha particles, under his guidance I was making somewhat similar measurements on the velocities of beta particles from Ra(B+C). The key to these precise measurements was a current balance which "weighed" the magnetic field used to deflect the particles.

In 1935-37, Briggs went overseas on sabbatical leave, spending time at the Cavendish and the University of California, Berkeley.

When the Government decided C.S.I.R. should establish a National Standards Laboratory, Briggs with N.A. Esserman and D.M. Myers were appointed to head its three Sections and proceeded to the National Physical Laboratory, U.K. to study the organisation and techniques of a national measurement laboratory and to order the basic equipment for the Australian laboratory. They were later joined by six other appointees, including Giovanelli and myself.

When war was declared in September 1939, our services were made available to N.P.L. for a period but we then again took up the task of preparing for the establishment of N.S.L., which was effected in 1940-41.

Dr. Briggs continued as head of the Physics Section (Division of Physics after 1945) until his retirement in 1958, when he was made an Honorary Research Fellow and continued research until failing eyesight and ill health intervened. His chief concern at this time was the measurement of the gyromagnetic ratio of the proton and, as an offshoot from this, the development of electrical resistors which were particularly stable (to about 1 part in 10^8/a).

While Briggs' principal interest was in physical research, he proved himself a good administrator and under his leadership the Division of Physics of N.S.L. quickly came to be well regarded both nationally and internationally.

Initially in 1940-45, it was heavily engaged in work related to the war effort but thereafter concentrated on its primary purpose of establishing and maintaining national physical standards in such fields as temperature measurement, photometry, viscometry, colorimetry and the maintenance of the volt.

In 1946-47, Briggs was seconded as Scientific Adviser to Dr. H.V. Evatt at the first meeting of the U.N. International Commission on Atomic Energy in New York and later in the same capacity as adviser to Paul Hasluck. He made this the occasion to see something of the development at the Massachusetts Institute of Technology of a device for liquifying helium, which served as a basis for the establishment of the Division's research program in low temperature physics.

Being very research minded and recognising the danger of a national standards laboratory lapsing into mediocrity if it did not maintain an active scientific program, Briggs' encouraged "pure" physical research in parallel with developments for and services to science and industry through the maintenance of national physical standards. Under Briggs, the Division established an international reputation for its research on solar physics and solid state physics.

Dr. Briggs was appointed to the National Standards Commission when it was established in 1950 to advise the Minister in regard to the establishment and maintenance of units and standards of physical measurement. Briggs played an important role in the formulation and implementation of this weights and measures legislation and served on the Commission until his retirement as Chief of the Division of Physics.

Having worked with George Briggs for most of my professional life, I cannot speak too highly of the leadership and inspiration he provided. He was an excellent and understanding mentor. Although a man of many parts, physics was always his principal interest. He took a leading role in the organisation of physics in Australia, first through the Section of Physical Science of the Royal Society of N.S.W. of which he became the Secretary in 1927, then President of the Australian Branch of the (British) Institute of Physics (1950). In the latter capacity he initiated the proposal that Australia form its own Institute of Physics. This proposal, when put to the vote of the Branch members, proved a little premature because of the reluctance of many to break away from the British body. The proposal was resubmitted in 1962 when, with the lapse of time and unequivocal support of the British body, it was overwhelmingly adopted. Dr. Briggs was made an Honorary Fellow of the Australian Institute in recognition of the part he played in its formation.

Among Briggs' other interests were walking and touring in remote regions with his wife, conservation in regard to all natural phenomena, tennis, the lack of teaching in physics for girls in N.S.W. State secondary schools, and the propagation of the Callitris pine which he regarded as a native tree of outstandingly beautiful habit. He was the representative of CSIRO on the UNESCO Conservation Committee and during 1953 - 55 Chairman of the UNESCO Australian Committee for Natural Science.

In 1924, George Briggs married Edna Dorothy Sayce, also an Honours graduate in Physics from Sydney University. They remained closely attached all their lives which is not surprising having regard to their many interests in common. Edna predeceased her husband by about four years. They had two daughters, Margaret and Barbara, and it must have been a matter of much pride and satisfaction to them that both daughters graduated, one in Physics and one in Botany, and hve made their mark in their chosen professions.

George Briggs was truly a man one can be proud to have known and from association with whom I and innumerable others have benefited. He was a fine man in all respects.

A.F.A. Harper, A.O.

HENRY JAMES EMMERTON

(1917-1987)

Henry James Emmerton, BSc, formerly of Gordon, N.S.W., was a member of the Royal Society of New South Wales for 47 years. He passed away on February 27th, 1987. After gaining his B.Sc. from Sydney University in 1940, he joined the staff of the Materials Testing Laboratory, N.S.W. Department of Public Works as an analytical chemist engaged in the chemical testing of portland cement, soils, mortars, concretes etc., related to major State structural undertakings during his period of service. He attained the rank of Senior, or Chief chemist in 1958, and retired in 1977.

One of Mr. Emmerton's "outside" interests lay in the historical preservation of steam locomotion, he being a member of the Railway Historical Society, N.S.W. Rail Transport Museum as well as that of the Lachlan Valley Railway Society.

To his wife, Eve and sons Kelvin and Ian, we extend our sincere sympathy in their sad loss.

John Mc. C. Shortis

DAVID BENJAMIN PROWSE

David Prowse died on 28th February 1988 at the tragically early age of 49 years.

David grew up in Victoria and after graduating M.Sc. in Physics he commenced his professional career with the Defence Scientific Service working in the Metrology group at the Defence Standards Laboratories (later called the Materials Research Laboratories) at Maribyrnong. He spent some time at Monash University where he obtained his Ph.D. degree before returning to Defence.

When the Matrology group at DSL was disbanded David elected to join the CSIRO Division of Applied Physics and he commenced work at the National Measurement Laboratory at Lindfield early in 1978 with the group concerned with standards of mass, force and pressure and in 1981 became leader of the group. In the six years left to him David achieved a great deal and his work was recognised at the highest level when he became a member of the Consultative Committee on Mass of the International Bureau of Weights and Measures. On the local scene David played a leading role in the work of NATA being Chairman of the Metrology Registration Advisory Committee and a very active assessor.

David Prowse was elected a member of the Royal Society of N.S.W. in May 1978, and was a member of Council for 3 years - 1980, 1981 and 1982.

His other interests included cricket, which he played at a high level, scouting and Amnesty International. He also played a leading role in the Management Committee of the Uniting Church at Lindfield.

David will be greatly missed by a side circle of friends but by none so much as his family, his wife Lorraine and children, Jenny, Rohan, Trevor and Olwen to whom we extend our condolences.

G.A. Bell

DAVID GORDON DRUMMOND

(1908-1987)

Dr. David Gordon Drummond, who was always known as "Gordon", was born in Newcastle-upon-Tyne, England, on 25th May, 1908, the eldest son of the local bank manager. At the age of eleven he was sent as a boarding pupil to Barnard Castle School. He did well at school, winning various swimming events and taking high marks at his university entrance examinations in 1926. Between 1926 and 1934 he was a student and graduate student of Armstrong College, University of Durham in Newcastle-upon-Tyne, where he gained his BSc in 1929, MSc in 1933 and PhD in 1934.

On leaving college in 1934 England was in the grip of the great depression. Ordinary jobs were scarce and research jobs almost non existent. Gordon received the highest possible recommendations from his professor who stated that "Such an outstanding talent must not be wasted". He was one of the only two graduates taken on by the British Cotton Research Association being employed as a spectroscopist in their laboratories at the Shirley Institute in Manchester. His initial work, built on his Ph.D., was naturally applied research, but he still found the time to produce "The Infra Red Spectra of Quartz and Fused Silica" published by the Royal Society of London in 1936.

In December 1935 he married Mary Pollock (Mollie) his long time fiancee, a biology teacher he had known since 1927 at Armstrong College. His first son, David, was born in 1937, and his second surviving son, Allan, was born in 1942.

During 1942 six Electron Microscopes were brought to England from America to meet wartime exigiencies. The Shirley Institute's Director, Sir Robert Pickard had wanted to be first with the latest but got the second instrument. Pickard then looked around to find someone to "drive" it. Dr. Drummond was chosen on the basis of his impressive theoretical physics background and his research record. It was a new field and Gordon was very much a pioneer in developing techniques for specimen preparation and storage as well as having to be to a large extent his own technician, wartime problems having resulted in no manuals accompanying the equipment. The practitioners in his new field were few in number and he was in regular contact with the other five as he struggled to commission the equipment and perform desperately needed work on the impregnation of fibre assemblies with polymer compositions. Nonetheless he still served at nights as a sergeant in "Dads Army".

In November 1943 he delivered the inaugural paper at the newly formed Electron Microscope Group of the Institute of Physics. The meeting was held in the Royal Society's rooms in Burlington House, London.

His work at the Shirley Institute continued and his skills in Electron Microscopy grew. He became a Fellow of the British Institute of Physics and a Fellow of the Royal Microscopical Society.

In 1950, with encouragement of Sir Charles Darwin (the grandson of the evolutionist), Gordon published "The Practice of Electron Microscopy" under the auspices of the Royal Microscopical Society. This publication was a seminal work, occasionally referred to even today. The same year attending an international conference in Paris he met a towering figure of this new science the German Dr. B. von Borries, who as he said in a sane world had more right than anyone else to be there.

Dr. Drummond became Chairman of the Electron Microscope Group of the Institute of Physics in England in 1956, and in 1957 accepted an appointment as the first Director of the Electron Microscope Unit at Sydney University bringing this young science to Australia. He was invited to join the Australian Academy of Science and became Chairman of the Academy's Standing Committee for Electron Microscopy. After sixteen years, he retired in 1973, having seen the Electron Microscope Unit grow from small beginnings to a well established and important research unit in Sydney University.

Throughout all the years of a long research career Gordon was always regarded with affection and respect by his colleagues. As director of the Unit at Sydney University he used to say that his most productive personal research was behind him and that it was now his duty to foster others' new ideas and to provide the climate in which ideas, innovation and excellence could flourish. "The Doc." is remembered kindly by his Sydney research colleagues, numbers of whom are still at the Unit.

He retired in 1973 and became interested in genealogy; it was another form of research and this interest became a passion and great consolation when Mollie died in 1982.

He joined the Royal Society of N.S.W. in 1975 and served on its Council in 1986/87.

Gordon died on 20 November 1987 from a heart attack following major surgery for cancer. He was rational and courageous to the last and for this we are grateful. He is profundly missed by his friends and family, an unassuming, kindly man with a great love of true things and a great talent for discovering them The Electron Microscope Unit is an enduring monument to one man's spirit.

Allan Drummond.

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A "Style Guide to Authors" is available from the Honorary Secretary, Royal Society of New South Wales, PO Box 1525, Macquarie Centre, NSW 2113, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarized below.

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Spelling follows "The Concise Oxford Dictionary".

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All stratigraphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra.

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THE ROYAL SOCIETY OF NEW SOUTH WALES

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Problems and Prospects of Preserving the Portable Scientific and Technological Heritage

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Problems and Prospects of Preserving the Portable Scientific and Technological Heritage: Introduction

RAGBIR BHATHAL

INTRODUCTION

It was fitting that the Royal Society of New South Wales as the premier scientific society in Australia should have taken the initiative in conjunction with the National Trust of Australia (New South Wales) and the Museum of Applied Arts and Sciences to organise the seminar on the "Problems and Prospects of Preserving the Portable Scientific and Technological Heritage".

The objectives of the seminar were:

(a) to serve as a forum for the discussion of issues concerning the preservation of the scientific and technological heritage,

(b) to bring to the attention of policy makers some of the problems associated with the preservation of heritage, and

(c) to discuss issues arising from legislation and costs associated with the preservation of heritage.

While some of the issues and problems in preserving our scientific and technological heritage were raised in the papers defined at the seminar, many others were highlighted in the discussions throughout the various sessions at the seminar. Since this was the first attempt to bring together people with common interests in the preservation of the scientific and technological heritage in New South Wales it was not possible to cover all aspects of this fascinating, complex and important subject.

We were nonetheless pleasantly surprised and encouraged to note the overwhelming response to the seminar. It is intended to arrange another seminar on the same topic probably next year and to cover a much wider range of topics than had been possible at the present seminar.

The papers for the seminar were divided into three sessions:

1. scientific heritage
2. technological heritage
3. legislation and costs

No seminar such as this could afford to neglect the issue of legislation, particularly its limitations and the costs involved in implementing it. A set of papers on the technological heritage investigated issues arising from industrial sites and artefacts, and the role of museums in preserving and documenting the industrial heritage. The papers on the scientific heritage were concerned with the preservation of scientific artefacts and archives especially in relation to scientific and technological institutions. These institutions have a tendency to discard obsolete equipment or drastically modify them for other purposes and hence add to the loss of the scientific heritage for future generations. Over the last few years, in a number of cases, scientific artefacts of significance were thrown away by organisations which reorganised themselves and moved to new premises.

The conversion of a scientific institution into a museum of astronomy posed new challenges and since this was the first time such a project had been undertaken in Australia, it should provide several lessons for others in the field. I hope the experience gained on this project will be of use to the group involved in the conservation and restoration of Tebbutt's Observatory in Windsor.

The preservation of the scientific and technological heritage has its special problems which are compounded by the rapid obsolescence that is built into the scientific and technological enterprise. In a sense one should be collecting today for tomorrow. Where the objects are small, portable and collectable they do not pose any major problems. The real problem comes when faced with industrial complexes with large machines (mills, blast-furnaces, steam engines, etc) and structures. Another development that has created a problem and an issue is the recent interest in industrial environments and the argument that many historical engineering items can only be appreciated in the context of their utilisation. In essence this means that although the ultimate objective might still be to preserve artefacts, they should be exposed in their original contexts. It may, therefore, be desirable because of the complexities of the issues involved, to set up a specialist committee of scientists and engineers within the Heritage Council to provide guidelines for assessing the issues which arise in the preservation of the scientific and technological heritage of New South Wales.

One of the last but by no means the least important items on the agenda of the seminar was the passing of resolutions. In our deliberations and the passing of the resolutions we bore in mind the constraints imposed by resources and the economic situation we are living in.

On behalf of the Royal Society of New South Wales, I thank the members of the Organising Committee, the staff of the National Trust and the staff of the Museum of Applied Arts and Sciences for all the assistance they gave us in organising this seminar. I also wish to thank the Honourable Minister for Planning and Environment and Minister for Heritage, Mr Bob Carr, for not only gracing the occasion with his presence but also delivering the opening address and declaring the seminar open. It is a credit to the Minister that he accepcted the resolutions passed at the Seminar and had them included in the Heritage(Amendment) Act 1987 assented to on 3rd April, 1987.

Dr Ragbir Bhathal
Vice President
Royal Society of
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Opening Address, 2nd August, 1986

THE HONOURABLE R. J. CARR,
MINISTER FOR PLANNING AND ENVIRONMENT AND MINISTER FOR HERITAGE

A little over a month ago, I was strolling through the Iron Bridge Gorge Museum in the United Kingdom. It is located in the valley that saw the first industrial revolution, it was indeed the silicon valley of the 18th century; the valley where the first experiments were made in producing iron with coal instead of charcoal. Visitors came from all over Europe to look at these industrial processes. According to the paintings that record the spectacle, they were dark satanic mills, vast works spewing out flames and black smoke into the atmosphere of a once idyllic valley. That museum, probably the leading industrial museum in the United Kingdom, records these processes. It houses and preserves all sorts of small enterprises as well as major industrial establishments, processes, equipment, ceramic works and even blacksmiths' shops. It reminded me that heritage is about more than conserving the graceful historic country mansion; about more than protecting outstanding features of the natural environment. Of course, it is relatively easy to create public interest in these two areas of heritage. I have to say, however, that it is much harder to interest people in saving swamp lands for example, than it is in saving the most glamorous rainforests. In the built environment, some parts are also more immediately attractive and suitable for a conservation case than other parts. Anzac House, for example, which the Heritage Council sought to have protected with a Conservation Order and which the Royal Australian Institute of Architects was very keen to save, probably commends itself less to the public (as does the first Qantas House, which is in the same category) than our built environment of the early 19th century. Nevertheless, the built environment and natural environment are areas of well worn conservation arguments. It is harder to interest people in the portable, scientific and technological heritage. Yet in France, the boats of Breton fishermen are regarded as part of the nation's cultural heritage and are protected accordingly. In Denmark, you can see a museum that features radio equipment used by the Danish resistance. Those examples suggest that the portable, scientific and technological heritage cover a wide range.

In New South Wales, the Heritage Council has been actively working for conservation of various items and collections of portable heritage since its inception in 1978. Wherever possible the Council strives to keep these objects in situ and maintain the relationship between them and their cultural context. This has been achieved through negotiation, legislative control, research studies and acquisition. Let me touch on some examples.

Historic pipe organs form an important category of the portable heritage and in recognition of this the Heritage Council has formed a pipe organ advisory panel to give advice on the conservation of these musical instruments. The Walker and Son pipe organ at the Pitt Street Uniting Church and the Charles Richardson organ at the Balmain Presbyterian Church are two examples where small financial grants have been used by the local parishioners for essential conservation to maintain the instruments as working artefacts.

Indeed, collections of portable relics exist all over the State. Coppabella Station, at Tumbarumba, contains a complete mid-19th century blacksmith's shop. The Department of Environment and Planning has been advising the sympathetic owners of the site on the long term care and management of the collection.

Chaffers Tannery at Chatswood, Sydney, is a similar example. This 1885 industrial site was the last of the tanneries which once characterised the Chatswood area. Heritage Conservation funds provided for the detailed recording of the place, its contents and the industrial processes employed there. The business has since moved and the owners will keep and house the most significant pieces of equipment in the new factory, maintaining a link with the past.

Eveleigh Railway Workshops, Redfern, is the home of an outstanding collection of engineering-heritage items relating to the production and maintenance of steam locomotives in New South Wales. The collection includes timber patterns from a locomotive, components, stampers, lathes and steam engines. Critics of the industrial relations practice of the State Rail Authority will argue that these are all in good condition because very little work has been performed with them. A National Estate Grant is currently being used to compile an inventory of the collection and make recommendations for its care, control and management.

In Mungo National Park, in the south west of New South Wales, I can recall seeing a 19th century shearing shed, preserved and in very good condition. In order to maintain its oleaginous authenticity, shearing is conducted there once a year; a necessity to keep the timber oiled and maintain it in that pretty harsh climate. I suppose the difficulty in deciding when we have enough old shearing sheds preserved to give us a representative sample is a little like United Kingdom heritage experts talking about the Yorkshire Barns - there are so many of them dotted over the landscape, it would be an extravagant effort to preserve and restore them all. When do you have a representative sample?

In other areas, funding has been provided by the Department of Environment and Planning to purchase part of the contents of historic Rouse Hill House, which is now administered by the Historic Houses Trust. The contents are vast and various. I would think that whoever is in charge of arranging the presentation is going to have one of the most difficult jobs ever presented in this area. The State Government has also provided funding for a detailed research study on one category of portable relics, utilitarian glass, which will be completed by the end of the year. We have acquired the site of the first male orphanage at Fairfield, in Sydney's west, to protect the relics associated with this important welfare institution.

As far as the protection of portable heritage is concerned, I am currently reviewing the Heritage Act which was passed in 1977. One of the aspects being given particular attention is the question of tighter controls for the removal or movement of relics, to complement the recent Federal Protection of Moveable Cultural Heritage Bill, 1985 and the National Parks and Wildlife Act which protects aboriginal relics.

The significance of historical archaeological relics has been recognised by the State Government and is illustrated by our commitment to conserve the First Government House site. I look forward to being able to make available sufficient funding for the final phase of the archaeological project: the research and analysis of the thousands of artefacts which have the potential to reveal much more information on the site's history. The question of the long term storage, curation and management of archaeological artefacts needs careful consideration and falls into an area where the Heritage Act stops short. The Museum of Applied Arts and Sciences is, I think, the most appropriate institution to accept this responsibility and through the new Ministry of Heritage I will be initiating discussions on this question between the Heritage Council and the Museum.

Today's seminar promises to be very interesting and it should help to focus attention on this area of cultural heritage and the problems and prospects of its conservation. I think it is very topical and there is no doubt that we are now moving out of something we can call the industrial age and into a system of economic organisation which has very different characteristics. It is therefore important for us to act now and conserve our industrial archaeology, because otherwise, with the restructuring and shake out of the manufacturing industry, we stand to see a lot of these processes, and a lot of this equipment, lost for all time. In decades from now there will be an enormous fascination with the ingenuity used by Australians to grapple with technological problems and the problems of scientific and technological challenges presented by our unique environment.

While interest in it may not be apparent at this time, it is important that informed people, like those of you here, lead public debate and act now before we lose slabs of this heritage. I note that the speakers and participants today represent all of the government and academic institutions concerned with portable heritage. I congratulate those responsible for organising this seminar, and I am sure that the mutual exchange of ideas will be an important first step in a number of achievements in this area. It gives me a great deal of pleasure to declare the seminar open.

The Honourable R. J. Carr
Minister for Planning and Environment
and Minister for Heritage
Parliament House
Sydney, NSW
Australia

Opening address to the Seminar on "Problems and Prospects of Preserving the Portable Scientific and Technological Heritage" organised by the Royal Society of New South Wales, the National Trust of Australia (New South Wales), and the Museum of Applied Arts and Sciences, Sydney, on 2nd August, 1986.

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Resolutions — Portable Scientific and Technological Heritage

This meeting believes there is rising concern among associations, professional people and significant parts of the community about the disappearance of the portable scientific and technological heritage. It believes there is danger that "by inaction we will further maim our nation life" (Beaglehole).

For this reason sixty five participants from some 30 institutions and professional organisations attended this seminar.

The Minister's attention is directed to the following points arising from the papers read which were the focus of discussion at the Meeting:

(1) That in his review of the NSW Heritage Act the Minister make provision for protection of portable items of the scientific and technological heritage.

(2) That this heritage must be seen to include both artefacts and archival material.

(3) That such provision be extended to include all portable heritage items.

(4) That particular attention be given to retention of these items in situ as a first option.

(5) That a single authority be responsible for the coordination, registration and management of these items.

(6) That attention be given to increase the public awareness in this field.

(7) That institutions and individuals represented at this Meeting request the opportunity for continuing dialogue.

The Meeting requests that the Minister take account of the concern of this professional group and formally addresses the issues raised in the attached proceedings, which will shortly be published, by means of legislation as appropriate.

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Sydney Observatory: Scientific Institution, Museum and National Heritage

RAGBIR BHATHAL AND IAN SANSOM

INTRODUCTION

As a conservation architect and amateur astronomer, Ian Sansom remembers well his first visit to the Observatory to commence planning the current building programme. It triggered the release of surprisingly clear memories of schoolboy visits; wonderfully gloomy interiors crammed with instruments and books. It was, for a young boy, the imagined epitome of a nineteenth century scientific interior. Together with the weathered stone tower and the south-facing front facade, perpetually in shade, it was a set from a Saturday matinee movie.

We have shared these memories with you, not as an exercise in nostalgia, but because it mirrors the reaction of almost everybody we have spoken to who has visited the Observatory in the past. It demonstrates perhaps the impact of what can be called the "sense of place", the ability to evoke a sense of the history of the institution, as well as the structure, accurately or otherwise.

In addition to our fond memories, we saw a building and its contents exhibiting the symptoms of seventy years of inadequate maintenance. Behind the character overlaid by the more significant architectural features, fittings and instruments, we saw large areas of crumbling plaster, dangerous wiring in crudely installed conduits, fibro ceilings and the inevitable coats of pale Public Service grey paint.

In other words, a ready-made museum interpretation of maintenance policies of the 1950s.

Against this backdrop the messages of one hundred and twenty three years of continual occupancy by the scientific institution of the Observatory still signalled. Balanced against the preservation of these messages were the equally important requirements of carrying out a major building maintenance programme and accommodate the Government decision to convert the Observatory to a museum. So we had a major renovation programme and a change of use to contend with, without reducing the cultural significance of the site, and without diminishing this powerful evocation of the history of the institution which visitors in the past have experienced. (UNESCO, 1972)

It was, in our opinion, appropriate to redirect the diminishing scientific role of the Observatory, in 1982, to the expanding educational and popularisation of science role it could offer under the Museum of Applied Arts and Sciences. An important part of the ongoing history of the site is the change of use of the Observatory to a museum as well as the conservation works to the building. The work currently in progress seeks to halt the declining standards of past maintenance, to provide the buildings with legally required standards of safety and amenity for staff and visitors, and to accommodate satisfactorily the special services and functions required of a museum.

Museologically, this may require compromises between what is perceived to be the most "efficient" utilisation of the rooms available and the need to maintain sensitively their cultural significance. These compromises have been minimised by logical museum policies and careful planning.

Prior to commencing planning, a detailed history of the Observatory and its site was prepared (Barripp, 1984), together with an archaeological study (Higginbotham, 1986) and a room-by-room analysis recording the architecturally significant details and finishes. An assessment was made of the historic and scientific significance of room functions, including the serviceability of the older instruments, fittings and furnishings.

Obviously, certain areas had only minor historic interest or had been substantially altered for modern functions. However, other areas clearly communicated their original uses, and in some cases retained instruments, fittings and furniture from the nineteenth and early twentieth centuries. A hierarchy of significance was established to help determine future room uses and visitor flow patterns. This information is being collated into a conservation study which is to be read in conjunction with the conservation study and management plan for Observatory Hill, currently being prepared under the supervision of the Government Architects Branch.

CHRONOLOGY

A brief chronology of the development of the Observatory Hill site and the Observatory as an institution presents the raw material, at least, from which their obvious cultural significance can be assessed.

Originally known as Windmill Hill, this commanding position was the site of the Colony's first windmill, built in 1797 as a small stone tower. It is thought to have been located in the original eastern carriageway of the Observatory, not far from the present main entry doors. It is recorded that the standard of workmanship of the unknown convicts was not high: by 1800 the foundations were collapsing. Five years later the head of the mill was displaced by a storm and by 1810 the mill had become a derelict tower with no sweeps.

On 4th May, 1804, the rebellion of three hundred convicts at Castle Hill prompted Governor King to build a fort on Windmill Hill. Work commenced immediately, but the initial momentum was unsustained because by 1807 partial dismantling of uncompleted work on the fort began, and by 1840 the fort was partially demolished, never having fired a shot in anger. Three superb stone walls, dating from 1804, remain today.

By the 1820s, the volume of shipping in Sydney Harbour had increased sufficiently to require a nautical signalling system. Around 1825 two flagstaffs were erected on Fort Phillip to communicate with the signal station at South Head. The site now became known as Flagstaff Hill. A Signal Master's residence and Telegraph House, designed by the Colonial Architect Mortimer Lewis, was built in 1848. This two storey stone cottage, so superbly sited on the ramparts of Fort Phillip, is leased to the widows of former Maritime Services Board employees since 1939.

A small Messenger's Cottage was built immediately to the north-east of the Observatory in 1862.

By this time Flagstaff Hill had undergone its third and final name-change to Observatory Hill, after construction of the existing building had commenced in 1857.

Sydney Observatory traces its roots back to the first attempts to study astronomy in Australia by the early European settlers. Lieutenant Dawes of the First Fleet established a temporary observatory at what is now called Dawes Point in Sydney. However, the observatory fell into disrepair when Dawes left the colony a couple of years later.

Parramatta Observatory was set up in the colony as a private observatory by Governor Brisbane and was acquired by the Colonial Government as a government observatory in 1827. Parramatta Observatory was in operation until 1847 when upon a recommendation by a Commission headed by Captain P P King the observatory was closed down. In his letter dated 11 July, 1847 to the Colonial Secretary, Governor Charles A Fitzroy wrote:

> "Since receiving the report of the Commission, I have been informed ... that the building cannot be even temporarily repaired without considerable expense, I have in order to preserve the instruments, etc, from further injury, directed that they should be packed up in boxes and placed in charge of the Ordinance Storekeeper."

The instruments were packed away until a decision was made by the Colonial Government to establish another observatory in Sydney. By the 1850s a large majority of the people in the colony had spent a major portion of their lives in Australia and they regarded Australia as their home. They wished to see the colony not only grow in independence but also in cultural and educational pursuits. The various movements to self-government leading to the establishment of a responsible government by the Act of 1855 were all manifestations of this desire for a degree of independence. During this period institutions of learning especially of science were established. Scientific societies began to flourish. The Royal Society of New South Wales which had been set up in 1821 with Sir Thomas Brisbane as its first President was resurrected and given a new lease of life. It was thus not surprising that there was a strong push for the establishment of an observatory in Sydney for reasons other than just for assistance for navigation purposes.

The reasons for the establishment of an observatory on Fort Phillip were pragmatic. There was a crying need for a time ball mechanism to provide a standard of accurate time for the community and ships in the harbour. The time ball was to drop down a pole at precisely one o'clock to indicate the correct time by which to set the clocks.

In addition to the time ball it was proposed by Captain Phillip King that the building should also comprise of an observatory for the study of astronomy. This would, he said, complement and assist in the keeping of accurate time.

On 22 May, 1852 the Colonial Secretary sent King's plan and letter to Edmund Blacket, the Colonial Architect and asked him to prepare estimates of the "expense of erecting a building according to the plan, with the additional rooms, or dwelling for the Meteorological Observer who will probably be placed in charge of the time ball ... bearing in mind the suggestion ... respecting the ultimate re-establishment of an observatory."

It was left to the new Governor, Sir William Denison, to promote the building of the observatory. Denison obtained the approval of the Executive Committee to build the observatory. He argued as follows:

> "There are many circumstances which would in my opinion, make it very advisable to re-establish

the Observatory ... In the first place provision has already been made for the erection of a building to contain the machinery of a time ball and for the purchase of the machinery but the time ball will, in point of fact, be worse than useless unless there are means for determining the time correctly, that is, unless there are proper clocks and proper instruments for determining the time; all these instruments are in the hands of an observer responsible to the Government for their proper application ...

In the second place, I am anxious for the establishment of an Observatory in the immediate vicinity of Sydney, as affording to all persons, and especially those educated at the University, a practical example of the application of science to the determination of matters altogether beyond the scope of our ordinary uneducated reason ...

In the third place, I am desirous to establish an Observatory for the purpose of connecting it with the trigonometrical survey of the country and thus, by means of the perfect and absolute determination of the position on the earth's surface of one point to be enabled to lay down with perfect accuracy the whole of the remainder of the country not merely with relation to that spot, but with relation to the remainder of the earth's surface.

In the fourth place, I am anxious for the establishment of an Observatory as a means of connecting this colony with the scientific societies of Europe and America."

The Observatory was thus set up not only to carry out scientific investigations but also to be concerned with practical matters such as time-keeping and the trigonometrical survey. It was also to be used as a place for public education to illustrate the practical application of science and to provide links with the scientific societies in the metropolises of Europe and America.

In 1855, as Sydney acquired a steam train service to Parramatta, 1,700 pounds were approved for the construction of rooms for a Meteorological Observer and Time Ball Tower on the Hill. Plans were prepared by Blacket's successor, Colonial Architect William Weaver, but construction did not commence until May 1857, under the direction of Weaver's successor, Alexander Dawson. By October 1858 the southwest dome and equatorial telescope, omitted from the original design, was added as additional funds became available.

SCIENTIFIC PROGRAMMES

From its beginnings until 1982 when it was handed over to the Trustees of the Museum of Applied Arts and Sciences the Observatory's programmes covered a range of both pure and applied science projects.(Wood, 1983). Apart from the time keeping service the Observatory's scientific programmes covered the following areas:

1. The formation of a catalogue of the southern stars.
2. Trigonometric survey of New South Wales.
3. Meteorological observations.
4. Magnetic observations.
5. Tidal observations.
6. General observations of eclipses, occultations, minor planets, comets and double stars.
7. Establishment of longitude.
8. Fixing the boundaries between New South Wales and Victoria.

9. Seismographic recordings.

However, in the period 1900 to 1950 a number of the programmes such as surveying, meteorology, magnetic and tidal observations, and seismographic recordings began to be carried out by other more specialised agencies. As a consequence of this the main scientific work of the Observatory began to be confined to astronomy only.

Of the seven Government Astronomers for the period 1858 to 1982 perhaps the one that had the greatest influence on the course of the programmes of Sydney Observatory and its high profile in the international world of astronomy was H C Russell. He was as famous as his contemporary John Tebbutt, an amateur astronomer who ran his private observatory at Windsor. (Bhathal, 1985). Russell, a graduate of Sydney University, was the Government Astronomer from 1870 to 1907. He was a great experimentalist and designed and built a number of instruments for use both in astronomy, meteorology and geodesy. (Russell, 1871-1907; Sydney Observatory, 1859-1880). He also prepared a design for the mounting of an equatorial reflector with a yoke at the upper end of the polar axis. This is very similar to the arrangement for the 200-inch telescope on Mount Palomar in the United States of America. Being a scientific institution before it became a museum in 1982 no attempt was made to preserve the instruments that had become obsolete. They were probably either discarded or parts of them used to build other instruments. Harley Wood, the sixth Government Astronomer notes that when he joined the Observatory in 1936 he found much of the steel parts for a telescope designed by Russell to be rusting in the grounds of the Observatory. Unless scientific institutions and industrial laboratories are made aware of the importance of preserving the tools and technology of their trade for future generations and historians of science the chances are these artefacts will be lost to the scientific and technological heritage of the nation. In passing, it is interesting to note that Lawrence Hargrave was employed as an assistant astronomer at the Observatory for the period from 1878 to 1883. While there he worked on an adding machine of his own design. When the Observatory was transferred to the Museum this unsuccessful device was discovered amongst the bits and pieces of equipment left in the storeroom of the Observatory.

Russell was also involved in the application of photography to astronomy. (Russell, 1887). At the 1887 conference on stellar photography held in Paris Russell was given the responsibility of compiling by photography a catalogue of stars for the Sydney (-52° to -64°) and Melbourne (-65° to the Pole) regions. All the photographic material on astronomical subjects produced by the Observatory since Russell started the programme has been well preserved. This goes as well for the scientific publications that emanated from the staff of the Observatory. For his extensive work in southern astronomy Russell was made a Fellow of the Royal Society of London. He served several times as the President of the Royal Society of New South Wales and in 1888 was elected as the first President of the Australasian Association for the Advancement of Science which is today called the Australian and New Zealand Association for the Advancement of Science. This Association was initiated in 1886 by A Liversidge in his role as President of the Royal Society of New South Wales. (Liversidge, 1886).

ARCHITECTURE

From 1858, architecturally and historically significant alterations and additions were made to the buildings and grounds until the time of Russell's departure in 1907. After this the works, generally of a minor nature, reflected economy and expediency rather than sensitivity thus downgrading the significance of the site.

During the Edwardian period the site was well cared for and was at its maximum cultural significance. This reflected the role of H C Russell as Government Astronomer, and the attitudes of the then government and society to science before the disruption of the Great War and the Depression. It was therefore chosen as the period of interpretation of the building fabric and the grounds.

The Observatory was originally planned with a wing of scientific offices to the south and west, and a residence on the east. The two areas connect only at ground floor level and possess quite different architectural characters. This quality perfectly accommodates the museum philosophy.

The residence contains a number of domestic-sized rooms with fireplaces, painted joinery and turn-of-the-century pressed metal ceilings. These areas are of considerable architectural interest but of minor historic significance and are planned to accommodate, on the ground floor, the bookshop, lecture room and main orientation space. Offices, staff amenities and library are to occupy the first floor of the residence.

Originally more austere in its finishes, the western and southern wings contained the astronomer's office, telescope domes, transit telescope room, general offices and the basement workshop. The two general offices are larger spaces and will become flexible exhibition areas. Other spaces are smaller and contained fixtures such as telescopes, equipment cabinets and panelled screens, all of which will be conserved with the building fabric. Instruments have been catalogued and where necessary, restored by the Museum of Applied Arts and Sciences. These fixtures together with the dark Australian cedar joinery and the muted brown and drab of the earlier colour schemes will evoke strongly the rather sombre atmosphere of the interior in 1907.

New electrical services, thermal detector fire alarms, public address systems and movement detectors are being installed throughout the building. The display areas will contain three circuits of flexible museum lighting together with the other services in a system of white tubes attached to the ceilings. These are seen as modern items of furniture, alongside the computer terminals and VDUs, simply attached to the building fabric. These "loose fit" services are capable of great flexibility for changing displays, and bring the standards of building services and public safety into the late twentieth century.

DISPLAYS

In arranging the displays with the building fabric we will be seeking creative solutions to not only provide a "sense of place" which will reinforce the history of this scientific institution but also to allow for the dissemination of astronomical information through displays and public programmes. Superimposed on the hierarchy of significance, which were mentioned earlier on, is a museum policy which has been influenced by similarities with Greenwich Observatory. In coming to these conclusions a number of museums with astronomy programmes, planetariums and observatories which had been converted into museums were studied. A solution which commended itself and had a lot of merits was the method Greenwich Observatory, which was previously a scientific institution, had been turned into a museum. It has kept the character of the building. While parts of the building have been left to show its earlier use as a scientific institution, other parts of the building are now used as a display gallery on astronomy and public programmes. The solution is interesting because it preserves some aspects of the work of the Observatory as a scientific institution and thus gives the visitor a feeling of the earlier usage of the institution by astronomers for the study of the heavens. The section devoted to museum displays allows the institution to provide an explanatory role and to display objects which are relevant to the study of astronomy. The section devoted to public programmes allows the Observatory to run lectures, film shows, etc, which provide information of a different quality and depth which is not easily transmitted through the displays.

Basically the use of Sydney Observatory as a museum will include the following:

1. Showing the earlier use of the Observatory as a scientific institution.
2. Displaying of exhibitions on astronomy and space exploration.
3. Disseminating of information on astronomy through talks, lecture-demonstrations, hands-on workshops, film and video-shows.
4. Observing the night sky through the Observatory's telescopes.

We believe this multi-level and multi-sensory approach will maintain the sense of scientific discovery and exploration traditionally associated with the Observatory. (Henry, Lomb, Wilson, Kennard and Bhathal, 1984-1986).

The displays will be mounted in such a way as to be sympathetic to a building that was used as a scientific institution. The room that housed the transit telescope will be restored and conserved to the period of its use. The telescope will be conserved and placed on display as it was originally used. Since Sydney Observatory traces its roots back to Dawe's and the Parramatta Observatory it will have a display which will illustrate the development of this early history and the scientific work of Sydney Observatory with particular reference to H C Russell's pioneering work. Most of the instruments from the Parramatta Observatory were transferred to Sydney Observatory when the former was closed down. These instruments have been restored and will provide an appreciation by the public of the scientific and technological heritage of this State. To give the public a feeling for the experimentation that is carried out by scientists and astronomers parts of the displays will be constructed in such a way as to provide interactive or "hands-on" exhibits on some of the more interesting aspects of astronomy.

For example, visitors will be able to use a series of lenses and mirrors on an optical bench to set up their own telescopes in order to find out the differences between different types of telescopes used by astronomers. They will also be able to learn how and why lenses in telescopes have to be corrected for chromatic aberration and why astronomers use the infra-red and radio wavelengths of the electromagnetic spectrum to study the universe . Discreetly located videos will allow the visitors to watch programmes that will answer questions such as: what are quasars and black holes, what is the origin of the universe, is the universe expanding, etc. They will also be able to understand why planets travel faster when they are nearer the Sun then when they are further away from it. In carrying out these simple experiments with the exhibits on display it is envisaged that the visitors will obtain an appreciation of the excitement and the curiosity that the work of an astronomer generates. The exhibits will enhance the social, historical, theorectical and practical aspects of the study of astronomy. It is also planned to use the previous instrument room in the basement of the Observatory as an area where visitors and school groups can attend workshops on mirror grinding, the construction of simple astronomical equipment and the carrying out of simple experiments on the optics of telescopes. It is also planned to extend the present programme of lectures and film shows to include lecture-demonstrations along the lines of those run by the Royal Institution in London since the days of Michael Faraday. The lecture-demonstrations are intended to provide a vivid explanation of some of the principles and applications of astronomy through the use of simple scientific equipment and artefacts.

BUILDING AND GROUNDS

Externally, the landscaping to 1900 was ideally suited to the functional requirements of the Museum and so, in accordance with the conservation philosophy, will be reinstated. Elegant iron gates hung between a pair of stone gate pillars will once again afford the visitor a vista along the eastern carriageway, which will lead to the main entry.

Structures such as the shade-temperature pyramid have been reconstructed, and the garden beds, paths, seats and lawns will be conserved where remaining, or reinstated.

For more than a century, lively academic debate has pursued alternative building-conservation philosophies ranging from "preservation in aspic" to free interpretation of adaptive "reuse". (Feilden, 1982).

The Observatory will remain as an operating public observatory. The historic significance of the site will be undiminished, but now capable of interpretation to many more visitors. The focus of the Observatory will, under the Museum of Applied Arts and Sciences, accommodate increased leisure time and increased demand for public education and information programmes. These shifts in the use of the Observatory have occurred regularly throughout the history of the institution, particularly as the Federal Government assumed responsibility for many of the programmes earlier this century.

Architecturally, the building and grounds will not be preserved as found in 1982 as it would have meant preserving half the building areas as a residence decorated in a 1967 taste. As with shifts of use in the continuum of an institutions history, so the building maintenance work now in progress will be a part of the building's history, and will continue, hopefully, to be a regular part of that history from now on.

However, guided by an understanding of the significance of the parts of the building, its contents and its grounds, a great deal of care has gone into the present programme to make the transition as gentle as possible. The Observatory building is not seen as a convenient shell into which insensitive museum functions can be slotted.

It will not only remain as a public Observatory, but more importantly become the first museum of astronomy in Australia. The programmes that were mentioned earlier in the text will in effect give substance to some of the ideas put forward by Governor Denison when he established the Observatory ie "as affording to all persons ... a practical example of the application of science".

REFERENCES

Barrip, A., 1984. History of the Observatory buildings. (Unpublished report for the Public Works Department)

Bhathal, R., 1985. John Tebbutt: Australia's premier comet observer. Sky and Telescope, 69/2. 160.

Feilden, B., 1982. Conservation of historic buildings. Butterworth Scientific, London. pp 472.

Higginbotham, E., 1986. Archaeological survey of Observatory Hill. (Unpublished report for the Public Works Department)

Henry, D., Lomb, N., Wilson, T., Kennard, D., and Bhathal, R., 1984-1986. Discussion papers on exhibitions and public programmes for Sydney Observatory. (Unpublished discussion papers for Sydney Observatory)

Russell, H.C., 1887. Astronomical and meteorological workers in New South Wales, 1788-1860. Report of the first meeting of the Australian Association for the Advancement of Science. 1, 45.

Russell, H.C. 1871-1907. Annual Reports. Sydney Observatory.

UNESCO, 1972. Preserving and restoring monuments and historic buildings.UNESCO Paris. pp267.

Wood,H., 1983. Sydney Observatory 1858-1983. Proceedings of the Astronomical Society of Australia. 5(2), 273.

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Preserving Our Scientific Heritage

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It is impossible to draw any clear dividing line between science and technology. For the purposes of this discussion, I am considering science to include a wide range of activities. There is the science of pure academic research. Although principally a mental process, this is often manifest in apparatus, notebooks and published papers. Observational sciences such as astronomy and meteorology also use instruments and produce records. The natural scienes, founded in part on the collection of specimens and samples, also draw on the techniques of the physical sciences. Medical research and medical practice should also be included, and technical disciplines such as surveying. Scientific activity undertaken in an industrial context should not be neglected.

To these directly scientific disciplines we must add several related activities. We should bear in mind the importation or manufacture of scientific equipment and materials, the rise of voluntary societies, professional associations and formal instiutions, and science publishing in Australia.

Many approaches to the study of our scientific heritage can be taken. The materials for such studies present several difficulties. They are scattered between several types of institutions: archives, libraries and museums. Much remains in private hands. A significant amount has been irrevocably lost. The destruction of many of Ferdinand von Mueller's letters earlier this century is a famous case but by no means unique. More importantly there is no co-ordinated policy to ensure a balanced approach to the preservation of our scientific heritage. The published record of Australian science is generally well preserved. It is the informal materials - those things which can give us the colour and personality of scientific endeavour - which are unevenly preserved. These tend to fall into two groups: archival materials and three-dimensional artefacts.

Archival materials include laboratory notebooks, correspondence, administrative papers, rough drafts and photographs. When these are generated in institutions there are sometimes provisions for them to be deposited in the archives of that institution. Some organisations, such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO), are required by legislation to maintain their archival records according to well defined criteria or to deposit them in a central archive. While this is not the case for university research records, university archivists in Australia are generally willing guardians of such records. Many of the larger companies maintain archives. I do not know to what extent these reflect industry-based scientific research in Australia. A considerable body of archival materials from Colonial Sugar Refinery (CSR) has been deposited with the Business and Labour Archives in Canberra. How many companies' records have gone to the tip when they went out of business or were taken over? (I was recently told of a firm that made scientific instruments - when it was taken over, the shop was cleared out, everything was piled into a council truck. One thing was rescued off the top of the pile: a theodolite which had been used to survey the coast of Patagonia in the 1849s!) Many scientists maintain their own records throughout their careers and on retirement store these records in a back room or garage with little thought to their long-term preservation. I know of one professional association which has archives accumulated over nearly a century. I believe these archives are in need of attention and better storage. There must be many bodies which do not necessarily wish to part with their records but which would benefit by professional archival assistance. Certainly the archives of the Museum of Applied Arts and Sciences have gained a new lease of life after several years' attention from archive students at the University of New South Wales.

The prospect for science archives in Australia has brightened considerably in the last year or so with the advent of the Australian Science Archives Project (its initials give an apt sense of urgency). This project, based at the University of Melbourne, does not provide a repository for archives but catalogues collections of papers before depositing them with suitable archival repositories such as the Basser Library of the Australian Academy of Science or the University of Melbourne Archives. The Contemporary Scientific Archives Centre in Oxford has been operating successfully since 1973 and has published more than 100 catalogues of papers. The fledgling Australian Science Archives Project has some 15 collections in hand. These are mostly the papers of individuals, including those of Sir MacFarlane Burnet, although institutional collections are also processed. Funding has so far been short term, but the Project has attracted some corporate sponsorship. Its continued vitality will be a significant factor in the preservation of records of Australian science.

Before turning to artefacts, let me draw out a couple of points implicit in the foregoing discussion. Material does not have to be of great antiquity to be of historical significance. Anything we can do to reduce the gap between the generation of records and their preservation reduces the risk of fate intervening to our disadvantage. This is not to say that everything should be preserved, but preservation should be by choice and not chance.

In many cases there exist institutions prepared to accept historical materials but which do not have the resources to solicit such material or to process them. The Australian Science Archives Project has shown the value of an intermediary which can actively seek material and then pass a well prepared package to a permanent repository.

Let us now turn to the instruments and apparatus of science. The categories we are considering are laboratory apparatus, optical and meteorological instruments, surveying and navigational equipment, medical instruments, weights and measures, and calculating and computing devices. These categories are not always mutually exclusive. Many of these types of instruments are associated with institutions and a number have survived through a combination of benign neglect and recognition of historic value. Medical and surveying equipment was more often associated with individuals. We should not forget, however, that at least until the mid-nineteenth century many scientists were amateurs and that the hobbyist's possession of a microscope or telescope is nothing new.

Those instruments that survive either remain with the original institution (or the descendants of the original owner), enter the antique market, or find their way into a museum. Sydney has a number of institutional collections of scientific equipment. Significant examples of instruments and demonstration apparatus are to be found at Sydney University. The School of Physics has some very impressive items of late-nineteenth century physical appartus including sine and tangent galvanometers, a Breguet metallic thermometer and a large Nicol prism apparatus. Some of these instruments were almost certainly bought by Richard Threlfall, the first professor of physics and a great experimentalist. The Geology School possesses a rare set of Sopwith stratigraphic models. Sopwith was a friend of William Smith, pioneer of stratigraphy.

Some institutions have arranged showcase displays. There is for example a small display of surveying instruments in the Department of Lands building, and we have all seen foyer displays left over from long-forgotten open days. These often reflect a recognition of the importance of the artefacts without a clear sense of long-term objectives for their preservation or disposal.

The trade in antique scientific instruments in Australia is very limited. Microscopes, surveying equipment, medical instruments and barometers are probably the chief collecting areas. (Clocks are generally outside the scope of this discussion). Few local dealers regularly stock scientific instruments. Universities sell surplus stock which may include microscopes and calculators. Disposal stores sometimes have navigational equipment. Some collectors buy from overseas. By and large it is not a market capable of dealing with the exceptional. Early last year a microscope was offered for auction at Parramatta. The microscope, made by C.W. Dixey, probably in the 1840s, is of silver in a wooden case, complete with a large number of accessories. The dealer who bought it shipped it to London where it was recently sold for 10,000 pounds. He had paid $540 for it.

Few museums in Australia actively collect scientific instruments. There are, however, some local initiatives outside the state and national museums. Graeme Morrison, Curator of the Pathology Museum at the Sydney University Medical School, has recently been very industriously collecting and restoring old medical apparatus which will go on display later this month. A teaching museum for the history of science is being established in the School of Chemistry at the University of New South Wales. Some of the apparatus already collected date from the nineteenth century and were inherited from the Sydney Technical College when the University was founded in 1949. As I understand it, this Museum has few resources and has no plans to collect instruments from outside the University. The Macleay Museum at Sydney University has long maintained a small collection of scientific instruments including microscopes. Its principal collections though are in natural history (including the very historic entomology collection), ethnography and historic photographs.

The Museum of Applied Arts and Sciences is the main museum in New South Wales concerned with historic apparatus of science and has indeed been collecting scientific instruments from its earliest years. Although it has for the most part been a passive collector - receiving donations as they were offered - it represents the different categories just discussed. Not a few of the Museum's scientific instruments are survivors from its own research laboratories. (Some of these will be included in a display on the old museum when the Powerhouse Museum opens in 1988). The Museum gained possession of another institutional collection when it took over responsibility for Sydney Observatory as we heard in the previous paper. Most of the remainder of the science collections have come as donations from universities and government departments although several interesting items have come from private donors over the years. The Powerhouse project has seen a period of lively acquisition of scientific instruments for a number of long-term displays scheduled to open in 1988. Although some of these are very significant instruments and add greatly to the Museum's science collections, almost all have been purchased overseas and therefore contribute nothing directly to the preservation of Australian science. It is much to be hoped, however, that their display will raise the awareness of practising scientists to the historical value of instrumentation.

Unlike archival materials, scientific instruments are rarely collected for their individual associations. Rather they are representative of types. While there is a growing awareness of the importance of collecting information on the provenance and particular use of an acquisition, this is often dependent on hearsay and surmise. Special attention should be given to one-off apparatus or instruments developed in Australia. For mass-produced instruments artefact collections should be complemented by the gathering of trade literature.

Other museums in Australia collect scientific instruments. Most notably among them the Museum of Victoria, which has several instruments of Australian importance, including the reconstructed prototype of the atomic absorption spectrophotometer invented by Alan Walsh of the CSIRO in the 1950s. The inchoate National Museum of Australia has a very wide acquisition policy which has sections bearing upon scientific and medical instrumentation. There are other museums which have specialist collections such as the Australian War Memorial in Canberra and the Museum of Mapping and Surveying in Brisbane. So far I have considered social history museums. What of the natural history museums. Their specimen collections are often of considerable historical interest. Much could be done to express this in the display galleries. The physical sciences tend to be treated historically in social history museums but natural history is largely excluded as the province of natural history museums which themselves rarely treat the social history of their subject. There is much to be gained by a more active co-operation between the natural and social museums in the preservation and interpretation of materials for the history of Australian science.

Australia's museums have a potentially significant role in the preservation of our scientific heritage. To achieve this, however, the museums must commit themselves to policies backed by staffing and funding. I am not aware of any museum curator in Australia with a sound knowledge of the broad range of historical scientific instrumentation. Any policy for our museums to participate actively in the acquisition and conservation of historical artefacts of science depends on the development of such curators.

The Museum of Applied Arts and Sciences is currently reviewing its policy on science and technology collections. It is much to be hoped that this review will produce clear policy guidelines for a much more lively role in the preservation of scientific artefacts. The Museum of Victoria likewise has great potential. The Museum is, as I understand it, still accommodating itself to the merger of the National Museum of Victoria with the Science Museum of Victoria a couple of years ago. And surely we can look forward to a national science collection at the National Museum of Australia with a major emphasis on the CSIRO.

We saw earlier that some archives of science enjoy legislative protection. Could legislation help with the preservation of artefacts? This topic will be explored in other papers today. In general, I suspect that most scientific artefacts that a museum would wish to preserve are likely to be available without legislative protection. The same may well not be the case for industrial artefacts. Regarding scientific instruments, however, one area does come to mind. Earlier I mentioned the Dixey microscope. It may be appropriate to consider the introduction of export controls on such items to evaluate their possible local significance.

In the main then, I see the task of preserving our scientific heritage relying on initiative and co-operation. There is much to be achieved through co-operation between scientists, historians of science, archivists and museum curators. This community should work together to establish priorities for the preservation of our scientific heritage. There are several goals which our museums should work towards. I have already mentioned the importance of experienced curatorial staff. These curators must have the opportunity to pursue original research. Documentation on scientific instruments is often very difficult to obtain. The acquisition of such instruments needs to be matched by an active programme of collecting contemporary books and trade literature as well as modern secondary references.

Another area deserving special consideration is modern instrumentation. Earlier instruments have often been small and have had sufficient visual appeal to have been saved from the scrap heap. Modern instruments rarely have the same "mantlepiece" appeal. Now is the time to be collecting post-war instrumentation, much of which is being superseded by microchip technology. We can't collect all of it of course, but we have an opportunity to acquire a reasonable selection now. Another ten years may be too late.

Our museums should undertake research in conjunction with academic historians of science and develop teaching programmes based on their collections. An important part of the development of a community of science curators would be a programme of exchange visits with musems abroad. Museum-based research fellowships should also be considered.

These ideas clearly show the scope for initiative and co-operation. There is no point talking about it and doing nothing. I therefore propose the establishment of a Group for Scientific and Technological Collections. This will provide an Australia-wide network for communication between science and technology curators as well as interested historians and archivists. I believe that it is only through such co-operation that the types of goals I have outlined will be achieved. Given the distances between Australian cities such people cannot often meet. Indeed most of those concerned with historical instruments of science are presently working in almost total isolation from each other. Through a newsletter the Group for Scientific and Technological Collections will do much to break this isolation. National meetings could be organised in conjunction with the annual conferences of bodies like the Museums Association and the Australasian Association for the History, Philosophy and Social Studies of Science. We should also target Australian and New Zealand Association for the Advancement of Science (ANZAAS) congresses and the historical sections of professional associations.

In order to launch this Group I have prepared an expression-of-interest form, copies of which are available today. I will also send copies to museums in other states. If you can suggest particular people I should send forms to, I would be glad to hear them. I will prepare a newsletter in the new year.

Much needs to be done to ensure a balanced preservation of our scientific heritage. This can only be achieved on a national basis. I am confident that the establishment of the Group for Scientific and Technological Collections will provide a forum for the development of national policies.

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Museums and Items of Technological Heritage: Collection Problems and Guidelines

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INTRODUCTION

Assigning a "heritage value" to technological or engineering heritage artefacts does not ensure their permanent preservation.

At the moment, such artefacts are in limbo. Legislation does not cover them and institutions, such as museums, are not obliged to respond to them.

For a long time, the expectation has been that museums should acquire these items and hold them on a permanent basis in the public trust.

This paper deals with the current role state museums play when considering these artefacts, the problems that occur and how they deal with them.

It will also deal with the envisaged role of the museum as a legally designated repository. Some guidelines will also be outlined for an effective repository.

This paper will not discuss heritage significance or criteria used to assign significance to a particular item.

CURRENT ROLE

State museums are viewed by the public, various heritage groups and authorities, and by their own staff as the only suitable repositories for artefacts assigned some sort of heritage value or merit.

This is particularly the case with technological and industrial artefacts. They are often large, cumbersome, obsolete and of no further commercial value. Rarely do they enter the collectable or antique markets, so museums are seen as the only alternative to the refuse tip.

Just about every day the Museum of Applied Arts and Sciences is expected to make a decision whether to acquire some of these artefacts or not. As the disposer of the item is under no obligation to wait for the museum to research the acquisition adequately, museum staff are often pressured to make ill-informed, hasty decisions. Often the offer is rejected immediately because of resource constraints. The museum is no more required to respond than the owner is required to offer, though both feel obliged to do so.

Such a situation adds up to a rather unfortunate current role for state museums. Artefacts of significance exist, the public, heritage authorities and museums staff know they exist yet no one is required or able to do anything about them, although all agree that permanent retention in a public repository is the solution if the item cannot be preserved where it is.

THE PROBLEMS

It is generally presumed that state museums are suitable repositories just requiring a bit more money and space to provide for artefacts of this type. But is the state museum as it exists and functions at the moment really a suitable repository ?

Obviously it does not currently fulfill expectations because of lack of compelling legislation to determine the actions of donor/vendor and museum, and because of lack of adequate resourcing. But there are other factors which determine repository suitability.

These factors are the selection, acquisition, management, storage and research procedures currently observed in the museum. While these factors are adequate for "normal" collection activity they are not set up to handle the scale and scope demanded when collecting and utilising artefacts of heritage significance, particularly if the artefacts are needed as research collections.

Current selection and acquisition procedures in state museums are generally highly individual activities undertaken by specialists in the various subject areas. Procedures are usually generated by the specialist in response to demands from exhibitions, collection policies or the timely availability of something in the market-place. Research is part of that selection procedure.

In the case of the imminent disposal of an item of technological heritage significance by its owner, however, such procedures are too detailed. Certainly the museum specialist is not used to outside recommendation instigating selection or acquisition, and often the item does not fit snugly into collection policies. Research time is not available, nor are the facilities for removal, heavy freight or cartage available at short notice.

Evaluating and acquiring the artefact becomes too difficult or redirects resources from normal activities which always have priority. So the museum elects not to respond positively.

Management, documentation, storage and conservation procedures currently used are also not really set up to cater for numerous, quickly acquired objects which need to be available to outside researchers. Even with specific resources to handle such items, the intricate and centralised registration systems, non-public high security decentralised storage areas and intensive rather than preventative conservation treatments preclude utilisation and access to the collections by the public. This is acceptable for normal collections but it is not a preferred situation for research collections.

Anyone outside the museum staff who has ever tried to do some research using the collection will know how difficult and complex the situation is.

THE ENVISAGED ROLE

This section will deal specifically with the future role of the Museum of Applied Arts and Sciences as a legally designated repository for items of heritage value. Although regional state supported museums may be preferable repositories in may instances this subject will not be discussed in this paper.

One of the future roles of the museum will be that of a legally designated institution required by legislation to evaluate and then accept, if suitable, technological items of heritage significance. Part of that role will be to make those items as accessible as possible to bona fide researchers.

However, if the museum is entrusted and required to act as such a public repository in the future, it will either have to make some major revisions to its procedures, expectations and standards or it will be required to create a particular and separate collection management plan to handle and process such collections. The latter is preferable for a number of reasons:

1. A separate management plan allows for clear definition of activities requiring specific grants and resources on top of current allocations.

2. Disruption of systems and procedures used now need not occur or is minimalised.

3. Separation allows a degree of autonomy which is absolutely essential if artefacts held in perpetuity are to be utilised for research purposes by persons other than the museum staff.

There are many reasons why items of heritage value should be preserved, however, there is no reason for long term storage of these items unless the museum uses them for display or research or the public uses them in academic or professional pursuits in much the same way as a library is used.

GUIDELINES FOR AN EFFECTIVE REPOSITORY

The particular management plan required to handle and process items and collections of heritage significance can be suggested briefly here. A great deal more explanation, discussion and elaboration is required to adequately establish an effective procedure and plan for a suitable repository. The following factors and points can be considered a useful framework. Most of them are taken directly from the United States Department of Interior report on "The Curation and Management of Archaeological Collections: Pilot Study".

The crucial elements of the plan are as follows:

1. A scope of collection activity statement - what generally is to be collected, geographical/time parameters, particular emphasis or exclusions and other relevant factors.

2. A statement of purpose - to collect, house, research, display.

3. An acquisition policy which includes strict definition of heritage significance and criteria for selection.

4. An operation manual which should outline:

   (i) selection and identification procedures,
   (ii) removal and transport procedures,
   (iii) registration procedures which include particularly the need for simple systems accessible by the public,
   (iv) storage procedures outlining logical item type or collection groupings,
   (v) conservation recommendations stressing stabilisation and including guidelines for physical examination and access by the public and professional,
   (vi) guidelines for the researcher regarding access times, limitations, costs, etc.,
   (vii) other relevant procedures.

CONCLUSION

The major conclusion to be reached from this discussion is:

That the Museum of Applied Arts and Sciences needs to provide an ethics statement about portable items of technological heritage significance separate from that which applies to other areas of the Museum's collection. That this statement must encompass the philosophy and procedure of collecting those items, afford them equal status with other objects in the collection and recognise their individual requirements. This ethics statement should either be compatible with or transferrable to other institutions acting as repositories and should be written in collaboration with state heritage authorities.

REFERENCES

Heritage, Conservation and Recreation Service. United States Department of Interior 1980. The Curation and Management of Archaeological Collections: A Pilot Study". Cultural Resource Management Series. Unpublished Internal Report.

Hitchcock, Ann, 1980. "Collections Policy". Manitoba Museum of Man and Nature. Gazette 13 (2), pp 40-48.

Schadla-Hall, Tim and Davidson, Jamie, 1982. "It's very grand but who's it for? Designing Archaeology Galleries". Museums Journal, vol 82, no. 3. pp 171-175.

Whitmore, R.L., 1980. "The Evaluation of Engineering Heritage". Proceedings of the Institution of Engineers Conference, Adelaide, 1980.

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Industrial Archaeology and the Portable Heritage

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INDUSTRIAL ARCHAEOLOGY - A BRIEF PERSPECTIVE

The discipline of archaeology can be regarded as the study of man's past by the material he has left behind him. The term material as used in this paper is to be taken in its widest sense and encompases everything shaped and used by man in the establishment of a culture, including buildings such as St. Mary's Cathedral, the remains of a meal eaten in a cave on the Franklin River bank 10,000 years ago and the drawings and documents held by the New South Wales state archives.

Australian Archaeology is divided relatively clearly into prehistory and historical archaeology. Prehistory concerns the remains of aboriginal societies while historical archaeology examines almost exclusively the material culture of post colonial occupation. It should be noted that the distinction between the two is not so clear overseas. Some countries have long periods of overlap. Australian prehistorians examine material which may have been laid down as long ago as 40,000 years. On the other hand the historical archaeologist works with relics that are seldom over 200 years old.

The methodology of historical archaeology varies greatly from that of the prehistorian in that in many cases the historical archaeologist has available documentary evidence from which hypotheses can be generated, or from which information can be gleaned to prove or disprove existing hypotheses. In other words, the historical archaeologist has an extra tool which he can use to inform us of the society and culture of earlier times.

Industrial Archaeology can be viewed as a part of historical archaeology. Industrial Archaeology is concerned with the machines, the tools, the workplaces, structures and sites of a past society although that may be a very recent past indeed. And in some cases industrial archaeologists make studies of industries which are still functioning in a traditional manner. It should be noted that although archaeology concerns the study of man's past it no longer implies merely the excavation of the physical remains of human beings or their habitats. In fact, industrial archaeology involves only on rare occasions any excavation at all.

DEFINITIONS AND SCOPE

There is no simple definition of industrial archaeology. Angus Buchannan of the Centre for the Study of the History of Technology in Bath, England, stated in part that 'industrial archaeology is a field of study concerned with the investigation, surveying and recording and, where necessary, the preservation of relics and remains of industrial activity'.

The study is 'archaeological' in so far as it is related to the meticulous examination of the physical remains of industrialisation. However unlike conventional or, say, classical archaeology it relies heavily on documentary material of many kinds and is closely related to a study of both industrial and social history.

The scope of industrial archaeology is dauntingly broad. Tony Brassil, formerly of the National Trust, of Australia (NSW) using a variety of sources stated that it was incorporated by the six main categories of primary industries, manufacturing industries, service industries, transport, government and semi-government activities and towns or areas which meet the particular needs of industrialisation.

These six categories were then expanded in such a way that:

(a) primary industries are composed of rural industries such as pastorial agricultural and dairying industries and non-rural industries such as mining, quarrying, fishing and forestry;

(b) manufacturing industries include those such as gas works, electricity generation and distribution, water reticulation, education and recreation industries;

(d) transport industries and systems include roads, bridges, railways and wharves;

(e) tertiary industries encompass those of retailing and retail structures, warehouses and government and semi-government activities; and

(f) townscapes and areas of industrial archaeological significance are those with a unique character derived and developed from the close association with a primary or secondary industry.

There are then, six basic categories and a minimum of some seventy industries. However under a single industry the range of topics available for study is still very large. For example, under transport there are four subheadings, one of which is rail. Under rail there are trams and trains. Taking trains there is concern for the permanent way, for bridges and culverts and tunnels, for stations and sidings, for workshops and water towers and ash pits as well as for the whole range of locomotives and rolling stock.

THE RELEVANCE OF INDUSTRIAL ARCHAEOLOGY

It is accepted that a study of history is essential in understanding the world in which we live. The history of technology, which deals with the way in which our physical world was shaped (with the help of politicians and soldiers) is an essential and inseparable part of that history. The material remains of that history of technology are the artefacts of industrial archaeology.

The industrial archaeological record can be said to consist of two classes of artefact. Those which are portable, like engines and tools and those which are stationary or permanent fixtures such as bridges, buildings and structures. It is the permanent ones which have until recently received greatest attention. Items such as Lansdowne Bridge, the Lithgow Zig Zag railway system and Glen Davis kerosene-shale mining and refining complex are all well known and are all protected, to some extent at least. In this way these sites or items can be placed in the same class as historic houses as they are readily recognised as important parts of the cultural heritage.

The architect of many of the historic houses is quite often well known as is the history of the original owner, his family and, in some cases, the later occupants. However all too often practically nothing is known of the artisans, who, with their tools and machines laboured to erect the house. The same can be said of the great industrial archaeological relics. The designer or engineer may be known to many but the craftsmen and tradesmen, the riggers, the fitters and turners and the nailmakers are not remembered, nor are their tools, their machines, nor their workplaces.

The workplace though, of all relics, should not have been neglected. The workplace, whether it be a scientific laboratory, office, factory or workshop was where people spent their most productive hours. (And here I should add that I am not including the child rearers and home builders who must wait for another writer to tell their story.)

It was in the factory where tools, motors and engines were made to power other primary and secondary industries. It was where bricks were made and iron was cast and steel fabricated to form the built environment. The workplace was the focus of a person's life as much as the home and family. The workshop, be it 19th or 20th century, was crammed with items of the portable heritage. Such a workshop could tell us more of the skill patterns, capabilities, attitudes to health and safety, attitudes to work and social values than the mere end products of the workshop such as the buildings and structures which ironically survive.

INDUSTRIAL ARCHAEOLOGY IN AUSTRALIA

In Australia the history of industry and technology are particularly close to our political and social history. Australia's modern history began as a European Colonial settlement and it grew out of conditions created by the industrial revolution in England. Early settlement, progress and expansion were confined to the exploitation of primary resources and limited at all times by restrictions of transport, communications and the provision of services. The geography of the country exacerbated problems of colonisation and communications between the colonies and the isolation from Europe produced a unique cultural heritage.

The early industrial spirit was entrepreneurial and exploitative. This spirit was carried over into the twentieth century when Australia had a manufacturing industry, admittedly heavily protected, in which cars, aeroplanes, railway locomotives, electric motors, pumps and brick making machinery, to name but a few items, were manufactured in quantity.

Over time many of these industries underwent changes of various kinds for a variety of reasons. Sometimes the changes were rapid, and at other times slow. In some instances the change was easily accepted, but in others the change was so dramatic that a whole industry had to be totally reconstructed. These changes, whether in outlook or technology, led to the creation of a unique set of technologies in Australia and set the stage for the industrial archaeologist.

The industrial archaeological universe is the totality of former industrial sites plus those sites which are soon to undergo or have recently undergone a fair degree of change.

Within one kilometre of Observatory Hill in Sydney there are the Walsh Bay Wharves, Parburys Bond Store, Oswalds Bond Store, the remains of Darling Harbour Goodsyard, North Sydney Railway Station, the overseas passenger terminal and the Circular quay jetties which are all items of the industrial heritage earmarked to undergo irreversible change.

ITEMS OF THE PORTABLE HERITAGE

The sites which are the real concern of this paper are those which contain items of the portable heritage. These sites can be divided into those which are operating and those which are non-operating.

Non-operating or abandoned sites have usually been stripped of all machinery and tools and the building badly vandalised. Sites which are relatively intact and which contain an almost complete set of machines and equipment are rare and where they exist they are usually very isolated or they have recently ceased production. The equipment at 'The Willows' sawmill near Laggan and that of 'The Glen' tin mine near Torrington are relatively intact simply because collecting and transporting the items to a commercial centre for sale or reuse is not economical. Two important Sydney sites which still have much of their machinery intact are the old WD & HO Wills tobacco factory at Raleigh Park and the Crago Flour Mill at Newtown. Both the Wills and the Crago sites contain not only artefacts of the portable heritage but much documentary information such as instructions to employees, flow charts and diagrams which will allow interpretation of the site as a whole as well as interpretation of the individual machines.

Operating sites which are of greatest interest to industrial archaeologists are those which are industrial anachronisms. Some sites such as the Glen Innes Brickworks and Grahams Foundry at Newtown are still functioning with equipment which is all seventy or eighty years old. Other industries have undergone change in most departments but still have one or two items of venerable age such as the old nail making machine of Australian Wire Industries at Five Dock and the old screw cutting lathe at Spurway Cooke in Alexandria.

It is almost always possible to obtain information about the age, the maker, method of construction, maintenance procedure and work schedule of equipment in operating sites. These sites usually provide much more information about work practices than non-operating sites and the information is usually more reliable and more easily checked.

ASSESSMENT

There are literally hundreds of industrial archaeology sites in New South Wales (NSW) containing thousands of artefacts. Some of these artefacts are portable items of considerable heritage significance. It is possible to keep and conserve only a very small portion of these items. For this reason those chosen for conservation will have to be selected by the application of a very carefully considered set of criteria.

Several well structured organisations already exist which formally or informally select artefacts for conservation. There are many other less structured organisations as well as individuals throughout the state who select items of portable heritage for collection or conservation.

This second group usually acts in an ad-hoc manner without a set of established aims and is concerned with obtaining artefacts and placing them in private or semi-private collections. The selection criteria of these groups are not the concern of this paper.

Of the structured organisation in NSW there are the various museums, the Industrial Archaeology committee of the National Trust of Australia (NSW) and the Heritage Committee of the Institution of Engineers of Australia (IEA). Display potential appears to be a significant criteria for selecting items for museum collections, however this is seldom a major consideration for either of the other committees.

The Industrial Archaeology Committee of the National Trust has, since 1975, been recommending items of the portable scientific and technological heritage to the Council of the National Trust for inclusion on the Trust's register. In order to receive a classified listing an item or artefact (which both come under the term 'place') must be one of those

> environment of Australia, that have aesthetic, scientific or social significance or other special value for future generations, as well as the present community.

The guidelines for a classified listing are extremely broad and it is possible that several physically similar items may be classified because of their historic significance or because of their special significance to a local community.

The Heritage Committee of the IEA has tried to be more objective and has been more precise in defining the criteria for assessment. Professor Ray Whitmore in a paper delivered to the society in 1980 stated that an object had to have engineering significance to be included on the IEA's Heritage List. Engineering significance was defined as:

> '....creative or technical accomplishments evident in an original design, the materials of construction or in the methods of use of materials in turning a design into reality'.

He went on to say that other criteria may be the demonstration of an obsolete industrial, technological or engineering process, in which case the piece was important in interpreting past techniques. A third, but nonetheless important criteria was a link with an important person.

Another method of assessment was devised by M F Barbey for the Institution of Civil Engineers' Panel for Historical Engineering Works in Britain in 1974. The Barbey formula attempted to objectify what had been a relatively subjective process. The formula weighted heavily criteria such as age and rarity and gave little more than recognition to some others. Marks were awarded in the various categories and totalled. In some instances marks could be subtracted for disuse or disrepair. When a final mark was established artefacts were assigned to classes A,B,C,D or E depending on their score. Those which received an A or A+ were national monuments (or artefacts) and were the best of the nation's engineering heritage. Those which received an E were not regarded as being worthy of inclusion on the register.

The Heritage Committee of the IEA has adopted a modified version of the Barbey method and it has brought a degree of consistency to the assessment procedure.

The Barbey method has several requirements. The first demands the availability of sufficient assessors of the right calibre and experience (although no explanation is given of calibre). The second requires that sufficient technical and historical data has been assembled, while the third suggests that the site actually be seen by the assessor or a series of excellent photographs be provided. Lastly Barbey states that all assessors should understand the method and undertake some sort of training.

Barbey attempted to introduce an engineer's objectivity to the selection process and he was certainly, in part, successful. But there is no way that assessment of items can be wholly objective when criteria such as aesthetics, proportion and fitness to function are to be considered.

Both the National Trust and the Institution of Engineers assess items primarily by determining whether they are of sufficient significance to be included on their respective registers. Even if an item is included on both registers there is no guarantee that it will be protected. A museum, when assessing an artefact to determine a possible inclusion in its collection, will use a vastly expanded set of criteria which will depend on the particular museum's collection policy.

If the scientific and technological heritage is to be protected then it would appear that an entirely new approach will have to be made to assessment. It may be necessary to develop a philosophy that has no immediate connection with any existing philosophy. It is probable that new priorities will have to be established. It may be that artefacts, illustrating a purely Australian development or innovation, will receive higher priority than some artefact from overseas which may have had a greater technological impact on society.

What is really needed is the identification of the whole, or at least a substantial part, of the total universe of the portable technological heritage. Then with aims and objectives clearly stated and available resources in mind, a sample could rationally be selected which would represent say the major developments in any field of science or industry with perhaps a bias towards local innovation.

However it would appear initially, at least, that assessment of portable items will follow the same path as did places of cultural significance. Items will be judged individually by experts using a combination of methods appropriate to the class of artefact until sufficient resources are found to employ more sophisticated procedures.

THE RANGE OF ITEMS IN THE INDUSTRIAL ARCHAEOLOGICAL SECTION OF THE PORTABLE HERITAGE

The Register of the National Trust lists both individual items of heritage significance as well as sites which contain assemblages of artefacts. Individual items of heritage significance on the Register include the Sydney Harbour ferries South Steyne, Kanimbla, Karribee, the Second World War spy vessel Krait, the Sydney Maritime Services Board barge 'Sheerlegs' and the massive Galloway steam engine which powered the rolling mill at the Australian Iron and Steel Works at Port Kembla. The more important assemblages of significant items are contained in such sites as Glen Innes Brickworks, the Walsh Bay wharves and Eveleigh Railway Workshops. In the near future it is proposed to recommend more individual pieces as well as assemblages of items at various power stations, brickworks and saw mills. The Trust, however, has only scratched the surface of the total universe of portable items which are staggering in their sheer number and diversity.

It would appear that it may be more satisfactory from several points of view to protect a complete assemblage of artefacts rather than individual items. At Garden Island Dockyards in Sydney it was proposed as part of the refurbishing of the Naval Stores Building as offices to abolish part of the hydraulic hoist system. The system consisted of a motor, a pump, a water reservoir, five hydraulic rams and five external jib cranes. The proposal was to leave only the jib cranes as they enhanced the external view of the building. When it was pointed out in a conservation analysis that the building owed its very form to the existence of hydraulic technology and that this system was the only one of its type existant in NSW the architects decided not only to keep the whole system but to restore it to operating condition. It should be added that the Museum of Applied Arts and Sciences quite rightly rejected the offer made by the relevant authorities to accept ownership of part of the system and display it in the museum. It is expected that the hydraulic system with its five jib cranes will be operating on selected days by the end of 1987.

Traditional industries which are still operating provide industrial archaeologists with much more information on work practices than non-operating sites. Similarly assemblages of artefacts are more easily interpreted than individual items.

Glen Innes Brickworks, for example, is a small country brickworks that has been operating on the one site for at least sixty years. It is the only surviving factory wholly powered by steam in NSW and one of the few brickworks where the kiln is still fired with wood. Much of the equipment has been on the site since its establishment and is still in daily use. Some of the artefacts are the only known surviving examples of their type. These include the Tangye steam-engine, the Marrickville brick-press, the Hodgkinson brick-press and the Pennsylvania boiler. All of these are relatively large pieces of equipment and have heritage significance in their own right. But there are many other pieces of ancillary equipment such as the Worthington steam-pump, the Marrickville underdriven pan-crusher, and a complete set of maintenance equipment which are all essential for the successful operation of the works. These pieces have no intrinsic value themselves but must be included in the assemblage if the brickworks is to be fully understood and successfully interpreted.

Brownes Stonemasonry at Maitland closed down some four years ago. Brownes contained one of the oldest and certainly the least sophisticated set of sandstone working equipment in NSW. There were two massive gang-saws weighing over 5 tonne each, a stone profile planer made predominantly of cast iron, several wooden-bed stone lathes and an old circular stone saw. As well as the machinery and tools necessary to shape stone and fix it in place there was a collection of handtools, chisels, squares, levels, plumbbobs and templates which allowed the master mason to set out, shape and carve letters in stone with great accuracy. Each large piece of machinery was readily recognisable as an item of heritage but without the smaller and apparently less impressive items the industry of stonemasonry could not be understood.

The South Maitland Railways (SMR) complex is perhaps the largest assemblage of portable artefacts that has been classified by the National Trust. This single industry is one of the most important industrial archaeology sites in NSW. Admittedly there are some items which cannot be regarded as portable such as the buildings, the permanent way and some of the safe working equipment. But if any of the portable items, no matter how small or apparently insignificant, are taken from the site then the complex is no longer whole. The SMR was a total system. It operated trains on its own permanent way, had its own safe working system, its own locomotives and rolling stock as well as its own workshops where almost any repair including the rebuilding of boilers could be carried out. It still has a wheel-lathe, a turrett-lathe, massive sheet-metal rollers, rivetting gear, a foundry, coppersmith shop, blacksmith's shop and spring-making shop, an overhead-crane and several steam-hammers. As well it has a collection of early micrometers and gauges which were in use until the closure of the workshops. SMR is in reality a massive collection of items of the portable heritage placed in close proximity to a railway line.

Recognition of the importance, the diversity and sheer volume of the portable and technological heritage, and the ability to adequately assess various items represent one issue while conservation is an entirely different one. It is quite possible to place individual pieces such as small steam engines, small boats, Oliver steam-hammers and huge Davey steam-presses in museums or collections. But assemblages of artefacts present different problems. Assemblages such as those found at Brownes Stonemasonry at Maitland, in the Power House at Cockatoo Island Dockyard, at Eveleigh Railway workshops, at Inverell Foundry, at Grahams Foundry, any number of mining and refining sites, at Ballina Slipway, Broadwater Sugar Refinery, Bezzants Saw-mill need very special attention.

In some cases individual items and small assemblages may be collected, conserved and displayed away from their environment. But in other cases, such as that of South Maitland Railways, it would appear that conservation on site is the only correct course to follow.

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Portable Scientific and Technological Heritage: The Present Legal Status in New South Wales

HELEN TEMPLE

Our portable heritage comprises the things we make and use, the tools, ornaments and furnishings with which we decorate ourselves and fill our houses and work places. These portable artefacts or relics are the details of our cultural environment. The existence of museums and art galleries confirms that Society values those portable relics traditionally considered worthy of collection. Not all portable relics can or should be housed within museums so the question of their legal protection is critical. Conversely, those relics for which museums are responsible must be the subject of sound curation and management practice.

For clarity in today's proceedings I distinguish between two arbitrary categories of portable relics:

(1) archaeological artefacts and assemblages (artefacts found in association with each other) which have been excavated from, or associated with, a particular place or activity. An example would be the 1,700 boxes of artefacts from the First Government House Site excavation in Sydney project which represent the European occupation phases on that site, from 1788 to the present day, and

(2) personal chattles: moveable, tangible articles of property of such diversity as a steam locomotive or Mrs Macquarie's teaspoons, articles which have not been recovered from an archaeological context.

Issues arising out of the legal status of portable relics include:

- The available avenues for protecting portable relics, both chattels on the one hand and archaeological artefacts on the other. Of particular concern is the question of the movement or removal of such relics from context.

- ownership and the long term curation and management of those items.

This paper is confined to an analysis of the existing protective provisions in New South Wales for portable historic relics as manifested in the New South Wales Heritage Act, 1977. It does not cover Aboriginal relics, or the regulations and laws of other States or Federal authorities (1).

The Heritage Act, 1977 : Legal Definitions of "Environmental Heritage" and "Relic"

In NSW, the Heritage Act, 1977 provides a number of strong, legal devices for protecting the State's "environmental heritage." This is a blanket term which includes the total range of cultural and natural places and objects.

Let us start with the definitions. First,"environmental heritage" is defined as: "those buildings, works, relics or places of historic, scientific, cultural, social, archaeological, architectural, natural or aesthetic significance for the State" (2).

A "relic" is also defined in the Act as: "any deposit, object or material evidence relating to settlement prior to 1 January 1900 or such other date as may be prescribed of the area that comprises NSW not being aboriginal settlement." (3)

These two definitions establish the basic framework for the terms of reference of this seminar. We are here to discuss the protection and management of portable artefacts or personal chattels (moveable, tangible articles of property) (4).

Personal chattels may be "relics"as defined in the Act and, therefore, as long as they conform to the legal definition ,particularly the pre-1900 date, all the protective provisions of the Act which refer to "relics" can be applied to chattels or moveable artefacts.

Protective Provisions Relating to 'Relics' in the Heritage Act 1977

There are several provisions and I will deal with them one by one.

(i) Excavation Permits

The most commonly cited controls for historic 'relics' in New South Wales relate to the excavation of land containing, or believed to contain 'relics'.

Any 'relics' which are directly related to real property (land), are protected by sections 140 and 57(1)(c) of the Heritage Act, 1977. These require a person wishing to expose, move or discover a 'relic' to hold an archaeological Excavation Permit issued by the Heritage Council of New South Wales.

This requirement applies to all the State except that owned by the Commonwealth Government or a Commonwealth instrumentality. The Heritage Council's policy is that Excavation Permits are only issued to excavators with recognised qualifications or demonstrated practical experience, and also for excavation projects for which there is a demonstrated research goal. Permits are not issued for purely teaching excavations, to amateurs or for projects where artefact collection (treasure hunting), is the only goal.

The conditions on which the permits are issued include stabilisation of the excavated features and artefacts; backfilling of trenches for reasons of longterm conservation and public safety; organisation and deposit of excavation records for archival purposes; and the adequate reporting of findings.

Finally, any person who discovers a 'relic', (including chattels), in the course of other works, is required under section 146 of the Act to notify the Heritage Council of the find in order that it can be investigated.

These legal requirements protect a variety of places and relics including whole sites, the individual structures and artefacts which comprise those sites, historic cemeteries, and their individual graves, features such as bottle dumps and chance finds, once reported.

(ii) Conservation Instruments

'Relics' may be protected by three types of conservation instrument.

These are the section 130 Order which controls demolition; the Interim Conservation Order (ICO), which applies for up to two years; and the Permanent Conservation Order (PCO), which offer permanent protection. As far as relics are concerned, the conservation orders control the following activities:

- damage or despoilation;
- excavation of land on which the relic is located;
- development of land on which the relic is located;
- alteration of the relics;
- display of notices on the relic.

Any owner wishing to carry out these controlled activities must first have the consent of the Heritage Council.

Owners and lessees have the right of appeal against a ministerial proposal to make a PCO. Such appeals, are the subject of an independent Inquiry in the Land and Environment Court. As a result of the hearing, a recommendation is made for Planning and Environment either to proceed with the order or not.

(iii) Acquisition and Acceptance of Property

The corporation (being the Minister responible for the Act) is also able to acquire relics and therefore chattels by lease, purchase or exchange but only if they contribute to, or enhance, a land or building already in its ownership.

However, there is an anomaly, for the corporation is able to accept chattels as gifts without qualification.

The acquisition of property will normally only be considered as a last resort to ensure the conservation of that property.

(iv) Rating and Land Tax Relief

Land which is protected by a PCO is valued for rating and land tax according to a heritage valuation based on its existing use as opposed to its highest potential use.

> As historic relics are the property of the owner of the land on which they are located, this provision affects historic archaeological sites and artefacts in as much as it offers some compensation to owners who may have the use of their land restricted to protect the relics associated with it.

Discussion

Having outlined these provisions, let us look then at their implication for portable "relics" as personal chattels:

"Relics" fall within the definition of "environmental heritage" and therefore may be protected by conservation instruments. (5)

The Heritage Act generally applies to land fixtures and the popular extrapolation of this is that relics, and specifically chattels, can only be protected by those sections of the Act which relate to excavation and then only until those chattels are excavated.

Certainly, the way the Act has been administered to date has required all items, be they buildings, engineering works, ships, shipwrecks or archaeological relics to be related to land. (6)

To date, it has been the interpretation of those administering the Act that it is not possible to control the movement or removal of chattels. In fact, one of the amendments to the Heritage Act being considered in a current review of the legislation, is to strengthen the Act to ensure that movement of portable relics can be controlled more overtly. (7)

However, another interpretation of the existing wording of the Act in relation to portable relics, outlined below, may be valid and is being considered by the Department at the present time. If this is accepted, than some controls could already be placed on moveable relics:

- Chattels pre-1900 in date can be protected by a conservation instrument.
- Taking the next step, if it can be argued that the location/association of the chattels with a particular place, contributes to their significance or integrity, the Act could be used to control their removal.
- One of the activities controlled by a conservation order is "alteration." The Oxford Dictionary defines the verb "to alter" as "to change in characteristics, position." By inference, therefore, it is possible to protect the movement of particular chattels using a conservation order by relating those chattels to a land description. This would automatically require the approval of the Heritage Council under Section 57(1)(e) of the Act for their relocation.

In any event, the application of a conservation order to chattels, whether or not they are related to real property would still control "damage or despoilation" and "alteration" meaning change.

The major restriction on the use of these provisions to protect personal chattels, relates to the legal restriction of a relic being pre-1900 in date. This means that unless a chattel post 1900 in date can be argued to be "a work", it is not currently possible to protect it through the Heritage Act.

Since its inception, the Heritage Council has been asked to consider the possible protection of a number of movable heritage items. Some of these cases and their resolutions are outlined below:

The S.S. South Steyne, The Karrabee, The Lady Edeline

All three Sydney Harbour ferries were nominated for protection under the Heritage Act in 1981. The S.S. South Steyne is considered to be the ulimate development of the traditional Manly Steamer. It was built in Scotland and came to Sydney in 1938. The Karrabee and the Lady Edeline were both built in 1913 and at the time of consideration were the only surviving examples of the timber ferries which characterised the Harbour fleet for so many years.

Although the Heritage Council was sympathetic to the conservation of these vessels, it could not recommend use of the Act as their construction dates were 20th century and therefore they did not comply with the definition of 'relic' under the Act (9).

The Hydraulic Pump,Accumulator and Lift, Walsh Bay Wharves 8,9, Miller's Point, Sydney

This Hydraulic system consisted of 3 components, the pump accumulator and lift. The pump was manufactured by Clyde Engineering and was roughly contemporary with the erection of the wharves in 1912-20. The accumulator which stored the power generated by the pump, consists of brick ballast cemented on a cast iron base, penetrated by a steel ram and supported on an oregon frame. The lift is typical of early hydraulic lifts, the values on the lifting being activated by a steel rope.

The system was used to power the lifts, whips and wool dumps on Walsh Bay Wharves 8 and 9. It was closely associated with the wool industry between 1920-75. It is the only system of its type left in a position of public access and is considered to be a significant item of engineering heritage.

Its date precluded its protection as a 'relic' but it was argued that the system comprised an engineering 'work' within the definitions of the Heritage Act and an ICO was applied to it in 1981. This has lapsed pending negotiations with the Maritime Services Board over its long term future.

Christchurch St. Lawrence Sydney and its Historic Pipe Organ

Historic pipe organs are a category of artefact which, although often thought of as fixtures attached to buildings, are theoretically portable.

The Heritage Act has been used to protect a number of such items and maintain their association with the structure in which they are housed.

One such example is Christchurch St. Lawrence and its historic pipe organ, in George Street, Sydney. The church is a large Gothic revival sandstone Church consecrated in 1848 by Bishop Broughton. The tower and spire were designed by Edmund Blackett. The pipe organ, built by Hill and Son in 1892 for a private dwelling in Leichhardt, is a major example of its kind. In 1906 the organ was installed in Christchurch St. Lawrence where it remained unaltered until repairs and some controversial additions were made in

1979. At that time PCO was placed on the building and the organ as a 'work' which provides permanent protection to both and ensures continuity of association. (10)

South Maitland Railway

The South Maitland Railway system embodies many of the problems that are being addressed by this seminar.

The South Maitland Railway, now privately owned, is the last fully outfitted Edwardian steam railway in New South Wales. It incorporates a double track which extends approximately 40 km, signage, culverts, crossings, huts, signal boxes, wayside huts, cuttings and communication systems and the East Greta Junction workshop complex. The workshop is a fully equipped, operational workshop consisting of company offices, signal box and workshop, locomotive coal loader, the original sand heating, furnace, water towers, stores and sheds assoicated with steam enigne maintenance and the working routine of the men who drove and maintained the engines.

Additionally, there are 13 class 10 Beyer-Peacock locomotives, which were custom-made for the railway, several original coal waggons, guard vans and other rolling stock which do not fall within the jurisdiction of a conservation instrument. A Private Member's Bill to protect these items was submitted to Caucus in 1948, but it was not passed due to an alternative proposal to conduct a study of the economic and marketing feasibility of running steam trains along the South Maitland Railway.

Construction of the railway commenced in July 1892, the contractors being Messrs. Wright and Woodward. The line was initially built to transport coal from numbers 1 and 2, East Greta Coalmines. Additional sidings were built and the line was linked to neighbouring lines until in 1918, the East Greta and Hebburn Mining Companies amalgamated and the Australian Agricultural Company assets were taken over, thus forming the South Maitland Railways. The new company continued to service each of the collieries as they opened, thereby spanning the entire northern coal fields and totalling 30 mines. The railway also ran a large system of passenger trains, servicing the population between Cessnock and Maitland. Unfortunately, most of the carriages were destroyed in a fire during the 1930s.

The South Maitland Railway was bought by Coal and Allied Pty Ltd in the 1960s. The State Rail Authority now operates intermittent rail haulage, using diesel engines from Cessnock along the single up main track only. Coal and Allied operate a number of the South Maitland Railway steam locomotives on the 8 km stretch of the Richmond Main Line, between Hexham and Stockrington. These locomotives are maintained in working order by salvaging replacement parts from the other locomotives, stored specifically for this purpose. This section of track is virtually closed. The owners, while somewhat sympathetic to its heritage significance, do not wish to bear the cost and responsibility of maintaining the place for which they have no profitable use.

A National Estate Grant to the National Trust allowed the site to be recorded in detail. However, it is deteriorating through vandalism and lack of maintenance.

The system is characterised by a working association of structures, works and artefacts. The components were constantly renewed in the course of maintenance and in this way it is typical of many working industrial sites.

The portable chattels which animated it, the engine driver's kit, including billy boiler, cap, lamp, etc the tools and equipment, have disappeared and there is no mechanism for legally protecting the place because it does not comply with the definition of 'relic' in the Heritage Act, 1977.

Archaeological Artefacts

The second area of concern is for 'relics' associated with an historic site or an archaeological context.

These are protected by the sections of the Act which relate to excavation control.

Once excavated, however, historic artefacts are not so secure. The legislation presupposes that the artefacts assemblages and collections from historic site excavations or surveys will be retained permanently in the public interest. However, no provision exists within the Heritage Act or any other piece of New South Wales legislation to cover the longterm curation and management of these collections. No guidelines have been written to outline correct storage, curation or management of these collections.

This is a serious oversight, although some storage requirements may be enforced through the conditions of the requisite excavation permit. One initiative worth considering is to strengthen the permit conditions to require a plan of curation and management to be prepared prior to the commencement of the excavation. Historic artefacts have been collected in New South Wales since colonial times, increasing in the 1960s with the stirring of academic research on colonial sites. In the last decade, with the passing out of the various environmental laws requiring or facilitating site investigations, the volume of these collections has increased exponentially. The problems of storage, curation and management are now critical.

Archaeologists have long recognised the storage problem, but only in recent years has this concern been extened to the manner in which collections are cared for including, curation, conservation, access and use for research or display purposes. Unless standards are developed and adhered to, these collections will eventually be rendered useless as research tools by the processes of decay.

Criticism has also been levelled at field archaeologists for lack of discernment in their collecting behaviour. In times of increasing economic hardship, more discretion should be used in choosing data for permanent storage. For a number of years all the relics from excavations under Heritage Council Excavation Permits were deposited in the Heritage Council office. Following the excavation of a number of major sites, an informal arrangement was reached with the Power House Museum, Sydney, for these artefact collections to be temporarily stored in the Museum's warehouse. Only material from Mint and Hyde Park Barracks, Sydney, has been formally accessioned into the Museum's collection.

That is the current position with artefact collections from historic sites. There is no formal registration procedure because the artefacts are only there under sufference. There is no requirement for the excavation records (including photographs) to remain with the collections, there is no cataloguing, no conservation for access or ongoing research.

However, the problem cannot be solved just by nominating an institution as the legal authority responsible for these artefacts. Collection management is time-consuming and costly. Adequate funding must be provided and sound management practise adopted.

The whole question of curation and management of archaeological collections has been deliberated upon at length by the US Department of the Interior (11) and some of their conclusions will be discussed during the seminar by Richard MacKay. Suffice to say that, as the majority of historic site investigations are generated by the State, it seems that the burden of curation and management will largely fall on the government. In view of the difficulties faced by government archaeologists in gaining even limited funds for artefact analysis (which is not commonly perceived as essential), greater problems are anticipated in the future for extracting funds for storage and curation. This issue has to be faced and must be confronted by the responsible authorities.

The Mint and Hyde Park Barracks, Sydney

One archaeological project which highlights most of the problems which surround excavated relics from historic sites is the Mint and Hyde Park Barracks, Sydney. Responsibility for the excavated relics has been formally accepted by the Museum of Applied Arts and Sciences and therefore the collection is not typical, but is worth discussion. These two sites were the subject of a nine month archaeological investigation in 1981. The fieldwork was paid jointly by the Department of Environment and Planning and the Public Works Department and the project took place at the same time as both buildings were being refitted for use by the Museum.

The collection of artefacts resulting from the fieldwork is of outstanding heritage significance. The buildings served a variety of uses from construction in 1811 and 1817 respectively. Its uses include male convict barracks, female immigrant and orphan quarters, a lunatic asylum, the NSW Mint, and various medical and then legal functions. The artefact collection which resulted from the excavation represents all occupation phases and has outstanding research potential to contribute information not only on the construction methods and changing uses of the two places, but also to the social history of the inhabitants and the colony at large.

No funds were made available for the analysis of this material at the time of the investigation although this is being partly recified by two small grants to the Museum from the National Estate research grants which are paying for one part-time reseaech worker.

As the management authority responsible for the site (now a Museum of Social History) and the artefact collection, it is critical that the Museum acknowledges its responsibility to that collection and becomes more actively involved in research work. This will mean contributing financially. The Museum should also acknowledge that the two sites are themselves manifestations of cultural history rather than large museum cases for inanimate or active displays on a variety of disparate subjects.

The research potential of the artefact collection is to date an untapped resource and to leave it lyingdormant and decaying is irresponsible.

The whole question of the curation and management of this and other archaeological collections (including research) should be very seriously analysed by the Museum when considering the future areas of museum activity.

Conclusion

Portable historic relics have been slow to gain general recognition as heritage items and even slower to be the subject of comprehensive legal protection.

The application of the New South Wales Heritage Act, 1977, to protect movable relics has not yet been fully tested, although consideration is being given to stretching the use of the Act to cover this category of artefacts through a modified interpretation of the existing wording and also the current review of the Act.

As far as historic 'relics' from archaeological excavations are concerned, it is essential that an institution be nominated as responsible for their curation and management.

Looking at the existing legislative controls in NSW for portable relics, a number of concluding remarks can be made:

It is possible to place conservation orders under the Heritage Act, 1977, on personal chattels as long as they conform to the definition of 'relic' in the Act, (particulary the pre-1900 date).

These conservation orders provide a number of protective provisions which may include movement of chattels.

It is my opinion that both the one - 1900 date associated with the definition of 'relic' in the Heritage Act, and the mechanism for protecting the movement of relics needs to be addressed in the current review of the Heritage Act, 1977.

Historic archaeological relics are indirectly protected by the Heritage Act until they are excavted. However, in the absence of any institution being nominated as the responsible authority, a number of extremely significant archaeological collections are rapidly deteriorating. These collections require long term management and curation.

The Museum of Applied Arts and Sciences is the most appropiate institution to manage these archaeological collections.

As part of the management strategy, every encouragement should be given to the public and to teaching institutions to use these collections for research purposes, thereby increasing our knowledge of Australian history and furtherjustifying the retention of these collections.

Finally, it has been emphasised frequently that the protective provisions of the Heritage Act are used as a backstop - a formidable arsenal with which to encourage negotiation (12).

Particularly with regard to portable relics, the Heritage Act cannot effectively work alone. The Museum of Applied Arts and Sciences is responsible for portable heritage items. However, for many years, the Museum has been operating on a principle of artistic connoisseurship and technological rarity which has tended to overlook more pedestrian aspects of Australian cultural history.

Now that the Museum has a strong social history component, the opportunity is open for a closer working relationship between it and other organisations in NSW concerned with both the built environment and movable relics - organisations such as the Historic Houses Trust, the National Parks and Wildlife Service, the Department of Environment and Planning, and the Heritage Council of New South Wales. The newly announced New South Wales Ministry of Heritage however it will be manifested - has the potential to bring these groups much closer together and improve the avenues available to us for protecting portable relics.

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FOOTNOTES

1. See National Parks & Wildlife Act No.136, 1974 New SOuth Wales. The provisions for the curation and management of Aboriginal artefacts is also discussed briefly in Richard MacKay's paper delivered at this conference.

2. Heritage Act No. 136, 1977, New South Wales. p.6.

3. ibid p.7.
Note that Aboriginal settlement has been specifically excised from the Heritage Act to avoid overlap with the protective provisions of the National Parks and Wildlife Act.

4. P.G. Osborne LL.B., A Concise Law Dictionary Sweet & Maxwell, London 1964 p.68.

5. Department of Environment and Planning "The Protection of the Environment Heritage in NSW" Papers delivered at a Seminar for the Heritage and Conservation Branch of the NSW Planning & Environment Commission 8th May 1978 unpublished p.35.

6. This may be a result of the Act being administered through the Department of Environment and Planning which has used the traditional planning language and procedures relating to real property.

7. A general review of the Heritage Act 1977 has been initated by the Minister for Planning and Environment who administers the Act and this is currently underway.

8. The term "work" is not defined in the Heritage Act but is loosely interpreted as meaning engineering work such as roads, bridges, drainage or electrical systems and large pieces of machinery.

9. See minutes of the Heritage Council meeting held 3rd September 1981, Report No 307/81 No: 8(iii) "Conservation of Movable Relics".

10. See The N.S.W. Government Gazette No. 141, 22nd October 1982.

11. United States Department of the Interior The Curation and Management of Archaeological Collections, 1980.

12. See for example.
Helen Temple, "The Listing and Control of Archaeological Sites Under the NSW Heritage Act" Industrial and Historic Archaeology Seminar, 1979 , National Trust of Australia (NSW) 1979 p.63.

BIBLIOGRAPHY

Department of Environment ans Planning "The Protection of the Environmental Heritage in NSW." Papers delivered at a Seminar for the Heritage and Conservation Branch of the N.S.W. Planning and Environment Commission 8 May, 1978 unpublished.

Heritage Act No 136, 1977, New South Wales.

National Parks and Wildlife Act No. 80, 1974, New South wales.

O'Keefe, P.J. & Prott, L.V., 1984 Law and the Cultural Heritage. Professional Books Ltd., Oxford.

Osbourne, P.G. LL.B 1964 A Concise Law Dicitionary. Sweet and Maxwell, London.

United States Department of the Interior Heritage Conservation and Recreation Service, 1980. The Curation and Management of Archaeological Collections: A Pilot Study unpublished

Temple,Helen. 1979. "The Listing and Control of Archaeological Sites Under the N.S.W. Heritage Act.. Industrial & Historic Archaeology Seminar, 1979. National Trust of Australia (N.S.W.).

This address was part of a seminar on "Problems and Prospects of Preserving the Portable Scientific and Technological Heritage" organised by the Royal Society of New South Wales, the National Trust of Australia (New South Wales) and the Museum of Applied Arts and Sciences, in Sydney, New South Wales, on the 2 August, 1986.

In April 1987,amendments to the New South Wales Heritage Act were gazetted. These included a number of significant changes to the relics provisions of the Act. Relic was defined as:

"any deposit, object or material evidence -

(a) which relates to the settlement of the area that comprises New South Wales, not being aboriginal settlement; and

(b) which is 50 or more years old.

Further it is now possible to protect relics with conservation instruments and control their movement from one place to another.

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Provision of Statutory Protection for Artefacts

RICHARD MACKAY AND PETER JAMES

INTRODUCTION

It is almost universally accepted that significant historic sites - whether buildings, landscapes or even archaeological deposits and industrial remnants of established cultural significance, warrant the statutory protection and conservation measures now afforded to them. Although there are various statutory provisions which cater for the protection of Aboriginal artefacts, which is not dealt with in this paper, the value of our portable historic heritage is less well acknowledged. However, in many cases, artefacts, through intra-site relationships and context through intrinsic merit are equally important. In many cases artefacts rather than sites have a greater potential to reveal information about former technologies or social conditions. Artefacts, no less than the sites from which they come, provide valuable tangible evidence which, once removed from context or destroyed, is irreplacable.

BACKGROUND

The lack of provisions for protection, ownership, storage curation and management of artefacts has been addressed by various individuals over the past decade, (Wade, 1979, 1985; Birmingham 1981, Imashev, 1983,) all of whom recognise the need for official repositories, better protective measures and more precise assessment criteria. The problem to date has been that issues such as the definition used to classify these items or the source of funding for their management,have not been resolved by our legislators. Australia's Federal and State heritage legislation (such as it is) provides protection based on sites rather than artefacts. These sites include items of the built and natural environment, although shipwrecks also are protected in some states (Wade 1979).

The Federal Government has recently acknowledged the importance of our portable cultural heritage with the introdution of "The Protection of Movable Cultural Heritage Bill 1985". The list of items protected against "unauthorised export" as set out in section 7 (i) of the Bill is very extensive. As well as those items defined, the Section allows virtually anything else to be covered by "any other prescribed category". This covers export of all movable items of our cultural heritage. Whether such a definition is appropriate to the control of movement of such items within the country is debatable from a practical point of view. Notwithstanding the difficulties caused by the extensive definition in the Bill it is a welcome step in the protection of our portable heritage. Having such an Act, in due course, pre-supposes that there is also in place a mechanism to control and conserve the items within the country.

With the exception of this Bill, all other heritage legislation is largely deficient in the area of portable heritage. The present division of responsibilities between our state and federal legislation clearly suggests that universally applicable provisions are not possible. This paper will therefore deal primarily with the situation in New South Wales. The general issues and suggestions, however, should also apply at the federal level and to the other States.

For some time the New South Wales Department of Environment & Planning has been reviewing the New South Wales Heritage Act, 1977. The nine years of the operation of this Act and of the Heritage Council of New South Wales have seen tremendous change and development within the field of heritage conservation. There is little doubt that a number of changes to the Act are desirable to bring it into line with current community attitudes and conservation practice, as well as to streamline its effectiveness. The Act currently contains provision for statutory protection of structures, buildings, and even areas irrespective of their location or context. Artefacts however, to be protected even to the limited degree presently provided for, must normally qualify as "relics" (see below under Definition of 'Relics') in order to fall within the protective provisions of the Act.

An exception occurs in the case of artefacts already protected under other measures of the Act. Artefacts may be afforded protection, for example, by virtue of a conservation instrument preventing demolition (pursuant to section 130 or 136) or by inclusion in an area subject to a Permanent (Section 44) or Interim (Section 26) Conservation Order. The clear intent of the relevant provisions, however, is that they be used to provide statutory protection for buildings, structures or sites and not for artefacts.

The definition "relic" and the specific sections of the Act which relate to relics mean that only items which predate 1900 and which are in contact with land are afforded any measure of protection and that this protection applies only if and when the item concerned is to be removed from such context. As this provision stands, therefore, it affords limited protection to a limited range of portable artefacts.

The practical outcome of the present legislation, which requires that an excavation permit is issued prior to any relic being disturbed, excavated or moved, is that a large number of artefacts have been legally removed from context, but not properly dealt with therefore as there is no provision in the Act (or in any other Act to the authors' knowledge) for their permanent curation and management. In some cases, such provisions have been created by their inclusion in the conditions attached to an excavation permit issued by the Heritage Council pursuant to Section 141 of the Act.

However, normally, even collections of extreme and undisputed heritage significance are technically not covered by any provisions of the Act. The artefacts recently excavated from the site of Australia's First Government House site present a case in point. There are no statutory provisions for their ownership, curation or management (other than the primary right to ownership of the owner of the land on which the relics are located). Needless to say, this results in a situation where, in a number of cases, little or no care is taken to conserve, store, document or analyse the material, unless provision is made in the conditions of excavation permit. Seldom, if ever, is adequate provision for long term management made prior to the excavation of these items. This problem occurs in regard to artefacts excavated both legally and illegally and applies equally to collections compiled prior to and subsequent to the passing of the Heritage Act. This paper does not deal with any artefacts removed from context prior to the passing of the provisions recommended below.

In New South Wales, the situation with regard to Aboriginal artefacts in somewhat better. Part VI of the National Parks and Wildlife Service Act, 1974, provides that any Aboriginal artefact collected after January 1st, 1975 is the property of the Crown and must legally be deposited with The Australian Museum, expect where it remains in the custody of the National Parks and Wildlife Service Director. This section takes care of the issue of ownership and curation, but makes no provision for long term funding for the management of collections. The Australian Museum's resources are therefore being strectched to the utmost in that storage space for significant collections is not necessarily available, let alone any funds for adequate cataloguing or analysis. Clearly, therefore a solution for the curation and management of historical artefacts must go further than merely providing a legal repository and statutory ownership provisions.

New provisions of the Heritage Act or amendments which relate to the ownership, storage and curation of relics must be carefully considered so as not to impose unworkable and unreasonable restrictions on owners of historic collections. The aim of such legislation should be to solve the present problem of the management of 'unwanted' artefacts without creating a bureaucratic headache in relation to antiques and other "collectables". The solutions proposed by this paper to include protection not only for archaeological material but also for other portable items: - machinery, industrial, scientific and technological equipment, furnishings and in some cases components of building fabrics. It is not intended specifically to cover shipwrecks as this is already covered by Federal legislation.

Any new legal requirement or procedures must, wherever possible, be attractive to the owners and the excavators of artefacts. The resources available to the cultural resource managers who currently supervise the "relics" provisions are already stretched beyond capacity. The impossibility of policing adequately the innumberable sites and items involved has already been discussed by John Wade (1985) in relation to bottle collectors. In many cases, in the experience of the National Trust in New South Wales, co-operation and liaison with statutory authorities and large companies (often within a framework of legal compulsion) are, in the long run, a far more effective conservation measures than the threat of statutory penalties.

The issue of artefact curation and management is one which has already been addressed in other parts of the world, and particularly in the United States of America. In 1980 the U.S. Department of the Interior (Heritage Conservation and Recreation Service) commissioned a detailed report entitled "The Curation and Management of Archaeological Collections A Pilot Study" (U.S. Department of the Interior, 1980). This report examined in some detail the provisions and procedures for artefact management across the United States and made a number of recommendations concerning the management and curation of artefacts and historic material in federal ownership. The study, which was carried out over a period of some months, expanded on an earlier, but much more cursory, examination of the same problem carried out as part of "The Airlie House Report". (McGimsey and Davis, 1977).

From these reports, and from information received from practitioners, and administrators involved in artefact curation and management in the United States, one thing emerges clearly:- that the onus for long term preservation, conservation,curation and analysis of artefacts must lie fairly and squarely with the instigator of the project which results in their collection in the first place (U.S. Department of the Interior, 1980).

To this extent of provisions and procedures have been developed. Of these the most successful system is clearly one where State repositories are established and accredited as having the necessary resources to manage and curate artefacts. In these repositories the artefacts, together with catalogues in a standard format, and any relevant field notes, excavation records or other documentary material, are stored in perpetuity. The lodger of the material is required to deposit a comprehensive catalogue in a standard format together with a lodgment fee (see below under Funding) which enables the institution to manage the relevant artefacts. In many cases a sample only of the total collection is lodged if it is established that such a sample adequately represents the scientific potential of the total collection. A procedure for the assessment of the significance of artefacts is discussed below.

This paper does not present a detailed argument of why the system outlined above is the optimum solution to the problem. It is the authors' contention that the American experience has already demonstrated this fact. In view of the considerable problems which are now being faced by archaeologists and cultural resource managers in New South Wales, it is suggested that a thorough review of the provisions relating to relics in the New South Wales Heritage Act should be included as part of the present review of the Act which is currently in progress. This paper, therefore, concentrates on presenting a number of recommended changes in a form directly applicable to historic artefacts in New South Wales.

Ther are six aspects which need to be examined:

1. The definition of "relics" and the base date of items covered by the Heritage Act.
2. Excavation - the supposition that items must be in contact with "land".
3. Ownership.
4. Curation and Management.
5. Analysis.
6. Funding.

1. The Definition of "Relics:

One of the major problems faced at present is the control and protection of relics which do not fall within the current provisions of the Act. There are a number of issues to be considered here. The first is the definition and dating of "relics" which is presently dealt with in Section 4(1) of the Act. That definition is as follows:

"Relic means any deposit, object or material evidence relating to the settlement prior to 1st January 1900 or such other date as may be prescribed of the area that comprises New South Wales not being Aboriginal settlement"

The most obvious problem that presents itself is the date of "1st January, 1900." Leaving aside any reason why this date may have been chosen when the Act was passed, it is perfectly clear that what is required is a time span between the date of excavation and the date of the relic rather than any specific date as presently provided in the Act. Fifty years is a reasonable period. Consequently it is suggested that the definition of a "relic" should be altered to cover all items of heritage significance, which are more than 50 years old at the date when the relevant application is made under the Heritage Act. A number of artefacts which are not 50 years old are, nevertheless, highly significant. Provision must also be made for such items to be identified as significant and afforded the same protection as those which meet the time span criterion (see below under excavation).

2. Excavation

Division 2, (Part V) and Division 9 (Part VI) of the Heritage Act deal in some detail with activities controlled or prohibited in regard to sites covered by conservation instruments or items defined as "relics". The wording of the relevant sections (57, 138 and 139) of the Act continually refers to "excavation" or "Excavation Permit". The implication is that ground must be disturbed or excavated before a "relic" is protected by the provisions of the Act.

Many significant artefacts are not covered by these provisions as there is no need to disturb or excavate land before they are moved. The key words are "excavate" and "land". Clearly the aim of any statutory protection for artefacts should relate not to whether they are currently buried (or in contact with "land") but rather to their intrinsic value or their value in context, and should therefore cover moving as well as excavation.

The authors have found it extremely difficult to formulate any re-wording of Sections 57 and 139 of the Heritage Act without imposing unrealistic restrictions on owners of historic artefacts, while providing comprehensive protection for significant artefacts which have already been excavated or which are not in contact with "land". The crucial but common factor in all of these cases appears not to be contact with land, but rather a continuous history, related to a particular place. It is therefore suggested that Sections 57 and 139 should be amended to stipulate that a person shall not move an artefact, whether subject to a conservation instrument or not , from any location in which it has been for a period of fifty years or more, in addition to the present provision which prevents land being disturbed for the purpose of discovering or moving a "relic". These alterations would necessitate further changes including the introduction of a permit "excavation or removal" and a new definition for "relics".

The term "relic" itself is regarded as unfortunate and the more general term "artefact" is strongly recommended. It is proposed that an artefact be defined as an item which has been situated in a single location for fifty years or which is determined by the Minister on the advice of the Heritage Council of New South Wales to be a portable item of environmental heritage

3. Ownership:

The U.S. Department of Interior Heritage Conservation and Recreation Service in its report (U.S. Department of Interior, 1980) recommends that materials recovered belong in the first instance to the owner of the land upon which the site is located and that federal agencies should be responsible for the curation of only these materials for which they have legal title. (In Australia for 'Federal' read 'State' as the relevant authorities are the State Governments).

The major problem in New South Wales - and for that matter in the rest of Australia - is for the most part not one of competing demands for ownership but of no-one both willing and able to take the continuing responsibility for the management of the relics once they have been excavated or removed from their site. This applies whether or not their excavation was legal.

The essential aspect of these recommendations is that if excavation or movement of relics takes place there must be someone who or some authority which will be responsible for the curation and management of the relics. This person or authority must therefore also have the ownership vested in him/her or it. The problem is as much a financial as a legal one.

Unless there is a drastic change to the general principles of ownership of property in New South Wales the person who has the primary right to ownership of the relics is the person who owns the land upon which or in which they are found. Whilst it would be unreasonable to suggest that this general common law provision be changed, it is reasonable to make an owner comply with appropriate curation provisions and documentation (see below). If a landowner wishes to retain ownership of items but does not desire to comply with these provisions then he / she has the right to refuse permission for any excavation or moving of relics and the consequent duty not to excavate or move them himself. This is consistent with the present procedures which require that the owner(s) of any land about to be excavated signs the excavation permit application, thereby giving his, her or their consent to the proposed activity. The continuation of a system where ownership of any artefact is vested with the landholder has an attraction from the conservation point of view. The proposed compulsory management and curation measures will, in many cases, act as an incentive not to disturb the material at all.

It is recommended that where a landowner renounces ownership then the relics will vest in the Crown (without any payment of compensation to the landowner) and further, that such relics must be deposited with the Museum of Applied Arts and Sciences (see below).

The same comments apply to Crown land. The Department which might control the site may claim the items, but if that Department is not prepared to be subject to the necessary curation provisions then again the relics must be deposited with the Museum.

There are various difficulties at present in the depositing of relics with the Museum of Applied Arts and Sciences. One is the question of cost to the Museum, (see below). Another is that an amendment to the Museum's Act will be required. At present the Act does not provide that the Museum must accept any items offered. Any necessary amendment must be carefully worded so that it neither allows items covered by the Heritage Act (as it is proposed to be amended) to be refused by the Museum, nor burdens the Museum with unwanted items not intended to be covered by the Heritage Act. The present proposals for the protection of relics in New South Wales will be ineffectual if the Museum is not required to accept items offered, (except in accordance with the exemptions outlined below).

The question of loans of such items from the Museum on a permanent basis also requires investigation, but is not the subject of any comment in this paper.

The circumstances in which the Museum would not be bound to keep the artefacts would be those where the landowner did not wish to retain them and where they were considered by the Heritage Council of New South Wales to be of such minimal significance that their retention was not necessary. In those cases the artefacts could be disposed of in whatever manner the landowner wished, but only with prior written approval from the Heritage Council. The intention here is to prevent the obligatory collection and curation of items which technically qualify as artefacts but which are established as having little or no heritage value. Damaged building components which are not to replaced as part of a conservation programme are a case in point.

As the Museum of Applied Arts and Sciences is the nominated repository for the material it is suggested that the relevant legisation (Heritage Act 1977 and Museum of Applied Arts and Sciences Act 1945-61) be amended to require that a report on any item proposed for disposal, be made by the Museum's staff for the consideration of the Heritage Council. A provision should also be made which allows immediate consent to destroy in obvious cases, as should a provision for disposal of items which have been previously deposited.

Rare situations will occur where the opinion of the Heritage Council is in direct conflict with advice received from the Museum, (in cases, for example, where numerous similar items are already held). The Heritage Council may also be of the opinion that the artefacts should remain in situ. In both cases the onus should fall on the Heritage Council either to recommend that a Conservation Instrument be placed on the site and the artefacts be included, or that the Heritage Council itself receive from the owner the necessary financial contribution to enable the artefacts to be covered. In most cases it will be more economical for the owner to maintain the items with the advice of the Heritage Council rather than handing over the care control and management (and associated financial assistance) to the Heritage Council.

4. Curation and Management

The need for Australian Museums to become official repositories has been argued in detail elsewhere (Wade, 1979). Certainly in other States institutions such as the Queensland Museum and the Western Australian Museum have already demonstrated this capacity in specific areas.

As the primary historic artefact curation, materials conservation and analysis institution in this State, the Museum of Applied Arts and Sciences is the logical repository for any artefacts or other "relics" excavated or recovered. The Museum is, furthermore, the only organisation within New South Wales which is presently capable of carrying out such work. The benefits to the cultural resources and to the Museum should be self-evident. At present artefacts illegally and legally collected as part of excavation processes are stored in a myriad of repositories : garages, under beds, in laboratory cupboards, as well as folk museums and other semi-professional institutions. Fortunately in recent years the Museum of Applied Arts and Sciences has agreed to take receipt of a number of collections. However, as a result of inadequate funding provisions, little, if any, thorough or effective conservation work has been carried out on the bulk of excavated and collected material. There is no doubt that it is deteriorating as a result.

Furthermore there is little or no control over its cataloguing or accessioning, storage display or publication. The benefits of the imposition of a standard cataloguing process and a standard method of recording should also be self evident.

Any review of the relics provisions of the Heritage Act should therefore include provisions to make regulations for the standardisation of recording, cataloguing, indexing and conservation, storage, publication, and possible display, of artefacts which fall within the control of the Act.

It is therefore recommended that a set of standards be prepared which will cover:

a) conservation of any artefacts recovered,
b) the production of a comprehensive catalogue of all artefacts, field notes and associated material recovered and the establishment of a standard catalogue format,
c) production of a comprehensive index to all collections and artefacts,
d) storage,
e) provision for regulated public access to these records and collections,
f) provisions, where appropriate to cover the display of artefacts and collections either by the Museum or by any other appropriate institution,
g) publication,
h) review of need to retain,

These should be prepared in conjunction with, and probably by, the Museum of Applied Arts and Sciences. Clearly it will also be necessary for the Museum to take a high profile at the stage when artefacts are collected. This applies especially to archaeological sites, where it is suggested that the Museum's role must include artefact cataloguing, recording and conservation procedures. The issue of standards is covered at some length in the U.S. Department of Interior report (1980). The summary of management and curation procedures presently in that report should be invaluable assistance in the establishment of similar provisions which apply to historic resources in New South Wales.

The establishment of the necessary facilities, management structure and staff to carry out the system proposed should not be regarded as the sole responsibility of the Museum of Applied Arts and Sciences. An integral component of the changes recommended must be a short term grant programme to establish and operate this system until the funds from artefact and record lodgement fees are sufficient to cover the day to day running costs. A useful adjunct would be a close examination of the resources already available. (Piggot 1975; Wade 1979).

5. Analysis

The archaeological record is a finite resource. One of the prime scientific and archaeological values of this resource is its use in answering a large number of questions about the history of the Colony and State which cannot be answered from historical research alone. The resource often has 'public' or social value in its capacity to demonstrate facets of our history.

For this archaeological resource to be conserved adequately it is imperative that if any deposit has to be destroyed as a result of excavation, or any artefacts have to be removed from context, that this be done in a proper way. Prior to the issuing of any Excavation or Removal Permit the applicant must be required to submit a comprehensive research design which outlines in full detail the questions which the project is intended to answer. To a large extent this procedure is already the current practise (see Heritage Council Newsheet Number 7; Excavation Permit Application Form). The philosophy must be to extend such requirements beyond the site to cover the artefact collections themselves.

It must be recognised that the available funding which is directly associated with an excavation or artefact removal project of any kind is only available at the time of the project. Although it is not yet possible to estimate precisely the funding necessary it is nevertheless imperative that sufficient funds and time for analysis be allocated by the instigator of the project at this stage and that the analysis be carried out.

6. Funding

It is evident from the above that basic to the operation of these new provisions is the provision of adequate funding to carry out the necessary work referred to above in respect of the curation proper and maintenance of the relics.

It is recommended that a system be adopted which is similar to that operating in the United States, and that any instigator of a project which involves the excavation or moving of a relic must provide the necessary finances for the additional stages of conservation, storage and analysis. Accordingly, it is recommended that the following issues should be considered and incorporated in the issuing of any permit for excavation or moving of relics:

(1) A fee scale will have to be established with sufficient flexibility to accommodate the number, size, nature of items and the associated documentation, curation and storage in perpetuity.

(2) Provision must be made for the payment of the fees calculated in accordance with (1) above by the instigator of the project.

A project instigator will fall into one of three categories.

i) a developer - a development project.

ii) an academic institution for research or associated purposes- an academic project.

iii) a conservation organisation or an individual involved in conservation - a conservation project.

Regardless of the category of the instigator it falls to that person or organisation to ensure that adequate provision for fees is made whether they be paid by them or by someone else. These fees should be looked upon as a normal part of the cost of any project which involves excavation or moving of relics for whatever purpose, whether it be commercial or otherwise.

Provision must be made for fees to be paid to either the owner or to the Museum of Applied Arts and Sciences depending upon the intended ultimate ownership and management of the items and who is to carry out analysis of the artefacts. The lodgement fee should include a capital sum calculated to provide sufficient income for permanent storage of the artefacts. Clearly the final cost of the curation, storage, and management of the relics cannot be calculated precisely until the excavation or moving of relics has been completed, although a reasonable estimation should be incorporated into the overall costing at the commencement of the project.

CONCLUSION

The comments contained in this paper relate primarily to New South Wales and to the amendments required under the Heritage Act (1977) and the Museum of Applied Arts and Sciences Act (1945-61), to ensure a more responsible and effective system for the long-term protection and conservation of artefacts within the State. The Heritage Act, by virtue of the Australian Constitution, has no authority over Commonwealth action or Commonwealth property and consequently it is recommended that the Australian Heritage Commission, which is responsible for the administration of the Australian Heritage Commission Act, consider the comments contained in this paper insofar as they could be adopted to ensure the protection of relics which come under the jurisdiction of the Commonwealth.

Unfortunately there would appear to be, at this stage, no adequate provisions in the other States of Australia, and again it is suggested that all other States and Territories should consider similar provisions in their respective legislation.

It was made clear in the introduction to this paper that these comments excluded Aboriginal relics. However, bearing in mind the difficulties which have been faced by The Australian Museum in endeavouring to curate and maintain the enormous number of Aboriginal relics which have been placed within its care, the principles put forward in this paper, particularly those in respect to funding, should be considered in an endeavour to assist that Museum to care for and maintain the Aboriginal relics within its control.

BIBLIOGRAPHY

Birmingham, J.M. 1981. Historical Archaeological Materials, Storage Of Artefacts From Historic Sites. Unpublished report to the Archaeological Advisory Panel of the Heritage Council of New South Wales.

Birmingham, J.M. 1983. Cultural conflict and the control of archaeological evidence. In M. Bourke, M. Lewis and b. Saini (Eds)
PROTECTING THE PAST FOR THE FUTURE PROCEEDINGS OF THE UNESCO REGIONAL CONFERENCE ON HISTORIC PLACES. Australian Government Publishing Services, Canberra.

Heritage Council of New South Wales, N.D. Excavation Permits Under The Heritage Act 1977 Heritage Council Newsletter No 7.

Heritage Council of New South Wales, N.D. Application For Excavation Permit Under Section 140, Heritage Act, 1977.

Imashev, G., 1983. Historical Archaeology and the museum. In M. Pearson, and H. Temple (Eds), Historical Archaeology And Conservation Philosophy. Papers From The Historical Archaeology Session, Anzaas Congress, Sydney 1982 Heritage Council of NSW, Sydney.

McGimsey, C.R.III: Davis, H.A. (Eds), 1977. The Management Of Archaeological Resources. The Airlie House Report. Special publication of the Society for American Archaeology.

Piggot, P.H. (Chairman), 1975. Museums In Australia, 1975 Report of the Committee of Inquiry on Museums and National Collections including the report of the Planning Committee on the Gallery of Aboriginal Australia, Chairman P.H. Piggot.Australian Government Publishing Services, Canberra.

U.S. Department of the Interior, 1980. The Curation And Management Of Archaeological Collections: A Pilot Study Cultural Resource Managements Series, Heritage Conservation and Recreation Services.

Wade, J. 1979. The Protection and Preservation of Archaeological sites and Portable Relics. ASHA Newsletter 9 pp 3-6

Wade, J. 1985. Bottle Collectors on Archaeological Sites. Historic Environment 4, (4)pp 35-37.

LEGISLATION

1. Moveable Cultural Heritage Act 1986 (Commonwealth)

2. Museum of Applied Arts and Sciences Act 1945-1961 (State)

3. National Parks and Wildlife Service Act 1974

4. N.S.W. Heritage Act. 1977 (State)

This address was part of a seminar on "Problems and Prospects of Preserving the Portable Scientific and Technological Heritage" organised by the Royal Society of New South Wales, the National Trust of Australia (New South Wales) and the Museum of Applied Arts and Sciences, Sydney, New South Wales, 2nd August 1986.

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POSTSCRIPT

A number of changes recommended in this paper were adopted by the New South Wales State Government and included in the Heritage (Amendment) Act, 1987 assented to on 3rd April, 1987.

"Relics" are now defined "Any deposit object evidence(a) which relates to the settlement of the area that comprises New South Wales, not being Aboriginal settlement;(b) which is 50 or more years old ".

Museum of Applied Arts and Sciences is nominated as the official repository for this material. The issue of funding is not specificially covered by the new legislation.

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Problems and Prospects of Preserving the Portable Scientific and Technological Heritage

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All stratigraphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra.

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Demise of the Dinosaurs and Other Denizens — by Cosmic Clout, Volcanic Vapours or Other Means

F. L. SUTHERLAND

ABSTRACT. Three of the more dramatic events in natural history - extinction of species, meteoritic impacts and volcanic outbursts have come together in a scientific controversy.

Did the dinosaurs die out suddenly? Did other organisms die out with them? A thin layer of sediment found at many places on land and ocean floor marks the boundary of Cretaceous and Tertiary time 65 million years ago. It shows an unusually strong enrichment in heavy metal elements such as iridium. This is claimed to mark a catastrophic event, giving dust clouds that reduced sunlight and blighted vegetation world wide. The break down of food chains is blamed for suggested demise of both large land animals such as dinosaurs and microscopic marine forms.

One school favours an extraterrestrial impact for the 'catastrophe' marker bed, another violent volcanic discharges from the earth's core. The evidence is conflicting. This paper sorts through these scenarios and seeks a solution. Australian evidence is rarely considered in the balance of the arguments. New concepts on Australia's past volcanism will be discussed, as they seem to suggest vigorous volatile volcanism 65 million years ago.

Where does the balance lie after a decade of deep discussion on this tantalizing topic?

INTRODUCTION

Dinosaurs, visitations from space and volcanoes are all part of the natural order, but they hold a particular fascination for us. They form the butt of many cartoons, such as the modest effort used in advertising this Presidential Address to The Royal Society of New South Wales (Fig. 1).

These three items came together in a scientific debate that gathered momentum in the

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* Expansion of a Presidential Address delivered before the Royal Society of New South Wales on the 6th April, 1988.

Fig. 1. Cartoon used to advertise topic of address in the Royal Society of New South Wales newsletter.

1980's and engaged scientists of many disciplines. The debate continues unabated in late 1988, as protagonists for the main schools of thought provide steady streams of new and often conflicting evidence and opinions. Indeed, the whole topic of extinctions in the geologic record is offered as a special study course at the International Geological Congress to be held in Washington, D.C., USA, in July 1989.

The controversy began after a team of workers (Alvarez et al. 1979) reported on cores of sediments deposited over the Cretaceous-Tertiary (C-T) interval. Their geochemical studies found abnormal amounts of trace elements, particularly iridium, in a very narrow unit marking the C-T boundary, normally dated around 66.4 My Before Present (BP), using the time scale of Hardenbol and Berggren (1978). Putting things together, the team linked the disappearance of the dinosaurs and other life forms at this time with the 'Ir-anomaly' and a catastrophic meteorite impact that created a fallout of trace element components (Alvarez et al. 1980). They held that this impact set up a chain of consequences which so debilitated the dinosaurs and other biota that they failed to evolve into the Tertiary. This dramatic denouement caught the imagination of scientists, who quickly generated impressive amounts of new data, much of it seemingly in support of the said scenario.

Some workers doubted such a 'single hit' wipe out of large and small creatures and questioned whether cosmic causes were responsible for the terminal malaise. Volcanic outbursts of great magnitude, initiating similar effects to those of meteoritic impacts, came under suspicion. These two means for disrupting life were weighed against each other in increasingly sophisticated studies. Papers appeared in quick succession, first pushing the pendulum towards cosmic impact, next swinging the argument back to a volcanic view. This survey reviews the available evidence and adds any information known from Australia. It seeks a solution to conflicting conclusions on the demise of dinosaurs and other life forms at the now celebrated C-T boundary.

THE DINOSAUR VIEW

Dinosaurs dominated the age of the reptiles during the Mesozoic Era from about 200 to 65 My BP ago (Norman, 1985; Bakker, 1986). They vanished from the record at the height of their diversity in the late Cretaceous, when over twice as many genera existed as in the late Jurassic. They and other organisms, showed an absence of up to 75% of formerly existing species at the start of Tertiary time (Hallam, 1979; Russell, 1979a,b). Great inroads were made on marine invertebrates (ammonoids and belemnoids, cephalopods, various gastropods, brachiopods, echinoderms). Some reptilian groups like crocodiles and snakes and birds and various mammals survived with little change. Land plants continued (White, 1986; Wolfe and Upchurch, 1986); deposits spanning the boundary often showed sudden changes in the flora, but some flora prematurely vanished before the end of the Cretaceous (Hickey, 1981; Hickey et al. 1983).

These changes intrigued scientists and sparked much work on populations that perished *en masse*, not only at the C-T event, but also at other intervals since Precambrian time (Kerr, 1984). An entertaining account of the variety of views and inherent problems in postulating extinctions is given by Hoffman (1982). Some hypotheses, such as testicular frying and poisoning of dinosaurs are not testable within the limitations of the fossil record (Gould, 1984).

Three main questions are examined -

1. Did groups die out because they were complex evolutionary end lines, incapable of supporting themselves under slight or gradual changes in their environment?

2. Was their end hastened by severe, but otherwise normal climatic and oceanic changes?

3. Were they wiped out by an abnormal catastrophic event, either terrestrial or cosmic?

Further, whatever the causes, did they represent one-off events or repetitions of some wider manifestations? Finally, where does Australian data fit into this global gathering of evidence?

Outline of the Problems

Evolutionary induced decimations

The arguments for purely evolutionary induced decimations depend on detailed palaeontological considerations. This cause is difficult to sustain, as more groups would be expected to survive across the now well documented C-T boundary in on-shore, near-shore, and deeper sea sections. Some studies argue for less sudden extinction of the dinosaurs, perhaps a gradual decline over several million years with a quick finish over 0.3 My (e.g. Sloan et al. 1986), but this is under dispute (Russell, 1984; Smit and Van der Kaars, 1984; Retallack and Leahy, 1986; Sheehan and Morse, 1986; Bryant et al. 1986; Sloan and Rigby, 1986).

There is also evidence of dinosaurs being able to adapt to more extreme conditions in high latitudes. A site on the north slopes of Alaska shows dinosaurs existed at high polar latitudes just before the C-T extinction (Brouwers et al. 1987; Paul, 1988). The remains, in beds dated between 65-76 My BP, are mostly hollow crested, duck billed dinosaurs, but also include *Tyrannosaurus* (Fig. 2). The palaeoflora suggests a herbaceous deltaic plain with upland mild to cold temperate conifer and broad leaf plant forests. The site then lay 70-85° North and juveniles amongst the dinosaurs suggest an annual life within the Arctic Circle with its months of winter darkness and cold air temperatures. Some of the conclusions regarding the implications for darkening and lowering of temperature were challenged (Galbreath, 1988; Wolfe, 1988) and answered (Brouwers et al. 1988).

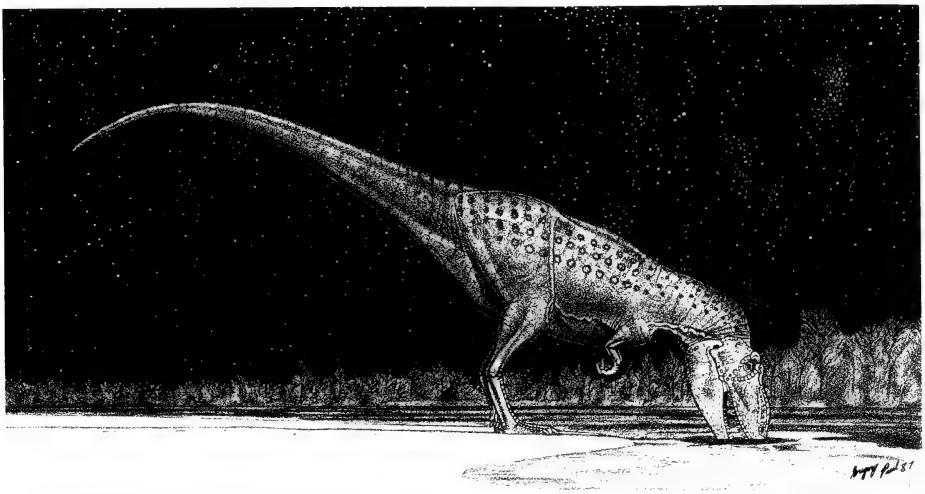

Fig. 2. Thirsty tyrannosaur breaking thin ice to drink at a river side on the North slope of Alaska, north polar region during late Cretaceous time. Reproduction of a drawing by Gregory S. Paul in his paper on Cretaceous polar dinosaurs (Paul, 1988).

Another site, in southern Victoria in Australia, contains dinosaur remains in late early Cretaceous volcaniclastic beds in graben fills (Rich et al. 1988). These beds date around 100 My BP and include remains of endemic, small bird-footed dinosaurs existing with relict larger carnivorous dinosaurs like *Allosaurus* . The local florae were largely gymnosperms, lycopods and ferns typical of humid cool temperate climates. Oxygen isotope studies on the sediments, assigned to a braided river environment, however, indicate colder conditions than do the fauna and flora. These colder conditions probably relate to meltwaters descending from snow or glacially capped volcanic highlands. Palaeogeographic reconstructions place this area within the Antarctic circle, perhaps as far as 80-85^{o} South, suggesting that these animals had adapted to periods of up to three months of winter darkness. The Arctic and Australian polar dinosaur sites challenge hypotheses which rely on sudden catastrophic collapse in temperature and sunlight (cosmic impact, volcanism) or even gradual temperature loss to remove the dinosaurs (Paul, 1988).

Extinctions due to fluctuations

Arguments for extinctions resulting from climatic, oceanic, and tectonic fluctuations, rather than exotic events, cover a variety of possibilities. They include temperature falls related to lowering of sea levels (Hallam, 1984). This would deplete dinosaur populations in sensitive environments. Rifting, with opening of new waterways could allow large influxes of brackish or colder waters with consequent drastic impacts on established marine groups (Thierstein and Berger, 1978; Gartner and Keany, 1978; Stanley, 1984). Some arguments favour cyclic rise and fall of seas, related to plate movements over convection cells, in perturbing animal populations rather than cosmic causes (Hallam, 1987; Ager, 1988).

The relationships between climatic evolution and tectonic configurations can be complex. Recent modelling suggests that land-sea configurations in high latitudes exert a strong influence on the magnitude of summer warmings, and are as important as variability of CO_2 in climatic changes (Crowley et al. 1987). Abrupt climatic changes can follow slowly changing conditions in some climate models and thus potentially trigger a biotic crisis (Crowley and North, 1988). Such responses may be modified in the short term by ancillary effects so that they produce step-wise rather than sudden extinctions.

Catastrophic control

Arguments for catastrophic controls of C-T extinctions (Fig. 3) came to the fore with discovery of a trace element marker horizon. The abnormal enrichment of noble and other elements, atypical of crustal rocks, but found in a thin, fine sedimentary layer, became the global iridium-anomaly. First identified in Italy and Denmark, the association of platinoid and other siderophile as well as calcophile elements was equated with fallout from an asteroidal impact on earth (Alvarez et al. 1979, 1980, 1984). This correlation made distant cosmic causes of dinosaur extinction,

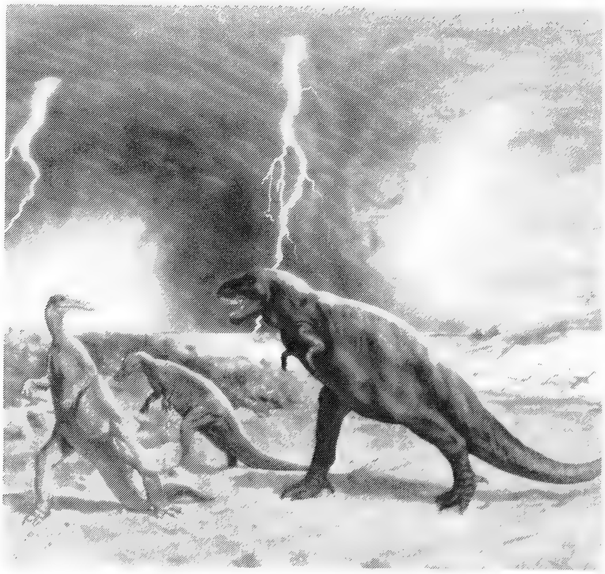

Fig. 3. A late Cretaceous scene in North America, depicting the catastrophic cosmic impact theory for the doom of the dinosaurs. Tyrannosaurus rex threatens two Trachodons (duck billed dinosaurs). Photographic reproduction of an artistic impression by K. Gregg, modified from an original painting by Z. Burian, for the Planet of Minerals Gallery, The Australian Museum, Sydney.

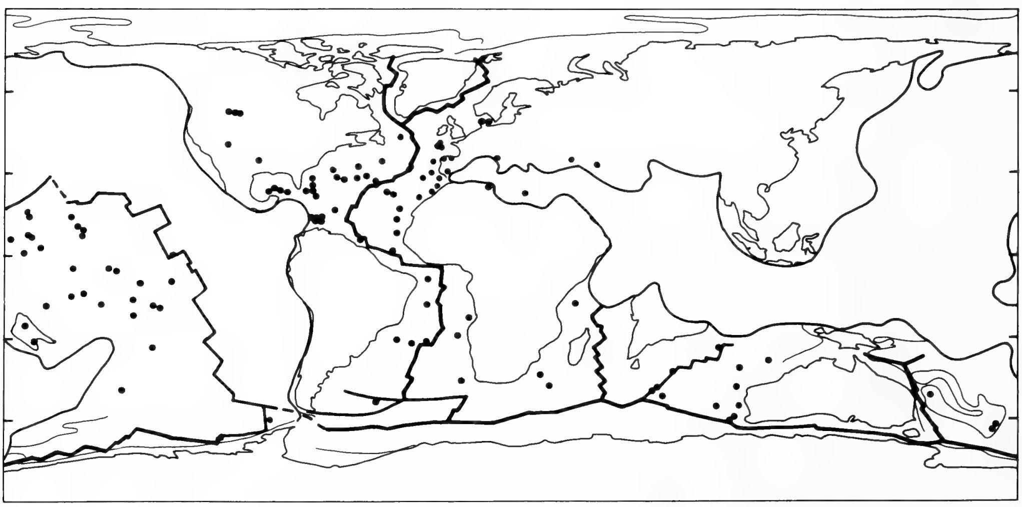

Fig. 4. Distribution of continental Ir-anomaly sites and deep sea drill sites that intersect C-T boundary sediments (dots). The late Cretaceous continent-seafloor reconstructions and mid ocean ridges system (heavier lines) are based on the projection used by Barron (1987).

such as radiation from a super nova (Schwartz and James, 1984) or changes in radiation flux arising from the sun's oscillation about the galactic plane (Rampino and Stothers, 1984), less likely. However the question of comets as a mass killer remains a live issue (Angier, 1985).

Now recorded from over 75 sites, most C-T Ir-anomalies lie either in onshore marine beds or in deep sea sections (Alvarez, 1986). The distribution is shown in Fig. 4, using an end Cretaceous plate reconstruction (Barron, 1987). The few terrestrial freshwater sites are critical in discounting concentration of these elements exclusively through marine precipitation or reworking processes (Kerr, 1981). This is shown by non-marine sites in the New Mexico-Colorado area, USA, which have anomalous Ir in claystones, partly contained in carbonaceous shale and coal sequences (Pillmore et al. 1984). New Zealand has well exposed C-T Ir-anomaly sites (Brooks et al. 1984). Some of these sites as well as some Antarctica sites show the extension of the anomaly well into the Southern Hemisphere (Strong et al. 1987). Largely due to lack of systematic searching Australian sites are generally missing in the global C-T inventory. An early proposal by D.J. Swaine, Commonwealth Scientific and Industrial Research Organization (CSIRO) to test an Australian section for the anomaly was not supported. Australia has been slow in co-ordinating studies of such sites for integrating with well studied Ir-anomaly sites elsewhere. For present purposes, it is assumed that the anomaly exists in Australian C-T sections.

The meteorite impact theory had immediate appeal to explain features of the Ir-anomaly but the "violent volcanic" view gained ground. Such volatile emissions would lead to acidic rains, reductions in alkalinity and pH of the ocean surface, global atmospheric temperature changes, and ozone layer depletion (Officer and Drake, 1985; Officer et al. 1987; Hallam, 1987). The iridium and related elements would be introduced from deep subcrustal basaltic domains where their concentrations are greater than in typical crustal rocks. These fall out effects coupled with major sea level falls in the late Cretaceous were considered sufficient explanation for selective removal of many animal groups.

A negation of these catastrophic notions as decisive factors in the dinosaur die-out leads to the exploration of other environmental causes. In a reconsideration of the controversy, McCartney and Niensted (1986) thought terrestrial causes more likely than extraterrestrial catastrophies. In a thorough recent review Paige (1988) suggests that a combination of terrestrial and extraterrestrial causes were possibly involved. This presidential address examines the detailed evidence claimed for impact or volcanic events before weighing their relative merits for evolutionary exterminations.

THE COSMIC BODY IMPACT VIEW

The end Cretaceous scene in America (Fig. 3) is based heavily on the anomalous metal concentrations found in Ir-anomaly layers. High Ir-levels are considered extraterrestrial meteoritic introductions, as this element is ten thousand times more abundant in nickel-iron meteorites than in typical terrestrial rocks (Crocket, 1981). Such interpretations also rely on accompanying exotic features which include shocked mineral grains, spherules, and sphaeroids of various mineral compositions.

Firstly, sedimentation processes must be eliminated as causes of such concentrations. Sediments are not satisfactory for estimations of background iridium descending onto Earth from space. However measurements made at the South Pole suggest an Ir-flux around $(7.3 \pm 3.1) \times 10^{-17}$ g m^{-3} (Tuncel and Zoller, 1987). This is insufficient to account for the Ir-levels in anomalies. On the other hand meteoritic material contributes substantially to Co, Fe and Mn values; annual accretion of background extraterrestrial material is estimated at 11,000 tonnes. The concentration of Ir in seawater is 11×10^{-12}g 10^{-3}cc (Hodge et al. 1986). A column of water 720 km high would be required to precipitate the values of Ir per cm^3 found in the shallow marine Fish Clay, the main Ir-bearing layer in the Denmark section (Schmitz et al. 1988). A representative value for Ir in the basal layers at the boundary anomaly is given at about 80 ng cm^{-2} (Kyte et al. 1985) and in seven anomaly sites Ir exceeds 120 ng cm^{-2} (Strong et al. 1987).

As well as the Ir-anomaly, claims are made that Pt/Ir and Au/Ir ratios at the Denmark boundary agree closely with values for these ratios in type I carbonaceous chondrite meteorites (referred to as CI chondrites) if the entire part of the boundary layer is sampled (Kastner et al. 1984). This would suggest a cometary rather than iron or stony-iron source since CI chondrites are thought to be related to comets rather than other "meteorites". However, some of the Danish metal ratios differ from CI chondrite values (e.g. Ni/Ir about one quarter chondrite ratio; Palme, 1982) and variations are found between different sites (e.g. Ni/Co ratio about half the Danish ratio at Woodside Creek, New Zealand; Brooks et al. 1984). At the Flaxbourne River, New Zealand site, Strong et al. (1987) assessed nine elements (Ir, Ni, Cr, Fe, Co, Cu, Zn, As, Sb) in relation to values typical of meteoritic material. They found Ni/Ir and Cr/Ir ratios near unity, i.e. close to those of CI chondrites and substantially different from the ratio for crustal (80) and mantle rocks (15) on earth. The remaining element ratios compared to Ir were close to terrestrial values. A non-volcanic origin for the Ir, As, Sb, Zn and Cu values was considered likely on their values when scaled against the known volumes of volcanic rocks assigned to the C-T boundary event (Deccan Basalts). The high

Ir in the Woodside Creek (NZ) site is paralleled by high N, suggesting that nitrogen was intimately involved with the primary fall out and remained with the Ir during secondary processing (Gilmour et al. 1988).

Whether the Ir and other metal concentrations at the C-T boundary represent pristine fallout values constitutes a problem. Detailed work on the Danish site (Schmitz et al. 1988) showed that changes in reducing or oxidising conditions as well as in bacterial activity caused selective concentration of metal accumulation. Kerogen recovered from the Ir-anomaly layer there and at Caravoca, Spain, showed enhanced concentrations of Ir to over 1100 ppm, i.e. up to about half the Ir in the bulk of the clay layer. This was related to Ir being carried in organometallic complexes before precipitation around organic matter. Similarly, within the metal-rich pyrite spheres in the boundary clay the sulphur had very low $\delta^{34}S$ values which is typical of that formed under intensive anaerobic bacterial activity. Such activity could concentrate Ni, Co, As, Sb and Zn in the pyrite spheres. Furthermore, fish scales in the clay had precipitated rare earth elements from seawater up to enrichments of four times for lanthanum. If the Ir was similarly enriched this would mean initial Ir-concentrations of around 20 ng cm^{-2}. Thus, although seawater precipitation could not account for an initially high Ir levels, it could considerably change metal concentrations within the sediments.

The first data on rhodium (a metal allied to Ir) and its concentrations at a C-T boundary section were presented by Bekov et al. (1988). They concluded that the maximum Rh concentration (24.2 ng g^{-1}) and Rh/Ir ratio (0.34 $\pm$ 0.06) were close to cosmic ratios of these elements and pointed unambiguously to an extra terrestrial origin. Osmium isotope ratios at the boundary suggest it is dominated by non-crustal material (Krähenbühl et al. 1988). In a resurvey of the Italian sections Crocket et al. (1988) sampled shales and limestones from 2.85 m above to 219 m below the C-T boundary. They found Ir concentrated 63 times in the shales, but other noble metals (Pd, Pt, Au) only enriched by 2.2 times or less above background values. They located four distinct Ir maxima in addition to the major Ir enrichment. They considered that the sedimentation interval involved at least 3 x 10^5 years. For an extraterrestrial impact model, these Ir maxima called for a shower of multiple, spaced impacts resulting in the constrain of the impact model.

Shocked and high temperature minerals

The presence of up to 25% shocked quartz grains in the Ir layer at Montana, USA (with multiple planar features, strain asterism and traces of the high pressure silica mineral stishovite) was taken as evidence of a high pressure accompanying event (Bohor et al. 1984). Shocked quartz occurs in meteorite craters and was taken as compelling grounds for a C-T impact on at least partly silicic rocks. Rare shocked quartz is also found in volcanic fallout deposits of very large eruptions, e.g. Toba volcano in Indonesia (Carter et al. 1986). The rarity (<1% of quartz grains) and formation of only one set of planar features compared to the more complex, multiple sets typical of impact events was stressed by Izett and Bohor (1987).

The global distribution of the 'impact-like' shocked quartz (Fig. 5) was outlined by Bohor et al. (1987). In their comprehensive study of the Italian C-T boundary, Crocket et al. (1988) found shocked quartz grains occuring with each of the multiple Ir peaks in the section. These grains seem to show partially recovered shock mosaic structures with accompanying recrystallisation thought to be characteristic of explosive pressures associated with major eruptions. In cathodo-luminescence studies of Montana C-T boundary shocked quartz Owen and Anders (1988) contended that the quartz showed a diversity of luminescence colours not matched by volcanogenic quartz and more in keeping with an impact origin.

Sanidine feldspar is a mineral formed in microspherules found with shocked quartz at some C-T sites (Smit and Klaver, 1981). This feldspar was thought to represent solidified droplets of melt, probably caused by an impacting body. However, the high K/Na ratio of the sanidine was atypical of most meteorites and was considered more likely to relate to comets or metal-sulphide-silicate planetesimals. Microspherules of magnetite and glauconite also appear in C-T boundary clays and were thought to form from original plagioclase feldspar, pyroxene and olivine (Montanari et al. 1983). The magnetite microspherules contain anomalous levels of Ir and siderophile elements and this coupled with the wide distribution of microspherule minerals led Smit and Kyte (1984) to suggest an accretionary 'impact' event. Sanidine is found in both volcanic and contact metamorphic fused rocks (Deer et al. 1963), so that its diagnostic value for such origins is qualified. A non-impact and even low-temperature origin for the sanidine was suggested from detailed examinations (Nausland et al. 1986; Hansen et al. 1986; Izett, 1987). Confinement of these unique mineral microspheres to the C-T boundary clay led Alvarez (1986) to explain them as droplets of impact melt which solidified and suffered authigenic alteration to sanidine, glauconite and magnetite.

Feldspar grains, as distinct from the sanidine microspheres, can also show shock features and such grains are associated with shocked quartz with each of the multiple Ir peaks in the Italian C-T sections (Crocket et al. 1988). Here, however, these authors favour a volcanic origin for them. A variety of shocked minerals and composite grains recovered from just above the C-T level in the New Mexico and Colorado sites included microfeldspar, quartz, quartzite and oligoclase (Izett and Pillmore, 1985). These were interpreted as fragments of granitic rocks and their size range was taken to indicate possible impact sites only some 200 km away in a continental area. Glass bombs and lithic clasts are recognised in the boundary clays at C-T sites in Wyoming, USA, due to their staining by secondary goyazite (Bohor, 1988). This supports an origin as ejecta from a North American continental impact site. Hollow spherules here are thought to be originally glassy micro-tektites or clinopyroxene spherules that were altered to goyazite (Bohor and Betterton, 1988).

Impact sites

The shocked granitic debris at C-T boundaries suggests existence of associated continental impact craters. Craters of required age limits, falling within the errors of the dating techniques and stratigraphic uncertainties, were described from western USSR (Masaytis and Mashchak, 1984). These craters were two pairs of twin craters in which glassy impactites gave a K-Ar age of 60 ± 10 My BP. They were thought to lie along a trajectory which extended through similar twin impact craters in Libya. An impact crater uplifting uppermost Cretaceous sedimentary beds at

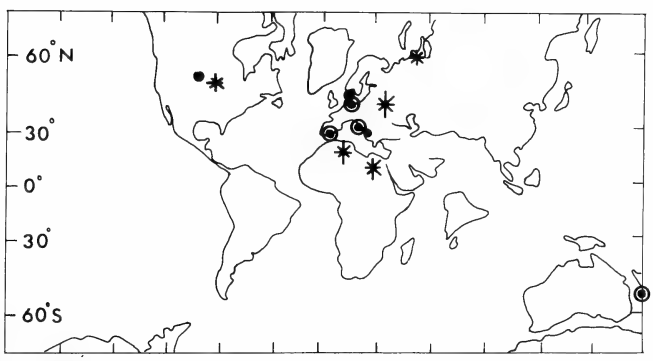

Fig. 5. Latest Cretaceous continental reconstruction showing impact features; C-T boundary sites with shocked quartz grains (dots) after Bohor et al. (1987), carbon anomalies (circles) after Wolbach et al. (1985, 1988) and suggested crater sites for this period (asterisks) after Masaytis and Mashchak (1984), McHone and Greeley (1987) and Kerr (1987).

Talemzane has also been identified in neighbouring Algeria (McHone and Greeley, 1987). These craters are generally impacts in carbonate sediments and cannot explain the granitic debris in the New Mexico-Colorado sites. The general trajectory also extends across the Arctic through the 32 km diameter Mansons Crater in Iowa, USA, intially dated at 61 $\pm$ 9 My BP. These craters (Fig. 5) are not precisely dated to the C-T event and do not easily explain the geochemical and mineralogical features at this boundary (see Kerr, 1987).

These conflicts in the impact story can be overcome by postulating that the main impact was near-continental and involved continental shelf sediments (around 15%) and mantle material (around 85%), a mixture based on the rare earth element levels at the C-T boundary (Hildebrand and Boynton, 1987). This would involve excavation into the mantle resulting in a 15,000 square km and 50 km deep crater floor. Such an enormous structure is unknown, but a Cretaceous location in the eastern Pacific might now be swallowed by plate movements into a subduction zone below north America (Kerr, 1987).

Support for an extraterrestrial C-T impact can be reinforced by comparisons with known meteorite impact-sites associated with Ir-anomalies. One meteorite impact was identified in late Cainozoic deep sea cores in the south-east Pacific seafloor and spread impact debris over 600 km (Kyte et al. 1988). This horizon is associated with an Ir-rich impact melt and some meteorite fragments and metal grains related to a low-metal mesosiderite meteorite. The impactite is not contaminated with oceanic crustal material and appears to mark a strike into a local deep without producing a crater. The melt contains Ir up to concentrations of 20 ng g^{-1}, which is comparable to initial values estimated at the Danish C-T boundary. The impacting body is estimated at some 0.5 km diameter and the resultant splash is thought to have injected a minimum of 2 x 10^{12}kg of water into the stratosphere, perhaps triggering a cooling effect and a glaciation.

COUPLED CATASTROPHIC VIEW

A catastrophic impact will produce severe second order effects and evidence for these are found at the C-T sites. The identification of these effects need not directly prove the impact as such effects can also arise from terrestrial agencies.

Tidal waves (tsunami deposits)

A sandstone bed immediately underlies the Ir-anomaly layer in an otherwise undisturbed mudstone sequence on a Texas C-T site (Bourgeois et al. 1988). The sandstone contains reworked pieces of mudstone and carbonate nodules and is interpreted as a tsunami deposit, consistent with a wave some

80-100 m high. Bourgeois et al. consider an impact into water by an extraterrestrial body is a more likely cause than a major submarine landslide or volcanic explosion. Coarse giant wave deposits also interbed within two separate clay layers that show Ir, Au and Re anomalies (Hildebrand and Boynton, 1988). This sequence was interpreted as fireball and ejecta layers with intervening wave deposits from a nearby oceanic impact site.

Acid rains and poisons

An impacting body not only produces shock effects on earth, but also creates shock effects in the atmosphere. The chemical effects of projectile entry and ejection of the blast material back into the atmosphere are discussed by Crutzen (1987) and Prinn and Fegley (1987).

Nitric oxide would be a major product and the nitric and nitrous acids so produced would come down in acid rains. A cometary body would give a very acid global rain and an asteroid a localised strong acid rain with a weaker regional acid fallout. This rain would change the acidity of the oceanic mixing layer and affect calcite stability in the seawater. The extinction of calcareous marine creatures would lead to increased CO_2 in the atmosphere and hence a greenhouse warming effect. An additional possibility is the release of cyanide from a fallen comet poisoning calcareous marine plankton and causing a catastrophic rise in the calcite-compensation level in the oceans (Hsu, 1980).

Cloud covers

A large impact would pollute the atmosphere with dust and water vapour flung up from the surface. These materials would cloud the sun's radiation forming a 'winter' effect. Such conditions might last over a year or more and adversely affect survival of life forms (Alvarez, 1986, 1987). With nitrogen oxide production, other effects would eventually come into play. Organisms would be exposed to greater radiation and temperatures as the ozone layer became catalysed and broken down (Crutzen, 1987) and the atmosphere became richer in the 'greenhouse' gases.

The demise of some 90% of marine calcareous nannoplankton in the fossil record at the C-T boundary, coupled with carbonate and oxygen isotope data on the sediments, suggests further climatic effects. The elimination of the calcareous phytoplankton would severely reduce the release of dimethylsulphide by these organisms (Rampino and Volk, 1988). This chemical has been shown to nucleate cloud condensation in the atmosphere over the sea. Its reduction by 80% would greatly lower cloud reflectivity and so produce an increase in rapid global warming of more than $6^{o}C$.

Global fires

Some C-T sites (Fig. 5) contain concentrations of carbon of thousands to tens of thousands times normal values (Wolbach et al. 1985), which is attributed to widespread wild fires from ignited forests and possibly burning of fossil fuel deposits. Ignition by fire balls from the impact is cited, but other causes are possible and were closely discussed (see correspondence in Science, V.234, pp. 261-264, 1986). Vegetation killed by major blasts would be highly susceptible to ignition by lightning (Alvarez, L.W., 1987). Local glasses contained in charred organic matter at the C-T site in Germany show trace metal concentrations within the range found within C-T boundary clays and bituminous shales (Cisowski, 1988). Their Ni/Ir ratios fall in the range of the boundary clay values but Ir/Au ratios are strongly crustal in signature. This indicates a fused soil or burnt combustible shale material.

Extremely detailed analyses of the soot and other carbon forms in relation to Ir levels were made at the least disturbed C-T site, at Woodside Creek, New Zealand (Wolbach et al. 1988). These analyses showed that the soot build up coincided with the Ir-layer and contained changes over three thin layers lying between 0-0.6 cm above the boundary. In the lowest 0.3 cm layer Ir increased 1,500 times, elemental carbon 210 times, soot 3,600 times, and kerogen over 15 times while $\delta^{13}C$ isotope values in carbonate and kerogen and $\delta^{18}O$ isotope values decreased. In the next layer carbonaceous components declined in abundance and the isotopes became heavier. In the final layer carbonaceous abundances continued to drop, but $\delta^{18}O$ decreased. These environmental changes over this narrow interval are considered to be best explained by an impact followed by huge fires. organic geochemical evidence in the form of polycyclic aromatic hydrocarbons enhancement at C-T boundary sites further supports the wild fire concept (Venkatesan and Dahl, 1989).

As the soot occurs with the first fallout of Ir, this was taken to indicate prompt rather than delayed fires. The swing to lower $\delta^{13}C$ isotope values for kerogen during deposition of the boundary layers is thought to mark the initial impact on the marine ecosystems. The rapid and large swing to heavier isotope values is assigned to rapid burial of dead plankton. In all a global fallout of 7×10^{16}g of C-T soot is inferred from a conflagration which would add to clouding, darkening and chilling and result in a greenhouse warming of around $9^{\circ}C$. This compounding of the initial event by secondary effects would greatly increase environmental stress upon organisms.

THE VOLCANIC VIEW

Paroxysmal volcanism is preferred as the agency behind Ir- anomalies and C-T extinctions (Officer and Drake 1985; Sarkar, 1986; Officer et al. 1987; Hallam, 1987). A number of arguments are marshalled in its favour. It would also produce acid rains, decrease in surface ocean alkalinity, global temperature changes and ozone layer depletion. The volcanism was linked to hot spot activity over mantle plumes and was genetically part of a wider scenario of plate movements with consequent late Cretaceous marine regression.

A critical point is the need to explain sufficient Ir in the fallout to produce the observed boundary anomaly levels. The main volcanic outburst considered to coincide with C-T time was the Deccan flood basalts which are thought to mark migration of India over a large mantle hot spot (Devey and Lightfoot, 1986). The amounts of basalt, H_2SO_4, and HCl needed to produce the C-T iridium flux (63 x 10^{-9} Ir g cm^{-2}) were estimated from Ir, H_2SO_4 and HCl values observed at a Hawaiian volcanic vent (Olmez et al. 1986). This gave 11 x 10^6 km^3 of basalt, 17 x 10^{12} t H_2SO_4 and 27 x 10^{10} t HCl. Thus the Deccan basalts at 1 x 10^6 km^3 in volume fail by an order of one magnitude to account for the Ir anomaly on their own. Based on actual measurement of Ir in Deccan basalts rather than an assumed equivalent to Hawaiian vents (0.0062 ng g^{-1} cf 0.32 ng g^{-1}) the calculations fail by an order of three magnitudes to match Ir values at a New Zealand C-T site (Strong et al. 1987). However, it might be assumed that the higher degassing value is more relevant than residual lava values. Even higher Ir values (1.5 ng g^{-1}, i.e. 30% of the Ir-anomaly concentration) are recorded from volcanic aerosols over Hawaii (Zoller et al. 1983).

Proper examination of the volcanic Ir contribution requires

(a) a precise correlation of age of the Deccan basalts, and

(b) a global survey of volcanic outbursts which also date to that boundary time.

(a) The exact Deccan age has been contentious (Courtillot et al. 1986; Wensink, 1987; Courtillot et al. 1987). Detailed dating to settle the timing of lava sequences, over 2000 m thick, yields age estimates from 66.6 to 68.5 My BP (Duncan and Pyle, 1988) and between 65-69 My BP (with magnetostratigraphy suggesting eruption of the section under 10^6 y; Courtillot et al. 1988). Thus a large volume of basalt probably erupted over C-T time but the number of eruptive episodes was probably small with repose periods of 1,000-5,000 y (Cox, 1988). Thus any link to C-T mass extinctions was probably by episodic and accumulative environmental stress in a step-wise manner. This is compatible with the multiple, discrete Ir-enriched and shocked mineral layers found within a 4 m section at the Gubbio (Italy) site, where intensive volcanism was preferred over an impact origin (Crocket et al. 1988).

(b) As well as Ir from Deccan continental volcanoes, further Ir was probably contributed to the C-T budget from the oceanic ridge system active around India at that time (Courtillot et al. 1986). This would be released as IrF_6 from volatile-rich youthful mantle during rifting of the ocean floor (Campsie et al. 1984). The Seychelle Islands are intruded by many alkaline rocks which range in age from 60-66 My BP (Dickin et al. 1986). They are considered to represent initially asthenospheric upwelling and rifting and this may form a further extension of the Deccan related Ir output.

Some volcanic ash directly overlies the C-T boundary preserved in rifted ridges at Broken Ridge, Indian Ocean (Leg 121 shipboard scientific party, 1988). This may indicate abnormally low planktonic production or increased eruptions from the nearby Ninetyeast Ridge hot spot (Duncan, 1979). The potential Indian Ocean-Deccan active ridge - hot spot system for Ir contribution at C-T time is shown in Fig. 6.

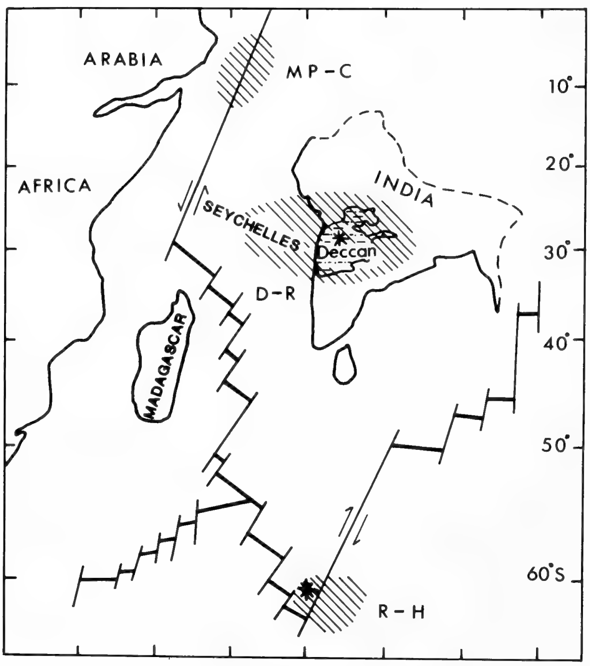

Fig. 6. Reconstruction of the Deccan basalts relative to the Indian Ocean spreading ridge system (stepped lines) and postulated hot spot positions at end Cretaceous (66 Myr) time, after Courtillot et al. 1986. Asterisks represent the presumed Deccan and Rajmahal hot spot positions after Duncan (1979). General regions of potential hot spot and rift related volcanism at C-T time (shaded areas) are represented by the Deccan/Seychelles-Reunion/Rodriguez hot spots (D-R), the Mascarene Plateau-Comaros hot spot (MP-C) and the Rajmahal-Heard Island hot spot (R-H).

Other potential volcanic sources of C-T Ir were suggested for a peak in volcanism along the Walvis Ridge, a hot spot trace in the southeastern Atlantic Ocean (Officer et al. 1987), and for the South American - Antarctic region (Hallam, 1987). Other hot spots and ridges (Morgan, 1983; Hartadeny and le Roex, 1985; Lawver et al. 1985) are known in the southern Atlantic region (Fig. 7). If these also flared into greater activity at C-T time marked increase in the Ir-levels could be produced.

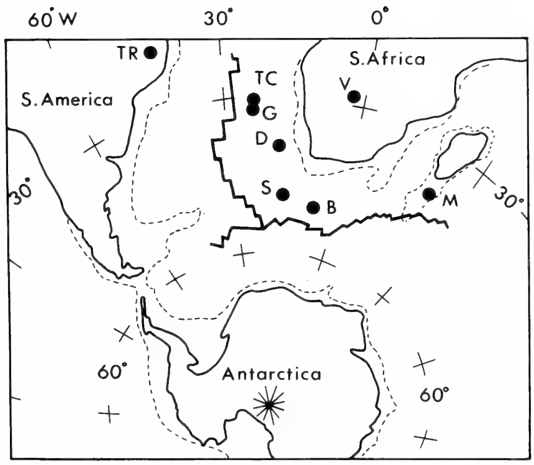

Fig. 7. Distribution of South Atlantic-Southern Ocean hot spots at C-T time, estimated from hot spot traces modelled by Morgan (1983) and Hartadeny and le Roex (1985). The mid-ocean ridge system (stepped lines) is taken from the Anomaly 28 (64 Myr) reconstruction of Lawver et al. (1985) and its position at C-T time (66 Myr) would be slightly closer to the hot spots around Africa. The depicted hot spots are Trindade (TR), Tristan da Cunah (TC), Gough (G), Discovery (D), Vema (V), Shona (S), Bouvet (B) and Marion (M).

Continuing in this vein, hot spot traces associated with C-T rift volcanism can be sought elsewhere in an endeavour to close the discrepancy between C-T boundary and Deccan basalt Ir- levels. Australia has much potential here as Sutherland (1983, 1985, 1988) linked an extensive continental and seafloor volcanic migration back to a triple point rift system that opened the Coral- and North Tasman-sea floors around 65 My BP (Fig. 8). This hot spot volcanism seems to gain strength back in time, so that the proposed initial outbursts along the Coral-Sea rift would be expected to yield relatively greater Ir. Other Australian rifts, some with voluminous volcanics of probably latest Cretaceous/ earliest Tertiary age, include the Bass Basin and the main Tasman spreading rift which is possibly linked to Antarctic hot spots. Zircons found in abundance in alluvial wash in the gemfields of central Queensland include common pale grains that gives a fission track age of 66 My BP and is a low uranium-type (<50 ppm U) typical of kimberlitic zircons (Sutherland et al. 1986). Kimberlitic sources, though small in volume, would be expected to discharge relatively higher Ir- levels than basalts when degassing.

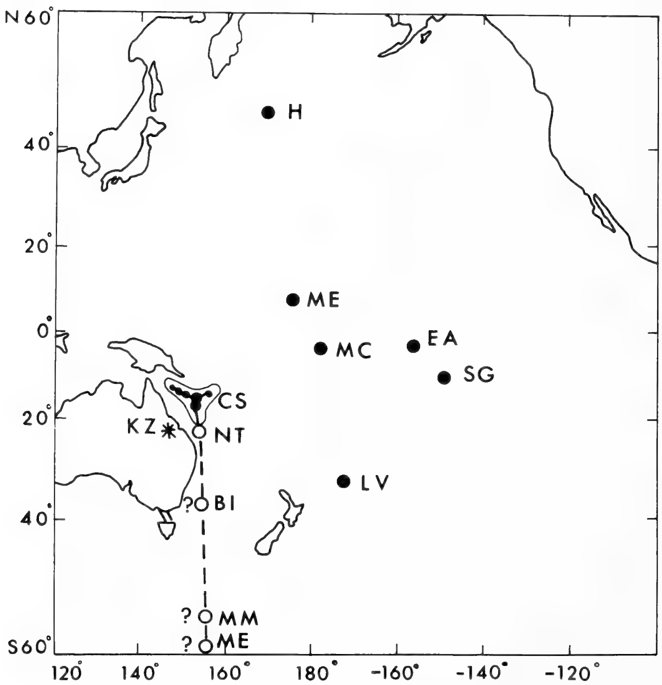

Fig. 8. Distribution of postulated Australian-Pacific hot spots at C-T time, based on hot spot tracks suggested by Sutherland (1988) and estimated from tracks modelled by Duncan and Clague (1985). Hot spots related to the Coral Sea and North Tasman rifts are shown as enclosed dots (CS-NT), hot spots related to the older Tasman rift are shown as circles linked by dashed lines (Balleny Islands BI, Mt. Melbourne MM and Mt. Erebus ME hot spots). Pacific hot spots (solid circles) represent the Hawaii (H), Mehetia (ME), Macdonald (MC), Easter (E), Sala y Gomez (SG) and Louisville (LV) traces. Kimberlitic zircons of C-T age in central Queensland gem fields are indicated by an asterisk (KZ).

A major line of basaltic activity, the Cameroon Line (Fig. 9), extends across continental west Africa and the eastern Atlantic sea floor for over 1600 km and commenced activity along its length around 65 My BP (Fitton and Dunlop, 1985; Fitton and James, 1986). The line is linked to adjacent rifting but was probably produced by early mantle upwelling (Halliday et al. 1988) and would be a likely Ir-donor around C-T time (Figs. 8 and 9). Two of the world's present largest hot spot volcanoes, Hawaii and Iceland, may also have sprung into activity close to C-T time. Dating of the Hawaiian-Emperor chain shows its north end ranging back to over 65 My BP (Duncan and Clague, 1985). There are older seamounts but these are less precisely dated (74 ± 3 My BP nannoplankton date) and are isolated relative to the main seamount chain. Thus the main, volcanism seems to start nearer C-T time. Iceland's hot spot shows an early position under Greenland which laterally fed sea floor rifts going back to a minimum age of 60 My BP in the Scoresby Sound, Vøring Plateau and Faroes Islands region (Vink, 1984). Allowing for corrections for new radiometric constants for the dating, these age results would suggest the initial rifting and deep seated volcanism extends back towards C-T time.

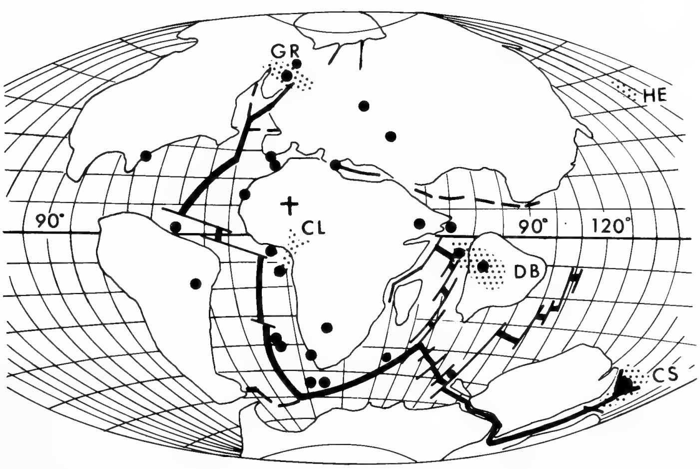

Fig. 9. Global pattern of continental disposition relative to mid-oceanic ridges dispersing the old Pangean assembly and location of likely hot spots at C-T time. Particularly large hot spots and volcanic rift lines thought to generate at this time include the Greenland hot spot (GR), the Cameroon Line (CL), the Deccan-Seychelles Basalts hot spot (DB), the Hawaiian-Emperor hot spot (HE) and the Coral Sea hot spot (CS).

Other small volcanic fields scattered around the globe, such as basalt fields in Bohemia, Odenwald and Kraichgau in central Europe (Lippolt, 1982), would provide a host of minor contributions to the final C-T boundary Ir budget. Thus, basaltic volcanism of this age (Fig. 9) is probably more prevalent than previously pointed out and in the final analysis, may be sufficient to supply the C-T flux of 63 x 10^{-9} Ir g cm^{-2}. Much of this widespread C-T volcanism seems to be hot spot related and to represent a cyclic upsurge of hot material from the core-mantle boundary within the Earth (Loper et al. 1988). Abrupt discharges of volatiles at the surface would add substantial amounts of CO_2 and sulphates to the atmosphere so that the combined effects of pollution by gases and particles would produce deleterious climatic effects on existing life. In this scenario the Ir-boundary anomaly represents a sudden flushing from the earth's mantle. Not all widespread alkaline volcanism associated with rifts need represent these deep hot spot outbursts. An example is volcanism in eastern North America which occurred along old rift lines but did not trace continental movement over a hot spot (Phipps, 1988). It may be significant that such episodes do not correspond closely with the proposed C-T and other extinction times. Some significant magmatic pulses, which peak between 65-70 My BP, are present in places such as Kodiak Islands, Alaska (Moore et al. 1983). However, these are calcalkaline in nature and their relationships to any associated volcanism and contribution to Ir-anomalies are obscure.

DISCUSSION

Features related to C-T boundary events, including Ir-anomaly sites, shocked mineral finds, potential impact craters and volcanic rift and hot spot sources form a global pattern (Figs. 4, 4 and 9). The Ir-anomaly associated with evidence of wide-spread fires, mass extinctions and distinct isotopic changes across the C-T boundary clearly indicate momentous happenings. Nevertheless evidence for a cosmic, volcanic or other cause remains in conflict on some points.

Some impact craters (Kara and Manson craters) did not date as precisely to the C-T boundary (66 My BP) as do some volcanic events e.g. Deccan basalts (av. 61 $\pm$ 10 My BP cf av 67.4 $\pm$ 0.7 My BP). New dates on the Kara (USSR) craters give conflicting results (c. 77 My BP from Hecht, 1988 cf 66 My BP from Koeberl et al. 1988) and make their correlation uncertain. However a further date on the Manson (USA) crater fits closely (Kerr, 1988). Other features such as the patterns in and properties of shocked quartz (Owen and Anders, 1988), elemental ratios in the Ir-anomaly (Rh/Ir, Bekov et al. 1988) and a report of stishovite (Kerr, 1988) seem to clearly favour an impact origin. The cause ascribed to the formation of the shock features is critical. Alexopoulous et al. (1988) examined the rare shocked grains from the Toba volcanic tuff, Indonesia. They concluded that the single set of discontinuous and fuzzy features per grain were not equivalent to those produced by known impacts (multiple, well defined, sharp and continuous sets). They also demonstrated that multiple planar sets in shocked impact quartz could survive annealing and healing over heating periods of 6 months at temperatures of up to 1000°C. This makes it most unlikely that the Toba sets were relicts of multiple sets exposed to explosive eruptions around 700°C as discussed by Carter et al. (1986). The elemental Ir-ratios to other noble metals are less easy to evaluate. This is partly due to authigenic precipitation of mineral phases which distort the representation of presumed impact materials (Schmitz et al. 1988).

Another conflict is a singular or multiple formation for the Ir-layer. Single events were suggested for New Zealand boundary sites where separate anomaly sites showed identical normalised Ir concentrations (134 ng cm^{-2}, Strong et al. 1988). If assigned to asteroidal or cometary impact, the extraterrestrial components of the layer would be 1.4% compared to 1.6% for Gubbio (Italy) 21% for Stevens Kleint (Denmark) and 0.6-2.5% for Raton Basin (USA). This observation is at variance with a re-analysis of the Gubbio section where the C-T boundary Ir-peak is only the major one of several Ir-peaks (Crocket et al. 1988). All peaks were associated with shocked minerals and straddled the sedimentary boundary sequence ($\pm$ 2 m), which would represent events over a period of at least 3 x 10^5 y. The preferred interpretation was intense volcanic activity to provide the sustained Ir-flux.

Multiple events, either from cometary showers (Davis et al. 1984; Hut et al. 1987) or deep seated volcanic paroxysms (Officer et al. 1987; Hallam, 1987; Loper et al. 1988) form a better match with the biologic evidence as proof of step-wise extinctions become more apparent in the stratigraphic record. For example Sarkar (1986) included in his discussion shallow marine forms (echinoids from the Mangyshlak, USSR site) as such fossil sequences are relatively rare amongst C-T boundary sites (Hallam, 1987). Sarkar's work suggested that both the Deep Sea Drilling sections and terrestrial C-T sections indicated a colder regime before and at the boundary and that previous correlations of extinctions with warming effects were not generally applicable. He indicated a drop of 14°C over 3000 y for the Mangyshlak site. He also refuted a boundary food web catastrophe where lowly planktonic forms died out causing the demise of higher marine forms (ammonoids, bivalves). He cited the example of the Zumaya Spain C-T site where larger forms vanished well before the Ir-layer. Fairly convincing evidence for a gradual change in both macro- and microbiota over some decimetres or metres above a strong Ir-anomaly is presented for a new marine section at the C-T boundary in southern Turkmenia (Alekseyev et al. 1988).

In the deep sea, a relatively undisturbed North pacific C-T site with a palaeodepth around 2400 m shows a strong suppression of pelagic marine life over 0.5 My (Zachos et al. 1989). The data indicate that cooling began 0.2 My before the boundary and a peak surface warming of $3^{o}C$ occurred 0.6 My after the boundary event.

Step-wise extinctions were related to direct and indirect effects of substantial and rapid falls in sea level at the end of the Cretaceous by Hallam (1987). In another view, McDougall (1988) related the high ratio of strontium-87 to strontium-86 in sea water at C-T time to dissolution of large amounts of strontium from the continental crust as a result of increased weathering. McDougall related the weathering to an acid precipitation from nitrogen oxides produced by shock passage of a cosmic body. Hallam, in contrast, considered the Ir-anomaly and related climatic effects to be factors caused by disturbed-mantle volcanism rather than by cosmic showers. Locally high As, Cu, Mo and Zn values certainly indicate highly anoxic conditions during deposition at some C-T sites, e.g. Marlborough, New Zealand (Strong et al. 1988).

The contribution of Ir from cosmic or volcanic sources depends on which mechanism best explains the observed overall Ir-flux at the boundary.

Some comets probably have compositions similar to those of volatile-rich CI chondrites, e.g. Halleys Comet (Kissel et al. 1986). Estimations of reliable Ir and related heavy metal contents in comets may prove difficult as grains gathered by probes sent across the path of Halleys Comet showed large variations in light H, C, N and O and stony Mg, Si, Fe and O materials (Balsiger et al. 1988). Hallam (1987) considered that Ir-concentrations in comets were insufficient to explain the anomaly and that repeated impacts of iron meteorites to account for the Gubbio anomalies were improbable.

The present study shows sufficient volcanism around C-T time to perhaps contribute enough Ir to the main anomaly. On the other hand it is unclear whether the volcanism was all synchronous or whether, if spaced, it could account for total Ir-fallout in several layers. For its viability some assumptions are needed, one being that explosive, more Ir-charged outbursts (Ir >0.3-1.5 ng g^{-1}) preceded many of the lava effusions (Ir typically 0.006 ng g^{-1} for Deccan basalts). Alternatively, such outbursts may have also issued from some of the inferred rift lines. The most efficient form of delivering Ir into the atmosphere from basaltic volcanic degassing (Stothers et al. 1986) seems to be as the fluoride IrF_6. From a study of Cl and F in volcanic gases Symonds et al. (1988) showed that HCl and HF were several orders more abundant than other species and that about 0.06-6 Tg of HF was discharged by volcanoes annually. Only an average of <10% of the emissions took place as large explosive eruptions which transmitted the gases efficiently into the stratosphere. However, such eruptions did inject considerable amounts of HCl and HF into the higher levels. A greater proportion of large explosive basaltic eruptions would probably take place during major hot spot outbursts.

Cyclic Context

One way of resolving the relative merits of cosmic versus volcanic C-T boundary extinctions is to examine correlations of similar Ir-anomalies with mass extinctions suggested within the geologic record (McLaren, 1983). Proponents of cyclic causes, whether cosmic (Kerr, 1984; Kauffman and Hansen, 1985; Hut et al. 1987), volcanic (Rampino and Stothers, 1988; Loper et al. 1988) or other tectonic (Nance et al. 1988; Ager, 1988) events, all appear in the literature so that the track record of each cyclic proposal can be closely scrutinised. This is too large a task to be presented in this analysis but some aspects will be considered.

A mass extinction periodicity of 26 My (Raup and Sepkowski, 1986) finds close correlation with an impact crater cycle of 28.4 My (crater diameters >10 km across: Alvarez and Muller, 1984). Thus evidence for Ir-anomalies and major impact should occur around 38-40 My in the Tertiary for comparison with the 66 My C-T event. An impact is recorded by means of micro-tektites and crystal-bearing spherules in late Eocene deep-sea deposits in several oceans, and on balance of evidence the spherules belong to a single event (Glass and Burns, 1987). The micro-tektites have very similar composition to tektites strewn across the North American continent (Koeberl and Glass, 1988); their fission track ages of 34 My agree with a time of diverse extinctions (Ganapathy, 1982). Both microtektites and spherules are considered to be impact melts, the former produced from loess or greywacke material, the latter from more mafic terrestrial material. However, only the spherules are associated with an iridium-anomaly and are older than the tektite layer (Glass and Burns, 1987). This tektite impact is slightly younger than predicted from impact periodicity which blurs the case for cyclic impact events. The Deep Sea Drilling sites in the Pacific, which intersect late Eocene-early Oligocene sediments of 35-42 My age, include an Eocene-Oligocene boundary at 38 My clearly marked by faunal and floral extinctions as well as by a universal marine oxygen shift (Kennett et al. 1985). A peak in the volcanic record also appears at this boundary so that evidence for a discrete Ir-impact event is equivocal.

The impact cycle predicts later Tertiary Ir-linked extinctions at around 13 $\pm$ 2 My. Tektites and impact craters are known in Europe dated close to 15 My (the Czechoslovakian 'moldavite' tektites and Ries impact crater, South Germany) which, though showing similar Nd-Sm and Sr-Rb, may not be directly linked as they differ in O isotope values (Shaw and Wasserburg, 1982). Ir-anomalies are not notable at such tektite horizons and O'Keefe (1987) points out that some impact craters show siderophile element patterns consistent with glassy projectiles rather than meteorites or comets. An impact, with an Ir-anomaly, is recorded in late Pliocene sequences over 600 km of ocean floor in the southeast Pacific (Kyte et al. 1988). This event at 2.3 My is not linked to obvious extinctions of organisms but may mark an onset of glaciation. The event falls outside of the predicted periodic impact cycle but does illustrate the complexities of the pattern. The 66, 34 and 2.3 My events, in fact, reasonably fit the periodicity suggested for perturbations of cometary orbits by instellar dust or gas clouds arising from oscillations of the Solar System about the galactic plane (31 ± 1 My; Rampino and Stothers, 1984).

A similar periodicity (32 ± 1 My) is also given for flood basalt volcanism on earth over the last 250 My by Rampino and Stothers (1988). They link both cosmic impact and internal mantle events with dates of mass extinctions. Some extinctions seem more clear cut or more disastrous than others (McLaren, 1983). More major extinctions may reflect either episodes of more severe impact showering and/or mantle upwelling or other coincidences of several factors unfavourable to evolving biota. The periodicity problem is summarised by Loper et al. (1988) who also show a correspondence between the Earth's magnetic reversals and mass extinction events. They envisage a thinning of the thermal boundary at the base of the mantle with upwelling of the hot material increasing the energy supply to the geodynamo and hence the frequency of reversals. At the same time the associated abundant hot spot volcanism gives significant CO_2 and sulphate discharges. The similar model of Courtillot and Besse (1987) relates exceptional volcanism and mass extinctions at the C-T and Permian-Triassic boundaries to released thermal activity after unusually long periods exhibiting no magnetic reversals. Both models regard periodicities of mass extinctions and climate as a consequence of thermal and chemical activity within the inner Earth. Even after initial hot spot breakouts, intense volcanism may continue for periods of over 10 My (Vink, 1984; White et al. 1987) and exert a prolonged influence on changed conditions. Thus, Earth's hot spots are not only a key link in the plate tectonic cycle (Vink et al. 1985) but perhaps also in evolution - e.g. as a process driven by extinctions which allow other groups to adapt into new ecological niches (Smith, 1987). Hot spot cycles may also tie into major supercontinental cycles (Nance et al. 1988) as major amalgamations of continental crust will act as a blanket and focus thermal outbreaks (Anderson, 1982).

The largest extinction in the Phanerozoic record lies at the Permian-Triassic boundary but was unlikely to be impact related (McLaren, 1983). It has been linked with Siberian flood basalts, as a possible expression of the Jan Mayen hot spot (Rampino and Stothers, 1988). The boundary shows a large shift in C isotopic ratios typical of other extinction boundaries (Magaritz et al. 1988). However, the boundary incorporates an extended, multiple and complex geochemical change spaced over a million years or so and unlike the change at the C-T boundary (Holser et al. 1989). The European boundary includes an Ir-anomaly and probably marks partly gradual and partly step-wise extinction due to marine retreats rather than a simple catastrophic event. A study of brachiopod shells at Spitzbergen suggested declines in atmospheric oxygen and nutrients as causes of the mass extinctions (Gruszczynski et al. 1989). New studies of the boundary in China did not confirm earlier reports of Ir anomalies there (Zhou and Kyte, 1988). Instead, trace elements in the boundary clays are strongly enriched in Cs, Zr, Hf, Ta and Th and depleted in Cr, Co and Ir. This favours an origin as altered ash from massive silicic volcanism of Toba eruption scale. Hot spot activity is not precluded as this can range from mafic to silicic. In an Australian study, Sutherland (1987) proposes major hot spot magmatism associated with rifting on the eastern margin prior to this boundary. However this activity was largely obscured by orogenic events.

A possible impact correlated extinction is proposed for the succeeding late Triassic event (McLaren, 1983), but there is no good correlation between that extinction and the closest flood basalt activity (211 $\pm$ 8 My *cf* 200 $\pm$ 5 My North American episode; Rampino and Stothers, 1988). However a fresh cycle of hot spot volcanism, starting about this time has been suggested for Australia (Wellman, 1983; Sutherland, 1987).

Further back in the geologic record, correlations become increasingly obscure between extinctions, impacts, hot spot volcanism and iridium-anomalies. Iridium-anomalies, located in late Devonian carbonate sequences in the Canning Basin in Australia, are assigned to organic concentrations by the cyanobacterium *Frutexites* (Nicoll and Playford, 1988). Stratigraphically these Ir-anomalies do not correlate directly with the boundary which is thought to mark a significant decrease in biomass by McLaren (1983). Algal 'blooming', possibly produced by Devonian mass extinctions, and its appearance in the (Burdekin Basin, Northeastern Australia), was considered by Heidecker (1988). After studying evidence from Devonian vertebrates outside the few classic European sequences, Young (1988) considered that major faunal changes were due to biogeographic factors and that resulting extinctions were only of local significance. A close study of the Ordovician-Silurian boundary in China contradicted earlier results and showed an Ir-anomaly which was supported by carbon isotope shifts and palaeomagnetic evidence (Chai, et al. 1988). This new evidence implied a sudden event similar to that for the C-T boundary.

Confusion over a postulated extinction event at the Cambrian/ Precambrian boundary is summarised by Donovan (1987). Based on the evidence of body-and trace fossils and of carbon isotopes, Donovan concluded that early metazoan radiations across this boundary were unpunctuated by any real extinction event. He formed this conclusion despite an iridium-anomaly and a shift in C isotope ratios in sequences in China (Hsu et al. 1985). The identification of some of Australia's largest impact structures (10-35 km diameter) potentially lie close to this boundary (Tonkin, 1973; Gostin et al. 1986; Stewart and Mitchell, 1987).

An impact related origin for life has been proposed for early Earth; as opposed to impact extinctions but such an origin is subject to criticism (Miller and Bada, 1988).

CONCLUDING REMARKS

The preceding discussion evaluates considerable accumulated evidence for impacts and widespread volcanism coinciding with C-T boundary extinctions. Either or both agencies seem capable of producing a rapid fallout of siderophile elements to account for the observed Ir-anomalies at the boundary. Global fires, acid rains, blanketing of normal radiation, and greenhouse effects arising from such extreme disruptions would place certain evolutionary groups under severe environmental stress. The evidence favours step-wise extinctions, perhaps even for the dinosaurs.

The precise cause and time of dinosaur demise is uncertain. Padin (1988) points out that most of their genera and taxa were gone long before those remaining in the Montana deposits which constitute the only reasonably complete and well studied record in C-T boundary sediments on land. The dinosaurs were probably on the wane and less fit to survive any C-T holocaust than some other related vertebrate groups, though there were hardy, social dinosaurs in polar climates (Paul, 1988). Amongst the myriads of untestable theories for their final fade-out, one candidate is a change in the oxygen content of the atmosphere. Studies of air bubbles trapped in amber of Tertiary and late Cretaceous ages, show that 80 My ago the atmosphere was richer in oxygen by at least 50% (Anderson, 1987). The drastic changes, introduced by nitrogen oxides produced by extraterrestrial entries or by CO_2 introduced by hot spot volcanic outbreaks, could alter the oxygen balance and thus adversely affect large-bodied oxygen breathers like dinosaurs.

Dinosaurs loom large in the public mind but were only a small part of the overall C-T extinction record. One view considers them to be warm blooded animals with families and species continually in an extinctory flux in response to normal environmental perturbations; their families showed an average endurance of 25 My cf 55 My for cold blooded reptiles (Bakker, 1986). Probably they finally became victims of a state of chaos that periodically regulates the biosphere (McLean, 1988). During periods of steady-state mantle heat flow and CO_2 degassing onto the Earth's surface, feedback systems become organised around that steady state. However, it is far from an equilibrium state and fluctuations can grow into structure breaking waves, which shatter the feedback organisation. Mushrooming clouds, such as produced by Deccan volcanic outbursts or impacting bodies would destabilise the energy flow from sun to earth and back into space, shattering the late Cretaceous organisation of the biosphere and triggering a C-T transition into chaos. Explosive volcanism, not only from mafic but also from silicic sources, producing shocked minerals, came from a whole mantle convective surge at C-T time (Rice, 1987).

The Deccan eruptions are singled out by some authors as a prime example of hot spot volcanism for breaking up the Cretaceous environment. However, the cause remains open. The timing to the C-T boundary has been settled, but an actual hot spot origin for the basalts is rejected by Pandey and Negi (1987). They relate the basalts to a world-wide peak of magmatism matching a galactic catastrophic cyclicity of around 33 My. However, they place the origin of the basalts to depths of less than 40 km which diminishes their potential as a source of deep-mantle Ir.

Not only does the true extent of C-T hot spot activity need further evaluation but its distribution may also have an important effect on the climatic consequences. Global surface-temperature responses to major eruptions differ between the Northern and Southern Hemispheres (Sear et al. 1987). Those eruptions in the north immediately affect average surface-temperatures in that hemisphere but have little impact on southern average temperatures. However those in the south affect temperatures of both hemispheres some 6-12 months after eruption.

In a dramatic joining of the impact and hot spot causations Alt et al. (1988) correlated large flood basalt areas like the Deccan system with major impact cratering which depressurises the mantle. This process then initiates hot spot and ocean ridge volcanism. This marriage does not exclusively solve the Ir-anomaly contribution, i.e. whether of meteoritic, volcanic or mixed fallout origin. The craters would need to be well over 50 km across because seismic data on impacts up to this size suggest relatively shallow structures (< 8 km deep; Sharpton et al. 1988) which hardly extend into the mantle.

The post-mortem on the fate of the dinosaurs is certain to continue for fascinated scientists and public alike. This is obvious from the views paraded at the "Global Catastrophe in Earth History" meeting at Snowbird, Utah, just after Luis Alvarez (the catalyst of the controversy) died in early September 1988 (Trower, 1988; Hecht, 1988). Nearly every viewpoint was challenged, even including the existence of many extinctions at the C-T boundary, but the impact theory was favoured (Kerr, 1988). On the popular scientific side, a recent book (Dixon, 1988) describes even a presumed evolution of the dinosaurs if they had not died out, but lived on to populate today's world (Gee, 1988)! An example of enterprising lateral thinking is the suggestion that the moon's surface layers should be examined for the C-T iridium-anomaly as ejecta could fall on the moon from a large Earth impact (Shevchenko, 1988).

As an antipodean analyst I would place my geological guess on a combined catastrophe, i.e. a coincidence of both impact and volcanic cycles combining together, but not necessarily the first directly causing the other.

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Finally, the author dedicates this address to the late Luis Alvarez (1911-1988) who galvanised global debate on catastrophic extinctions (Trower, 1988).

REFERENCES

Ager, D., 1988. Cosmic collisions and Earth history - a geologist's view. *Journal of the British astronomical Association, 98*, 85-88.

Alekseyev, A.S., Nazarov, M.A., Barsukova, L.D., Koselov, G.M., Nizhegorodova, I.V. and Amanniyazov, K.N., 1988. The Cretaceous-Palaeogene boundary in southern Turkmenia and its geochemical characteristics. *International Geology Review, 30*, 121-135.

Alexopoulous, J.S., Grieve, R.A.F. and Robertson, P.B., 1988. Microscopic lamellar deformation features in quartz: Discriminative characteristics of shock generated varieties. *Geology, 16,* 796-799.

Alt, D., Sears, J.M. and Hyndman, D.W., 1988. Terrestrial maria: the origins of large basalt plateaus, hot spot tracks and spreading ridges. *The Journal of Geology, 96,* 647-662.

Alvarez, L.W., 1987. Mass extinctions caused by large bolide impacts. *Physics Today, 40,* 24-33.

Alvarez, W., 1986. Towards a theory of Impact Crises. *Eos, 67,* 649.

Alvarez, L.W., Alvarez, W., Asaro, F. and Michel, H.V., 1979. Anomalous iridium levels in the Cretaceous/Tertiary boundary at Gubbio, Italy: Negative results of tests for super nova origin. *in* CRETACEOUS/ TERTIARY BOUNDARY EVENTS SYMPOSIUM, II, PROCEEDINGS, p. 69, Christensen, W.K. and Birkeland, T. (Eds.). University of Copenhagen, Denmark.

Alvarez, L.W., Alvarez, W., Asaro, F. and Michel, H.V., 1980. Extraterrestrial cause for the Cretaceous/Tertiary extinction. *Science, 208,*1095-1108.

Alvarez, W., Kauffman, E.G., Surlyk, F., Alvarez, L.W., Asaro, F. and Michel, H.V., 1984. Impact Theory of mass extinctions and the invertebrate fossil record. *Science, 223,* 1135-1140.

Alvarez, W. and Muller, R.A., 1984. Evidence from crater ages for periodic impacts on the Earth. *Nature, 308,* 718-720.

Angier, N., 1985. Did Comets Kill the Dinosaurs? *Time,* May 6 1985, 58-65.

Anderson, D.L., 1982. Hot spots, polar wander, Mesozoic convection and the geoid. *Nature, 297,* 391-393.

Anderson, I., 1987. Dinosaurs breathed air rich in oxygen. *New Scientist, 116,* 25.

Bakker, R., 1986. THE DINOSAUR HERESIES. 1st edn. Longman Scientific & Technical, Great Britain.

Balsiger, H., Fechtig, H. and Geiss, J., 1988. A close look at Halley's Comet. *Scientific American, 259*(3), 62-69.

Barron, E.J., 1987. Cretaceous plate tectonic reconstructions. *Palaeogeography, Palaeoclimatology, Palaeoecology, 59,* 3-29.

Bekov, G.I., Letokhov, V.S., Radaev, V.N., Badyukov, D.D. and Nazarov, M.A., 1988. Rhodium distribution at the Cretaceous/ Tertiary boundary analysed by ultrasensitive laser photo-ionization. *Nature, 332,* 146-148.

Bohor, B.F., 1988. K-T Boundary Claystone is a Distal Ejecta Deposit. *Meteorites, 23,* 258-259.

Bohor, B.F. and Betterton, W.J., 1988. Are the Hollow Spherules in K-T Boundary Claystones Altered Micro-Tektites? *Meteorites, 23,* 259.

Bohor, B.F., Foord, E.E., Modreski, P.J. and Triplehorn, D.M., 1984. Mineralic evidence for an impact event at the Cretaceous-Tertiary boundary. *Science, 224,* 867-869.

Bohor, B.F., Modreski, P.J. and Foord, E.E., 1987. Shocked quartz in the Cretaceous-Tertiary boundary clays: Evidence for a global distribution. *Science, 236,* 705-708.

Bourgeois, J., Hansen, T.A., Wiberg, P.L. and Kauffman, E.G., 1988. A Tsunami Deposit at the Cretaceous-Tertiary Boundary in Texas. *Science, 241,* 567-570.

Brooks, R.R., Reeves, R.D., Yang, X-H., Ryan, D.E., Holzbecher, J., Collen, J.D., Neall, V.E. and Lee, J., 1984. Elemental Anomalies at the Cretaceous-Tertiary Boundary, Woodside Creek, New Zealand. *Science, 226,* 539-541.

Brouwers, E.M., Clemens, W.A., Spicer, R.A., Ager, T.A., Carter, L.D. and Sliter, W.V., 1987. Dinosaurs on the North Slope, Alaska: High Latitude, Latest Cretaceous Environments. *Science, 237,* 1608-1610.

Brouwers, E.M., Spicer, R.A. and Clemens, W.A., 1988. Letters, Arctic Dinosaurs and Terminal Cretaceous Extinctions. Response. *Science, 239,* 11.

Bryant, L.J., Clemens, W.A. and Hutchinson, J.H., 1986. Cretaceous-Tertiary Dinosaur Extinction. *Science, 234,* 1172.

Campsie, J., Johnson, G.L., Jones, J.E. and Rich, J.E., 1984. Episodic volcanism and evolutionary processes. *Eos, 65,* 796-800.

Carter, N.L., Officer, C.B., Chesner, C.A. and Rose, W.I., 1986. Dynamic deformation of volcanic ejecta from the Toba caldera: Possible relevance to Cretaceous-Tertiary boundary phenomena. *Geology, 14,* 380-383.

Chai, C.F. and Kong, P., 1988. Chemical Speciation Study of Anomalous Iridium from K-T Boundary. *Meteoritics, 23,* 263.

Chai, C.F., Ma, J.G., Kong, P., Zhou, Y.Q., Ma, S.L. and Wang, X.F., 1988. Geochemical anomaly across the Ordovician-Silurian (O-S) Boundary, Yichang, China, and their implications. *Meteoritics, 23,* 263.

Cisowski, S.M., 1988. Magnetic properties of K/T and E/O microspherules: origin by combustion? *Earth and Planetary Science Letters*, *88*, 193-208.

Courtillot, V. and Besse, J., 1987. Magnetic field reversals, polar wander, and core-mantle coupling. *Science*, *237*, 1140-1147.

Courtillot, V., Besse, J., Vandamme, D. Montigny, R., Jaeger, J.J. and Cappetta, H., 1986. Deccan flood basalts at the Cretaceous/Tertiary boundary?. *Earth and Planetary Science Letters*, *80*, 361-374.

Courtillot, V., Vandamme, D. and Besse, J. 1987. Reply on comments on "Deccan flood basalts at the Cretaceous/Tertiary boundary?" by H. Wensink. *Earth and Planetary Science Letters*, *86*, 122-123.

Courtillot, V., Feraud, G., Maluski, H., Vandamme, D., Moreau, M.G. and Besse, J., 1988. Deccan flood basalts and the Cretaceous/Tertiary boundary. *Nature*, *333*, 843-846.

Cox, K.G., 1988. *Mass Extinctions*. Gradual volcanic catastrophes?. *Nature*, *333*, 802.

Crocket, J.H., 1981. Geochemistry of the platinum group elements. *Canadian Institute of Mining and Metallurgy Special Volume*, *23*, 47-64.

Crocket, J.H., Officer, C.B., Wezel, F.C. and Johnson, G.D., 1988. Distribution of noble metals across the Cretaceous/Tertiary boundary at Gubbio, Italy: Iridium variation as a constraint on the duration and nature of Cretaceous/Tertiary boundary events. *Geology*, *16*, 77-80.

Crowley, T.J., Mengel, J.G. and Short, D.A., 1987. Gondwanaland's seasonal cycle. *Nature*, *329*, 803-807.

Crowley, T.J. and North, G.R., 1988. Abrupt Climatic Change and Extinction Events in Earth History. *Science*, *240*, 996-1002.

Crutzen, P.J., 1987. Acid rain at the K-T boundary. *Nature*, *330*, 108-109.

Davis, M., Hut, P. and Muller, R.A., 1984. Extinction of species by periodic comet showers. *Nature*, *308*, 715-717.

Deer, W.A., Howie, R.A. and Zussman, J., 1963. ROCK FORMING MINERALS. Vol. 4 Framework Silicates. 1st edn. Longmans, London, 435 pp.

Devey, C.W. and Lightfoot, P.C., 1986. Volcanological and tectonic control of stratigraphy and structure in the Western Deccan traps. *Bulletin of Volcanology*, *48*, 195-207.

Dickin, A.P., Fallick, A.E., Halliday, A.N., MacIntyre, R.M. and Stephens, W.E., 1986. An isotopic and geochronological investigation of the younger igneous rocks of the Seychelles microcontinent. *Earth and Planetary Science Letters, 81,* 48-56.

Dixon, D., 1988. THE NEW DINOSAURS: An Alternative Evolution. 1st edn. Grafton, London, 120 pp.

Donovan, S.K., 1987. Mass extinctions Confusion at the boundary. *Nature, 329,* 288.

Duncan, R.A., 1979. Geochronology of basalts from the Ninetyeast Ridge and continental dispersion in the eastern Indian Ocean. *Journal of Volcanological and Geothermal Research, 4,* 283-305.

Duncan, R.A. and Clague, D.A., 1985. Pacific plate motion recorded by linear volcanic chains. *in* THE OCEAN BASINS AND MARGINS. 7A the Pacific Ocean, pp. 89-121, Nairn, A.E.M., Stehli, F.G. and Uyeda, S. (Eds.). Plenum Press, New York & London.

Duncan, R.A. and Pyle, D.G., 1988. Rapid eruption of the Deccan flood basalts at the Cretaceous/Tertiary boundary. *Nature, 333,* 841-843.

Fitton, J.G. and Dunlop, H.M., 1985. The Cameroon line, West Africa and its bearing on the origin of oceanic and continental alkali basalt. *Earth and Planetary Science Letters, 72,* 23-38.

Fitton, J.G. and James, D., 1986. Basic volcanism associated with intraplate linear features. *Philosophical Transactions of the Royal Society of London* A, *317,* 253-266.

Galbreath, G.J., 1988. Letters. Arctic Dinosaurs and Terminal Cretaceous Extinctions. *Science, 239,* 10.

Ganapathy, R., 1982. Evidence for a Major Meteorite Impact on the Earth 34 Million Years Ago: Implications for Eocene Extinctions. *Science, 216,* 885-886.

Garntner, S. and Keany, 1978. The terminal Cretaceous event: a geological problem with an oceanographic solution. *The Journal of Geology, 6,* 708-712.

Gee, H., 1988. Tales of future past. *Nature, 335,* 505-506.

Gilmour, I., Boyd, S.R. and Pillinger, C.T., 1988. Nitrogen Isotope Geochemistry of a K-T Boundary Site in New Zealand. *Meteoritics, 23,* 269.

Glass, B.P. and Burns, C.A., 1987. Late Eocene crystal-bearing spherules: Two layers or one. *Meteoritics, 22,* 265-279.

Gostin, V.A., Haines, P.W., Jenkins, R.J.F., Compston, W. and Williams, I.S., 1986. Impact ejecta horizon within late Precambrian shales, Adelaide Geosyncline, South Australia. *Science, 233,* 198-200.

Gould, S.J., 1984. Sex, Drugs, Disasters, and the Extinctions of Dinosaurs. *Discover, 4,* 67-72.

Gruszczynski, M., Halas, S., Hoffman, A. and Malkowski, K., 1989. A brachiopod calcite record of the oceanic carbon and oxygen isotope shifts at the Permian/Triassic transition. *Nature, 337,* 64-68.

Hallam, A., 1979. The end of Cretaceous. *Nature, 281,* 430-431.

Hallam, A., 1984. Pre-Quaternary sea level changes. *Annual Reviews of Earth and Planetary Science, 12,* 205-243.

Hallam, A., 1987. End-Cretaceous Mass Extinction Event: Argument for Terrestrial Causation. *Nature, 238,* 1237-1242.

Halliday, A.N., Dickin, A.P. Fallick, A.E. and Fitton, J.G., 1988. Mantle Dynamics: A Nd, Sr, Pb and O Isotopic Study of the Cameroon Line Volcanic Chain. *Journal of Petrology, 29,* 181-211.

Hansen, H.J., Gwozdz, R., Bromley, R.G., Rusmussen, K.L., Vogensen, E.W. and Pedersen, K.R., 1986. Cretaceous-Tertiary boundary spherules from Denmark, New Zealand and Spain. ***Bulletin of the Geological Society** of Denmark, 35,* 75-82.

Hardenbol, J. and Berggren, W.A., 1978. A new Palaeogene numerical time scale. *in* STUDIES IN GEOLOGY, 6, 213-234. Cookee, G.V., Glaessner, M.F. and Hedburg, H.D. (Eds.). American Association of Petroleum Geologists, Tulsa, USA.

Hartadeny, C.J.H. and le Roex, A.P., 1985. Southern Ocean hotspot tracks and the Cenozoic absolute motion of the African, Antarctic and South American plates. *Earth and Planetary Science Letters, 75,* 245-257.

Hecht, J., 1988. Evolving theories for old extinctions. *New Scientist, 120,* 28-30.

Heidecker, E.J., 1988. Mineral landscaping towards 'blooming events' - Devonian extinction record with modern management implications. *Geological Society of Australia Abstracts Series, 21,* 182.

Hickey, L.J., 1981. Land plant evidence compatible with gradual, not catastrophic change at the end of the Cretaceous. *Nature, 292,* 529-531.

Hickey, L.J., West, R.M., Dawson, M.R. and Choi, D.K., 1983. Arctic terrestrial biota: Palaeomagnetic evidence of age disparity with mid-nothern latitudes during the late

Cretaceous and early Tertiary. *Science*, *221*, 1153-1156.

Hildebrand, A.R. and Boynton, W.V., 1987. The K/T impact excavated oceanic mantle: Evidence from REE abundances. *Lunar and Planetary Science*, *XVIII* (2), 427-428.

Hildebrand, A.R. and Boynton, W.V., 1988. Impact Wave Deposits at the Cretaceous/Tetiary Boundary Imply on Oceanic Impact Site. *Meteoritics*, *23*, 274.

Hodge, V., Stallard, M., Koide, M. and Goldberg, E.D., 1986. Determination of platinum and iridium in marine waters, sediments and organisms. *Analytical Chemistry*, *58*, 616-620.

Hoffman, P., 1982. Asteroid on trail. Secrets of an ancient catastrophe. *Omega Science Digest*, Nov/Dec issue, 92-97.

Holser, W.T., Schönlaub, H-P., Attrep Jn., M., Boeckelmann, K., Klein, P., Magaritz, M., Orth, C.J., Fenninger, A., Jenny, C., Kralik, M., Mauritsch, H., Pak, E., Schramm, J-M., Statteger, K. and Schmöller, R., 1989. A unique geochemical record at the Permian/Triassic boundary. *Nature*, *337*, 39-44.

Hsu, K.J., 1980. Terrestrial catastrophe caused by cometary impact at the end of the Cretaceous. *Nature*, *285*, 201-203.

Hsu, K.J., Oberhänsli, H., Gao, J.Y., Shu, S., Haihong, C. and Krähenbrühl, U., 1985. 'Strangelove ocean' before the Cambrian explosion. *Nature*, *36*, 809-811.

Hut, P., Alvarez, W., Elder, W.P., Hansen, T., Kauffman, E.G., Keller, G., Shoemaker, E.M. and Weissman, P.R., 1987. Comet showers as a cause of mass extinctions. *Nature*, *329*, 118-121.

Izett, G.A., 1987. Authigenic "spherules" in K-T boundary sediments at Caravaca, Spain and Raton Basin, Colarado and New Mexico, may not be impact derived. *Geological Society of America Bulletin*, *99*, 78-86.

Izett, G.A. and Bohor, B.F., 1987. Comment on dynamic deformation of volcanic ejecta from the Toba caldera: Possible relevance to Cretaceous-Tertiary boundary phenomena. *Geology*, *15*, 90.

Izett, G.A. and Pillmore, C.L., 1985. Shock metamorphic minerals at the Cretaceous-Tertiary boundary, Raton Basin, Colorado and New Mexico provide evidence for asteroid impact in continental crust. *Eos*, *66*, 1149-1150.

Kastner, M., Asaro, F., Michel, H.V., Alvarez, W. and Alvarez, L.W., 1984. The precursor of the Cretaceous-Tertiary boundary clays at Stevns Klint, Denmark, and DSDP hole 465a.

Science, *226*, 137-143.

Kauffman, E.G. and Hansen, T., 1985. Stepwise mass extinctions associated with major oceanic and climatic perturbations: Evidence for multiple impacts? *Eos*, *66*, 813-814.

Kennett, J.P., Borch, C. von der, Baker, P.A., Barton, C.E., Boersma, A., Cauler, J.P., Dudley Jnr, W.C., Gardner, J.V., Jenkins, D.G., Lohman, W.H., Martini, E., Merrill, R.B., Morin, R., Nelson, C.S., Robert, C., Srinivasan, M.S., Stein, R., Takeuchi, A. and Murphy, M.G., 1985. Palaeotectonic implications of increased late Eocene-early Oligocene volcanism from South Pacific DSDP sites. *Nature*, *316*, 507-511.

Kerr, R.A., 1981. Non marine Iridium Anomaly Linked to Extinctions. *Science*, *212*, 1376.

Kerr, R.A., 1984. Periodic Impacts and Extinctions Reported. *Science*, *223*, 1277-1279.

Kerr, R.A., 1987. Searching Land and Sea for the Dinosaur Killer. *Science*, *237*, 856-857.

Kerr, R.A., 1988. Huge Impact Is Favoured K-T Boundary Killer. *Science*, *242*, 865-867.

Kissel, J., Sagdeev, R.Z., Bertaux, J.L., Angarov, V.N., Audouzell, J., Blamont, J.E., Buchler, K., Evlanov, E.N., Fechtig, H., Fomenkova, M.N., Hoerner, H. von, Ingamov, N.A., Khromov, V.N., Knabe, W., Krueger, F.R., Langevin, Y., Leonas, V.B., Levasseur-Regourd, A.C., Managadze, G.G., Podkolzin, S.N., Shapiro, V.D., Tabald, S.R. and Zubkov, B.V., 1986. Composition of Comet Halley dust particles from Vega observations. *Nature*, *321*, 280-282.

Koeberl, C. and Glass, B.P., 1988. Chemical composition of North American microtektites and tektite fragments from Barbados and DSDP Site 612 on the continental slope off New Jersey. *Earth and Planetary Science Letters*, *87*, 286-292.

Koeberl, C., Murali, A.V., Nazarov, M.A., Sharpton, V.L. and Burke, K., 1988. The Kara Impact Structure (USSR) and the K/T-Boundary Event. *Meteoritics*, *23*, 280-281.

Krähenbühl, U., Geissbühler, M., Bühler, F. and Eberhardt, P., 1988. The Measurement of Osmium Isotopes in Samples from a Cretaceous/Tertiary (K/T) Section of the Raton Basin, USA. *Meteoritics*, *23*, 282.

Kyte, F.T., Smit, J. and Wasson, J.T., 1985. Siderophile interelement variations in the Cretaceous-Tertiary boundary sediments from Caravaca, Spain. *Earth and Planetary Science Letters*, *73*, 183-195.

Kyte, F.T., Zhou, L. and Wasson, J.T., 1988. New evidence on the size and possible effects of a Late Pliocene oceanic asteroid impact. *Science, 241*, 63-65.

Lawver, L.A., Sclater, J.G. and Meinke, 1985. Mesozoic and Cenozoic reconstructions of the South Atlantic. *Tectnophysics, 114*, 233-254.

Leg 121 shipboard scientific party, 1988. Ocean Drilling Program. A tale of two ridges. *Nature, 335*, 593-594.

Lippolt, H.J., 1982. K/Ar Age Determinations and the Correlation of Tertiary Volcanic Activity in Central Europe. *Geologisches Jahrbuch, D, 53*, 113-135.

Loper, D.E., McCartney, K. and Buzyna, G., 1988. A model of correlated episodicity in magnetic-field reversals, climate, and mass extinctions. *The Journal of Geology, 96*, 1-15.

McCartney, K. and Nienstedt, J., 1986. The Cretaceous/Tertiary Extinction Controversy Reconsidered. *Journal of Geological Education, 34*, 89-94.

McDougall, J.D., 1988. Seawater Strontium Isotopes, Acid Rain, and the Cretaceous-Tertiary Boundary. *Science, 239*, 485-487.

McHone, J.F. and Greeley, R., 1987. Talemzane: Algerian impact crater detected on Sir-A Orbit Imaging Radar. *Meteoritics, 22*, 253-264.

McLaren, D., 1983. Impacts that changed the course of evolution. *New Scientist, 100*, 588-593.

McLean, D.M., 1988. K-T transition into chaos. *Journal of Geological Education, 36*, 237-245.

Magaritz, M., Bär, R., Baud, A. and Holser, W.T., 1988. The carbon-isotope shift at the Permian/Triassic boundary in the southern Alps is gradual. *Nature, 331*, 337-339.

Masaytis, V.L. and Mashchak, M.S., 1984. Impact events at the Cretaceous-Paleogene boundary. *Doklady Earth Science Sections, 265*, 195-197.

Miller, S.L. and Bada, J.L., 1988. Submarine hot springs and the origin of life. *Nature, 334*, 609-611.

Montanari, A., Hay, R.L., Alvarez, W., Asaro, F., Michel, H.V., Alvarez, L.W. and Smit, J., 1983. Spheroids at the Cretaceous-Tertiary boundary are altered impact droplets of basaltic composition. *Geology, 11*, 668-671.

Morgan, W.J., 1983. Hot spot tracks and early rifting of the Atlantic. *Tectnophysics, 94*, 123-139.

Moore, J.C., Byrne, T., Plumley, P.W., Reid, M., Gibbons, H. and Coe, R.S., 1983. Palaeogene evolution of the Kodiak Islands, Alaska: consequence of ridge-trench interaction in a more southerly latitude. *Tectonics, 2,* 265-293.

Nance, R.D., Worsley, T.R. and Moody, J.B., 1988. The Supercontinent Cycle. *Scientific American, 259* (1), 44-51.

Nausland, H.R., Officer, C.B. and Johnson, G.D., 1986. Microspherules in Upper Cretaceous and Lower Tertiary clay layers at Gubbio, Italy. *Geology, 14,* 923-926.

Nicoll, R.S. and Playford, P.E., 1988. Upper Devonian iridium anomalies and the Frasnian-Fammenian boundary in the Canning Basin, Western Australia. *Geological Society of Australia Abstracts Series, 21,* 296.

Norman, D., 1985. THE ILLUSTRATED ENCYCLOPEDIA OF DINOSAURS. 1st edn. Salamander Books, London, 208 pp.

Officer, C.B. and Drake, C.L., 1985. Terminal Cretaceous environmental events. *Science, 227,* 1161-1167.

Officer, C.B., Hallam, A., Drake, C.L. and Devine, J.D., 1987. Late Cretaceous and paroxysmal Cretaceous/Tertiary extinctions. *Nature, 326,* 143-149.

O'Keefe, J.A., 1987. Craters produced by impact of tektite-like glasses? *Meteoritics, 22,* 219-228.

Olmez, I., Finnegan, D.L. and Zoller, W.H., 1986. Iridium emissions from Kilauea volcano. *Journal of Geophysical Research, 91,* 653-663.

Owen, M.R. and Anders, M.H., 1988. Evidence from cathodoluminescence for non-volcanic origin of shocked quartz at the Cretaceous/Tertiary boundary. *Nature, 334,* 145-147.

Padin, K., 1988. New discoveries about dinosaurs: separating the facts from the news. *Journal of Geological Education, 36,* 215-220.

Paige, S.C.B., 1988. End-Cretaceous mass extinctions - A summary and discussion of hypotheses concerning possible causes and effects. *B.Sc. (Hons) Thesis, University of New England, Armidale, Australia,* 74 pp. (Unpublished).

Palme, H., 1982. Identification of projectiles of large terrestrial impact craters and some implications for the interpretation of Ir-rich Cretaceous/Tertiary boundary layers. *Geological Society of America Special Paper, 190,* 353-371.

Pandey O.P. and Negi, J.G., 1987. A new

theory of the origin and evolution of the Deccan Traps (India). *Tectnophysics, 142,* 329-335.

Paul, G.S., 1988. Physiological, migrational, climatological, geophysical, survival, and evolutionary implications of Cretaceous polar dinosaurs. *Journal of Palaeontology, 62,* 640-652.

Phipps, S.P., 1988. Deep rifts as sources for alkaline intraplate magmatism in eastern North America. *Nature, 334,* 27-31.

Pillmore, C.L., Tschudy, R.H., Orth, C.J., Gilmore, J.S. and Knight, J.D., 1984. Geologic Framework of Nonmarine Cretaceous-Tertiary Boundary Sites, Raton Basin, New Mexico and Colorado. *Science, 223,* 1180-1183.

Prinn, R.G. and Fegley Jr., B., 1987. Bolide impacts, acid rain and biospheric traumas at the Cretaceous-Tertiary boundary. *Earth and Planetary Science Letters, 83,* 1-15.

Rampino, M.R. and Stothers, R.B., 1984. Terrestrial mass extinctions, cometary impacts and the sun's motion perpendicular to the galactic plane. *Nature, 308,* 709-711.

Rampino, M.R. and Stothers, R.B., 1988. Flood basalt volcanism during the past 250 million Years. *Science, 241,* 663-668.

Rampino, M.R. and Volk, T., 1988. Mass extinctions, atmospheric sulphur and climatic warming at the K/T boundary. *Nature, 332,* 63-65.

Raup, D.M. and Sepkowski, J.J., 1986. Periodicity of extinctions in the geologic past. *Proceedings of the National Academy of Science, 81,* 801-805.

Retallack, G. and Leahy, G.D., 1986. Cretaceous-Tertiary Dinosaur Extinction. *Science, 234,* 1170-1171.

Rice, A., 1987. Shocked minerals at the K/T boundary: explosive volcanism as a source. *Physics of the Earth and Planetary Interiors, 48,* 167-174.

Rich, P.V., Rich, T.H., Wagstaff, V.E. McEwan-Mason, J., Douthitt, C.B., Gregory, E.A., Felton, E.A., 1988. Biotic and geochemical evidence for low temperatures and biologic diversity in Early Cretaceous high latitudes of southeastern Australia. *Science, 242,* 1403-1406.

Russell, D.A. 1979a. The enigma of the extinction of the dinosaurs. *Annual Reviews of Earth and Planetary Science, 7,* 163-182.

Russell, D.A., 1979b. End-mesozoic catastrophe. *Episodes, 4,* 21-26.

Russell, D.A., 1984. The gradual decline of the dinosaurs-factor fallacy? *Nature*, *307*, 360-361.

Sarkar, A., 1986. The Cretaceous-Tertiary Boundary - an enigma in earth sciences. *Indian Journal of Earth Science*, *13*, 14-37.

Schmitz, B., Andersson, P. and Dahl, J., 1988. Iridium, sulfur isotopes and rare earth elements in the Cretaceous-Tetiary boundary clay at Stevns Klint, Denmark. *Geochimica Cosmochimica Acta*, *52*, 229-236.

Schwartz, R.D. and James, P.B., 1984. Periodic mass extinctions and the sun's oscillations about the galactic plane. *Nature*, *308*, 712-718.

Sear, C.B., Kelly, P.M., Jones, P.D. and Goodess, C.M., 1987. Global surface-temperature responses to major volcanic eruptions. *Nature*, *330*, 365-367.

Sharpton, V.L., Burke, K., Lucas, L. and Horz, F., 1988. Reflection seismic data from terrestrial impact structures: Evidence of shallow penetration? *Meteoritics*, *23*, 301.

Shaw, H.F. and Wasserberg, G.J., 1982. Age and provenance of target materials for tektites and possible impactites as inferred from Sm-Nd and Rb-Sr systematics. *Earth and Planetary Science Letters*, *60*, 155-177.

Sheehan, P.M. and Morse, C.L., 1986. Cretaceous-Tertiary Dinosaur Extinction. *Science*, *234*, 1171-1172.

Shevchenko, V., 1988. A Soviet view of a lunar base. *The Planetary Report*, *VIII*(6), 9-12.

Sloan, R.E. and Rigby Jr., J.K., 1986. Cretaceous-Tertiary Dinosaur Extinction. Response, *Science*, *234*, 1173-1175.

Sloan, R.E., Rigby Jr., J.K., Van Valen, L.M. and Gabriel, D., 1986. Gradual dinosaur extinction and simultaneous ungulate radiation in the Hell Creek Formation. *Science*, *232*, 619-633.

Smit, J. and Kaars, S. van der, 1984. Terminal Cretaceous Extinctions in the Hell Creek Area, Montana: Compatible with Catastrophic Extinction. *Science*, *232*, 1177-1179.

Smit, J. and Klaver, G., 1981. Sanidine spherules at the Cretaceous-Tertiary boundary indicate a large impact event. *Nature*, *292*, 47-49.

Smit, J. and Kyte, F.T., 1984. Siderophile-rich magnetic sphaeroids from the Cretaceous-Tertiary boundary in Umbria, Italy. *Nature*, *310*, 403-405.

Smith, P.J., 1987. REVIEW. Evolution's most worrisome questions. *New Scientist*, *113*, 59.

Stanley, S.M., 1984. Mass Extinctions in the Ocean. *Scientific American, 250*(6), 46-54.

Stewart, A. and Mitchell, K., 1987. Shatter cones at the Lawn Hill circular structure, northwestern Queensland: Presumed astrobleme. *Australian Journal of Earth Sciences, 34*, 477-485.

Stothers, R.B., Wolff, J.A., Self, S. and Rampino, M.R., 1986. Basaltic fissure eruptions, plume heights and atmospheric aerosols. *Geophysical Research Letters, 13*, 1525.

Strong, C.P., Brooks, R.R., Orth, C.J. and Mao X-Y, 1988. An iridium-rich calcareous claystone (Cretaceous-Tertiary boundary) from Wharanui, Marlborough, New Zealand. *New Zealand Journal of Geology and Geophysics, 31*, 191-195.

Strong, C.P., Brooks, R.R., Wilson, S.M., Reeves, R.D., Orth, C.J., Mao, X-Y, Quintana, L.R. and Anders, E., 1987. A new Cretaceous-Tertiary boundary site at Flaxbourne River, New Zealand: Biostratigraphy and geochemistry. *Geochimica Cosmochimica Acta, 51*, 2769-2777.

Sutherland, F.L., 1983. Timing, trace and origin of basaltic migration in Eastern Australia. *Nature, 305*, 123-126.

Sutherland, F.L., 1985. Regional controls in eastern Australian volcanism. *in* VOLCANISM IN EASTERN AUSTRALIA with case histories from New South Wales. Sutherland, F.L., Franklin, B.J. and Waltho, A.E. (Eds.). *Publications of the Geological Society of Australia, New South Wales Division, 1*, 13-32, (published by NSW Institute of Technology, Sydney, Australia).

Sutherland, F.L., 1987. A major thermal cycle contributing to late Palaeozoic-Mesozoic magmatism and mineralization, Pacific Rim, Australia. PACIFIC RIM CONGRESS 87 PROCEEDINGS, *Gold Coast, Australia, 26-29th Aug. 1987*, 413-416. Australasian Institute of Mining and Metallurgy.

Sutherland, F.L., ----. Cainozoic volcanism, eastern Australia: A predictive model based on migration over multiple hot spot magma sources. CAINOZOIC ENVIRONMENTS IN AUSTRALIA; A REAPPRAISAL OF THE EVIDENCE, M.A.J. Williams and P. De Decker (Eds). *Special Publication Geological Society of Australia* (In press).

Sutherland, F.L., Raynor, L.R., Hollis, J.D. and Temby, P.A., 1986. Prospective relationships between diamonds, volcanism, and tectonism in Australia. *4th International Kimberlite Conference, Perth, Geological Society of Australia Abstracts Series, 16*, 484-486.

Symonds, R.B., Rose, W.I. and Reed, M.H., 1988.

Contribution of Cl- and F-bearing gases to the atmosphere by volcanoes. *Nature*, *334*, 415-418.

Thierstein, H. and Berger, W.H., 1978. Injection events in ocean history. *Nature*, *276*, 461-466.

Tonkin, P.C., 1973. Discovery of Shatter Cones at Kelly West near Tennant Creek, Northern Territory. *Journal of the Geological Society of Australia*, *20*, 99-102.

Trower, W.P., 1988. Luis Walter Alvarez (1911-1988). *Nature*, *335*, 300.

Tuncel, G. and Zoller, W.H., 1987. Atmospheric iridium at the South Pole as a measure of the meteoritic component. *Nature*, *392*, 703-705.

Venatesan, M.I. and Dahl, J., 1989. Organic geochemical evidence for global fires at the Cretaceous/Tertiary boundary. *Nature*, *338*, 57-60.

Vink, G.E., 1984. A Hot Spot Model for Iceland and the Vøring Plateau. *Journal of Geophysical Research*, *89*, 9949-9959.

Vink, G.E., Morgan, W.J. and Vogt, P.R., 1985. The Earth's Hot Spots. *Scientific American* *252* (4), 32-39.

Wellman, P., 1983. Hotspot volcanism in Australia and New Zealand: Cainozoic and mid-Mesozoic. *Tectnophysics*, *96*, 225-243.

Wensink, H., 1987. Comments on "Deccan flood basalts at the Cretaceous/Tertiary boundary?" by V. Courtillot, J. Besse, D. Vandamme, R. Montigny, J-J. Jaeger and Cappetta, H. *Earth and Planetary Science Letters*, *85*, 326-328.

White, M.E., 1986. THE GREENING OF GONDWANA. 1st edn. Reed Books, Sydney, Australia, 256 pp.

White, R.S., Spence, G.D., Fowler, S.R., McKenzie, D.P., Westbrook, G.K. and Bowen, A.N., 1987. Magmatism as rifted continental margins. *Nature*, *330*, 439-444.

Wolbach, W.S., Lewis, R.S. and Anders, E., 1985. Cretaceous extinctions: Evidence for wildfires and search for meteoric material. *Science*, *230*, 167-170.

Wolbach, W.S., Gilmore, I., Anders, E., Orth, J. and Brooks, R.R., 1988. Global fire at the Cretaceous-Tertiary boundary. *Nature*, *334*, 665-669.

Wolfe, J.A., 1988. Letters. Arctic Dinosaurs and Terminal Cretaceous Extinctions. *Science*, *239*, 10-11.

Wolfe, J.A. and Upchurch Jr., G.R., 1986. Vegetation, climatic and floral changes at the Cretaceous-Tertiary boundary. *Nature*, *324*, 148-152.

Young, G.C., 1988. Frasnian-Fammenian extinction event - the evidence from Devonian vertebrates. *Geological Society of Australia Abstracts Series*, *21*, 436-437.

Zachos, J.C., Arthur, M.A. and Dean, W.E., 1989. Geochemical evidence for suppression of pelagic marine productivity at the Cretaceous/Tertiary boundary. *Nature*, *337*, 61-64.

Zhou, L. and Kyte, F.T., 1988. The Permian-Triassic boundary event: a geochemical study of three Chinese sections. *Earth and Planetary Science Letters*, *90*, 411-421.

Zoller, W.H., Parrington, J.R. and Phelan Kotra, J.M., 1983. Iridium enrichment in airborne particles from Kilauea volcano: January 1983. *Science*, *222*, 1118-1120.

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High Frequency Transport Properties of Colloidal Dispersions*

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ABSTRACT Colloidal dispersions occur in a wide range of scientific and technological situations and their proper characterisation is an important area of scientific activity. Almost all colloidal systems are composed of particles which carry a net electrical charge on their surfaces, unless special precautions are taken to remove that charge. Indeed, apart from particle size and shape, electrical charge is probably the most important property determining the behaviour in almost all situations.

Both the static (equilibrium) and the kinetic charge are normally determined and the two values used to develop a picture of the charge distribution in the region around each particle. That information can then be used to calculate the electrostatic interactions between the particles and hence, to estimate many important aspects of behaviour.

This paper describes some important new techniques for estimating the magnitude of the charge and its distribution in the neighbourhood of the surface. Important new insights are gained from the study of the conductance and dielectric behaviour at high frequencies (around 1 MHz) and by the study of the interaction of ultrasonic waves and electrical fields at the same frequencies.

INTRODUCTION

The work I will describe is based on the theoretical analysis of my colleague, Dr Richard O'Brien. His reexamination of the current theory of high frequency conductivity of colloidal sols and the behaviour of ultrasonic waves in colloidal suspensions has enabled us to focus our experimental activities to maximum effect. The experimental studies have been undertaken by Dr Brian Midmore with the assistance of two Honours B.Sc. students: David Diggins and Andrew Shortland. All have contributed to the material I shall describe.

DETERMINATION OF THE FIXED CHARGE ON A COLLOID

For certain colloidal systems, such as the mineral oxides and classical sols like silver iodide, the surface charge can be attributed to the adsorption of particular inorganic ions on the surface. Thus, for oxides it is the hydrogen or hydroxide ion which determines the charge and that charge varies from positive to negative as the pH is increased in much the same way as for a protein. These ions are called the *potential determining ions* (*p.d.i.*) and the number adsorbed can be estimated by titrating the colloidal sample with acid or base. By comparing the amount of reagent necessary to induce a certain change in pH of the suspension with the amount required to induce the same change for the background electrolyte, one can estimate the number of H^+ or OH^- ions adsorbed and, hence, the surface charge, σ_0. The only additional parameter required is the pH at which the sample has no charge (the *point of zero charge* or *p.z.c.*).

The charge on the colloidal particle is balanced by an equal and opposite charge in the surrounding solution and the combination is referred to as the *electrical double*

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layer. This charge distribution is governed by a balance between the electrostatic forces which draw the ions towards the surface and the thermal diffusive forces which tend to spread the charge away from the surface. Some of the countercharge may be stuck closely to the surface in the *compact* region whilst the remainder appears as a *diffuse* layer around the particles. (Fig. 1).

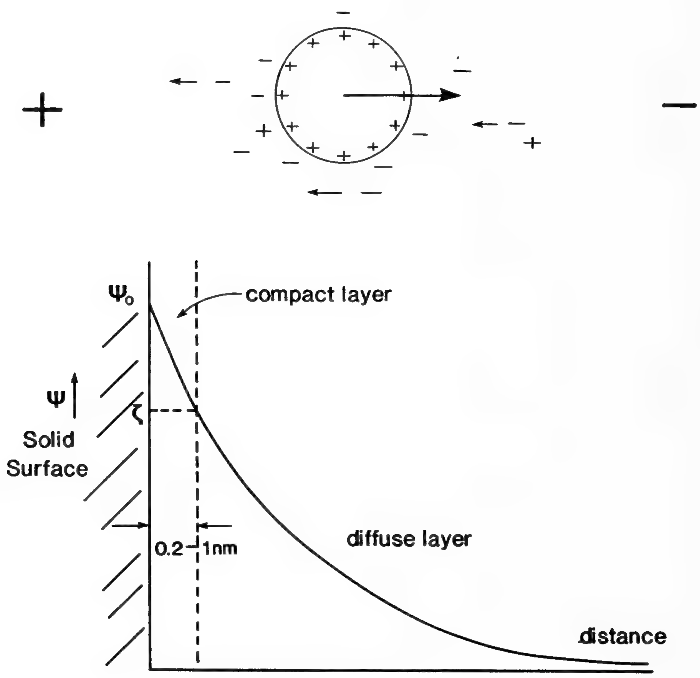

Fig 1. The standard model of the Double Layer showing the division between the compact and the diffuse part. In the compact region, the structure is determined by the details of molecular size and dipole/charge interactions as well as specific (chemical) effects. In the diffuse region, the forces are more physical in nature (electrostatic and thermal diffusion).

DETERMINATION OF KINETIC CHARGE

The kinetic charge is determined by observing the velocity of the particles in an electrical field. It is usually smaller in absolute magnitude than the surface charge because some of the counter charge remains firmly attached to the particle and moves with it in an electric field. The kinetic charge is an important parameter nonetheless because it seems to give a good estimate of the charge in the diffuse part of the double layer (Fig. 1). This represents the charge which is 'seen' by another approaching particle more closely than does the total charge and is therefore the more appropriate quantity to use in calculations of interaction energy.

CONDUCTIVITY AND DIELECTRIC BEHAVIOUR OF COLLOIDAL SUSPENSIONS

The theoretical description of the effect of an electric field on a colloidal dispersion is best considered under two separate regimes: the low frequency (<10 kHz) and the high frequency (1 - 10 MHz) regions. The dominating physical processes are different in the two cases. It is also appropriate to distinguish the theoretical treatments at low and high concentration since the approximations and limitations are different in the two cases. So too are the experimental difficulties. We have been able to study the high concentration systems at both high and low frequency but our apparatus was not sufficiently sensitive to make accurate measurements on dilute systems at high frequency.

The conductivity is, in general, a complex quantity with real and imaginary parts which depend in different ways on the frequency. These parts measure the dissipative and storage processes which occur when an electric current passes through a colloidal suspension.

What emerges from this theoretical and experimental work is the significance of a parameter which we designate λ: the *surface conduction parameter*. It is defined as:

$$\lambda = K_S/K^{\infty}a \qquad (1)$$

and measures the ratio of the conductivity through the double layer (K_S) to the value for the bulk electrolyte (K^{∞}). The particle radius, a, enters to make λ dimensionless. The theory allows the experimental results under all conditions (low and high frequency and low and high particle concentration) to be described with this one adjustable parameter and with no assumptions about the detailed structure of the electrical double layer around the particle. The only approximation involved is the assumption that the double layer is thin compared to the radius of the particles (κa>>1, where κ is the Debye-Hückel parameter). In practice this is the normal situation for particles bigger than about 100 nm; for smaller systems, like proteins, it will be true only at higher salt concentrations (> 0.1 M say). Only if one wishes to interpret λ in terms of particle charge is it necessary to introduce a double layer model and, as we shall see, even that is comparatively straightforward.

To understand the behaviour of the sol under the influence of a high frequency electrical field, consider the situation shown in Fig. 2. When the field is applied, the charges on the particle itself are assumed to be fixed but those in the double layer are able to respond. They will move in the direction indicated and are able to do so in a time of order 10^{-6} seconds. It is this relaxation process which dominates at megahertz frequencies. The movement of those charges backwards and forwards as the field direction changes is analogous to the behaviour of a dipole, and indeed, the particle is best characterised by its *dipole strength*, S, which is a complex quantity. The real and imaginary parts of S measure the in-phase and the out-of-phase components. In Fig.3 the experimental data for S is matched to the theory using a least squares procedure with λ as the adjustable parameter.

At low frequencies the dipole can keep pace with the field so the imaginary part is zero (Fig. 3). It rises to a maximum at about the *relaxation frequency* of the double layer (ϵ/K^{∞}, where ϵ is the permittivity) and then would fall to zero again as the frequency rises to a value where the ions no longer attempt to move. This occurs at about 20 MHz and at frequencies above that value the particles behave as though they were uncharged. The λ values shown in Fig. 3 show relatively little variation, considering the fact that the bulk conductivity shows a change of around 300% over this temperature range.

What sparked our interest in the parameter λ was the fact that when it was interpreted in terms of the standard double layer model, it yielded a value for the diffuse layer charge which was almost identical to that obtained for the total charge by titration, σ_0. For particles with such a low charge density (about 3 μC cm^{-2}) it would not be surprising to have the total and the diffuse layer charges equal: the electrostatic forces on the countercharge would not be expected to pull many ions into the compact region. It seemed likely, therefore, that we had here a means of directly measuring the diffuse layer charge and potential, quantities which are only rarely accessible and then only with considerable experimental effort.

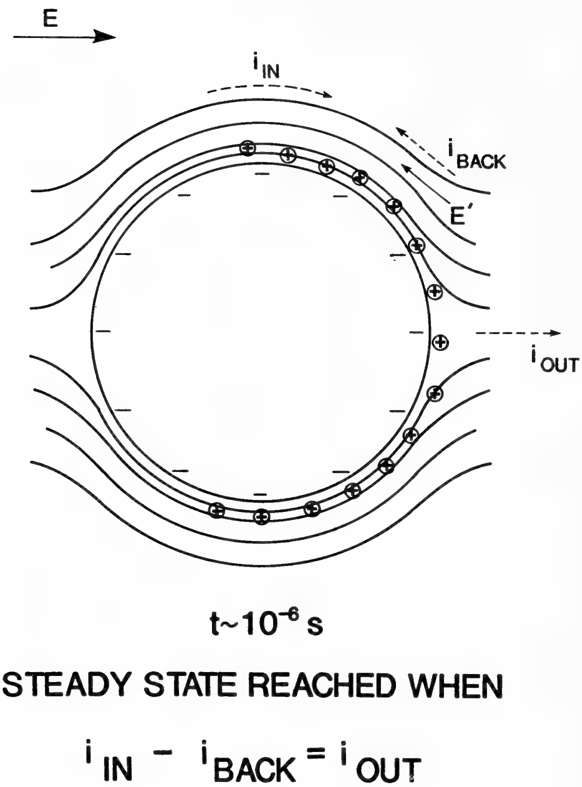

Fig 2. The polarisation of the double layer under the influence of an applied electric field. This movement takes place in a time of the order of 10^{-6} seconds.

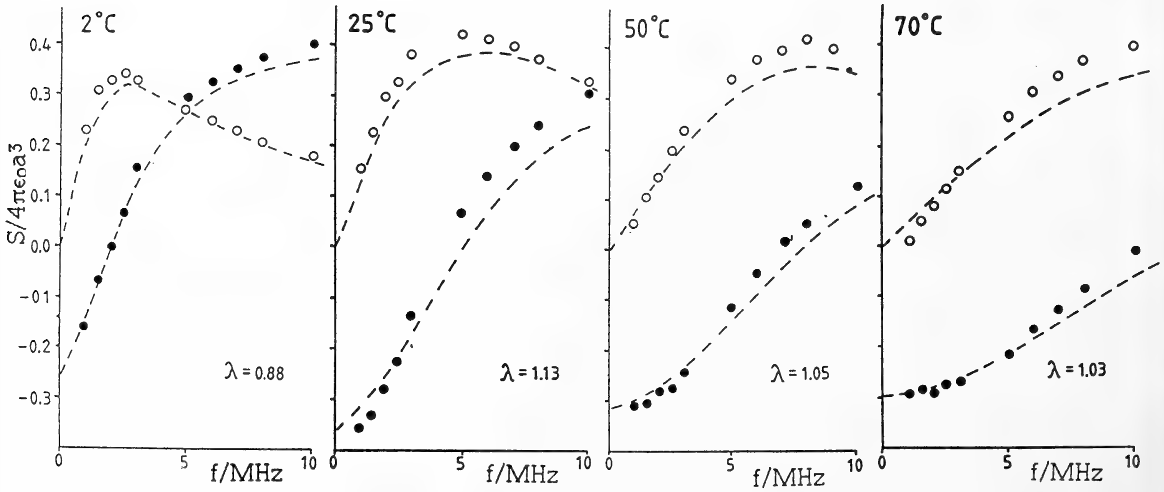

Fig 3. The dipole strength (in dimensionless units) as a function of frequency at several temperatures. The values of λ are essentially constant despite a change of three fold in the bulk conductance.

RELATION BETWEEN λ AND DOUBLE LAYER CHARGE

The simplest double layer model is that in which the shear plane, where the electrokinetic potential, ζ is measured (Fig. 1), corresponds to the beginning of the diffuse part of the double layer. If it is assumed that, outside that plane, the ions and the fluid are able to move in response to the field but inside it, they are fixed to the particle, then it can be shown that:

$$\lambda = \frac{K_s}{K^\infty a} = \frac{\exp(\tilde{\zeta}/2)(1 + 3m/z^2)}{\kappa a} \qquad (2)$$

where $\tilde{\zeta}$ is the reduced (dimensionless) ζ potential, equal to unity for ζ = 25.7 mV at 25°C.
m measures the ionic mobility in the double layer and
z is the valency of the counterions.
Given the value of $\tilde{\zeta}$, the diffuse layer charge, σ_d, follows directly from the standard Gouy-Chapman theory of the diffuse double layer:

$$\sigma_d = A\,c^{1/2} \sinh(\tilde{\zeta}/2) \qquad (3)$$

where A is a (dimensional) constant and c is the electrolyte concentration.

A more sophisticated model, and one which we have found useful for the description of the behaviour of latex systems, draws a distinction between the plane of shear and the beginning of the diffuse double layer. In this model (Fig 4) ions and liquid can move outside the shear plane but, in the region between the beginning of the diffuse layer and the shear plane, only the ions are able to move in response to the field. Inside the compact layer neither the ions nor the liquid can move.

A similar model had been introduced by Bikerman (1935) and modifications have been used since in various contexts (Dukhin and Deryaguin 1974). Our usage is consistent with at least some of those earlier ones but has the advantage that we are able to combine results from both the conductance and the electrokinetic work and so strengthen the conclusions from the model. According to Bikerman, the surface conduction for the model shown in Fig. 4 is given by:

$$K_s \triangleq \left[\sigma_{d+} \Lambda_+ + \frac{2\epsilon RT\sigma_{el+}}{\eta\, z_+} \right] / F \qquad (4)$$

where F is the Faraday constant and η the solvent viscosity. The subscripts d^+ and el^+ refer to diffuse layer and electrokinetic charge respectively, whilst Λ_+ is the equivalent conductance of the cation. The first term in the braces is the conductance and the second term measures the ion flow due to convective transport with the electro-osmotic flow of the liquid. Using the experimental value of λ (= $K_s/K^\infty a$), the value of σ_d could be estimated if we could estimate σ_{el}.

At first sight it would appear that the value of σ_{el} would follow immediately from the ζ potential using equation (3), but that is true only if the correct value of ζ is used. When the ions behind the shear plane are able to conduct an electric current (called *anomalous conductance*) the usual expressions for ζ are in error. Even the more sophisticated models of Overbeek (1943), Booth (1950) and O'Brien and White (1978) only allow for conductance outside the shear plane.

TABLE 1

Effect of changing 'indifferent' co-ion on σ_d and $\sigma_{el.}$ The counterion is K^+ in each case.

Ion	K^∞ mS cm^{-1}	λ	σ_{el} $\mu C\ cm^{-2}$	σ_d
Br^-	1.44	0.140	4.4	6.6
Cl^-	1.42	0.147	3.9	7.2
NO_3^-	1.39	0.149	4.1	7.1
SO_4^{2-}	1.34	0.151	4.7	6.6
F^-	1.21	0.175	4.1	7.3
IO_3^-	1.09	0.206	3.9	7.9
CH_3COO^-	1.03	0.201	3.1	7.3
			Mean =	7.1

Titration Charge = − 6.7 $\mu C\ cm^{-2}$.

TABLE 2

Effect of changing the counterion on the diffuse and electrokinetic charges for a latex in 0.01 M chloride solution.

Ion	K^∞ mS cm^{-1}	λ	σ_{el} $\mu C\ cm^{-2}$	σ_d
Li^+	1.06	0.120	3.7	7.0
Na^+	1.21	0.135	4.3	7.4
K^+	1.42	0.147	3.9	7.1
NH_4^+	1.42	0.156	4.2	7.7
Cs^+	1.45	0.118	3.8	5.3
$(CH_3)_4N^+$	1.12	0.052	2.6	2.5
$(C_2H_5)_4N^+$	1.01	0.018	1.6	0.9

A similar result is obtained when one uses a number of anionic counterions with a cationic latex (Table 3).

TABLE 3

Effect of various counterions on the diffuse and electrokinetic charge for a cationic latex dispersed in 0.01 M K^+ salts.

Ion	K^∞ mS cm^{-1}	λ	σ_{el} $\mu C\ cm^{-2}$	σ_d
F^-	1.21	0.169	−3.1	−8.7
Cl^-	1.41	0.141	−2.3	−6.8
Br^-	1.41	0.120	−2.1	−5.4
I^-	1.41	0.076	−1.3	−3.5

Titratable charge = + 16.8 $\mu C\ cm^{-2}$

Fortunately, it is possible to make the necessary correction. In the presence of anomalous conduction the electrophoretic mobility function E_m for large κa is given by (O'Brien 1986):

$$E_m = \frac{3\zeta}{2} + f(\zeta)\left[\frac{3\lambda}{1 + 2\lambda}\right] \qquad (5)$$

where the first term is the Smoluchowski expression. Thus the measured value of λ gives K_s and also corrects the ζ potential so that an estimate of σ_d can be obtained from K_s.

EFFECT OF CO-ION ON THE DOUBLE LAYER CHARGE DISTRIBUTION

The values of σ_d obtained by this procedure for a number of different co-ions are shown in Table 1. Note that although the conductivity of the background electrolyte varies over about 40% the estimates of σ_d are fairly constant and, although a little high, are very similar to the 'total' charge derived by titration. This is what would be expected on the basis of the accepted picture of the double layer. The co-ions are repelled from the double layer region and the particular nature of the co-ion would not be expected to have any influence on the distribution. These experiments were done on a polystyrene latex system similar to those for which we had earlier had to introduce this more complicated model of the double layer (Midmore and Hunter, 1987). Only by so doing could we account for the unusual dependence of ζ-potential on salt concentration observed with these systems; this anomaly has been under examination for some twenty years past. The present suggestion is consistent with the model presented by Midmore and Hunter (1987). It seems that the problem of anomalous surface conductance is particularly acute in polymer latex systems.

EFFECT OF COUNTERION ON THE ESTIMATED CHARGE

The effect of changing the cation involved while using the same latex system, is shown in Table 2.

In this case the behaviour of the first four ions is as before. These ions yield a value for the double layer charge which is a little higher than, but comparable to, the titratable charge. For the remainder of the ions, however, the diffuse layer charge is smaller than the titratable charge and it decreases as the ions become more hydrophobic or less well hydrated.

The last three ions are much more likely to be adsorbed to some extent into the compact layer so that the reduction in diffuse layer charge is to be expected. This cannot be taken as definitive evidence of itself, but we do know that latex sols with these last three ions as counterions are much less stable and more difficult to disperse than when the counterion is of the simple alkali metal type. Again this suggests that the procedure is indeed giving us a measure of the diffuse layer charge.

The anionic counterions are less well hydrated than the cations and therefore more likely to be adsorbed into the compact layer. Couple this with the higher electrostatic attraction involved in this case (because of the higher surface charge) and it is not surprising that the diffuse layer charge is much less than the titratable charge. The order is the usual 'lyotropic series' which has long been known to characterise the stability behaviour of positive colloids.

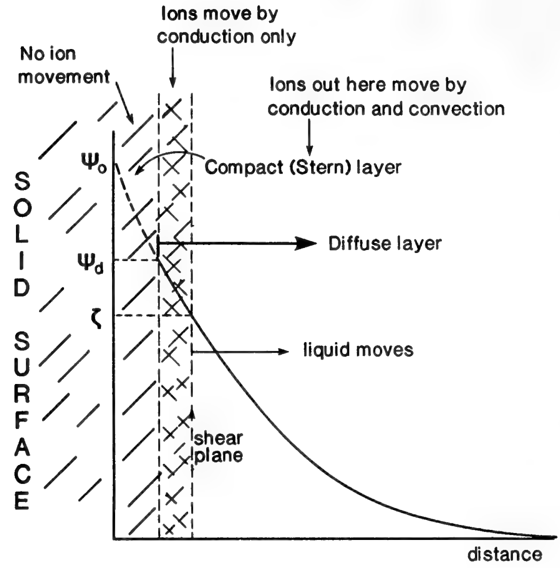

Fig 4. A more sophisticated model of the double layer in which some diffuse layer ions are permitted to move under the influence of an electric field without motion of the surrounding liquid.

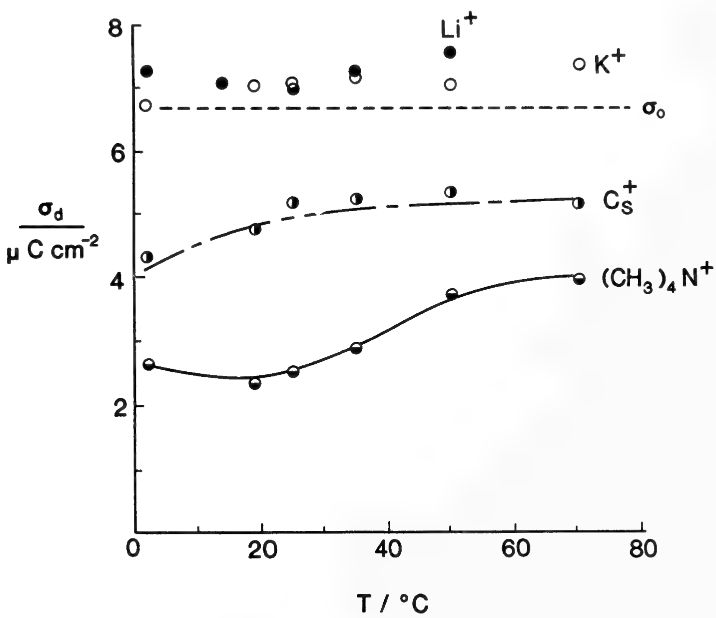

Fig 5. The diffuse layer charge at different temperatures for a number of monovalent ions. Note that for the simple alkali metal ions, the charge is constant and similar to the titration charge (σ_0) whereas for less well hydrated ions the diffuse charge is much lower. Furthermore, in these latter cases it appears to increase with increase in temperature.

EFFECT OF TEMPERATURE ON DIFFUSE LAYER CHARGE

We have examined the complex conductance behaviour of latex dispersions over a range of temperatures from near 0°C to 70°C and again the results are very significant. As indicated in Fig. 3, the value of λ does not change much over that range of temperature and Fig. 5 shows that when translated into terms of diffuse layer charge the change is negligible for well hydrated alkali cations. These values are again calculated from λ using the Bikerman equation to estimate σ_d after correcting the electrophoretic mobility for anomalous surface conduction effects. Note, however, that there is some evidence of adsorption into the compact layer ($\sigma_d < \sigma_0$) for the less well hydrated caesium ion. The degree of adsorption decreases with increase in temperature as one would expect. The tetramethylammonium ion exhibits the same behaviour to an even greater extent, again as would be expected.

BEHAVIOUR OF ULTRASONIC WAVES IN A COLLOIDAL SUSPENSION

A closely related phenomenon occurs when a high frequency sound wave passes through an electrolyte solution or a colloidal suspension. The sound wave causes relative motion of the ions or particles with respect to the surrounding water, assuming they are of different densities. The magnitude and phase of the displacement depend on the charge and inertia of the suspended matter compared to the fluid they displace. A pair of electrodes placed in the solution will pick up an electrical potential which reaches a maximum when the electrodes are at a spacing corresponding to an odd number of half wavelengths. (The wavelength of sound in water at 1MHz is of the order of a couple of millimetres.) The process was first studied in electrolyte solutions by Debye (1933) and it became known as the *ionic vibration potential*. For ions, the effect is produced by the differences in the mass and frictional coefficients of the ions causing the cations and anions to be differentially displaced by the wave.

The theory was extended to colloidal systems by Hermans (1938). In this case the *colloid vibration potential* or C.V.P. is much larger because much of the charge is carried by the large particles which are displaced much less readily than their countercharge. As the wave passes through the suspension, the double layer charge is displaced with respect to the particle, generating a dipole. There is an obvious similarity here to the effect of an applied electric field (Fig. 2). Extensions to the ultrasonic theory by Booth and Enderby (1952) have been tested by Yeager *et al.* (1953).

Again, our own work is based on the more recent theoretical analysis of Richard O'Brien, which corrects some errors made in the earlier work. New and improved ultrasonic techniques introduced by the Matec Corporation (Mass. U.S.A.) enable us to determine the colloid vibration potential as well as the reciprocal phenomenon: the acoustic wave which is generated when an electrical potential is applied to a colloidal suspension. This latter was discovered and patented by Matec and is called the ESA effect (for Electrically Stimulated Acoustic wave.)

O'Brien (1988) has shown that the two effects are indeed intimately related and that either can be used to determine the particle mobility and hence, the charge. The mobility at these high frequencies is not quite so large as it is at low or zero frequency but it is significant. According to O'Brien it falls to about half of its zero frequency value by the time the frequency has reached about 10 MHz. Our task on the experimental side has been to relate those estimates of high frequency ζ-potential to the estimates made at low or zero frequency and so to test the validity of O'Brien's analysis.

THE MEASUREMENT SYSTEM

Fig. 6 shows, very crudely, the principle of the Matec instrument. An electrical pulse of high frequency (1 MHz) and short duration is applied to a piezo-electric crystal and the resulting sonic wave pulse travels down the polystyrene delay rod. By the time the pulse reaches the suspension, the electrical driving signal has

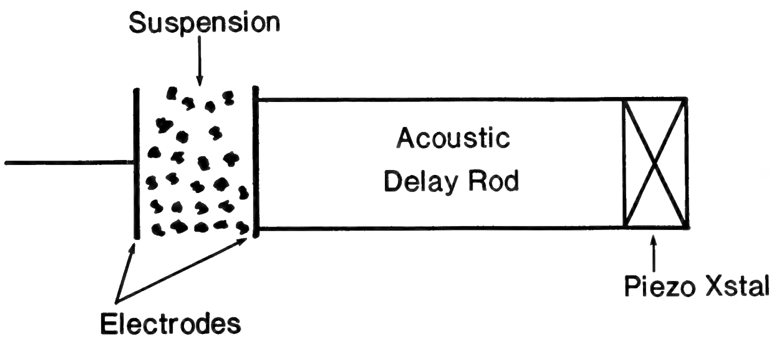

Fig 6. Illustrating the general principle of operation of the Matec Electrosonic Analysis apparatus.

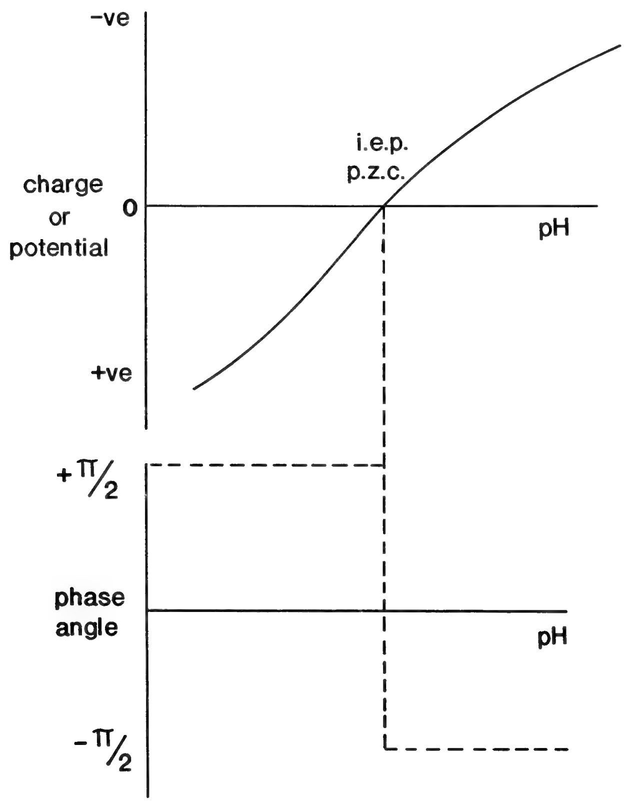

Fig 7. The phase relation between the applied electric field and the resulting sonic wave changes abruptly at the i.e.p., which is close to the point of zero charge in many cases. This change can readily be detected in the Matec instrument.

disappeared, so the electrodes in the suspension are able to detect the much smaller signal produced by the electro-acoustic effect without interference.

The magnitude of the signal is directly related to the electrical charge on the particles and O'Brien's analysis enables it to be estimated accurately instead of relying on a correlation derived empirically from measurements on other sytems of known charge.

Another feature of the instrument is that the phase relationship between the applied acoustic wave and the resulting electrical signal undergoes a shift of π radians when the system changes from being positively to negatively charged (Fig. 7). The instrument can provide a very precise estimate of the *iso-electric point* of the colloid, by detecting the pH value at which the phase inversion occurs. For many systems, this is the same as the *point of zero charge*, provided there are no specifically adsorbed ions present. The ease with which these important colloid parameters can be determined by this apparatus is one of its prime features.

THE CRITICAL TIME SCALES INVOLVED

We have alluded already to the time scale for relaxation of the double layer (Fig.2). This relaxation occurs in times of order ϵ/K^{∞} which, for 10^{-3} M KCl, is about 1 microsecond. The time scale for the particle to acquire its limiting velocity under the influence of the field is $a^2\rho/\eta$ where ρ is the density and η is the viscosity of the suspension medium. It is interesting to note that this too is around 1 microsecond. By comparison, the time taken to set up the steady state ion density distribution around the particle is much longer, of the order of 1 millisecond. The earlier, lower frequency work has been concerned mostly with that latter process. By moving to the megahertz frequency range, some simplifications can be introduced and although the theory is still rather formidable, some very useful results can be obtained.

O'BRIEN'S ANALYSIS

The theory shows that the colloid vibration potential should be given by

$$\text{C.V.P.} \propto \frac{|\mu_e|\ \omega\ \varphi\ \frac{\Delta\rho}{\rho}\ F\left[\frac{\omega L}{c}\right]}{K^*} \qquad (6)$$

where K^* is the complex conductivity,
ω is the frequency,
φ is the particle volume fraction,
F is a geometric factor depending on the cell length L and the velocity of sound c.
μ_e is the mobility which, at these frequencies, is a complex quantity and the C.V.P. depends on its magnitude.

The electrically stimulated acoustic (E.S.A.) wave has an amplitude which is proportional to the product of the C.V.P. signal and the complex conductivity. It is obvious from equation (6), then, that the E.S.A. signal can be used to estimate μ_e without knowledge of the conductivity of the sample.

Once μ_e is known at any frequency, it can be used to calculate the ζ-potential and charge in the usual way.

EXPERIMENTAL TESTING OF THE THEORY

Fig. 8 shows the effect of particle volume fraction on the C.V.P. signal at various values of background electrolyte concentration. The behaviour is obviously linear up to at least 10% volume fraction.

Fig. 9 shows a comparison between the values of mobility obtained at zero frequency

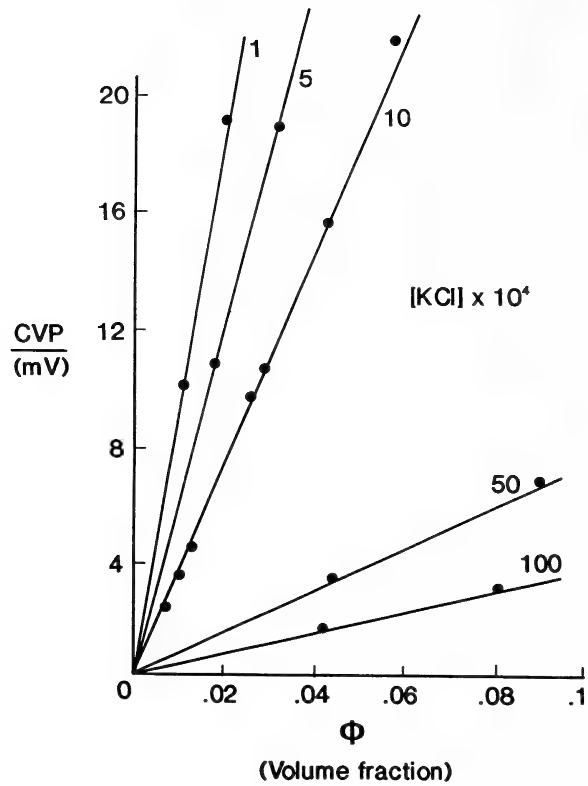

Fig 8. Dependence of the C.V.P. on volume fraction at a number of salt concentrations.

(marked x) and the estimates of $|\mu_e|$ obtained from the theory after correction for the inertial effects induced at high frequency. The agreement achieved here assumes that the surface conductivity parameter λ is zero. When the experimental value of λ is introduced, the agreement is much less satifactory. Just why these systems should appear to behave as though they had no surface conduction is, as yet, unclear.

SUMMARY

The combination of low frequency conduction behaviour and electrophoresis enables us to determine the diffuse layer charge. This has previously been a very difficult quantity to estimate, yet one which is of great importance since it is the parameter which is needed to calculate the electrostatic interactions between colloidal particles.

Measurements of high frequency conduction and electro-acoustic effects enable us to determine the high frequency mobility. From this quantity it should be possible to determine the ζ-potential and charge of colloidal systems in opaque suspensions and at particle concentrations much higher than is currently the case.

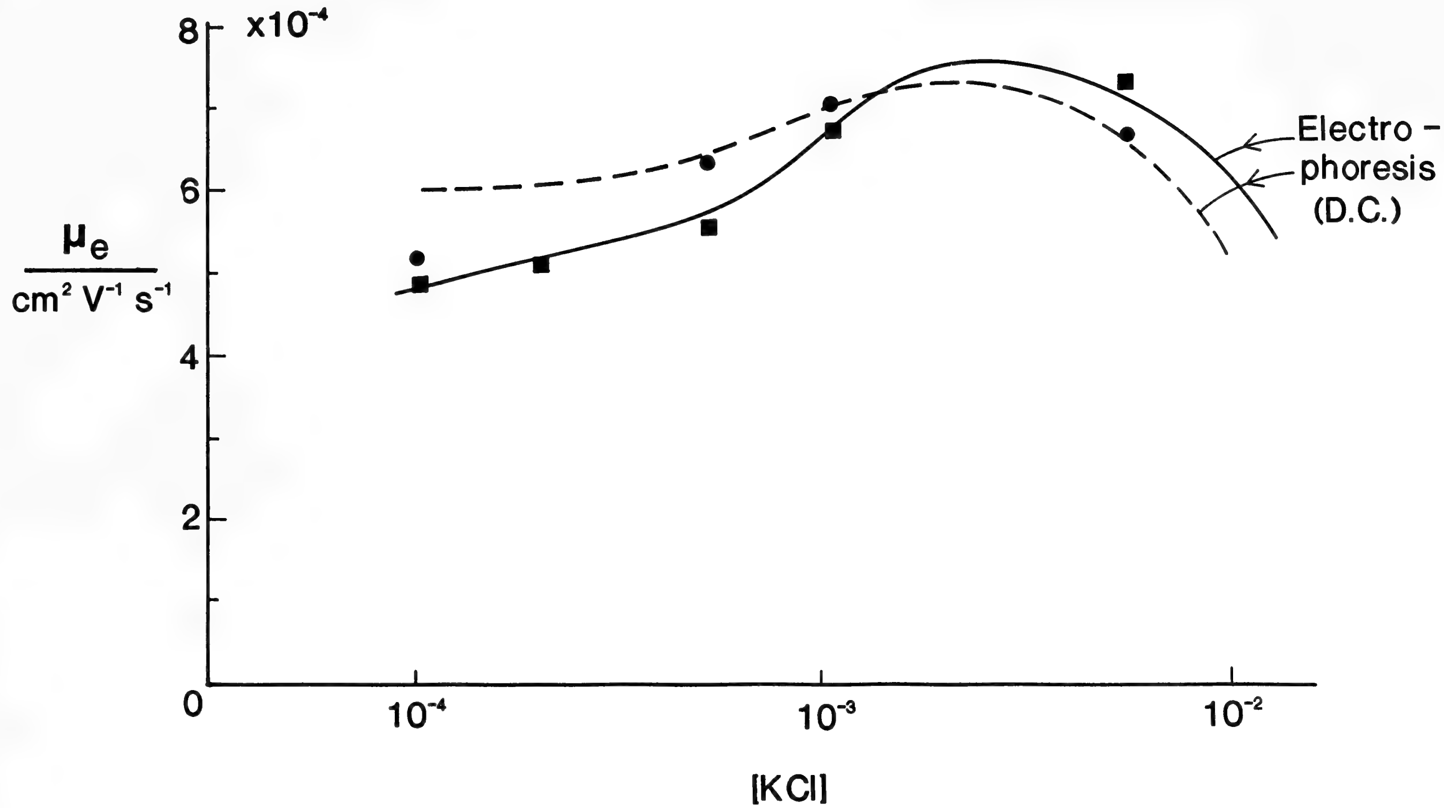

Fig 9. Comparison of the electrophoretic mobility measured at high frequency with the corresponding quantity evaluated under d.c. conditions. The surface conduction parameter is assumed to be zero in each case. Full line: Latex M (a = 0.88 μm), broken line : Latex 5 (a = 1.2 μm). Points are obtained from high frequency measurements after correction for inertial effects.

REFERENCES

Bikerman, J. J., 1935. *Kolloid Zeitschrift. 72*, 100.

Booth, F., 1950. *Proceedings of the Royal Society (London) A 203*, 514.

Booth, F. and Enderby, J.A., 1952. *Proceedings of the Physical Society, 208 A* 321.

Debye, P., 1933. *Journal of Chemical Physics 1,* 13.

Hermans, J., 1938. *Philosophical Magazine 25,* 426, 674.

Midmore, B.R. and Hunter, R.J., 1987. *Journal of Colloid and Interface Science 122*, 521–9.

O'Brien, R.W., 1986. *Journal of Colloid and Interface Science*, *110,* 477.

O'Brien, R.W., 1988. *Journal of Fluid Mechanics 190,* 71–86.

O'Brien, R.W. and White, L.R., 1978. *Journal of the Chemical Society (London) Faraday Trans. 2*, *74*, 1607.

Overbeek, J.Th.G., 1942 *Kolloid Beihefte 54*, 287.

Yeager, E. *et al.*, 1953. *Journal of the Acoustic Society of America 25*, 443.

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Geology of Tillegra Dam Site

S. K. SINGH

ABSTRACT. Geological investigation of the proposed dam site at Tillegra indicates that the site is suitable for construction of a concrete-faced rock fill dam. Arenites of variable composition are the predominant lithological constituents of the site. The beds are conformable, strike NNW and dip upstream into the pondage (westerly) with an average angle of 42°. Weathered horizons are present and sometimes may need excavation of more than 10m during foundation work for the dam. Rock mechanics and petrographic analysis favour the chosen construction mode. Unconfined uniaxial compressive strengths of up to 85 MPa for the arenites, indicates that the foundation is very strong. Most importantly the site does not exhibit any structural anomaly.

INTRODUCTION

The study area is situated between 680320 to 765320 and 680220 to 765220 (Allynbrook and Chichester, 1:25,000 sheets) and located 240 km north of Sydney (Fig. 1).

The construction of a "concrete faced rockfill dam" at Tillegra on the Williams River has been considered for the augmentation of the Newcastle water supply system.

The area has been mapped at 1:1200 scale by the author to define the structural and lithological elements of the site. The suitability of the site as well as the behaviour and performance of the rock mass are the major aspects of the geological investigation undertaken.

The rocks at the site consist predominantly of medium grained tuffaceous arenites and graywackes. The strata outcropping show a strike trend ranging from N10°W to N20°W, dipping westerly (upstream into the pondage) at an average angle of 42°.

The proposed dam site was first investigated by the Hunter District Water Board during 1951-52. That investigation consisted of the frilling of thirty four vertical drillholes for subsurface data.

The proposed dam site was subsequently investigated by the "Snowy Mountains Engineering Corporation" (1970). Investigations consisted of surface geological mapping, and of a search for suitable construction material. Individual lithological and structural elemeents present at the site were also defined. McDonald (1972) and Southgate (1972) mapped the geology of the surrounding areas (at honours levels).

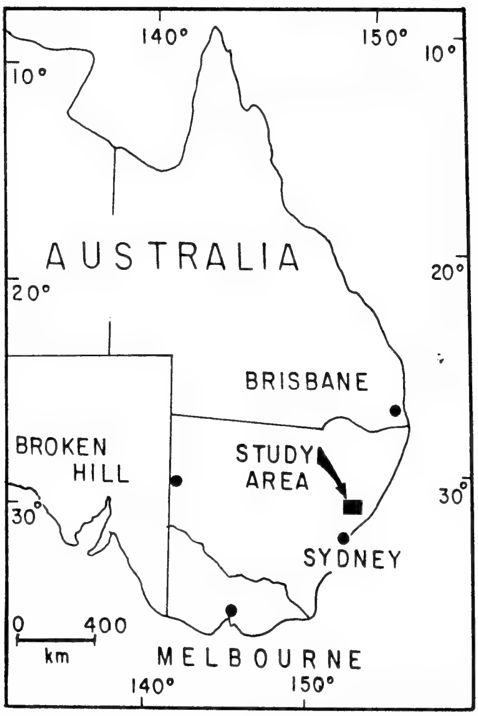

Figure 1. Location of the study area.

SPECIFICATIONS OF THE DAM

The concrete faced rock fill dam has been designed for a reservoir capacity of 450,000 ML. The height of the dam above the present ground surface will be 63.4 metres, with a slope ratio of 1:1.4 on both sides. The top water level is RL 150.9 metres. Length of crest will be 780 metres and the crest will be 9.1 metres wide. The designated crest is RL 154.3 metres, whereas the designated flood level is RL 152.5 metres. At full capacity, the reservoir will inundate an area of approximately 25 square kilometres.

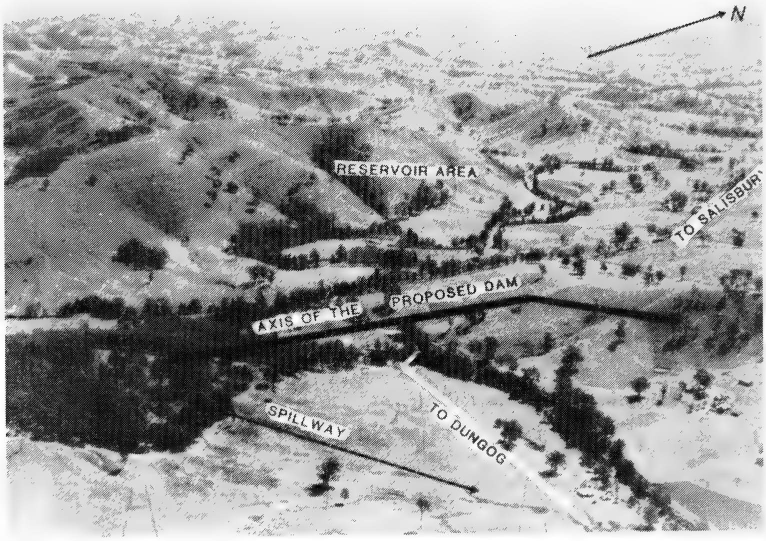

Plate 1. Topographic features of the dam site and reservoir area.

TOPOGRAPHY AND VEGETATION

Plate 1 shows the topographic features of the dam site and reservoir area. The physiographic relief in the area ranges from approximately 85m (in the river channel) to 160m (near the hill tops). The Williams River flows in a northeasterly direction under the Tillegra bridge cutting through a north-south trending ridge. The river channel is approximately 15m to 20m wide at the proposed dam axis. Channel deposits are made up predominantly of gravel, while reworked sand bodies occur as levee banks. The gravel layers are mainly composed of well rounded, but subspherical to spherical, pebbles and cobbles. Gentle to moderately sloping hills occur on both sides of the river, forming the abutments for the proposed dam. The eastern (downstream) part of the northern abutment has several steeply sloping sections. The eastern slopes of the southern abutment (proposed site for spillway) are gentle. Cliff faces, up to ten metres high occur on both banks of the river where the river meanders and has cut through arenite beds. The slope angles on the hillsides at the axis of the proposed dam range between 5^{o} and 10^{o}.

The southern abutment is characterised by a slope with grass and eucalyptus trees, whereas the northern abutment carries only grass cover. Exposed boulders and surface rock fragments, particularly along the ridges, indicate that only a poorly developed soil horizon is present.

STRATIGRAPHY AND LITHOLOGY

Rocks outcropping at the proposed Tillegra Dam site belong to the Allyn River Sandstone Member of the Flagstaff Formation. The age of this formation is middle Visean of the early Carboniferous. A range of sedimentary rocks, ranging from lutites to arenites cropout in the area of the proposed dam site. However, graywackes and medium grained tuffaceous arenites are the predominant lithological constituents at the dam site (Fig. 2). Direct mapping of lithological contacts is not possible over a considerable proportion of the area; however, exposure is good in the river and along road cuttings. Most rocks are dark grey to greenish in colour. Joint planes are often stained by coatings of limonite.

PETROGRAPHY

Most arenites examined microscopically had grain sizes in the range of 0.7 to 1.8mm. The majority of samples examined show the arenites as containing a large proportion of lithic fragments. Feldspar content ranges generally between 15% to 30%. Plagioclase content generally exceeds that of potash feldspars. Quartz constitutes approximately 20% to 30% of the rock with remaining constituents comprised of lithic fragments, micas and to a lesser extent chlorites, clay minerals and iron oxides. Zeolites and pumpellyite are present as socondary minerals. The arenites are mostly poorly to moderately sorted. The sphericity and roundness of the majority of samples range between 0.40-0.60 and 0.35-0.70, respectively. The extent of cementation is moderate to high, mainly of silliceous nature, and contributes to a very low pore volume and the low permeability of the rocks.

Bedding planes are only poorly developed in the coarse grained arenites on the microscopic scale. Distinct fracture plane traces show patterns near normal to each other under the microscope.

Both, penetrative and pervasive fractures are present. There is considerable similarity in spatial attitude of micro- and macro-features. The distortion, bending and kinking of mica flakes which is evident is regarded as a purely compactional feature.

The lutites examined consist predominantly of silt to clay size fragments of detrital quartz and feldspar. Clay minerals are additional important consitutents. Distinct bedding traces and fracture sets were also observed in the lutites. Microscopic determinations show that clay minerals constitute approxiamately 30% to 40% of the total rock components with quartz and feldspar making up 30% to 50% respectively. The remaining components consist of micas, chlorites, iron oxides and other accessory minerals.

The poor development of sphericity and roundness of component grains indicates that a high kinetic energy environment, active for only a short time, has probalby determined the depositional processes in the area.

Measurements of the extinction angles for detrital quartz and statistical evaluation using Basu et al's (1975) method have indicated a primary igneous source for the components of these rocks

STRUCTURE

The dam site is situated between the approximately north-south trending Brownmore and Tillegra Faults. The structure of the site is characterised by conformable beds of arenites to lutites, striking north-northwesterly. The thickness of the individual laminae ranges from 0.2cm to 1cm. Arenite layers are usually much thicker ranging from 20cm to 1m, and are sometimes massive. Typical thicknesses of individual beds range between 0.5m and 1m.

The average strike trend of the bedding planes is N12^{o}W (Fig. 3). A westerly dip is common to all these beds and varies between 38^{o} and 55^{o}. The bedding is thus dipping upstream towards the reservoir pondage, a situation structurally preferable for a dam site, since it minimises leakage across the foundation and through the abutments of the dam.

The rock exposures at the site exhibit well developed jointing. The spacing of joints is directly controlled by the nature (bedding thickness and grain size) of the rocks; thus widely spaced joints are characteristic of coarse grained arenites, whereas lutites exhibit very closely spaced joints. The spacing of the joints in coarse grained rocks ranges generally bwtween 10cm and 1m. In lutite beds, however, the spacing rarely exceeds 5cm. The cores from investigation drill holes show that joint development and joint frequency decrease with increasing depth.

Near surface joints are often coated on one or both faces with limonite, giving them a dark brown appearance. In lutites, the close spacing of joints has been responsible for the increased degree of weathering. The stereonet-analysis of over five hundred joint plane measurements clearly shows that four sets of joints are more prevalent (Fig. 3). Joint sets 1 and 2 are respectively parallel and normal to the strike of the strata. Joint sets 3 and 4 are normal to each other but diagonal to sets 1 and 2.

SOIL AND WEATHERED ROCK HORIZON

Slightly to completely weathered rock occurs on roadside exposures near the dam site. Sub surface cross sections have been prepared with help of bore hole data (Fig. 4). All the boreholes used in the cross-sectional diagram were drilled vertically and range in depth from 25.5 to 63.7 metres.

It appears that the extent of weathering at the proposed dam site, as interpreted from the diagram (Fig. 4), is controlled by topography, attitude of the bedding planes and the trend of the river (as well as by lithology and degree of jointing). The presence of a 2nd order channel between the boreholes T2 and T3 (Section a, Fig. 4) can be attributed to the unusually thick horizon of weathered rocks in bore T2 (Singh, 1987b). The channel occurs on the eastern side of bore T2, where the underlying strata dip in a westerly direction. Migration of water along the bedding planes appears to have resulted in the development of a thick weathered zone. The presence of fluvial sands, encoutered in boreholes T23 to T27 (Section b, Fig. 4), has contributed to an apparently thick soil horizon in that area.

COMPRESSIVE STRENGTH

Five rock types were assessed for their unconfined uniaxial compressive strength. Two samples of each rock type was tested and the mean compressive strength for that rock type was then computed. The strain rate for each test was kept at 50 microns/ minute and the height to diameter ratio varied between 2.5:1 and 2.7:1 (as suggested by Mogi, 1966). Table 1 gives the compressive strength data gathered from the experiment.

Table 1: Compressive Strength of Various Rock Type

Rock Type	Unconfined Uniaxial Compressive Strength (MPa)	Young's Modulus (MPa)
Fine to medium grained arenite	85	11700
Medium grained tuffaceous arenite-A	73	12100
Medium grained tuffaceous arenite-B	65	81000
Laminite - A	48	8300
Laminite - B	63	8300

Fine Fine to medium grained arenites were the strongest rocks, showing a compressive strength of up to 85 MPa. Some laminites have a compressive strength of only 48 MPa. A fatigue strength of 87% has also been established for greywackes (Singh, 1988). The inherent strength of the samples tested is many times more than the actual load likely to be exerted by the dam, when built. Therefore, the foundation is classed as decidely strong, for the proposed dam.

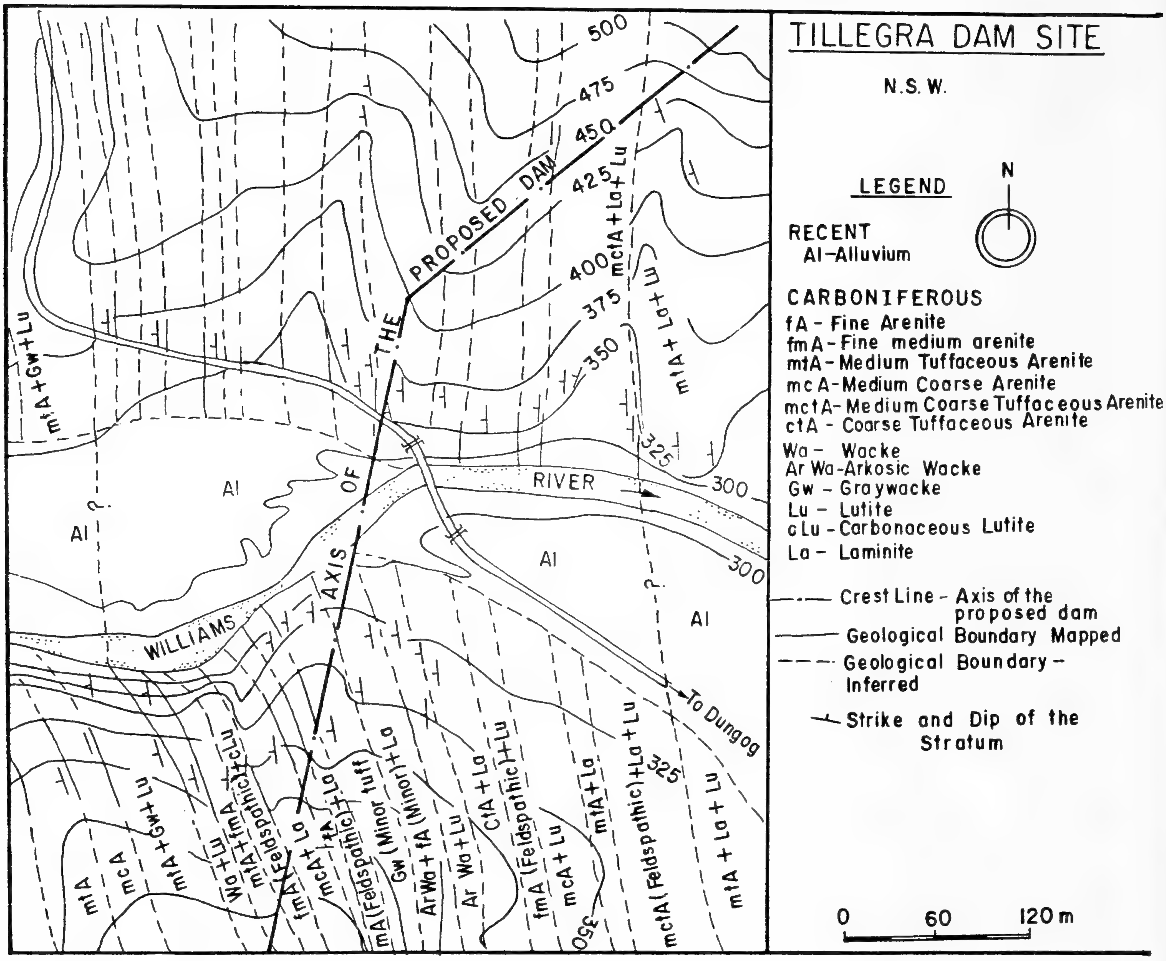

Figure 2. Geological map of the site.

CONCLUSIONS

Geologically, the proposed site appears suitable for dam construction. A few favourable points are noteworthy:

1. The site does not contain anomalous structural features.
2. The beds conformably dip upstream towards the pondage; leakage is thus unlikely to occur through the foundation or abutments.
3. No faults which could lead to seepage/leakage and stability problems are suspected at the proposed dam site.
4. Abutment slopes are gentle to moderate. Stability problems are unlikely to occur on these slopes (unless they are oversteepened during foundation excavation).
5. Thin soil and weathered rock horizons (except for localised anomalous areas) cover a large part of the proposed dam site. This should keep earth work to a minimum.
6. Very strong, medium grained tuffaceous arenites and greywackes constitute a large proportion of the rock mass at the dam site. Uniaxial compressive strength tests have indicated strength ranges of up to 85 MPa, indicating a very strong foundation.
7. Environmental parameters also do not impose major constraints to dam construction (Singh, 1987a).

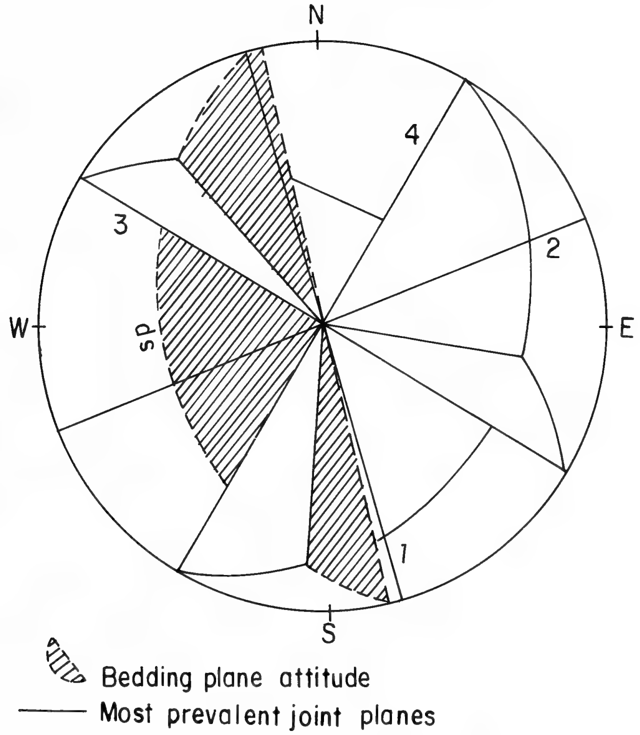

Figure 3. Stereogram showing average bedding plane and joint plane trends.

REFERENCES

Basu, Abhijit, Young, Steven W., Sutter, Lee J., James W. Calvin and Mack, Greg H., 1975. Re-evaluation of the use of undulatory extinction and polycrystallinity in detrital quartz for provenance interpretation. *Journal of Sedimentary Petrology, 45*, 4, 873-82.

Hunter District Water Board, 1951-52. Investigation of proposed Tillegra Dam site (unpublished report).

McDonald, L.K., 1972. The geology of Salisbury-Brownmore District, N.S.W. Unpublished Hons. Thesis, University of New South Wales, Kensington.

Mogi, K., 1966. Some precise measurements of fracture strength of rocks under uniform compressive stress. *Rock Mechanics Engineering Geology, 4*, 41-55.

Singh, S.K., 1987a. Tillegra Dam - An environmental assessment. *Journal of Engineering Geology, XVI*, 105-8.

Singh, S.K., 1987b. Dip of the strata - an important factor for soil formation. *Journal Geological Society of India, 30*, 236-38.

Singh, S.K., 1988. Fatigue and strain hardening behaviour of graywacke from Flagstaff Formation, New South Wales. *Quarterly Journal of Engineering Geology, 26(2)* (in press).

Snowy Mountain Engineering Corporation, 1970. Proposals for Augmentation of Newcastle Water Supply System. Report (unpublished) prepared for the Hunter District Water Board.

Southgate, S., 1972. A geological investigation of the Bendolba area. Unpublished Hons. Thesis, University of New South Wales, Kensington.

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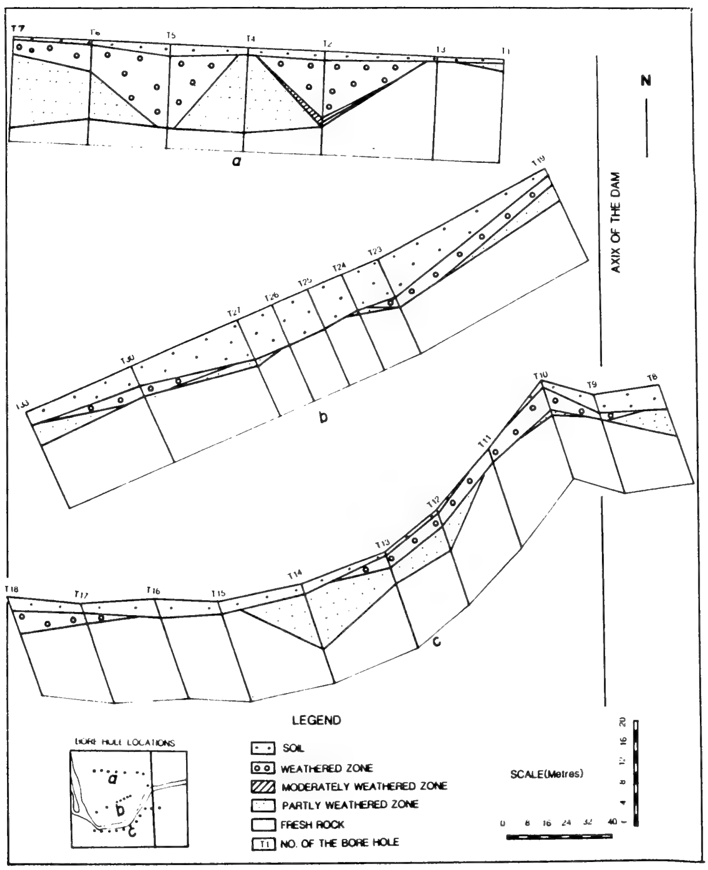

Figure 4. Soil and weathered rock horizons.

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M.Sc. Thesis Abstract (The University of Sydney): Characterisation of Urban Storm Water Run-Off Quality, Jamieson Park, N.S.W.

R. McNamara

During 1983 and 1984 the State Pollution Control Commission collected urban runoff water quality data from Jamison Park, a 17.1 hectare recently developed residential catchment in Sydney's outer western suburbs. Additional water quality data was collected during 1986 and 1987. Initial analysis indicated the significance of the urban environment as a source of pollution, with soluble pollutant concentrations (NH3—N, NOx—N and O.P) comparable to secondary treated sewage and suspended solids (NFR) been comparable to raw sewage. This was further demonstrated when pollutant loads were determined. For example, on the basis of this data it was estimated that about 680 kg/ha of suspended solids and 2.7 kg/ha of free ammonia would be removed via runoff from this catchment in a normal rainfall year. These values were consistent with those reported in both the local and international literature.

When the data was examined for temporal variations it was found that a first flush, i.e., highest concentrations in initial runoff, existed in all pollutants examined. In terms of load, about 45 — 60% of the total pollution load was removed by the initial 50% of runoff for most storm events sampled. It was found that pollutants washed out of the atmosphere by initial rainfall as well as a standing load of pollutants in the in—pipe drainage network that are rapidly mobilised by initial runoff were partly responsible for the first flush. Furthermore, when the upper reaches of the catchment begin to contribute runoff to the outlet hydrograph pollutants from this area are been diluted by relatively clean water that is been delivered from the lower reaches. When the infiltration rate of this catchment was overcome (> 5mm rainfall intensity) or when field capacity was reached (10 — 12 mm of rainfall) a second flush in both suspended solids and soluble pollutants was observed, with about 40% of the total storm pollution load been associated with this second peak. Therfore, urban runoff water quality is conceptually a two stage process with a first flush of pollutants from impervious areas and a second flush of pollutants from pervious parts of the catchment if the infiltration rate is overcome or if field capacity is reached. The implication of these findings for pollution abatement stratergies are that if a catchments "typical hydrograph" is comprised of runoff from both impervious and pervious areas then abatement measures will need to consider the pollution in runoff from both these sources.

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M.Sc. Thesis (The University of Sydney): Palaeoecological Studies of the Ordovician Fossil Hill Limestone, Central New South Wales

LEI YUE

The thesis incorporates the paleo-ecology of the Upper Ordovician Fossil Hill Limestone Formation, Cliefden Caves area, central New South Wales, with an appendix dealing with a group of new fossils Polylappetida Yue, Ord. Nov..

First, the biostrome in the Kalimna Limestone Member on Fossil Hill is entirely dominated by and composed of large *in situ* colonies of *Tetradium cribriforme*, which occupy some 90% of the biovolume. The minor elements stromatoporoid *Cystistroma*, corals *Bajgolia*, *Hillophyllum*, *Nyctopora*, the stromatolite *Cliefdenia*, together with brachiopods, bryozoans, gastropods, ostracodes and calcareous algae, occupy the interspaces of the *in situ* colonies of *T. cribriforme*. The slender columns of the stromatolite *Cliefdenia* cluster, the presence of birdseye's structures, diagenetic silts in the matrix, oncoids and algal-coated grains suggest the low sedimentation, shallow water origin of the biostrome.

Second, the algal-coated grain mounds of the Taplow Limestone Member to the west of the Boonderoo shearing shed produce a unique group of the coated grain deposits in the geological history. Three types of algal-coated grains are described and interpreted: 1) spherical dense coated grains; 2) subspherical-spherical loose coated grains; 3) spongy algal-coated grains. The type of the coated grains is controlled by the shape of the skeletal cores and the energy level. The elongated skeletons tend to be the core of the loose and spongy coated grains and the spherical-subspherical skeletons are related to dense coated grains. The higher the energy, the higher proportion of the dense coated grains. The lime mudstone mounds of the member produces a unique group of fossils: Polylappetida Yue, Ord. Nov.. The new order includes one family: Polylappetidae Yue, Fam. Nov., four genera and six species: *Cliefdenoconus regularis* Yue, gen. et sp. nov., *Dianfanoconus wyomingensis* Yue, gen. et sp., *Linoconus erectus* Yue, gen. et sp.nov. *Hillophyllum taplowensis* Yue, gen et sp. nov., *Hillophyllum regularis* Yue, gen. et sp. nov., *H. dunhillensis* Yue, gen. et sp. nov..

Last, the six specific coral/stromatoporoid associations from the Dunhill Bluff Limestone Member to the west of the Boonderoo shearing shed have been recognized: 1) *Cliefdenia*-dominated association; 2) Nyctopora-Labechiella association; 3) Coccoseris-Labechiella-Sphaerocodium association; 4)Stratodictyon-Labechiella association; 5) Labechiella-Coccoseris association; 6) Labechiella-Tetradium association.

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The Earth's Magnetic Field

D. E. Winch

ABSTRACT.

The Earth's main magnetic field changes slowly over a period of years, and also exhibits regular daily changes with both solar and lunar components, and magnetic storms. Studies of these changes can be used as a probe into the Earth's interior, the upper atmosphere and the oceans.

Everyone is familiar with changes in air temperature, barometric pressure, ocean temperature, and with the daily and seasonal changes of these quantities. Another variation, but perhaps not as widely known, is the steady, daily change in the Earth's magnetic field. It will be the theme of this talk that these steady daily changes provide an important probe into processes in the upper atmosphere, the oceans, and the Earth's interior.

The compass needle has the useful directive property of pointing northward over most of the Earth's suface and also has a regular daily movement backwards and forwards, of about a quarter of a degree. These regular movements are caused by the magnetic fields of electrical current systems associated with a dynamo action of movements of the upper atmosphere driven by the heating effects of solar UV radiation.

There are also disturbed movements of the compass needle known as magnetic storms, arising from electrical current systems flowing in the upper atmosphere as a result of the trapping of charged particles ejected by the Sun. The magnetic storms are associated with the simultaneous appearance of aurorae in both the northern and southern hemispheres where trapped particles from the Sun interact with the upper atmosphere in the same way that ionised particles give rise to a picture on our television screens by fluorescence.

The famous mathematician Gauss and his colleague Weber were interested in these magnetic variations, both the regular and the disturbance types. Just over 150 years ago they organised the Göttingen Magnetic Union to set up a world wide distribution of magnetic observatories in order to record hourly measurements of the magnetic field and to record the appearance of aurorae. One such observatory was set up in Hobart Town, Tasmania, and measurements were made by eye every hour. Photographic recording was eventually introduced, using light from a globe reflected from the polished end of a small magnetized bar onto some relatively insensitive photographic paper clamped on a rotating drum.

The idea of the organization of magnetic observatories to be operated all over the world at particular times continues to the present day: during the International Polar Year in 1933, the International Geophysical year in 1958 (100 observatories) and the International Quiet Solar Years in 1964-65 (130 observatories).

These days, proton precession magnetometers at unmanned observatory sites take a reading every minute which is recorded on magnetic tape and sent back over a telephone line automatically from a central office on demand. Low altitude satellites have also been used, one of the most successful being MAGSAT (an acronym from MAGnetic SATellite). MAGSAT flew in a polar orbit, remaining on the terminator, the line between day and night, for the entire duration of its flight. It provided the best available record of the Earth's magnetic field, albeit at some distance from the surface of the Earth. Magnetic instruments which are capable of recording for three months on the ocean floor at any depth and which are then able to be recovered have also been developed and deployed between Sydney and Auckland.

The mathematical analysis of the magnetic data, along the lines first set down by the mathematicians Laplace and Legendre, was first applied by Gauss to the magnetic charts available for 1835. The process is called spherical harmonic

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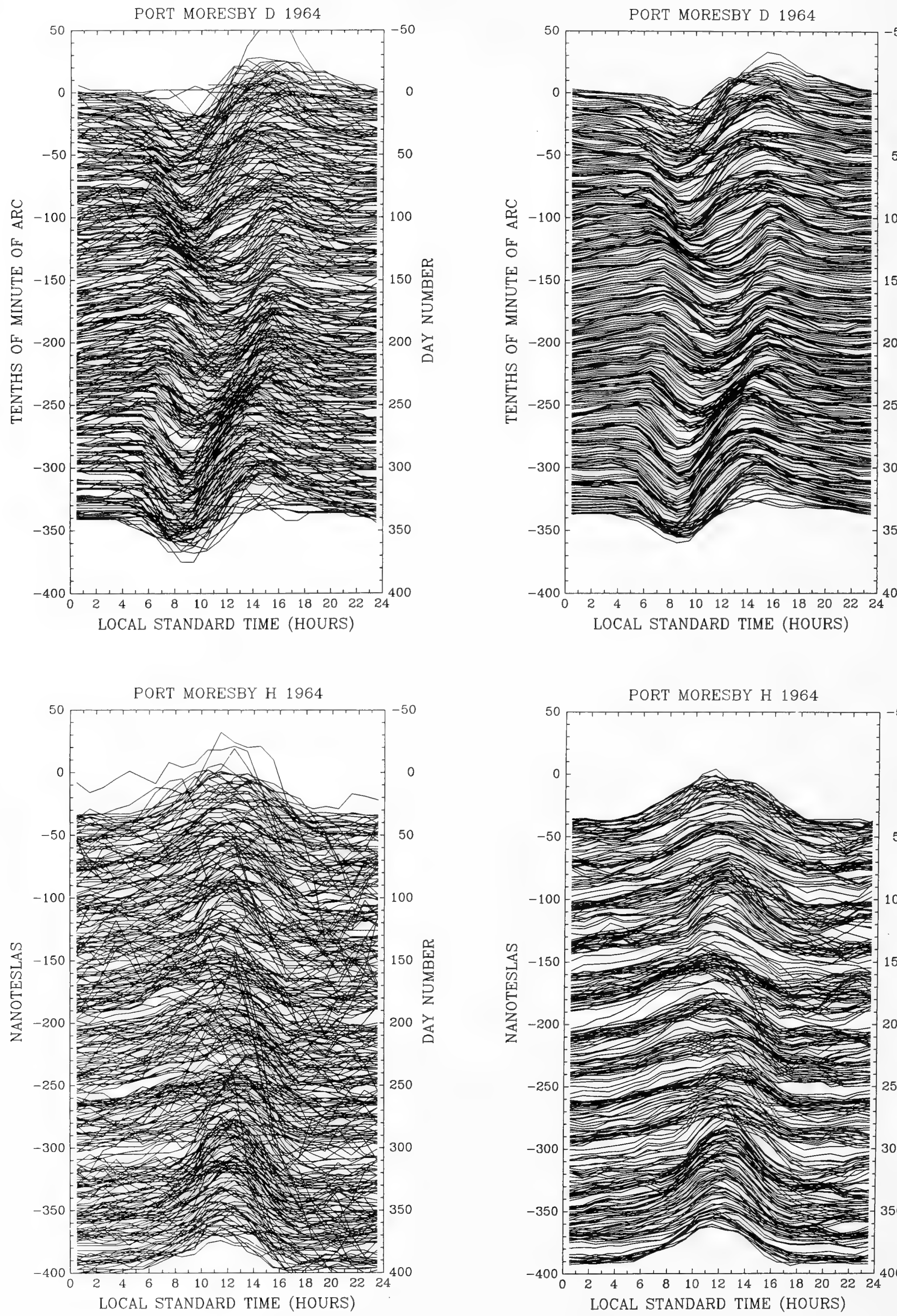

Figure 1. Hourly mean values of the magnetic field as recorded the Port Moresby Geomagnetic observatory for declination (the deviation of the compass needle from true north) and the horizontal intensity. The data has been graphed as a series of displaced graphs for each day of data, with smoothing applied to obtain the graphs shown on the right.

analysis because it is the spherical analogue of harmonic analysis of, for example, the displacement of a violin string or a series of equally-spaced observations. Spherical harmonic analysis of observatory data, early ship-board data, and modern satellite data, enables geomagneticians to model the magnetic field at ground level and provide values of the Earth's magnetic field, freed from any contribution due to sources of magnetism at the surface of the Earth, e.g. magnetised rocks. These values make it possible to use magnetic survey data to locate mineral deposits which can be of great economic importance.

Spherical harmonic analysis can be applied to the mathematical representation of quantities which have magnitude but no direction. For example, spherical harmonic analysis when applied to the study of the shape of the Earth forms the basis of geodesy; it is applied to the representation of the ocean depths in bathymetric studies as well as to heat flow from the Earth in geothermic studies.

When the process of spherical harmonic analysis is applied to a quantity such as the Earth's magnetic field which has both magnitude and direction, it is possible to determine which part of the magnetic field originates from within the Earth and which part from outside the Earth. There is no doubt that the origin of the main magnetic field is deep within the Earth in its liquid core where it is regenerated by a complex dynamo process. For this reason, Gauss's (1839) first analysis deliberately excluded the possibility of any source of magnetism outside the Earth, although Gauss was well aware of magnetic variations associated with magnetic disturbance and the simultaneous appearance of the aurora borealis.

For the daily variations the process of spherical harmonic analysis is a more complex task. First, the variation of each of the magnetic field components must be represented by means of sine and cosines and the spherical harmonic analysis applied to the results of the trigonometric or Fourier analysis. Typically, hourly mean values are analysed and only four harmonics are required to adequately represent the variation.

The spherical harmonic analysis of the daily variations shows that two-thirds of the variations originate from outside the Earth and the remaining one-third from within the Earth. This knowledge enabled Balfour Stewart in 1880 to infer that there was an electrically conducting region in the upper atmosphere, well before the experiments of Marconi who made use of this conducting layer now known as the ionosphere to transmit messages across the Atlantic using multiple reflections of electromagnetic radiation.

The magnetic variations are traditionally represented graphically by means of equivalent electrical current systems, and those for solar and lunar magnetic variations are shown in Figure 1. The current flowing between each contour is 10 kA, and because there is no source or sink of electrical current, the system is known as toroidal, having lines of flow parallel to the contours. Poloidal systems, which do have sources and sinks, have lines of flow directly across the contours.

The accepted nature of the mechanism, by means of which the solar and lunar magnetic variations are generated, is a dynamo mechanism associated with the thermal and tidal forcing of movements of the upper atmosphere. Atmospheric ozone, and to some extent water vapour, absorb solar UV radiation causing atmospheric movements. These movements are then propagated upwards through the atmosphere to give rise to substantial movements or winds in the electrically conducting region of the atmosphere at 90 to 100 km altitude. The movements of the electrically conducting layers across the Earth's magnetic field give rise to electromotive forces, resulting in an electrical current system flowing in the ionosphere. It is the magnetic field of this time-varying current system that is recorded at magnetic observatories.

Now the lines of magnetic force are almost horizontal along the equator, and almost vertical at the poles. They are in fact exactly horizontal along the magnetic equator and exactly vertical at the magnetic poles. It is this last fact which gave so much difficulty to early expeditions trying to find the magnetic north pole. If one hopes to follow the compass needle to the north magnetic pole, the directive property becomes weaker as the north magnetic pole is approached. The compass needle requires a horizontal component of field to cause it to point to the north. This horizontal component becomes weaker as the magnetic pole is approached and finally the compass needle swings around in circles without settling. The intrepid explorer has to rely on a magnetic dip needle pointing directly downwards. It is also useful to know that the vertical component of the magnetic field at the poles is twice the value of the horizontal component of the field at the equator.

Therefore the ionospheric dynamo mechanism would operate much more effectively at the poles where the magnetic field is vertical than at the equator. However, the Sun ionises the upper atmosphere more effectively at the equator than at the poles, and the result is that the effectiveness of the dynamo mechanism is greatest in middle latitudes.

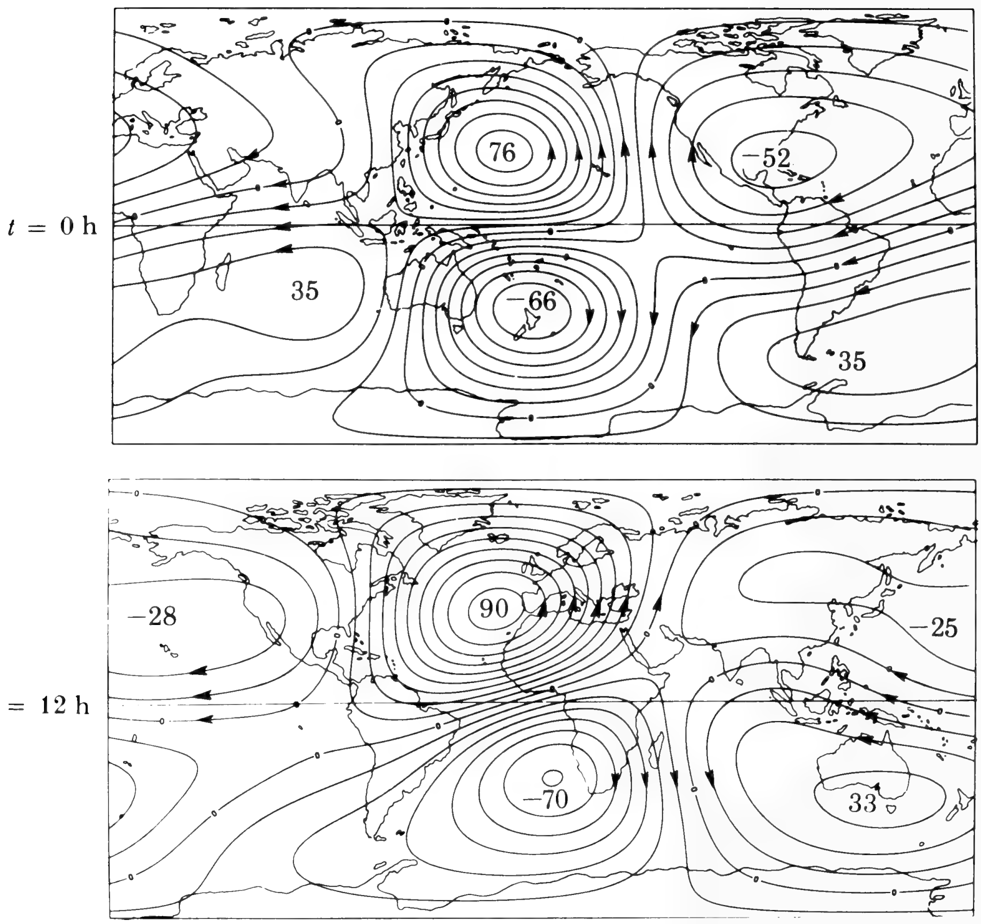

Figure 2. Current functions contours corresponding to the solar daily magnetic variation. Contours are given in units of kiloAmperes, and the contour interval is 10 kA. The Earth rotates beneath this electrical current system giving the daily magnetic variation.

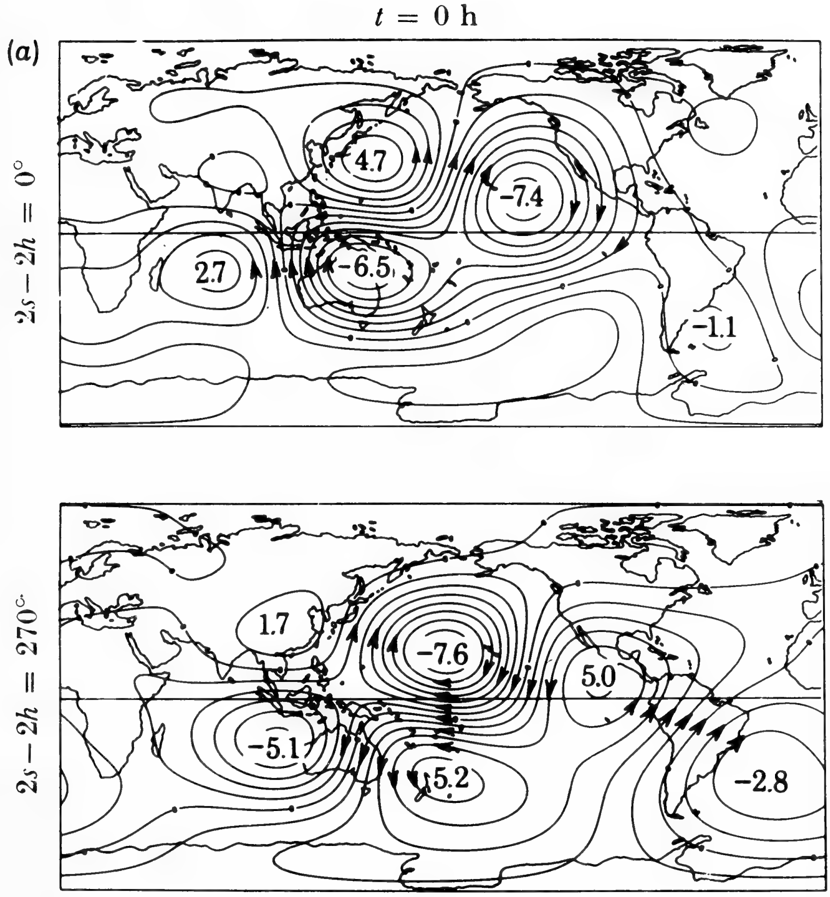

Figure 3. Current function contours corresponding to the lunar daily magnetic variation. Contours are given in units of kiloAmperes, and the contour interval is 10 kA. Contours are shown as at new Moon, for Universal Times 0h and 12h.

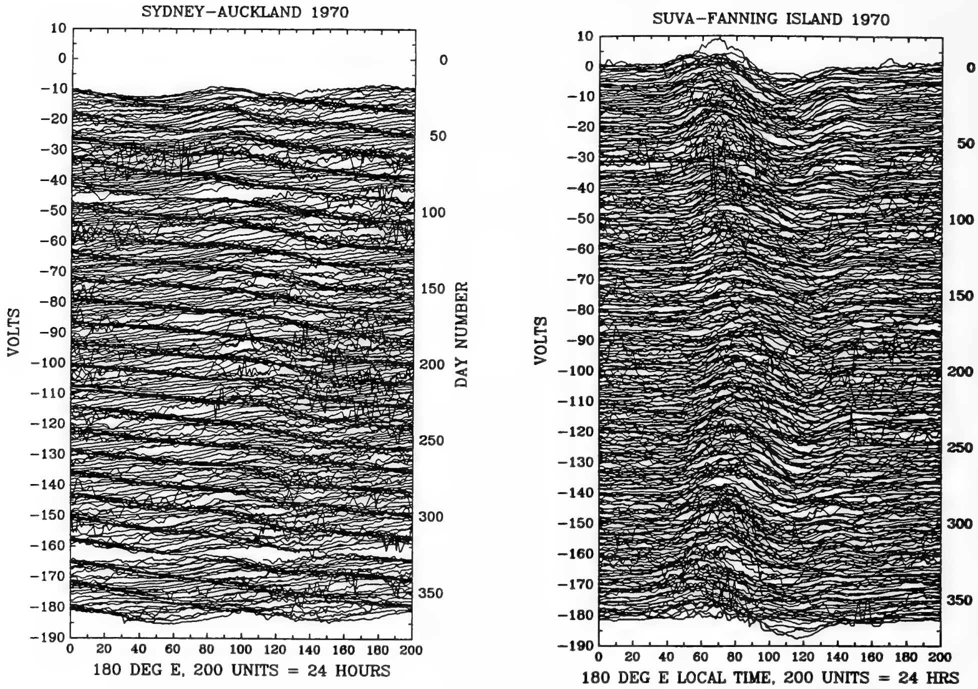

Figure 4. Graphs of daily variations in voltage as recorded on the undersea cables between Sydney and Auckland, and Suva and Fanning Island. The Sydney-Auckland cable voltage shows a very distinctive lunar semi-diurnal variation, which appears as a series of dark bands 14.77 days apart in this displaced daygraph representation. The ocean dynamo is not effective in equatorial regions and hence there is no lunar semi-diurnal voltage on the Suva to Fanning Island cable.

The component of the magnetic daily variation which is found to originate within the Earth has not yet been discussed. For the most part this internal component is formed by 'eddy' current systems which are induced within the electrically conducting Earth by the movement of the current systems in the upper atmosphere as they follow the Sun or Moon. This theory has provided reasonably satisfactory models of electrical conductivity within the Earth but there is a difficulty.

The difficulty is that the oceans are also electrically conducting and are not uniformly distributed over the Earth. The land-ocean distribution is relatively complicated and in order to make some progress a uniform thin, conducting shell is used to represent the ocean, enclosing a non-conducting shell of depth to be determined, in turn enclosing a conducting sphere of conductivity also to be determined. Thus from two pieces of information involving amplitudes and phase angles two further pieces of information are obtained: the depth to the conducting sphere and its conductivity.

The Moon also causes the ionosphere and the oceans to move, but by a gravitational process only and not by the dominantly thermal process which occurs in the solar daily magnetic variations. Lunar magnetic variations are much smaller in amplitude than the solar magnetic variations, i.e. approximately 2 nT against up to 50 nT for the solar daily magnetic variations. As they originate in a different part of the ionosphere, they complement the information available from studies of the solar magnetic variations.

The process of induction in the ocean by the ionospheric current systems was studied by the Bullard and Parker (1970) in a fundamental paper. Electrical current systems forming in the ocean in response to the solar transient daily variation are now reasonably well known. However, the ocean is forced to move by tidal forces and therefore can act as a dynamo in its own right in the same way as the ionosphere. To separate the ocean and ionosphere contributions, use is made of the fact that the ionospheric dynamo shuts down at night when the ionospheric conductivity is zero, but the ocean dynamo is 'open all hours' so to speak because the electrical conductivity of the ocean remains constant.

Thus it can be seen that the magnetic variations as recorded are a sum of magnetic variations from the upper atmosphere, from within the earth, and from within the oceans. The mathematical process of spherical harmonic analysis assists with the unravelling of these various contributions and thereby provides a probe on a global scale into these important regions which can otherwise be reached only with some difficulty.

To understand the information that magnetic variations give about movement in the upper atmosphere, we must first understand the nature of upper atmosphere movements or winds, particularly as revealed by the pressure variations recorded on barometers at ground level. The story is an interesting one, in fact it is a classic example of scientific detective work. The basic problem is that the dominant regular daily change in barometric pressure occurs twice daily rather than daily. This is rather remarkable when one considers that the dominant regular change in temperature is the 24-hourly term and not the 12-hourly term. Thomson (later Lord Kelvin), in a presidential address to the Royal Society of Edinburgh in 1882, argued that this occurred because the atmosphere had a resonant period of oscillation of 12 hours which amplified the semidiurnal oscillation. His interpretation occurred at a time before the nature of the change of temperature with height in the atmosphere was known and when all heating of the atmosphere was considered to take place at ground level.

The study of oscillations of the atmosphere is a complicated business, requiring representations of wind velocity, changes in presssure, density and temperature in terms of what are now called Hough functions, named after the English meteorologist Hough (1897,1898) who first calculated solutions of the Laplace Tidal equation. The calculation is not quite a standard eigenfunction calculation and one has to play an interesting game of 'hunt the eigenvalue' to obtain the solution. The calculation is a complex one and even with today's modern computers using standard eigenvalue packages it is difficult to obtain eigenvalues for particular tidal frequencies. Hough functions are special combinations of the spherical harmonic functions which have been referred to above.

The basic idea of the calculation, at least for the horizontal component of movement, is to obtain a set of equivalent depths corresponding to the depth of a uniform atmosphere with the same period of free oscillation. It turns out from the calculation that some of the equivalent depths are actually negative for some oscillations whilst others are positive.

The interpretation of these values is linked to the temperature structure of the atmosphere and rather than go through the technical names of layers of the atmosphere, it is enough to note that heating in the atmosphere occurs at ground level, in the stratospheric ozone layer and in the very high atmosphere. Temperature rises in the ozone layer and high atmosphere and falls above these heated layers. Hough functions with negative equivalent depths are found to be trapped between these layers whilst those with positive equivalent depths are propagated upwards (Longuet-Higgins, 1968).

It is found that the 24 hourly thermally forced oscillations have very small equivalent depths of about 0.2 km, whilst the 12 hourly forced thermal oscillation has an equivalent depth of 7.9 km. Over the depth of the ozone layer of some 40 km, the 24 hourly term is actually suppressed relative to the 12 hourly term. The resonance theory has thereby been laid to rest well and truly.

Each spherical harmonic component of each Hough function gives rise to a magnetic tide and under certain simple assumptions a combination of magnetic tide components can be unravelled to give the corresponding Hough function components of velocity. Wind velocity components found in this way are in agreement with other methods based on the analysis of the global distribution of pressure variations (Winch, 1981).

It also goes without saying that if there is an overall downward trend in the total ozone content of the atmosphere a general reduction in the amplitude of magnetic variations would result. Such a downward trend is observed in magnetic variations in the 1980's. It should be pointed out that magnetic variations also diminish with the relative sunspot number and that the relative sunspot number has diminished from a maximum in 1980 to a minimum in 1986 and is now increasing. Australian magnetic observatory data, particularly the magnetic observatories in Antarctica where a drastic depletion of ozone content has been noted, could play an important part in determining variations in ozone content over the years before direct readings of ozone content became available. The author been trying experiments using computer graphic displays of large amounts of geomagnetic data to see how disturbance effects might be separated from the much smoother effects associated with insolation of the ozone layer (Figures 2 and 3).

Magnetic effects associated directly with the dynamo effects of tidal movements of the ocean have not yet been determined, although it is obvious from analyses of magnetic variations that there are such ocean dynamo effects. It is possible to make corrections to data from each observatory by assuming the ionospheric contribution is zero at local midnight. The tidal movements of the deep oceans have been calculated and the various amphidromic points determined so that it should be possible to determine the resulting magnetic variation.

In an analysis of the annual change of the magnetic field Winch (1981) found a component which was dominantly of internal origin. Now, there is a steady change of the magnetic field known as secular variation, consisting mainly of a westward drift of the main magnetic field. This originates from within the Earth and gives a spurious contribution to the estimate of the one cycle per year term. When this effect is removed there is still a substantial variation of internal origin at one cycle per year. The equivalent electrical current system actually corresponds reasonably well with the land-ocean distribution and is consistent with the hypothesis that the effect is associated with an annual change in the global pattern of ocean circulation. Elementary dynamo theory shows that the ocean movements in a hypothetical ocean of constant depth should be very similar to the electrical current system flow lines.

The above is supported by some evidence from independent observations made of the electrical voltage differences as recorded on undersea cables between Sydney, Auckland, Suva and Fanning Island. I have some graphs of the actual data which show in an interesting way the relative and different contributions of solar and lunar frequencies on the different cables (Runcorn et al, 1989), Figure 4.

To conclude then: the steady magnetic variations of solar and lunar origin provide independent estimates of geophysical parameters such as the modal structure of upper atmosphere winds and annual changes in the global ocean circulation. The difficulties involved in mastering all that there is to know about geomagnetism, or oceanography or atmospheric physics, or meteorology, for example, leads to a tendency to work in just one particular discipline and to exclude others. Geomagnetism, and especially studies of magnetic variations, tend to be set to one side as a somewhat archaic study, but I hope that in this address I have presented enough of relevance to justify the continued study of this fascinating subject.

REFERENCES

Bullard, E.C. and Parker, R.L. 1970. Electromagnetic induction in the oceans. In: E.C. Bullard and J.L. Worzel (Editors), *The Sea, 4,* Wiley, New York, 695-730

Gauss, C.F. 1839. Allgemeine Theorie des Erdmagnetismus, Leipzig. (reprinted in Gauss, C.F. 1877. *Werke, 5,* Göttingen)

Hough, S.S. 1897. On the application of harmonic analysis to the dynamical theory of tides, Part I. On Laplace's 'Oscillations of the first species,' and on the dynamics of ocean currents. *Philosophical Transactions of the Royal Society of London, A, 189,* 201-257.

Hough, S.S. 1898. On the application of harmonic analysis to the dynamical theory of tides, Part II. On the general integration of Laplace's dynamical equations.' *Philosopical Transactions of the Royal Society of London, A, 191,* 139-185.

Winch, D.E. 1981. Spherical harmonic analysis of geomagnetic tides, 1964-1965. *Philosophical Transactions of the Royal Society of London, A, 303,* 1-104.

Runcorn, S.K., Richards, M., Strens, R., Molyneux, L., and Winch, D.E. Geoelectric potentials measured by ocean cables. *IAGA Bulletin No. 53, International Association of Geomagnetism and Aeronomy, 6th Scientific Assembly, Exeter (United Kingdom), 24 July – 4 August, 1989,* 166.

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The Essential Oils of Four Chemotypes of *Melaleuca citrolens* Barlow

J. J. Brophy and J. R. Clarkson

ABSTRACT The existence of four chemotypes of *Melaleuca citrolens* has been determined. One chemotype is characterised by having a high (up to 50%) 1,8-cineole content together with significant amounts (up to 20%) of terpinolene. A second chemotype is characterised by a relatively low (20%) 1,8-cineole content and much higher amounts (10%) of citronellal and citronellol. The third chemotype contains significant amounts of geranial/neral (up to 40%) and minor amounts of citronellal. The fourth chemotype is characterised by the presence (in up to 15%) of piperitenone, significant amounts (up to 25%) of 1,8-cineole and terpinolene but no citral or citronellal.

INTRODUCTION

The genus *Melaleuca* L. (Myrtaceae) has been the subject of considerable taxonomic review over recent years. A series of papers by Byrnes (1984,1985, 1986), Barlow (1987), Barlow and Cowley (1988) and Craven (1989) has led to the re-definition of a number of taxa. Amongst these is a group of entities from northern Australia related to *M. acacioides* F. Muell. Byrnes (1985) adopted a broad view of the complex and recognised a single, widespread, morphologically variable species, *M. acacioides*. This was not followed by Barlow (1987) who distinguished three taxa, *M. acacioides* F. Muell. subsp. *acacioides, M. acacioides* F. Muell. subsp. *alsophila* (Cunn. ex. Benth.) Barlow and *M. citrolens* Barlow, on the basis of morphology, ecology, phenology and distribution. Recent chemical analyses of leaf oils from *M. acacioides* (Brophy et al, 1987) support the maintenance of both subspecies. This paper reports the chemical constituents of Barlow's third taxon, *M. citrolens,* and briefly compares them with the oils from the two subspecies of *M. acacioides*.

EXPERIMENTAL

Description of Species

M. citrolens is a shrub or small tree reaching 6-8m in height. It occurs across tropical Australia north of latitude 19°S from the Roper River area in the Northern Territory to Cape York Peninsula, usually in open forests or woodlands on sandy, stony or loamy soils. The species is distinguished from *M. acacioides* by the arrangement of the flowers in monads rather than dyads or triads and the presence of more than 10 ovules per loculus (less than 10 in *M. acacioides*). The distinct citrus odour of crushed leaves used by Barlow (1987) as a key feature and for which the specific ephithet refers, does not hold for all individuals. It is common to find trees belonging to this species which have non-lemon scented leaves.

Selection of Material

Preliminary chemical analyses in 1987 (unpublished) of leaf oil from samples of *Melaleuca citrolens* collected at two sites on Cape York Peninsula suggested that a number of chemotypes existed and that more than one chemotype could be present within a single population. Leaf samples for preliminary analyses consisted of material from two individual trees and a bulk sample from 20 trees from each site. While it was clear that at least two chemotypes were involved, analysis of the bulk sample from one of the sites suggested that there might be more and that the differences were being masked by bulk sampling. For this reason the material used in the analyses reported here was obtained from individual trees. No bulk sampling was employed. Ten trees were selected at random at each of three sites and fresh foliage and terminal branchlets collected. At one site leaves from two trees were sorted to separate older leaves from the current flush new growth. All material was air dried before despatch to Sydney.

Location of Sampling Sites

The three sampling sites were located as follows:

Site #1 0.9 km north of Big Coleman River on the Peninsula Development Road. 14°34'S, 143°25'E. Altitude 240m. Voucher collections: J.R. Clarkson 7717-7721 & V.J. Neldner (inclusive).

Site #2 2.3 km south of the Morehead River on the Peninsula Development Road. 15°02'S, 143°40'E. Altitude 50m. Voucher collections: J.R. Clarkson 7724-7733 & V.J. Neldner (inclusive).

Site #3 0.5 km north of Koolburra Creek on the Peninsula Development Road. 15°26'S, 143°59'E. Altitude 70m. Voucher collections: J.R. Clarkson 7734-7743 & V.J. Neldner (inclusive).

Voucher Material

The identity of all material used in this study is vouched by specimens lodged with the Queensland Herbarium, Meiers Road, Indooroopilly.

Isolation of the Volatile Oils

Air-dried leaves were steam distilled with cohobation for 5 hours as described by Lassak (1979) after which time no more oil was being produced. The oils yielded were colourless to pale yellow and aromatic. Although Barlow has used the pleasant citrus odour emitted from crushed leaves as one of the characters to distinguish *M. citrolens*, it was obvious when collecting leaf material for this study that this did not hold for all trees. Even within a single population it was possible to encounter trees where crushe leaves smelled quite unlike citrus. This was confirmed in the laboratory where only some of the distilled oils had a citrus odour. Some smelled of 1,8-cineole while others has an odour somewhat similar to peppermint.

Identification of components

Analytical gas chromatography (glc) was carried out on a Shimadzu GC6 AMP gas chromatograph. SCOT columns of either SP1000 [85m x0.5mm] which was programmed from 65°C to 225°C at 3°C/min or OV1 [30m x 0.5mm], programmed from 65°C to 230°C at 5°C/min, were used with helium carrier gas. For combined gc/ms the gas chromatograph was connected to an AEI MS12 mass spectrometer through an all glass straight split interface. The mass spectrometer was operated at 70 eV ionising voltage and 8000V accelerating voltage with the ion source at 200°C. Glc conditions for combined gc/ms were the same as for the analytical glc . Spectra were acquired every six seconds and processed by a VG Display Digispec data system. Glc integrations were performed on a Milton Roy CI-10 electronic integrator.

Compounds were identified by their identical glc retention time to known compounds and by comparison of their mass spectra with either known compounds or published spectra (Stenhagen et al., 1974; Heller and Milne, 1978, 1980, 1983; Swigar and Silverstein, 1981). N.m.r spectra were recorded in $CDCl_3$ solutions on a Bruker AM500 spectrometer.

Some oil of *M. citrolens* chemotype 2 from site 2 was chromatographed on silica gel. Elution with pentane removed the hydrocarbons. Further elution with increasing amounts of diethyl ether in pentane eluted mixtures of the oxygenated monoterpenes. Fraction 8 contained α-terpineol, p-cymen-8-ol and piperitenone in the approxinate ratios of 5:2:3. This fraction, which was analysed by gas chromatography, was used for subsequent NMR analysis.

RESULTS AND DISCUSSION

The results of the analyses are summarised in Table 1. Four chemotypes are readily apparent. This is not unprecedented in the genus *Melaleuca* nor indeed for the family Myrtaceae. The presence of more than one chemotype within a single taxon has been reported for a number of species by various authors. Brophy and Lassak (1988) reported three chemotypes in *Melaleuca leucandra* L. and two in *M. dissitiflora* F. Muell. (Brophy and Lassak, 1983). In the genus *Backhousia* Hellyer et al (1955) found four physiological forms in the examination of volatile oils from eighteen individual trees of *B. myrtifolia* J.D. Hook & Harvey. Penfold et al (1951) recorded two forms of *B. citriodora* F. Muell. and a fourth chemotype of *B. angustifolia* F. Muell. (Brophy et al 1989) has recently been added to the three recognised by Cannon and Corbett (1962).

Site #1 yielded a single chemotype (chemotype I). The characteristic components of this were 1,8-cineole (30-56%) and terpinolene (11-29%). There were also significant

Table 1

Compounds identified in the leaf oils of *Melaleuca citrolens*

Peak	Compound	Chemo-type I	Chemo-type I	Chemo-type I	Chemo-type II	Chemo-type III	Chemo-type IV
		Site #3	Site #3	Site #1	Site #2	Site #3	Site #3
		7737A Adult	7737B Juvenile	7718	7731	7738	7736
		%	%	%	%	%	%
1	α-pinene	3.25	4.67	2.70	1.90	0.37	0.45
2	α-thujene				5.71	0.34	0.4
3	β-pinene	0.21	0.18	0.13	0.20	0.05	0.04
4	sabinene	0.00	0.22	0.14	0.61	0.02	0.03
5	myrcece					1.51	0.50
6	α-phellandrene	1.25	6.00	3.50	9.72	0.11	0.34
7	α-terpinene	0.36	2.00	0.41	1.22	0.00	0.07
8	limonene	3.15	3.20	2.90	2.67	1.87	1.40
9	1,8-cineole	52.23	33.00	39.90	26.89	14.19	12.23
10	γ-terpinene	1.82	6.80	3.14	7.31	0.88	0.64
11	β-trans-ocimene					0.00	0.00
12	p-cymene	7.53	1.04	1.40	4.60	1.20	1.41
13	terpinolene	5.43	29.00	12.10	15.16	2.68	2.78
14	p-mentha-1,3,8-triene	0.00	0.00	0.00	0.30		
15	p-mentha-1,4-8-triene				0.35		
16	α,p-dimethylstyrene	0.38	0.11	0.14	0.78	0.08	0.18
17	unknown	0.00	0.00	0.00			
18	trans-sabinene hydrate	0.04	0.03	0.00	0.03		
19	citronellal					0.26	30.13
20	bicycloelemene	0.00	0.00	0.82	0.03	0.00	0.02
21	cis-sabinene hydrate	0.14	0.19	0.12	0.45		
22	linalool	0.00	0.02	0.01	0.02	0.00	0.17
23	isopulegol					0.27	5.42
24	$C_{10}H_{16}O$					0.00	0.00
25	cis-p-menth-2-ene-1-ol				0.04		
26	isoisopulegol					0.00	13.16
27	terpinen-4-ol	0.48	1.67	6.13	2.52	0.00	0.04
28	β-caryophyllene	2.56	2.36	1.43	0.03	3.83	3.83
29	unknown	0.10	0.01	0.03			
30	trans-p-menth-2-ene-1-ol				0.00		
31	aromadendrene	0.15	0.07	0.96		0.10	0.62
32	acetophenone	0.10	0.02	0.00			
33	alloaromadendrene	0.17	0.46	1.48		0.70	0.24
34	$C_{15}H_{24}$				0.09		
35	$C_{15}H_{24}$				0.10		
36	unknown	0.22	0.04	0.07			
37	citronellyl acetate					2.32	5.17
38	$C_{10}H_{16}O$	2.33	0.48	0.40	0.63		
39	humulene					0.00	0.67
40	unknown	0.00	0.00	1.95			
41	neral					16.47	0.93
42	α-terpineol	6.61	5.22	5.85	4.91	3.12	2.63
43	viridiflorene	0.00	0.40	2.63		0.20	0.00
44	geranial					26.71	0.00
45	bicyclogermacrene	0.00	0.00	0.00	0.15	0.15	0.00
46	$C_{10}H_{16}O$				0.00		
47	$C_{10}H_{16}O$				0.09		
48	calamanene	0.00	0.00	0.00			

Table 1 (cont'd)

Peak	Compound	Chemo-type I Site #3 7737A Adult %	Chemo-type I Site #3 7737B Juvenile %	Chemo-type I Site #1 7718 %	Chemo-type II Site #2 7731 %	Chemo-type III Site #3 7738 %	Chemo-type IV Site #3 7736 %
49	citronelol					0.32	3.38
50	$C_{10}H_{14}O$				0.05		
51	$C_{10}H_{16}O$	0.00	0.00	0.00	0.10		
52	unknown	0.00	0.00	.0.00			
53	nerol					0.10	0.00
54	p-cymen-8-ol	1.46	0.14	0.27	2.09	1.93	0.70
55	geraniol					0.00	0.70
56	unknown	0.00	0.00	0.00			
57	piperitenone				12.62		
58	$C_{10}H_{16}O$				0.13		
59	palustrol	0.07	0.00	0.18		0.00	0.00
60	caryophyllene oxide	0.09	0.00	0.02			
61	$C_{15}H_{26}O$	0.87	0.00	0.00	0.00	0.00	0.00
62	$C_{15}H_{26}O$	0.00	0.00	0.25		0.00	0.94
63	$C_{15}H_{26}O$	0.00	0.00	0.10			
64	$C_{15}H_{26}O$	0.00	0.00	0.10		0.00	0.20
65	$C_{15}H_{26}O$	0.24	0.00	0.00		0.00	0.10
66	$C_{15}H_{26}O$	0.35	0.13	0.95	0.00	0.48	0.10
67	globulol	1.50	0.60	4.60	0.07	2.00	0.30
68	viridiflorol	0.20	0.14	1.00		0.16	0.06
69	$C_{15}H_{26}O$	0.30	0.00		0.00		
70	$C_{15}H_{26}O$			0.54	0.00	0.03	0.08
71	spathulenol	3.20	0.28	1.39	0.34	1.72	1.41
72	unknown				0.00		
73	thymol				0.20		
74	$C_{15}H_{24}O$	0.00	0.00	0.00		0.00	0.00
75	$C_{15}H_{24}O$	0.00	0.00	0.00	0.10	0.10	0.07
76	$C_{15}H_{24}O$	0.00	0.00	0.48		0.00	0.00
77	$C_{15}H_{24}O$	0.65	0.00	0.00		1.00	0.10
	Yield % (dry weight)	2.2	4.3	2.5	6.1	3.6	1.9

The oils listed in the table are from individual trees which are representative of each chemotype. The number "0.00" appearing in the table means that the compound was detected but at a level of <0.005%.

amounts (≤5%) of α-pinene, α-phellandrene, limonene, γ-terpinene, terpinen-4-ol and α-terpineol. Also present in similar amounts were the sesquiterpenoids β-caryophyllene, alloaromadendrene, viridiflorene, globulol, viridiflorol and spathulenol. All the trees from this site contained oils of similar composition. All told monoterpenes accounted for approximately 90% of the oil. On a dry weight basis the oil yield was 1.5-2.7%

A second chemotype (chemotype II), was identified from site #2. This was characterised by the presence of the monoterpene ketone, piperitenone, in 10-15% amounts. The major components of the oil were 1,8-cineole (8-32%) and terpinolene (13-27%). There were also smaller (≤6%) amounts of α-pinene, α-thujene, α-phellandrene, limonene and γ-terpinene, as well as terpinen-4-ol, α-terpineol and p-cymen-8-ol. Sesquiterpenes were present but only in small (≤1%) amounts, and overall accounted for approximately 5% of the oil. Small (but significant) amounts of the two menthatrienes, mentha-1,3,8-triene and mentha-1,4,8-triene were also present in this chemotype. These are not common in Melaleuca or Eucalyptus oils. The oil composition of all the ten trees sampled at random from this site were sufficiently similar in composition to indicate the presence of only one chemotype. The oil yield was higher than chemotype 1; being in the range 3-6% (on a dry weight basis).

The identity of piperitenone was confirmed both from its mass spectrum, which was identical to that published by Heller and Milne (1978), and also from the NMR spectrum of a fraction taken from column chromatography which contained α-terpineol (48%), p-cymen-8-ol (20%) and piperitenone (32%). The NMR spectrum of this fraction contained the following peaks due to piperitenone:- δ-1.85, s, 3H; 1.92, s, 3H; 2.08, s. 3H; 2.28,d, J=6Hz, 2H; 2.65, d, J=6Hz, 2H; 5.88, bs, 1H. This spectrum agrees well with the spectrum reported by Swigar and Silverstein (1981). The other two compounds in this fraction accounted for all the remaining NMR absorptions. The infra-red spectrum of the crude oil contained a strong absorption at 1670 cm^{-1}, consistent with an a,b,a',b' unsaturated cyclohexanone.

Two further chemotypes (chemotypes III and IV) were found at site #3, together with trees of chemotype I. Both of these chemotypes were characterised by a strong lemon smell. The main chemotype represented in this area (chemotype III) was characterised by the presence of neral/geranial (15-43% total) and small (≤1%) amounts of the corresponding alcohols nerol and geraniol. There were also small amounts (≤6%) of citronellyl acetate in the oils.

As well as the lemon-scented components there was a significant amounts of 1,8-cineole (12-27%) and smaller amounts of α-pinene, α-thujene, limonene, terpinolene and α-terpineol. Sesquiterpenes were present in variable amounts, with caryophyllene (trace-8%) being the principal member.

Chemotype IV contained either none or a small amount of neral/geranial, and instead contained the corresponding saturated aldehyde citronellal (20-30%) and its accompanying isopulegols. Citronellol and citronellyl acetate(≤6%) were also present, as well as 1,8-cineole (1-27%) and small amounts of the usual monoterpene hydrocarbons. In the two (from ten randomly selected) trees in which citronellal was a significant component, neral/geranial was in one case present in only trace amounts while in the other it accounted for 37% of the oil. This could perhaps indicate that in fact the two lemon-scented types belong to one chemotype in which the amount of neral/geranial and citronellal vary wildly. The oil yield of these last two chemotypes was 1-4% (on a dry weight basis).

Analysis of the oils from juvenile and mature leaves from the same tree showed that there were significant quantitative rather than qualitative differences. In both cases where leaves were separated this way (site #3) the oil yield from the juvenile leaves was approximately twice that from the adult leaves (≈5% :2.5%). The main difference in the components was that the terpinolene content was much higher in the juvenile oils (24%:4%). The majority of the monoterpene hydrocarbons were also more abundant in the juvenile leaves while p-cymene and p-cymen-8-ol were, not surprisingly, more abundant in the adult leaves. Spathulenol was also more abundant in the adult leaves while globulol was more abundant in the juvenile leaves.

The oil from the lemon-scented chemotypes can be compared with the oil of *M. acacioides* subsp. *alsophila* from north Western Australia. In this subspecies the main components were p-cymene (21%), terpinen-4-ol (27%), neral (8%), and geranial (19%), while the oil yield (based on fresh leaves) was 0.2-0.3%. In this particular chemotype 1,8-cineole was, for all purposes, absent. The main difference between *M. acacioides* subsp. *alsophila* and *M. citrolens* is that the former species is much richer in terpinen-4-ol (ranging up to 32%).

While it has been suggested that leaf oil chemistry may have only limited taxonomic significance (Hellyer et al, 1955), the analyses reported here and for *M. acacioides* by Brophy et al, (1987) elsewhere support Barlow's taxonomy of the *M. acacioides* complex.

It should be noted here that a subsequent collection of *M. acacioides* subsp. *alsophila* from Broome has shown the existance of a significant variation in this subspecies. In this sample 1,8-cineole accounted for approximately 50% of the oil and terpinen-4-ol 13%. α-Terpineol (7%) and limonene (5%) were present in significant quantities, though citronellal (2%), neral (2%) and geranial (3%) were considerably less than in the first analysed samples of this subspecies (Brophy et al. 1987).

REFERENCES

Barlow, B.A., 1987. Contributions to a revision of Melaleuca (Myrtaceae): 1-3. *Brunonia,* **9**, 163-177.

Barlow, B.A. and Cowley, K.J., 1988. Contributions to a revision of *Melaleuca* (Myrtaceae): 4-6. *Australian Systematic Botany,* **1**, 95-126.

Brophy, J.J. and Lassak, E.V. 1983. The volatile oils of *Melaleuca armillaris, M. dissitiflora* and *M. trichostachya. Journal and Proceeding of the Royal Society of New South Wales,* **116**, 7-10.

Brophy, J.J., Lassak, E.V. and Boland, D.J., 1987. Volatile leaf oils of the two subspecies of *Melaleuca acacioides* F. Muell. *Journal and Proceeding of the Royal Society of New South Wales,* **120**, 135-139.

Brophy, J.J. and Lassak, E.V., 1988. The leaf oil of *Melaleuca leucadendra* L. *Flavour and Fragrance J.,* **3**, 43-46.

Brophy, J.J., Clarkson, J.R. and Fookes, C.J.R., 1989. Angustifolenone, a ketone from *Backhousia angustifolia. Phytochemistry,* **28**, 1259-1261.

Byrnes, N.B., 1984. A revision of *Melaleuca* L. (Myrtaceae) in northern and eastern Australia, 1. *Austrobaileya,* **1**(1), 65-76.

Byrnes, N.B., 1985. A revision of *Melaleuca* L. (Myrtaceae) in northern and eastern Australia, 2. *Austrobaileya,* **1**(2), 131-146.

Byrnes, N.B., 1986. A revision of *Melaleuca* L. (Myrtaceae) in northern and eastern Australia, 3. *Austrobaileya,* **1**(3), 254-273.

Cannon, J.R. and Corbett, N.H., 1962. Physiological forms of *Backhousia angustifolia* F. Muell. *Australian Journal of Chemistry,* **15**, 168-171.

Craven, L.A., 1989. Reinstatement and revision of *Austeromyrtus* (Myrtaceae). *Australian Systematic Botany,* **1**, 373-385.

Heller, S.R. and Milne, G.W.A., 1978,1980,1983. EPA/NIH Mass Spectral Data Base, U.S Government Printing Office, Washington D.C.

Hellyer, R.O., McKern, H.H.G. and Willis, J.L., 1955. The essential oil of *Backhousia myrtifolia* Hooker et Harvey. *Journal and Proceeding of the Royal Society of New South Wales,* **89**, 30-36.

Lassak, E.V., 1979. The volatile leaf oils of three species of Melaleuca. *Journal and Proceeding of the Royal Society of New South Wales,* **112**,143 -145.

Penfold, A.R., Morrison, F.R., Willis, J.L., McKern, H.H.G. and Spies, M.C., 1951. The occurrence of a physiological form of *Backhousia citriodora* F. Muell. and its essential oil. *Journal and Proceeding of the Royal Society of New South Wales,* **85**, 123-126.

Stenhagen, E., Abrahamsson, S. and McLafferty, F.W., 1974. Registry of Mass Spectral Data, Wiley, New York .

Swigar, A.A. and Silverstein, R.M., 1981. Monoterpenes, Aldrich, Milwaukee.

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A Physical Identity for the Blood-Brain Barrier

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ABSTRACT

The finding that cerebral vessels are hydrophobic has resulted in the use of fixatives for electronmicroscopy which do not destroy hydrophobic surfaces or promote 'peeling' of any lining. The resulting electronmicrographs display a phospholipid lining consisting of 8-10 lamellae adjacent to the bilayer of the endothelial membrane and of equal spacing. This is unlikely to be artefact because two hydrophobic probes gave the spectral distribution of light under UV excitation characteristic of oligolamellar phospholipid, while both this effect and surface hydrophobicity were eliminated by phospholipid solvents. This oligolamellar lining to cerebral vessels could provide the physical identity of the elusive blood-brain barrier.

INTRODUCTION

For over a century it has been known that the brain displays a remarkable inability to take up a large group of substances from blood which other organs can readily assimilate, leading to the notion of a blood-brain barrier (Biedl & Kraus, 1898; Lewandowsky, 1900). This finding has been confirmed repeatedly as reviewed by Bradbury (1979). However, failure to demonstrate such a barrier as a physical entity, combined with the similar histology of capillaries in organs where there is no blood-tissue barrier (Ehrlich, 1902), has led many to consider the blood-brain barrier more as a physiological concept attributable to some special characteristic of the central nervous system in excluding certain solutes. Linked with any structural barrier, there must also exist active processes that regulate the environment of an integrated network of nerve cells where small variations may change the balance of delicately poised excitatory and inhibitory influences as reviewed by Kuffler, et al. (1984). However there remains an elusive physical component to what is now termed the "blood-brain barrier system".

While early morphological studies were concerned with the question of the size of the extracellular space and whether the barrier resided at the level of the glial sheath or the capaillary endothelium, the latter site is favoured by most indirect arguments (Bradbury, 1979). If endothelial cells *per se* provide the physical barrier, then it is imperative that they possess "tight junctions" or that the continuity of membrane endothelium be maintained by astrocytic "end-feet" in direct contact with the basement membrane of the capillary. When the electron microscope studies of Maynard et al. (1957) showed such a sheath to be only 85% complete, such interruptions were considered to preclude it from being the barrier. These and other ultra-structural studies of Schultz et al. (1957) and Wyckhoff & Young (1956) into astrocytes and the interrelated question of the extracellular space led to the suggestion that the blood-brain barrier was an illusion with more of the features of epithelia. However, in subsequent studies, Peters et al. (1976) have shown how astrocytic end-feet can complete a layer around a capillary while contacts between endothelial cells, glial cells and, especially, astrocytes have been viewed as five-layered junctions (Peters, 1962). In these, the outer of of the three laminae normally seen under the electron microscope fuse with those of the neighbouring cell to form a common structure.

A disconcerting feature of all endothelia and epithelia is the sloughing of cells, raising the obvious question of what maintains barrier properties until mytosis of neighbouring cells enables the gap to be filled. This is particularly pertinent to another barrier to many of the same solutes - the gastric mucosal barrier. In this case an oligolamellar lining of phospholipid has been demonstrated (Hills, 1989a) using fixation procedures that differ widely from conventional methods which employ aldehydes and especially glutaraldehyde known to destory hydrophobic surfaces. Since well rinsed cerebral vessels were found to be hydrophobic, it was therefore decided to use essentially the same fixation procedure to try to visualise the blood-brain barrier in case it had hitherto been obscured for the same reasons.

HYDROPHOBICITY MEASUREMENTS

In preliminary studies, the cerebral vessels of ten sheep were used which had been injected with Trypan blue 10 minutes before being killed painlessly by stunning and exsanguination. This dye facilitated recognition of blood vessels and confirmed that the BBB was essentially intact. In the first series of experiments hydrophobicity of the endothelial lining was assessed by placing a very small (5 μl) droplet of saline on the well rinsed and flattened surface and then measuring the contact angle (θ), i.e. the angle between the endothelium and the tangent to the air-liquid interface at the triple point where all three phases meet. The value of θ recorded was the plateau value plotted against drying time according to a standard procedure for biological material (Sherman, 1981). θ can range from 0 for a perfectly wettable surface to 105° for Teflon (Adamson, 1967) or above with typical values for endothelium of about 23° (Sherman, 1981). In these experiments small cerebral arteries, after rinsing with saline to remove any mucoid layer, gave $\theta = 77.4° + 2.8°$ (N = 20) which was surprisingly hydrophobic. The hydrophobicity was eliminated by solvents for phospholipid, notably chloroform or 2:1 chloroform: methanol, the rinsings containing phospholipid as analysed by standard thin-layer chromatography using the method of Rouser et al. (1966). Although such material could have been derived from endothelial membrane, no disruption could be observed by simple histological examination using light microscopy.

ELECTRON MICROSCOPY

Blocks taken from the dorsal aspect of cerebral cortex of ten sheep were fixed for conventional transmission electron microscopy using a hybrid process found successful in demonstrating the oligolamellar lining of surfactant (phospholipid) on the gastric mucosa (Hills, 1989a) and articular surface (Hills, 1989b). Each block was fixed for 72 h in 2.5% glutaraldehyde + 1% tannic acid buffered at a pH of 7.4 with 0.1M sodium cacodylate at 4°C. The very long (72h) fixation time was selected on the basis that diffusion of water-soluble fixatives is likely to be very slow in a barrier known for its low permeability to water-soluble solutes. Postfixation was effected with 1% osmium tetroxide buffered at pH = 7.4 with embedding in resin (Spurr mix 'A') polymerised at 60°C. Great care was taken to keep all fixatives isotonic so as to avoid 'peeling' of any phospholipid layer due to fluid shifts. Fixatives were introduced from the abluminal side so as to fix the polar ends of any adsorbed molecules *before* reaching the hydrophobic surface. The electron micrographs showed much oligolamellar phospholipid in extravascular sites such as myelin, which was to be expected, but also as the "whorls" reported in cerebral cortex by Rees (1975). These are very interesting because they are virtually indistinguishable from lamellar bodies - the highly surface-active 'packages' in which the alveolar Type II cell produces surfactant in the lung (Gil & Reiss, 1973).

The most surprising finding was the oligolamellar lining on the vessels. Typical e.m.s are shown for a cerebral capillary in Figure 1, a cerebral arteriole or small artery in Figure 2 and a cerebral venule in Figure 3. In all cases the phospholipid lining was 6-10 layers in addition to the bilayer of the endothelial membrane immediately adjacent and running parallel with equal spacing as though the whole membrane were 8-12 layers. Interlamellar spacing ranged from 45 to 51Å.

As a control, the same fixation procedure was used on sheep aorta and produced electronmicrographs depicting three equally spaced lines for the well rinsed endothelium, i.e. a bilayer plus an adsorbed monolayer or second bilayer depending upon how one interprets three lines (Hills, 1988).

HYDROPHOBIC PROBES

Although there was no reason to suspect that the e.m.s shown in Figures 1 - 3 were artefact, any doubt could be dispelled by epifluorescence microscopy using hydrophobic probes, i.e. stains by which oligolamellar phospholipid emits a unique spectrum under UV excitation. When stained with Nile Red, cerebral endothelium from the sheep produced the intense red fluorescence under UV excitation characteristic of oligolamellar phospholipid as opposed to the orange-gold of neutral lipids (Greenspan et al., 1985). The spectrum was compared with control samples of oligolamellar phospholipid synthesized by a standard technique (Bangham & Horne,

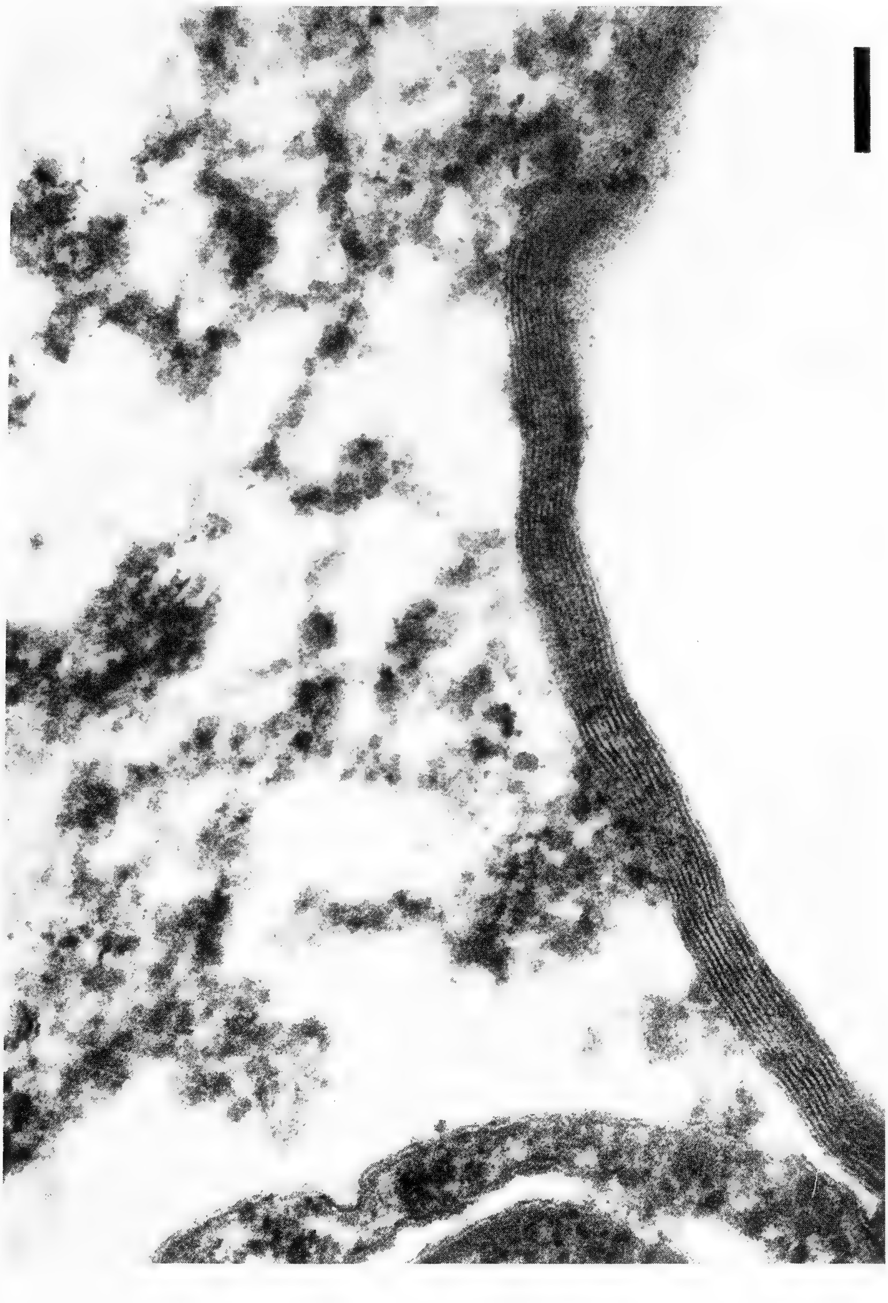

Figure 1. An electronmicrograph of cerebral cortex showing the endothelium of a capillary. Note the oligolamellar lining of phospholipid consisting of ten laminae, including the endothelial membrane. The bar represents 100 nm, giving an interlamellar spacing of 45-51 Å .

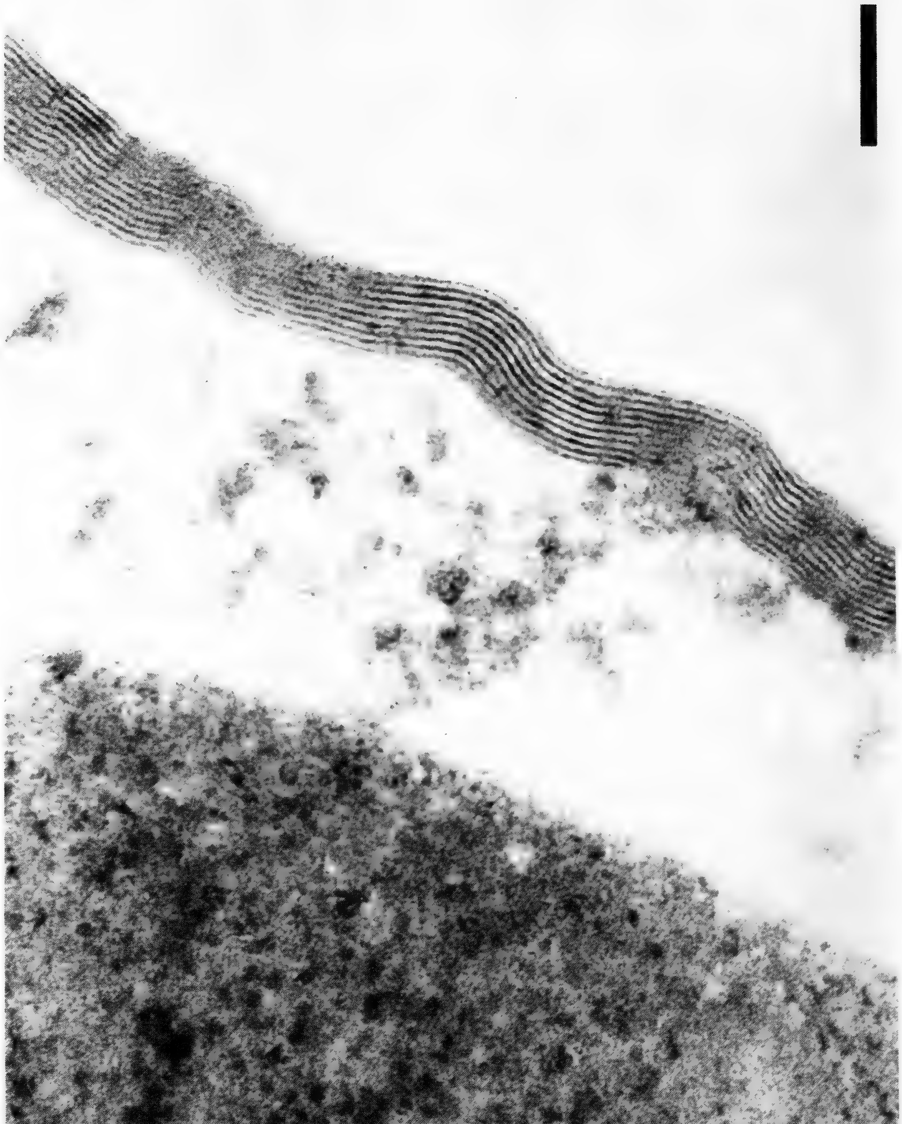

Figure 2. An electronmicrograph of cerebral cortex showing the endothelium of an arteriole or small artery. Note the oligolamellar lining of phospholipid consisting of 10-12 laminae, including the endothelial membrane. The bar represents 100 nm, giving an interlamellar spacing of 45-51 Å.

Figure 3. An electronmicrograph of cerebral cortex showing the endothelium of a venule or small vein. Note the oligolamellar lining of phospholipid and how it spans the junctions between endothelial cells. The bar represents 100 nm.

1964) of ultrasonicating egg lecithin into liposomes. The conclusion that the cerebral vascular lining was oligolamellar phospholipid was confirmed using a second hydrophobic probe - Phosphin E - used to confirm a similar lining on pulmonary epithelium (Ueda et al., 1985). This produced the green-gold colour characteristic of oligolamellar phospholipid. When the same solvents were used which eliminated the contact angle, they also eliminated or greatly reduced the fluorescence observed with both hydrophobic probes. The interlamellar spacing is about the same in both capillaries (Figure 1), arterioles (Figure 2) and venules (Figure 3), indicating a common endothelial lining.

DISCUSSION

The electron micrographs (Figures 1 - 3) present a remarkably well defined oligolamellar lining to the cerebral vasculature which, at first sight, would seem to provide a physical basis for the blood-brain barrier. This structure would seem unlikely to be artefact in view of the ancillary experiments using two hydrophobic probes and the hydrophobic nature of the walls of the larger cerebral vessels after rigorous rinsing with saline. This action probably removes most of the glycocalyx which would be adhering to the outermost lamella to render the surface more hydrophobic. Elimination of the hydrophobicity and the UV fluorescence by phospholipid solvents again tends to confirm the oligolamellar lining.

A blood-brain barrier consisting primarily of phospholipid would explain its very high permeability to lipids and substances of high lipid solubility, its low permeability to many water-soluble solutes and the overall membrane-like properties which Krogh (1946) describes. In the physical sciences, adsorption of surfactants to synthetic membranes has been shown by Fane et al. (1985) to change their permeability and evidence for similar changes occurring *in vivo* have been demonstrated by Dial et al. (1988) and discussed elsewhere (Hills, 1989c). An oligolamellar phospholipid blood-brain barrier could also explain the very unusual nature of some of the "barrier breakers" which include air emboli (Broman, 1946), fat emboli (Broman, 1946) and certain X-ray contrast media (Rapoport, 1976). All of these are two-phase systems with interfaces conducive to the adsorption or uptake of surfactant and would therefore compete for the surfactant shown in Figures 1 - 3 to be directly adsorbed to the vascular endothelium.

Solvents for phospholipid might also be expected to break the BBB and one of the most effective for both (Hills, 1987, 1988) is Freund's Incomplete Adjuvant (FIA). This offers a simple alternative explanation for its role in experimental allergic encephalomyelitis (EAE) - the model used for multiple sclerosis for which much clinical evidence has been amassed by Swank (1957) and James (1982) to implicate embolised fat - which is another effective solvent for phospholipid (Hills, 1987). An oligolamellar blood-brain barrier is consistent with the beneficial effects of steroids which, in the lung, at least, promote maturation of surfactant (Clements, 1982).

The hydrophobic nature imparted to cerebral vascular endothelium by the adsorbed phospholipid would raise the interfacial tension to about 55 mN/m (dynes/cm) based upon the mean contact angle measured, imparting a collapsing pressure to capillaries of about 35 mmHg. The blood-tissue interface itself could thus provide the mechanical tension which Bradbury (1979) considers the vital characteristic of the blood-brain barrier largely because the breakdown coincides with the loss of cerebral autoregulation as blood pressure is elevated.

Another advantage of oligolamellar surfactant as the blood-brain barrier is its capability to coat areas of the vessel wall denuded of endothelial cells as indicated at cell junctions in the lung by Ueda et al. (1985). It is difficult to associate any barrier with the lining cells themselves, however tight their junctions, when those cells are being sloughed off and continuously replaced. Surfactant would not only coat them as we see in Figures 1 - 3 but could also provide the "sealant" between them as it has been termed by Hills (1988) - see Figure 3. However, if oligolamellar phospholipid were acting as a 'sealant' for cell junctions, the intercellular continuity of the resulting layers and their low conductivity as measured *in vitro* by Ti Tien (1974) should lead to a much higher electrical resistance of the blood-brain barrier by comparison with other blood-organ barriers which is, indeed, the case (Crone, 1986); while its multilaminated structure would impart an inflexibility relative to normal cell membranes which could explain the absence of pinocytotic activity (Bradbury, 1979).

Whether these interpretations are correct or not, the results indicate an oligolamellar lining of phospholipid on cerebral vessels at just the locations where it could be providing the elusive blood-brain barrier.

REFERENCES

Adamson, A.W. 1967. PHYSICAL CHEMISTRY OF SURFACES. 2nd. edn. Wiley, New York.

Bangham, A.D. and Horne, R.W. 1964. Negative staining of phospholipids and their structural modification by surface-active agents as observed in the electron microscope. *Journal Molecular Biology, 8*, 600-8.

Biedl, A. and Kraus, R. 1898. Über einer bisher unbekannte toxische Wurking der Gallensäuren auf das Zentralnervensystem. *Zentralblatt inn. Medenin, 19*, 1185-1200.

Bradbury, M.W.B. 1979. THE CONCEPT OF A BLOOD-BRAIN BARRIER . Wiley, Chichester.

Broman, T. 1946. Quoted by Bradbury 1979.

Clements, J.C. 1982. Lung surfactant composition. U.S. Patent 4,312,860.

Crone, C. 1986. The blood-brain barrier: a modified tight epithelium. In: THE BLOOD-BRAIN BARRIER IN HEALTH AND DISEASE. A.J. Suckling, M.G. Rumsbey & M.W.B. Bradbury (Eds). Horwood, Chichester. 17-40 pp.

Dial, E.J., Huang, J., O'Neil, R.G., Hills, B.A. and Lichtenberger, L.M. 1988. Surface hydrophobicity and water transport of the toad urinary bladder: effects of vasopressin. *Journal of Membrane Biology, 106*, 119-122.

Ehrlich, P. 1902. Über die Beziehungen von chemischer Constitution, Vertheilung und pharmakologischer Wirkung. Reptrinted and translated in COLLECTED STUDIES OF IMMUNITY (1906). Wiley, New York. 567-95 pp.

Fane, A.G., Fell, C.J.O. and Kim, K.J. 1985. The effect of surfactant pretreatment on the ultrafiltration of proteins. *Desalination, 53*, 37-55.

Gil, J. and Reiss, O.K. 1973. Isolation and characterization of lamellar bodies and tubular myelin from rat lung homogenates. *Journal of Cellular Biology, 68*, 152-71.

Greenspan, P., Mayer, E.P. and Fowler, S.D. 1985. Nile Red: a selective fluorescent stain for intracellular lipid droplets. *Journal of Cellular Biology, 100*, 965-73.

Hills, B.A. 1987. Air and fat emboli in the lung and the brain. *Proceedings of the IXth International Congress on Hyperbaric Medicine, Sydney 1987*, 3-11 pp.

Hills, B.A. 1988. THE BIOLOGY OF SURFACTANT. Cambridge University Press, Cambridge.

Hills, B.A. 1989a. A physical basis for the gastric mucosal barrier (in prep.)

Hills, B.A. 1989b. Oligolamellar lubrication of joints by surface-actiave phospholipid. *Journal of Rheumatology, 16*, 82-91.

Hills, B.A. 1989c. Possible role of adsorbed surfactant in controlling membrane permeability and function. *Medical Hypotheses, 28*, 85-92.

James, P.B. 1982. Evidence for subacute fat embolism as the cause of multiple sclerosis. *Lancet, 13-2-82,*, 380-6.

Krogh, A. 1946. The active and passive exchanges of inorganic ions through the surfaces of living cells and through living membranes generally. *Proceedings of the Royal Society of Britian 133*, 140-200.

Kuffler, S.W., Nicholls, J.G. and Martin, A.R. 1984. FROM NEURON TO BRAIN. 2nd Edn. Sinauer, Sunderland, Mass. p. 363.

Lewandowsky, M. 1900. Zur Lehre der Cerebrospinal Flüssigkeit. *K. Klin, Med., 40*, 480-94.

Maynard, E.A., Schultz, R.L. and Pease, D.C. 1957. Electron microscopy of the vascular bed of the rat cerebral cortex. *American Journal of Anatomy, 100*, 409-33.

Peters, A. 1962. Plasma membrane contacts in the central nervous system. *Journal of Anatomy, 96*, 237-48.

Peters, A., Palay, S.L. and Webster, H. de F. 1976. THE FINE STRUCTURE OF THE NERVOUS SYSTEM: THE NEURONS AND SUPPORTING CELLS. Saunders, Philadelphia.

Rapoport, S.I. 1976. BLOOD-BRAIN BARRIER IN PHYSIOLOGY. Raven, New York.

Rees, S. 1975. A quantitative electron microscopic study of atypical structures in normal cerebral cortex. *Anatomy and Embryology, 148* , 303-31.

Rouser, G., Siakotos, A.N. and Fleischer, S. 1966. Quantitative analysis of phospholipids by thin-layer chromatography and phosphorus analysis of spots. *Lipids, 1*, 85-6.

Schultz, R.L., Maynard, E.A. and Pease, D.C. 1957. Electron microscopy of neurons and neuroglia of cerebral cortex and corpus callosum. *American Journal of Anatomy, 100*, 369-407.

Sherman, I. A. 1981. Interfacial tension effects in the microvasculature. *Microvascular Research, 22*, 296-307.

Swank, R.L. 1957. BIOCHEMICAL BASIS OF MULTIPLE SCLEROSIS. Thomas, Springfield, Ill., U.S.A.

Ti Tien, H. 1974. BILAYER LIPID MEMBRANES, Dekker, New York, U.S.A.

Ueda, S., Kawamura, K., Ishii, N., Matsumoto, S., Hayashi, O., Okayasu, M., Saito, M., and Sakurai, I. 1985. Ultrastructural studies of surface lining layer of the lungs: Part IV. Resected human lungs. *Journal of Japanese Medical Society of Biological Interface, 16*, 34-60.

Wyckoff, R.W.G. and Young, J.Z. 1956. The motoneuron surface. *Proceedings of the Royal Society of Britian, 144*, 440-50.

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Cook and His Contemporaries: Differences in Medical Emphases

JAMES WATT

INTRODUCTION. Surgeon Vice-Admiral Sir James Watt, MD, MS, FRCP, FRCS (England), Hon. FRCS (Edin.), Hon. DCh (Newcastle) had a distinguished medical career in the Royal Navy.

Among other senior appointments, he was Medical Director-General of the Royal Navy, 1972-1977; President of the Medical Society of London, 1980-81; President of the Royal Society of Medicine, 1982-84; and Honorary Surgeon to H.M. The Queen from 1978 to 1987.

He is currently President of the Institute of Religion and Medicine, Vice-President of the Society for Nautical Research, and Trustee of the Medical Society of London. Since retirement he has, among his many activities, become established as an important naval medical historian, and it was in this role - documenting the medical history of the First Fleet and early settlement on behalf of the Australian Government - that he came to Australia in 1986 and, as a Bicentennial Visitor, in 1988.

During the former visit he spoke to a meeting of the New England Branch of the Royal Society of New South Wales on 21st November 1986, and this paper is the written version of the talk he gave on that occasion.

INTRODUCTION

Throughout his naval service, Captain James Cook had received ample evidence that the success of maritime operations was often determined by health factors. In 1755, as an able seaman on board *HMS Eagle*, he had encountered the ravages of scurvy after only a few months' patrol off the English coast. Twenty-two men, including the surgeon, were buried at sea and 130 were landed sick. The experience was repeated when, on Palliser's recommendation, he was appointed master of *HMS Pembroke*. Scurvy was responsible for 26 deaths during her passage from Plymouth to Halifax, Nova Scotia, and her crew required four weeks' convalescence before she could join Boscawan for his attack on Louisburg. Its fall opened the way to the St Lawrence River which Cook successfully charted, enabling Admiral Saunders to negotiate the dangerous channel with 22 warships and 119 transports bearing Wolfe's army to capture Quebec in 1759 (R.T. Gould, 1978).

His reputation thus enhanced, Cook was next selected to survey the coasts of Newfoundland where his observations on an eclipse of the sun in August 1766 brought him to the attention of the Royal Society, which had him appointed as Commander of *HMS Endeavour* for the Society's expedition to Tahiti to observe the transit of Venus across the sun in 1769. That association was to influence and significantly modify Cook's provision for the health of his men.

THE INFLUENCE OF THE ROYAL SOCIETY

Cook's service on the North America station had taught him the antiscorbutic value of spruce beer (pine needles have 150mgm ascorbic acid/100g) and this remained his principal weapon for combating scurvy. Unfortunately, the Royal Society reflected the view of the Royal College of Physicians, the Admiralty's medical adviser, that the efficacy of the citrus fruits in the cure of scurvy was due to their acidity. Since fruits were also held to cause dysentery, elixir of vitriol was recommended as a suitable alternative and was carried by all ships (C. Lloyd and J.L.S. Coulter, 1961). It contained sulphuric acid, sugar, spices and spirit of wine. When the naval surgeon James Lind showed, by the controlled clinical trial he conducted at sea in 1747, that oranges and lemons, but not elixir of vitriol, could cure scurvy (J. Lind, 1753), the Admiralty Sick and Hurt Board rejected the evidence (Sick and Hurt Board, 1767).

The matter was further confused, because scurvy was regarded as a putrefactive disease, particularly by the Edinburgh School of Medicine which invoked the work of Joseph Priestley on carbon dioxide to promote a false hypothesis that tissue metabolism was influenced by 'pneumatic chemistry'. Developing this idea, Sir John Pringle, an Edinburgh graduate and President of the Royal Society, conducted a series of experiments to prove that fermentation inhibited putrefaction (K.J. Carpenter, 1986).

A young Dublin physician and former naval surgeon David MacBride, using Pringle's methodology, published the results of a series of experiments which purported to show that a substance like malt, which fermented in the digestive tract to liberate 'fixed air' or carbon dioxide, would prevent putrefactive diseases such as scurvy (D. MacBride, 1767). Pringle naturally gave his wholehearted support to the promotion of malt as an antiscorbutic though it contains no vitamin C. Malt therefore became Cook's

* Communicated by R.L. Stanton

second line of defence against scurvy. His third was sauerkraut, one of the antiscorbutics recommended by Lind. Lind, however, had powerful disciples, notably Nathaniel Hulme, an able and influential physician in London and also a Fellow of the Royal Society. Hulme ensured that Lind's ideas were communicated to captains and surgeons of naval vessels fitting out in the Thames, corresponded with the Admiralty and found a means of preserving lemon juice in bulk for long voyages (N. Hulme, 1768). It was this lemon juice which cured Banks of scurvy during Cook's *Endeavour* voyage (J.C. Beaglehole, 1962).

THE DEBT TO WALLIS

But Cook had also studied, with close attention, Wallis's journal of his circumnavigation from 1766-1768 during which he had discovered Tahiti, an ideal base for *Endeavour's* observation of the transit of Venus. Wallis had a remarkable health record: 3 died from dysentery and 2 from accident. He appears to have been the first commander to have applied Lind's measures conscientiously. They included natural foods, ship hygiene and personal cleanliness enforced by daily sea bathing. Slabs of concentrated animal offal called 'portable soup' were carried. Rich in protein and probably containing Vitamin A, they were boiled with local greens to make a highly nutritious and satisfying food. To Wallis also belongs the credit for first putting his men into three watches instead of the customary two (G. Robertson, 1948). It ensured adequate rest and allowed clothing to be dried, thus reducing stress and demands upon the body's stores of Vitamin C, which diminished the incidence of scurvy.

The success of the voyage was due to the rapport Wallis enjoyed with his surgeon, John Hutchinson, who impressed upon the ship's company the need to eat local greens and vegetables if they wished to avoid scurvy (G. Robertson, 1948). Large quantities of winter's bark, an effective antiscorbutic, were therefore gathered in the Magellan Strait and Wallis sent specimens to Dr. John Fothergill, an enlightened Quaker physician who seems to have been a close friend (J.C. Lettsom, 1784). Fothergill was a colleague of Dr. John Coakley Lettsom, friend of Nathaniel Hulme, who had been in close touch with Wallis and Hutchinson about the medical arrangements for the voyage (N. Hulme, 1766). This liaison seems to have persuaded Hutchinson to purchase an additional supply of medical stores out of his own pocket and Wallis also carried Lind's distillation apparatus. Hutchinson's report to Wallis on factors related to the prevention and treatment of scurvy appears to have been read by Cook, for it is enclosed in one of his holograph journals of the *Endeavour* voyage (J. Cook). Cook also sought the advice of his patron, Palliser, who had consulted Lind before undertaking a voyage to India in 1748 when he proved the value of Lind's methods (J. Lind). Fortunately for Cook, Palliser was Comptroller of the Navy during Cook's first two voyages and ensured that he got the ships, men and provisions he needed.

CARTERET

Carteret, whose unseaworthy vessel, the *Swallow*, had caused him to part company with Wallis in the Magellan Strait, discovered, to his dismay, that neither malt, nor oil of vitriol, had the antiscorbutic properties claimed for them. In a Pacific crossing of 246 scurvy-ridden days he lost one third of his ship's company, and abandoned all further exploration (H. Wallis, 1965). He returned too late to influence Cook, on his *Endeavour* voyage, but Cook may have read Carteret's narrative later because, in a rough notebook he kept on the value of various items of diet during the second voyage, he deleted a comment that malt was 'one of the best Antiscorbutic medicines yet known' and reserved that distinction for sauerkraut (J. Cook).

BYRON'S CONTRIBUTION

Cook must also have been impressed by the contrast between Anson's disastrous health record during his circumnavigation between 1740 and 1744 (J. Watt, 1985), and that of the Honourable John Byron, a survivor of that expedition, who appears to have adopted many of Lind's recommendations allied to his own practical experience. Although he made few discoveries, he deserves credit for being the first navigator to demonstrate that Pacific exploration could be achieved without prohibitive loss of life. In his voyage from 1764 to 1766, he reached Tinian in the Landrone Islands without losing a single man and, despite the ravages of malaria at Tinian and Batavia, lost only 6 out of 160 men in the *Dolphin* and 3 out of 125 in the *Tamar*. Cook would have found that the key to Byron's success lay in his attention to the hygiene, clothing and diet of his men, which he supplemented with fresh meat, fowls, vegetables and local antiscorbutic plants (J. Hawkesworth, 1773).

COOK'S HEALTH POLICY

The health policy which Cook adopted reflected all of these influences. It was displayed first in his choice of ships. They were commodious colliers with adequate space for men and provisions, unlike warships crowded with men, guns and ammunition, and he resisted overcrowding. It was the reason for his quarrel with Banks, who tried to encumber *Resolution* with a top-heavy structure to house his large staff, servants and specimens. Cook paid scrupulous attention to hygiene. His ships were kept clean, dry, fumigated and well-ventilated and, on the first two voyages, he was able to select his men, insisting upon their personal hygiene and the cleanliness of their hammocks and bedding which was aired daily. He issued heavy woollen "fearnought" jackets in cold climates and put his men into three watches, as Wallis had done.

Cook also chose routes which ensured, so far as possible, short passages between harbours which would afford natural fresh foods. For instance, in his *Endeavour* voyage, he called at Madeira and Rio for vegetables and fruits and, before rounding Cape Horn for the long passage to Tahiti, called at the Bay of Good Success in Tierra del Fuego to gather cress, scurvy grass, wild celery, winter's bark, cranberries, mussels and wild fowl, all excellent antiscorbutics. On his second voyage in *Resolution* and *Adventure*, his first Antarctic coastal sweep was planned to begin at the Cape of Good Hope and end at Dusky Bay, New Zealand, because of the fresh natural foods both provided, while he found a splendid sheltered anchorage at Christmas Harbour before rounding Cape Horn for the final sweep of the Atlantic ice-edge.

Yet, despite these admirable precautions, Cook's health policy had certain important defects. The influence of the Royal Society led him to accept, without critical appraisal, a variety of so-called antiscorbutics to the exclusion of lemon juice and this allowed scurvy to exact its toll on countless lives. Cook also quite ignored the value of cinchona bark against fevers, which Lind had emphasised, although he always endeavoured to obtain clean fresh water to avoid bowel complaints and carried a machine to sweeten it.

THE *ENDEAVOUR* VOYAGE 1768-1771

From a medical viewpoint, Cook's *Endeavour* voyage from 1768 to 1771 was not impressive. There were five outbreaks of scurvy and forty-one of the ship's company of ninety-four died; three from tuberculosis, three from alcoholic excess hastened, in two cases, by hypothermia. Buchan, the artist, died from epilepsy. Three were drowned and thirty-one died from malaria and dysentery or typhoid fever contracted at Batavia. However, to put the record into perspective, Cook had visited Batavia during the sickly season and at the height of an epidemic of typhoid fever. Prior to that, there had been only eight deaths and no more than three of these could have been avoided, while scurvy had not been serious (J. Watt). Nevertheless, despite the superb navigational and geographical achievements of *Endeavour's* circumnavigation, the Batavia debâcle underlined the defects of Cook's attitude to health, though he was ill himself (J.C. Beaglehole, 1962) and this adversely affected his relations with the Dutch East India Company (Koloniaal Archief, 1770). Cook was more concerned with his ship than with his men and, unlike Wallis, appears to have taken little interest in the medical arrangements on board. When Monkhouse the senior surgeon died, his assistant Perry found his medicine chest empty. Monkhouse had failed to keep a medical journal or to conduct four separate trials which Cook had been asked to ensure were done. Cinchona bark was expensive and seems to have been lacking, for Banks provided his own and Cook had apparently not appreciated the importance of this item. Perry, on the other hand, was a conscientious and skilled young man who seems to have brought the situation under control. He nursed Banks, among others, to health and became Banks' lifelong friend (J. Banks, 1788-90). Cook's indulgent attitude towards the drinking habits of his men, who were unsupervised and underemployed, was also a factor for the Dutch physician Bontius attributed the high incidence of dysentery among seamen to their drinking habits (J. Bontius, 1629). By contrast, Wallis took a very different line in Batavia. Like Cook, he was ill himself, but he followed Lind's precepts, stopped all shore leave and prohibited alcohol from being brought on board. He made a large sick berth in the ship, isolated affected patients and sterilised the drinking water in collaboration with his surgeon who proved 'indefatigable' (J. Hawkesworth, 1773).

RESOLUTION AND *ADVENTURE* 1772-1775

Having discovered the danger of relying upon a single ship, Cook embarked upon his circumnavigation of Antarctica in the *Resolution* accompanied by Tobias Furneaux, Wallis's second lieutenant, in *Adventure*. *Resolution* lost only four men, one from tuberculosis and three from accident. *Adventure* lost eleven, but eight of these were a boat's crew murdered by Maoris in New Zealand, though Furneaux's health measures were also less effective than those of Cook, who had learnt the lessons of the *Endeavour* voyage. If, however, we examine other records than Cook's own journals, it is clear that the cost in health had been rather higher than he cared to admit. For instance the physician-naturalist, Sparrman, described the effect of deteriorating rations upon the health and morale of *Resolution's* crew during the Pacific and Atlantic ice-edge searches (A. Sparrman, 1785), while the incidence of venereal disease was high and there were five episodes of scurvy albeit less severe than the two in *Adventure*.

RESOLUTION AND *DISCOVERY* 1776-1779

Cook took *Resolution* again, accompanied by Clerke in the *Discovery*, for his ill-fated third voyage from 1776 to 1779, which was to repeat Drake's attempt of 1579 to find a North-West Passage. By then, Palliser, his friend and patron, had left the Comptroller's office. Delays, leaking ships and uncooperative crews sorely tried Cook's patience, but he discovered the Cook Islands, Nootka Sound on Vancouver Island and the Hawaiian Islands where, in February 1799, he mishandled a trivial local incident to meet his tragic end.

The most likely explanation is that his insistence upon eating native foods caused a heavy infestation of the bowel by ascarides or round worms, which were prevalent in Tahiti and caused him to have an acute bowel obstruction during the second voyage. It was followed by failure to absorb the B complex of vitamins which produced the characteristic syndrome and personality change displayed by Cook on the third voyage and was the most significant feature of the events which led to his death. It could therefore be argued that Cook was ultimately a victim of his own health policy (J. Watt).

After the second voyage, Cook was awarded the Royal Society's Copley Medal for his success in preserving health at sea (J. Cook, 1776) and his contribution to this field is best judged by comparison with his eighteenth century contemporaries.

BOUGAINVILLE 1766-1769

The first of the French explorations of the Pacific was that of Bougainville from 1766 to 1769. In terms of mortality, it was deceptively good, for there were only 10 deaths in the *Boudeuse* and 2 in the *Etoile* out of a total of 333 men. Four were drowned, 1 died from tuberculosis, 1 from apoplexy and 1 from peritonitis. Scurvy claimed only 3 and 2 died from dysentery. Morbidity, however, was high and the several journals of the voyage edited by Taillemite (E. Taillemite, 1977) disclose 4 episodes of scurvy, 3 of dysentery and rampant venereal disease. At least 116 men were discharged to hospital at various ports of call, but their mortality and eventual disposal are unknown. Sickness frustrated discovery and St. Germain, the purser, bitterly recalled the islands they had sighted without exploring one of them (E. Taillemite, 1977).

Bougainville thought he had discovered Tahiti and reached it in the nick of time, for his men, driven to eating rats, were falling rapidly hostage to scurvy. By the time they had reached New Ireland, half of Bougainville's men were suffering from a third outbreak of scurvy, dry provisions were being consumed by cockroaches, weevils and rats, and the inadequately cured meat was foul. On their arrival at Ceram, 'no-one was able to declare himself entirely exempt from scurvy and half the crew was incapable of any work (L.A. de Bougainville, 1772). The spectre of disaster, which had pursued Bougainville throughout the voyage, finally drove him to abandon further exploration towards Australia which effectually prevented him from pre-empting Cook.

Among the causes from the expedition's failure were the ineptitude of the French Admiralty, overcrowded ships with inadequate storage space, badly packaged provisions of inferior quality (A. Carré, 1981), the indifference and clinical ignorance of the surgeons, neglect of sound nutritional principles, and the indiscipline of the crews, despite Bougainville's inspiring leadership. He was not, however, always successful in trading relations with natives and, unlike Cook, Wallis and Byron, was more concerned about his own creature comforts than the nutritional needs of his men, who therefore suffered most.

LAPÉROUSE 1785-1788

The next French expedition to the Pacific was under the command of Lapérouse, a Frenchman in the Cook mould and Cook's great admirer and emulator. He applied all Cook's health measures with signal success and had the benefit of Poissoniére-Despèrrieres' 'Traité des maladies des gens de mer', which had been published in 1767 and incorporated Lind's teaching. Louis XVI took a personal interest in the voyage and had studied Cook's journals and charts, so that the instructions given to Lapérouse abounded in expressions lifted directly from Cook's journals. The Medical Society of Paris also discussed with Lapérouse the sort of information they would like to receive, based upon the observations of Cook and Anderson, his surgeon and naturalist on his second and third voyages (J.F.G. de Lapérouse, 1799). Rollin's industry, perceptions and acumen provided the Paris Medical Society with the information it required and Lapérouse with healthy crews, yet the medical emphasis differed from that of Cook.

In a letter from Botany Bay on 7 February 1788, Lapérouse provided an apparently unambiguous statement that "fresh provisions and fresh provisions alone, either animal or vegetable, cure the scurvy" (J.F.G. de Lapérouse, 1799), but then went on to confuse the issue, as Cook had done, by recommending a blunderbuss approach to its prevention without even mentioning lemon juice. Moreover, what he really meant by fresh provisions was fresh meat, for he attributed the cure of scurvy at Samoa to the fresh pork they obtained there. While he made full use of Cook's spruce beer in northern waters, he was persuaded by Rollin to have it mixed with cinchona bark in the mistaken belief that quinine was antiscorbutic (R.T. Gould, 1978).

Like Cook, Lapérouse was reluctant to admit sickness and it is therefore difficult to compute the true morbidity. For instance, on arrival in Botany Bay, he boasted that there was not a man sick in either ship, yet English officers of the First Fleet learnt that wounds sustained in Samoa had not yet healed (D. Collins, 1798) and two died there. In all, 21 died from a boat accident in Alaska, 12 from a native attack at Samoa, 2 others from injuries, 1 from chronic disease, 1 from scurvy and 1 from dysentery, an overall mortality of 38. However, 12 others were landed sick during the voyage, some of whom appear to have died; so his health record, in which he sought to outshine Cook, was less impressive than it appeared in his writings.

MALASPINA 1789-1794

Cook's influence extended also to Spain: Malaspina's expedition from 1789 to 1794 was conceived, like that of Lapérouse, on the grand scale which had characterised Cook's voyages. In the Cook tradition, health assumed a high priority and Malaspina had two corvettes specially built to carry provisions which he selected himself. It led, however, to the paradox of departing with his ships stuffed with malt and sauerkraut from a port overflowing with oranges and lemons.

Fortunately, Malaspina carried two able physicians, Gonzalez and Flores, who had studied the works of Lind and Sir Gilbert Blane, Rodney's enlightened and influential physician on the West Indies station. They therefore took a quantity of lemon juice, which had been either filtered or concentrated to preserve it, and this proved effective in limiting scurvy during the Pacific crossing. There were only 10 recorded deaths: 8 from disease and 2 from accident, but inadequate data preclude comparison of Malaspina's health record with that of other Pacific navigators, because there were numerous desertions, exchanges and discharges to hospital and it is impossible to determine the ultimate fate of all who fell sick or even the number who completed the voyage (J. de Zulueta and L. Higueras, 1981). Nevertheless, this expedition had one important outcome. The experience enabled Gonzalez to publish a book on diseases of seamen in 1805 (P.M. Gonzales, 1805), which gave a Spanish accent to Lind's thesis of 1753 and complemented the French emphasis of Poissoniére-Despèrrieres.

VANCOUVER AND DENTRECASTEAUX 1790-1795

The last important voyages of the eighteenth century were the circumnavigations of Vancouver and Dentrecasteaux which, subject to similar political, environmental, psychological and physical influences, provide a useful comparison of the consequences of differing medical emphases upon the health policies they had inherited, directly or indirectly, from Cook. Both commanders suffered from a fatal illness. Dentrecasteaux died from scurvy and a haemorrhage from the bowel, mismanaged by his surgeon (J. Watt, 1986). Vancouver died three years after returning to England from the complications of fever, which he appears to have contracted during a previous commission in the West Indies and which plagued him throughout the voyage (J. Watt, 1987).

Both expeditions were delayed by conflict, the French by the Revolution and the English by the dispute with Spain. This was reflected in the poor workmanship evident in the ships. It also extended to Dentrecasteaux's provisions which were of an inferior quality (J. Carré, 1977). Vancouver's provisions were excellent (A. Menzies, 1791), and he was generously supplied by the storeship *Daedalus* during the voyage (G. Vancouver, 1798). He personally ensured that abundant antiscorbutics were carried, which included lemon juice, and he also carried a large stock of cinchona bark of the best quality (G. Vancouver, 1798).

Renaud, surgeon of the *Récherche*, compiled a somewhat garbled account of Dentrecasteaux's terminal illness (P. Renaud) and appears to have been less competent than his colleague, Joannet in the *Espérance*, who left a detailed record of 502 cases together with an account of the medical arrangements on board (L.D. Joannet). Despite instructions similar to those given to Lapérouse, the picture emerges of men living in squalor amidst the stench of the excreta of livestock for the officers' table, being prevented from washing, sleeping in wet clothing because they had no other, and obliged to live for long periods without fresh provisions or antiscorbutics. The sick were given vinegar, beer, honey and cream of tartar, with occasional 'limonade sêche' for there seems to have been little insight into the nature of the sea diseases. It is scarcely surprising that, after reaching the Pacific, scurvy and dysentery should dominate the clinical picture.

Vancouver, on the other hand, ran a taut, clean ship and meticulously followed the practices of his mentor, Cook, and the recommendations of authoritative medical writers. This difference in medical emphasis was high-lighted by the health records of the two voyages. Vancouver lost 5 out of the combined crews of 145 men. Only 1 died from disease and his consort *Chatham* did not lose a single man (G. Vancouver, 1798). By the time the French expedition had reached Java, 22 had died in the *Récherche* and 16 in the *Espérance*, including both commanders and the final death toll was in excess of 98 out of a combined complement of 219 men (J.H. de La Billardière, 1800).

CONCLUSION

It is therefore possible to conclude that health at sea during eighteenth century Pacific exploration derived largely from Lind's perceptions of the nutritional, hygienic and epidemiological aspects of the sea diseases, from the relationship of his disciple Hulme with Wallis and Hutchinson and from the influence of Wallis upon Cook, whose assiduous attention to hygiene, nutrition and the welfare of his men admirably complemented the superb navigational skills and uncanny intuition which were such features of his exploring genius. His emphasis upon the health aspects of voyages of discovery influenced all subsequent Pacific navigators and led to French and Spanish appraisal of Lind's work.

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REFERENCES

Banks, Sir Joseph, 1788, 1790. Sir Joseph Banks Papers MS 9/131, Perry to Banks, 16 June 1788, 7 October 1790. [Canberra:- Australian National Library].

Beaglehole, J.C., ed., 1962. THE ENDEAVOUR JOURNAL OF JOSEPH BANKS, 1768-1771 (2 vols.) Sydney: State Library of New South Wales, Vol. 2, pp. 301 and 242.

Billardière, J.H. de la, 1800. VOYAGE IN SEARCH OF LA PÉROUSE DURING THE YEARS 1791, 1793 and 1794. Translated by J. Stockdale, 1800, XIII.

Bontius, J., 1769. AN ACCOUNT OF DISEASES, NATURAL HISTORY AND MEDICINES OF THE EAST INDIES, 1629. English Edition, 1769, London, pp.14-16.

Bougainville, L.A. de, 1772. VOYAGE AUTOUR DU MONDE PAR LA FRÉGATE DUE ROI LA BOUDEUSE ET LA FLÛTE L'ETOILE EN 1766, 1767, 1768 ET 1769. (2 volumes). Paris. Vol. 2, p.60.

Carpenter, K.J., 1986. THE HISTORY OF SCURVY AND VITAMIN C. Cambridge University Press, pp.84-88.

Carré, A., 1981. EIGHTEENTH CENTURY FRENCH VOYAGES OF EXPLORATION, *in* STARVING SAILORS, pp.73-84, ed. J. Watt, E.J. Freeman and W.F. Bynum. London:- National Maritime Museum.

Carré, A., 1977. L' Expedition de Dentrecasteaux. Causes et lecons médicales d'un échec. *Actes du colloque franco-allemande d' Histoire de Médecine navale*, Dusseldorf.

Collins, D., 1975. An account of the English Colony in New South Wales 1798. Annotated edition. Sydney: *Roy. Aust. Hist. Soc.*, *1*, 14.

Cook, J., Holograph journal of HMS Endeavour. Australian National Library, Canberra.

Cook, J., Holograph notebook relating to second voyage. Add. Mss. 27, 889, British Library.

Cook, J., 1776. The method taken for preserving the health of the Crew of His Majesty's ship *Resolution* during her late Voyage round the World. *Philosophical Transactions, LXVI*, 402-406.

G.B. Admiralty Sick and Hurt Board, 1767. Letter to Admiralty Board, 1 July 1767 (Admiralty ADM/FP/10) National Maritime Museum.

Gonzales, P.M., 1805. TRADADO DE LAS ENTERMEDADES DE LAS GENTES DE MAR, Madrid.

Gould, R.T., 1978. CAPTAIN COOK. 2nd Ed., pp.22-23.

Hawkesworth, J., 1773. AN ACCOUNT OF THE VOYAGES UNDERTAKEN BY THE ORDER OF HIS PRESENT MAJESTY FOR MAKING DISCOVERIES IN THE SOUTHERN HEMISPHERE, *1*, 4-6, 49-50, 72, 84, 291.

Hulme, N., 1766. Letters to the Sick and Hurt Board, 3 July and 15 August 1766. G.B. Admiralty Series ADM/E/40; 9 July 1766, ADM/FP/9, National Maritime Museum.

Hulme, N., 1768. LIBELLUS DE NATURA AND A PROPOSAL FOR PREVENTING SCURVY IN THE BRITISH NAVY, London, pp.49-68.

Joannet, L.D. Journal de Maladies de la frégate l'Espérance pendant le voyage autour du monde par l'ordre de Monsieur D'Entrecasteaux. Marine 5JJ, 13S, Paris A.N.

Lapérouse, J.F.G. de, 1799. A VOYAGE ROUND THE WORLD PERFORMED IN THE YEARS 1785, 1786, 1987 and 1788 BY BUSSOLE AND ASTROLABE, ed. and translated by L.A. Milet-Mureau. London, Robinson, Edwards and Payne. (2 vols.), *1*, 136, 355; *2*, 503-504.

Lettsom, J.C., 1784. THE WORKS OF JOHN FOTHERGILL M.D. London, pp.321-328.

Lind, J., 1753. TREATISE ON THE SCURVY. Edinburgh, pp. 149-153, 29.

Lloyd, C. and Coulter, J.L.S., 1961. MEDICINE AND THE NAVY, 1200-1900. Livingstone, Edinburgh. (4 vols.) *3*, 294.

MacBride, D., 1767. EXPERIMENTAL ESSAYS ON MEDICAL AND PHILOSOPHICAL SUBJECTS; *57*, An Historical Account of a New Method of Treating the Scurvy at Sea, p.3.

Menzies, A., 1791. Journal of Vancouver's Voyage 1790-1794; Adm MSS *32*, p.641, 8 January 1791. (British Library, (British Library, f3)

Netherlands, Algerneen Rijkaarchieff, 1770. Koloniaal Archief inv. nr. 700, Resolution of 31 December 1770, p.438. The Hague, p.438. Copy in MS 3866, Australian National Library, Canberra.

Renard, P., Traitement de la Maladie de Mr. D' Entrecasteaux, Marine 5JJ4, Paris: Archives

Robertson, G., 1948. THE DISCOVERY OF TAHITI. A JOURNAL OF THE SECOND VOYAGE OF HMS DOLPHIN ROUND THE WORLD, under the command of Captain Wallis R.N. in the years 1766, 1767 and 1768. ed., H. Carrington, London, Hakluyt Society. (Hakluyt Society-Works, Series 2, no. 98, pp.6, 38-41, 116, 113).

Sparrman, A., 1785. A VOYAGE TO THE CAPE OF GOOD HOPE, Dublin, p.121.

Taillemite, E., 1977. BOUGAINVILLE ET SES COMPAGNONS AUTOUR DU MONDE 1766-1769. Journaux de Navigation établis et Commentés. Paris, Imprimerie National (2 vols.).

Vancouver, G., 1798. A VOYAGE OF DISCOVERY TO THE NORTH PACIFIC OCEAN AND ROUND THE WORLD. London. G.G. and J. Robinson (3 vols.) *1*, pp.xv-svi, xvi; *3*, p.499.

Vancouver, G., Journal de St. Germain, *2*, pp.109-114.

Wallis, M. 1965. CARTERET'S VOYAGE ROUND THE WORLD 1766-1769. London. Cambridge University Press for the Hakluyt Society. (Hakluyt Society Publications, Series 2, nos. 124-125, pp.444-454). (Note: Most of the manuscripts in this work belong to the Carteret Collection in the Dixson Library, Sydney).

Watt, J., 1985. Commodore Anson's Circumnavigation (1740-1744): The bequests of disaster at sea. *Transactions and Studies of the College of Physicians of Phiadelphia*, 7 (4), pp.223-238.

Watt, J. Medical aspects and consequences of Cook's voyages, *in* CAPTAIN COOK AND HIS TIMES, ed., R. Fisher and H. Johnston, London. Croom Helm, pp.136-144, 155-156.

Watt, J., 1987. The voyage of Captain George Vancouver 1791-1795; the interplay of physical and psychological pressures. *Canadian Bulletin of Medical History*, May 1987.

Watt, J., 1986. Voyages of peace in an era of conflict: Vancouver and Dentrecasteaux 1791-1795. *Journées Franco-Anglaises d'histoire de la Marine*, Rochefort.

Zulueta, J. de, and Higueras, L., 1981. Health and navigation in the South Seas: The Spanish Experience *in* STARVING SAILORS, ed. J. Watt, E.J. Freeman and W.F. Bynum. London: National Maritime Museum, pp.73-84.

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Clarke Memorial Lecture 1989

Introduction by the President Mr H.S. Hancock

Every two years the Royal Society of New South Wales has the honour to select a senior geologist to deliver a research lecture to commemorate the "Father of Australian Geology", the Reverend William Branwhite Clarke.

The Clarke Lecture and the Clarke Medal were established from a fund collected shortly after his death for the purpose of perpetuating the memory of Clarke's contribution to geology, to science in general, and to the Society.

This is the forty-fifth in the series of lectures.

Our present Lecturer, Dr Erwin Scheibner, is widely known in Australian geological circles, as well as overseas, for his energetic pursuit of a better understanding of geological problems, especially those relating to the origin of belts of folded rocks.

Dr Scheibner was born in Czechoslovakia and received his undergraduate geological education at the famous J.A. Comenius University in Bratislava.

After graduation in 1958, he lectured in geology and palaeontology at the university for nearly a decade, and simultaneously completed a research thesis to gain a Doctorate of Natural Sciences in 1964. His researches were principally devoted to studies of the Pieniny Klippen Belt of the western Capathian Mountains.

Following the upheaval in Czechoslovakian affairs during the Russian invasion in 1968 - the International Geological Congress in Prague was brought to an early end by this event - Dr Scheibner was briefly with the Geology Department of the Technical University in Zurich, Switzerland. Then, to our lasting benefit he was induced by Dr Cliff McElroy, then Director of the Geological Survey of New South Wales, to join the Geological Survey in Sydney.

From 1969 to the present he has been successively a Research Scientist, Senior Research Scientist and Principal Research Scientist within the Survey.

There can be no geologist working in Australia, certainly in eastern Australia, who has not read at least some of Dr Scheibner's extensive writings on the tectonics and structure of eastern Australia.

He early devoted himself to applying the then revolutionary principles of plate tectonics to a fresh analysis of the geological history of New South Wales. By the time of the International Geological Congress in Montreal in 1972 he had formulated the fundamentals of what was to become a widely acclaimed study - at once an analysis and a synthesis - of the geotectonic history and palaeogeography of New South Wales and eastern Australia, set in a plate tectonic framework.

At the same time Dr Scheibner carried out "standard" geological studies of a more directly practical nature:

* the detailed geological mapping and interpretation of a difficult area of about 2700 square kilometres around Taralga in New South Wales (north of Goulburn);
* extremely detailed mapping with colleagues of the coastal zone near Port Macquarie, N.S.W. to document and reveal important features whose existence had not previously been recognised, despite the excellent exposure;
* compilation of detailed and large-scale maps of many parts of New South Wales to facilitate the search for mineral deposits;
* and many others; the list of his achievements is a long one.

Dr Scheibner's international reputation is substantial, as was well demonstrated by the large attendance and high quality of papers presented at the Third Circum-Pacific Terrane Conference on tectono-stratigraphic terranes in Sydney in 1985, which he jointly organised. The resulting volume of preceedings was published by the prestigious American Geophysical Union.

It is apparent, then, that although the Royal Society had a number of other names before it of meritorious contenders to be invited to deliver this lecture, the Council adopted its committee's recommendation of Dr Scheibner unanimously and without hesitation.

It therefore gives me great pleasure to call upon Dr Erwin Scheibner to deliver the 45th Clark Memorial Lecture.

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The Tectonics of New South Wales in the Second Decade of Application of the Plate Tectonics Paradigm

Erwin Scheibner

45th Clarke Memorial Lecture, delivered to the Royal Society of New South Wales, 18th October, 1989

INTRODUCTION

Let me start with a quote of Thomas Jefferson: "Ignorance is preferable to error; and he is less remote from truth who believes nothing, than he who believes what is wrong". Perhaps this quote is out of context here, but I have to disagree with it in a scientific research context, and I am sure, so would have Reverend W.B. Clarke. I base this on a study of his publications which indicate a positive and progressive approach to geologic research, not to mention his acceptance of Charles Darwin's theory of natural selection at a time when it was considered to be heretical in religious circles.

Progress of knowledge is not possible if we limit our investigations, our thoughts, our ideas, just to be on the safe side, just to not commit the sin of being wrong. What Jefferson said in reality would mean voluntary sterility and emptiness. To achieve progress of knowledge, we have to commit ourselves to hypotheses, to the construction of models, and have the courage to admit that only some of them have developed into theories, and that some were partially or totally wrong. In this process we would have explored some new possibilities, and negative results have positive values also.

This bit of philosophising perhaps best illustrates my approach. It consists of data gathering, sorting, analysing, followed by a synthesis which results in a specific model or multiple models. The next step is the checking of the predictions of the model(s); their validation, modification or rejection in the process of back-feeding and revision.

The aim of this lecture is to assess the status of tectonics of New South Wales in the second decade of the application of plate tectonics. This paradigm on its own is nearly thirty years old, but its application in eastern Australia started about twenty years ago.

THE PLATE TECTONIC PARADIGM

History

The foundations of the plate tectonics hypothesis were laid by major advances in geophysics during the late nineteen-fifties, but they have to be looked at from the perspective of the mobilistic early ideas of Wegener (1912, 1929), Ampherer (1906), Argand (1924) and Du Toit (1937). We have to acknowledge the contributions of Carey (1958) to the revival of mobilistic thinking. These geophysical advances involved palaeomagnetism, marine geophysics and morphology of oceanic areas. Marine geophysics and systematic oceanographic studies resulted in the discovery of the mid-oceanic ridges. The then existing theories could not explain the longest mountanous region on Earth.

In 1960 Hess in a lecture (Hess, 1959) proposed a hypothesis which solved the puzzle of mid-oceanic ridges, but the first publication was by Dietz (1961), who independantly proposed a similar hypothesis. His article was called: "Continent and ocean basin evolution by spreading of the sea floor." He formulated the "spreading sea-floor theory", including four important postulates which are the basis of plate tectonics. In 1962 Hess published his ideas and further elaboration was done by Dietz (1963), Vine and Matthews (1963), Morley and Larochelle (1964), Hess (1965), Wilson (1963, 1965a, b) Vine (1966), Pitman and Heirtzler (1966) and Sykes (1967).

As with many hypotheses, it is difficult to retrace the exact history of the progressive formulation of plate tectonics. When the foundations were laid the time was "pregnant", and hence several scientists arrived at similar conclusions using slightly varying terminology. This diffusion of new ideas was enhanced by the early circulation of preprints. Morgan first formulated the hypothesis at the AGU meeting in Washington in April 1967 (Morgan, 1968). McKenzie and Parker (1967) concisely defined the plate tectonics hypothesis and used it to explain the mechanisms of earthquakes and other tectonic features around the North Pacific. Le Pichon (1968) showed that plate tectonics provided a coherent kinematic picture on a global scale, and he made a partly successful attempt to reconstruct plate kinematics for the Cainozoic. Isacks et al. (1968) made the first systematic use of plate tectonics to explain worldwide tectonic phenomena, mainly the distribution of earthquakes. This last paper probably had the widest impact on the earth science community.

While Morgan (1968) called the rigid spherical caps of lithosphere "blocks", McKenzie and Parker (1967) called them "plates", which seemed more appropriate in view of their relatively small thickness. The hypothesis itself has been variously called the "paving stone" theory by McKenzie and Parker (1967) and the "new global tectonics" by Isacks et al. (1968). The term "plate tectonics" was apparently first introduced by Vine and Hess in 1968, but published in 1970 by these authors after others had used their term in publications. Things were happening very fast...

After the explosion of general and applied regional papers, the first compendia appeared in the early seventies, like "Continents Adrift", readings from the "Scientific American" introduced by Tuzo Wilson (1973), and the handbook "Plate Tectonics" by Le Pichon et al. (1973), followed by many other handbook- type publications and special compendia. In 1973 the Geological Society of America published a bibliography of continental drift and plate tectonics (Kasbeer, 1973), and even if incomplete, it had 96 pages.

Concepts

In the late sixties the following three concepts were fully realized:

1) The primary rheological stratification of the upper mantle and crust into lithosphere and asthenosphere governs the mechanical behaviour of the upper layers of the Earth. Barrel already in 1914 formalized this model and named the top elastic layer the "lithosphere" and the fluid layer on which it floats the "asthenosphere". During development of the plate tectonics theory, Elsasser (1966), McKenzie (1967a) and Oliver and Isacks (1967) elucidated various aspects of this rheological stratification. However, it is valid for the first approximation only and is time dependant.
2) Most of the mechanical energy now spent at the surface of the Earth is spent within the narrow seismic belts. This was clearly demonstrated by Benioff (1954), but increased accuracy and volume of data increased the precision, and the plate tectonic explanation was provided by Isacks et al. (1968).
3) There are important geometrical constraints imposed on the displacements of rigid bodies at the surface of the Earth. The geometrical constraints resulting from displacements on a planar Earth were first described by Wilson (1965a) and those resulting from displacements on a spherical Earth by Bullard et al. (1965), i.e. application of Euler's theorem. Application of this theorem postulates that if plates, including continents have drifted as rigid bodies, their position prior to drift can be calculated by rotation about a radius through some point (pole of rotation) on the surface of the Earth. A complication arises because the Earth is not a regular sphere. Stresses are generated in plates as they move into areas with different surface curvature.

Definition

Plate tectonics explains most of the tectonic and seismic activity now occurring in the upper layer of the Earth as resulting from the interaction of a limited number of rigid, spherical lithospheric plates whose boundaries are the seismic (mobile) belts of the globe.

The boundaries between plates are of three basic types:

1) diverging boundaries where new lithosphere is created;
2) converging boundaries where lithosphere is being consumed;
3) conserving boundaries or neutral, where no lithosphere is created or consumed.

The above has to be qualified as being valid only as a first approximation in space and time.

The rheological properties of lithosphere are transient, i.e. time dependant on pressure and temperature distribution. While plates are rigid instanteneously, they do deform internally. However, the magnitude of plate margin and interior deformation differs by order(s) of magnitude. For example, if the large amounts of missing oceanic crust in the eastern Pacific, not to mention the absence in the present oceans of pre-Mesozoic oceanic crust worldwide, are considered, it is clear that thousands of kilometres of plate convergence occurred during Meso-Cainzoic time, and this has been absorbed in a few, relatively narrow mobile tectonic belts at plate margins, and substantially less by intraplate deformation, such as the foreland fold and thrust belts and various intraplate contractional structures. The present distribution of seismicity is in agreement with the last statement,i.e. little seismicity occurs in the plate interiors, but it should not be ignored.

Another important point is that the basic type of plate boundary is dependant on the configuration of the plate boundary and the geometry of the rotating plates. The consequence is varying types of plate boundaries along individual plates, cf. the western boundary of the Pacific plate. Convergence or divergence is seldom perpendicular to plate boundaries, with oblique geometry resulting in structural complexities and requiring episodic adjustments; an example could be the jumps in spreading centres. At conserving boundaries the changing geometry often results in transpression or transtension (Harland, 1971); an example could be sea-floor spreading along so-called "leaking transform faults".

Limitations

The above definition of plate tectonics imposes limitations in that it can provide reliable models explaining tectonic and seismic activity only for the time for which we have seismic records, i.e. for the present. We can construct quite precise models using the known age of the oceanic crust, i.e. we can well reconstruct the Meso-Cainozoic history of at least some parts of the world (Atwater, 1970). But to try to reconstruct the pre-Mesozoic tectonic history, we have to resort to hypotheses which are based on the acceptance of conceptual models as being correct, using actualistic principles for guidance. It is necessary to keep in mind the already mentioned qualifiers in respect of plate tectonic concepts and definition, and the fact that the early and popular plate tectonic conceptual models were too simplistic. Because so many variables come into play, the resulting complexities require revisions not only of the conceptual models, but in the first place, the early application of these models in regional tectonic studies - in our case, in the study of the Tasman Fold Belt System or Tasmanides.

Causes of Plate Tectonics

One view is that in essence the Earth appears to be a thermal engine, with escaping heat causing the formation of lithospheric plates. There appears to be little coupling between the asthenosphere and lithosphere. Because the bottom of oceanic plates is inclined, reflecting their progressive cooling and proportional thickening, oceanic plates can glide on such a surface due to the gravitational force. Once subduction starts at the site of the oldest and gravitationally most unstable oceanic lithosphere, the process will continue until a new plate kinematic regime is necessitated because of the unstable space relationship between the heterogenous rotating plates. Some authors have calculated that even if the sites of sea-floor spreading have extensional character, they also exert a push on the plates.

Another view helds that the above forces are negligible and the plates are driven by mantle convection. There definitely has to be a replacement flow in the asthenosphere from the sites of subduction to the sites of sea-floor spreading.

A recent study (Dziewonski and Woodhouse, 1989) of three-dimensional Earth structure based on seismic tomography indicates that mantle convection involves the whole mantle. The large, low velocity anomalies persist in the main areas of sea-floor spreading and hot spots (Pacific and Atlantic) throughout the mantle. It is possible that these lower velocity mantle anomalies are in turn influenced by the over 200 m.y. long cyclical growth of supercontinents (Middle Proterozoic, Late Proterozoic and Late Palaeozoic)(cf. e.g. Hoffman, 1989). The supercontinents assemble over downgoing currents and, after a prolonged period of during which they act as a thermal blanket, they cause accumulation of heat resulting in rearrangement of mantle convection. New upwelling currents subsequently form beneath the supercontinents leading to their dispersal. So, in essence, the thermal lithospheric lids influence the deep mantle circulation which might drive them ...

"Irreversible" versus "Reversible" Trends in Mantle Differentiation

In the seventies all the evidence pointed to an irreversible trend in mantle evolution and overturn (Rubey, 1951, 1955; Ringwood, 1969, 1972). It was thought that mantle evolution proceeds through a process of proto-mantle degassing and differentiation. This process was considered irreversible in the sense that, once segregated, the easy melting and volatile components of the mantle cannot be recycled to recreate the proto-mantle. During the process of degassing, accretion of the outer spheres, i.e. atmosphere, hydrosphere and lithosphere, of the Earth takes place. One of the ultimate products of proto-mantle evolution is continental-type crust. Segregation of continental crust can occur by vertical and lateral differentiation, and because of its bouyancy it was thought that it can not be subducted and so recycled. The vertical differentiation involved fractional melting of the proto-mantle and buoyant rise of the low-melting lighter components into crustal levels. The lateral differentiation of the proto-mantle (Ringwood, 1969) had two stages. The first was derivation of the mafic crust and residual mantle at centres of sea-floor spreading, and second derivation of the easy melting component by partial melting of oceanic lithosphere in subduction zones. I accepted these premises in my tectonic studies at that time (Scheibner, 1972a, 1976).

Advances of knowledge, however, force revision of the above ideas.

First it has to be considered that the present global spreading ridge is the site where almost one-quarter of global heat is dissipated, basically with the help of seawater cooling. In this important physical event, vast chemical changes occur (Fyfe,1987). The oceanic lithosphere becomes hydrated and charged with other volatiles, such as CO2 and sulphur species. At the same time the content of lithophile elements such as Na, K, U, is increased. In cooler regions away from the spreading centres there is increasing evidence for serpentinization of ultramafic rocks, perhaps on large scale (MacDonald and Fyfe, 1985). Such a process, while not yet fully quantified, loads the oceanic lithosphere with volatiles and even heat-producing elements before subduction. So what is subducted is a spilitic crust and an unknown amount of serpentinite in the upper mantle.

Gilluly (1971) suggested that some sediment subduction was necessary to explain the chemistry of subduction-related magmas and importantly, the lack of sediments at some converging plate margins, e.g. the western edge on North America. However, this view was strongly opposed by some contemporary geochemists, particularly those working on Sr isotopes. Also geophysicists considered that light materials could not be subducted due to their buoyancy. But now with modern observations these objections can be refuted.

Reflection seismic data show that some trenches are sediment starved but in others subduction of sediments does occur, for example by tectonic underplating. Further, sediment subduction is facilitated by tensional faulting on the downgoing oceanic lithosphere, resulting in formation of grabens and horsts. The subducting lithosphere is like a conveyor belt, with the buckets being grabens filled with sediments and also offscrapings from the ridges (Hilde and Uyeda, 1983).

Subduction and recycling of sediments has become respectable. The subducted sediments appear to supply elements which strongly influence crustal and mantle melting, and recently Ozima et al. (1985) suggested that carbon isotopes in some diamonds had biological precursors! All these ideas raise doubts not only about the irreversible development of the mantle, but also about the permanency of continents (Fyfe, 1987). If sediments are recycled in masses of the order of km3 per year, and continental margins can be tectonically eroded during subduction, Fyfe (1987) posses the question: "are continents recycled into the mantle on significant scale?" He thinks the answer is yes, as suggested earlier by Anderson (1981). He posses the question is there a tendency to ingass instead of the generally perceived degassing of mantle? Of course we cannot neglect the opposing views (e.g. McLennan and Taylor, 1980) which suggest that the growth of continental crust is not steady state, but that 65-75% of it formed in the Archaean time.

There is another aspect which needs clarifying, namely that if continental- type crust is thinned during rifting and extension to about one-third (about 10 km) or less, it can be subducted in a similar fashion to oceanic crust. The deciding factor in subduction is really the dense upper mantle component of the lithosphere. Yet there is another process which can contribute to recycling of the crust, namely delamination of the basaltic lower crustal layer in which some felsic rocks are interspersed, as suggested by Bird (1980) and Kay (1987). Basalts at a certain depth (P/T conditions) convert into eclogites, the density of which exceeds the density of the upper mantle into which the eclogites would sink due to negative buoyancy.

At present it appears that the mantle experiences degassing and ingassing, and the early simplistic models have to be modified. Chemical geodynamics (Zindler and Hart, 1986) suggests that the mantle is heterogeneous on both very small (tens of metres) and very large (over 1000 kilometres) scales. Patchett et al. (1981), studying Hf isotopes, invisaged mantle models where depleted and enriched areas appear to be closely juxtaposed. Depleted patches have been involved in melting, whereas enriched patches may be subducted oceanic lithosphere. Against these heterogeneity-generating mechanisms is set large and small-scale mantle convection which eradicates heterogeneities.

The model proposed by Anderson (1981) suggesting continuous recycling of continental material into mantle, with some variation allowing for faster rate of accretion during Archaean time, appears to be consistent with the present state of knowledge.

Modified Plate Tectonics

Some of the advances of plate tectonics have been dealt with; however, time does not allow discussion of many other important aspects. Therefore, some of these can be only listed:

1) A-type subduction (A stands for Ampherer or Alpine) refers to subduction of continental-type lithosphere as opposed to B-type (B stands for Benioff) which involves subduction of oceanic lithosphere (Bally and Snelson, 1980). B-subduction can involve disposal of thousands of kilometres of oceanic lithosphere, whereas A-subduction is in the order of tens to hundreds of kilometres, usually below 500 km.

2) B-type subduction has two modes: in the Mariana-type there appears to be absence of coupling between the converging plates, whereas in the Chilean-type, usually having a lower angle of dip, coupling is common (cf. Uyeda, 1981). Back-arc regions in these settings differ: extensional in the Mariana-type as opposed to contractional leading, for example, to foreland fold and thrust belts (A-type subduction) in the Chilean-type subduction setting.

   Related to type of subduction is the style of the accretionary prism. If complete decoupling of converging plates occurs, all the sediments can be subducted without the formation of an accretionary prism. The other extreme is such strong coupling that all the sediments are scraped off the lower plate and the result is a wide accretionary prism. A full range of variations between the above extremes can develop, including progressive change. In extreme cases of coupling the upper plate can be tectonically eroded during subduction. The upper plate can be tectonically underplated with sediments or with parts of, or the whole, lower plate.

3) A subduction-related igneous arc develops only if an asthenospheric wedge is between the upper and lower plate. An unresolved problem remains the question: does the asthenosphere have to be "primordial" mantle, or can it develop by metasomatism and partial melting of the upper plate. The lower plate is progressively dehydrated and water plus other volatiles cause partial melting of the overlaying asthenosphere and to lesser degree the lower plate itself. The upper plate functions as a thermal and gravity filter, with magmas derived by partial melting rising to levels of neutral buoyancy and spreading out laterally. The result is igneous underplating which increases the density and temperature of the upper plate. Subsequent batches of magma can rise higher, and eventually the hydrostatic head enables eruption on the surface.

4) The various types of orogenic igneous rocks, M-, I-, A- and S-type, characterize certain types of tectonic regimes (Pitcher, 1987). M-types are developed in ensimatic intra-oceanic volcanic arcs and in areas of strong extension. I-types occur in volcanic arcs and continental margin magmatic arcs. A-types (Collins et al., 1982)(A stands for alkaline and not anorogenic) appear to characterize rifts and volcano-tectonic depressions. S-types (Chappell and White, 1974) occur in high-temperature metamorphic belts of varied origin and in belts where large-scale overthrusting of continental crust has occurred.

5) The complex relationships observed now and similarly in the past in areas of plate interaction are the rule rather than the exception. Oblique plate movements are examples.

6) Lateral segmentation in plate convergent (orogenic) belts is caused by major, along strike variations in the dip of subducting plates and by varying lithospheric properties of involved plates.

7) During plate convergence, especially B-subduction, various, often exotic lithospheric fragments, the so-called tectonostratigraphic terranes, can be accreted to upper plates. In orogenic belts which formed at active, mainly converging plate margins, the regions beyond the autochthonous miogeoclinal zone could contain "suspect" terranes (Coney et al., 1980). They are "suspect" in that their original palaeogeographic settings are uncertain, and for some terranes there is palaeontological and/or palaeomagnetic evidence which shows that they originated in regions far removed from where they now occur. It is suspected that allochthonous tectonostratigraphic terranes do occur in the Tasmanides (cf. Leitch and Scheibner, 1987) (figures 1 and 2). The probability of the presence of terranes increases with distance away from the old craton. The general concensus is that exotic terranes occur in the New England Fold Belt, while those in other fold belts remain contentious. The individual fold belts can be regarded as super-terranes characterized by different times of terrane accretion. Episodes of terrane accretion and tectogenic/orogenic activity appear to be closely related.

8) Besides continuous deformation in the accretionary wedge or prism, episodes of deformation (tectogenic, less frequently sensu stricto orogenic) are associated with changes in the mode of subduction, coupling of converging plates, docking and collision of tectonostratigraphic terranes and other types of collisional events, which can range from collision of intra-oceanic volcanic chains, oceanic plateaux, volcanic arcs, through microcontinents to collision of continental plates.

Even from this brief list it is obvious that the early conceptual plate tectonic models were too simplistic and we have to keep this in mind during the formation of regional tectonic syntheses. To give an example, let me mention the often repeated argument that the Early Palaeozoic volcanic arcs in the Tasmanides were not proper arcs as they do not appear to have associated acrretionary prisms. Firstly, the arc complex could represent an allochthonous teranne and be separated from its associated accretionary prism, and secondly, the style of subduction could have been such that no accretionary prism developed due to complete decoupling of converging plates.

STRUCTURAL FRAMEWORK OF NEW SOUTH WALES

It is necessary to emphasize that structural geology and tectonics (tectonic geology) are not synonymous. Structural geology is concerned with the description of structural elements and the mechanism of deformation, whereas tectonics is concerned with the form and evolution of the Earth's crust and lithosphere. Much confusion in regional geology stems from the failure to recognize essential differences between past palaeogeographic or palaeogeologic situations (units), and

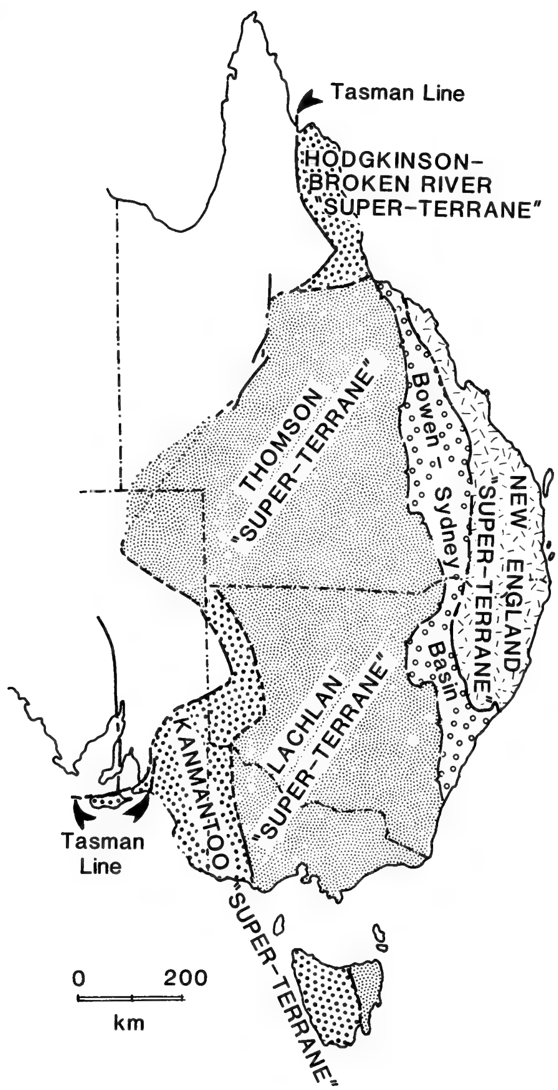

Figure 1. Schematic map of the super-terranes in eastern Australia. Modified from Leitch and Scheibner (1987).

Figure 2. Schematic map of suspect terranes in eastern Australia. Modified from Leitch and Scheibner (1987).

those of presently existing structures which developed from them, i.e. between the stratotectonic and morphotectonic or structural regimes of Rast (1969) (cf. also Scheibner, 1972b, 1976; Rickard and Scheibner, 1975). While description of structures, i.e the structural framework as it exists now, can be quite objective, stratotectonic interpretations are based on conceptual models and are to a lesser or larger degree hypothetical.

The eastern third of Australia, and New South Wales being part of it, comprises three main structural elements:

1) The composite, Early to Middle Proterozoic Australian Craton on the west, with associated epicratonic basins and paratectonic fold belts (Rutland, 1976) (figure 3);

2) The composite, orthotectonic Tasman Fold Belt System (TFBS) or Tasmanides, in the east (Scheibner, 1974b, 1987) (figure 3);

3) The widespread, Late Carboniferous to Holocene platform cover of sedimentary and volcanic rocks, some of which are related to post-Gondwanaland break-up and separation (Veevers, 1984).

The Australian Proterozoic Craton and Paratectonic Fold Belts

The Early to Middle Proterozoic Australian Craton is further subdivided into major structural units exposed in shield-like blocks outside NSW (Geological Society of Australia, 19781; Plumb, 1979; Rutland, 1976). In NSW these complexes form an internal massif -Broken Hill and Euriowie Blocks-in the paratectonic Adelaide Fold Belt. The Late Proterozoic to Palaeozoic sedimentary cover of the Craton is related to the development of the Tasmanides (Late Proterozoic rifting), and the part which has been deformed is the Tasman Paratectonic Zone of Rutland (1976). The southern part of this zone, the Adelaide Fold Belt, was deformed during the Middle Cambrian to Ordovician by the Delamerian Orogeny of Thomson (1970).

The Tasman Fold Belt System

The boundary between the Proterozoic Craton and the Tasmanides follows the Tasman Line of Hill (1951) as emended by Harrington (1974) and Scheibner (1974b), and more recently by Murray et al. (1989).

The Tasman Fold Belt System (TFB)(Scheibner, 1974b, 1987) comprises five orthotectonic orogenic belts and a foredeep basin. The fold belts become progressively younger from west to east: Kanmantoo, Thomson, Lachlan, Hodgkinson-Broken River and New England (figure 4). These structural elements differ in the timing of their stages of tectonic evolution from the pre-cratonic stage (active plate margin setting) featuring turbiditic sedimentation, widespread orogenic igneous rocks and scarce ophiolites and greenstone, through the transitional tectonic stage with molassic sediments, bi-modal volcanics and post-kinematic intrusives, to the final cratonic (neocratonic) stage, which is followed by platformal sedimentation. The transitional tectonic basins (Doutch, 1972; Scheibner, 1972, 1976) are usually referred to as "foreland, downwarp and successor basins" in the North American tectonic literature.

The youngest New England Fold Belt in the east is separated from the older fold belts by the Bowen - Sydney Basin, a rift-initiated molassic foredeep.

New South Wales (figure 5) is built by the Kanmantoo, Lachlan and New England Fold Belts, and the Bowen-Sydney Basin (mainly its sub-basins the Sydney and Gunnedah Basins). Very minor parts of the Thomson Fold Belt possibly occur in the northern border region (cf. Murray et al., 1989; Finlayson et al., 1989).

The Kanmantoo Fold Belt

The Kanmantoo Fold Belt (KFB)(Scheibner, 1972c, 1976, 1987) occupies western Tasmania, west of the Tamar Fracture Zone (Williams, 1978), western Victoria, west of the Woorndoo Fault (Ramsay and VandenBerg, 1986), the adjoining southeastern part of South Australia east of the paratectonic Adelaide Fold Belt (Preiss, 1987), and an area in northwestern NSW (west of the Koonenberry Fault Zone and also the Morden Block just to east of it), all west of the Darling Depression, which is part of the Lachlan Fold Belt. Large tracts of this orogenic belt are concealed below the Cainozoic Murray Basin, but aeromagnetic and gravity anomalies help to link outcrops and subsurface features (Brown et al., 1988; Murray et al., 1989), namely the Stavely Greenstone Belt and Dimboola Gravity-Magnetic Ridge in Victoria with the Lake Winlow High, and thus delineate the eastern margin of the KFB. Proterozoic basement inliers occur in Tasmania and NSW.

The relationship of the east-verging Stawell Zone in Victoria to the KFB is a problem. While the fold and thrust belt structure of it is clearly related to the deformation of the Lachlan Fold Belt (Cox et al., 1983), in a stratotectonic sense this zone may be in a similar relationship to KFB as the complexes in the Morden Block in NSW, where Cambrian strata are unconformable beneath the Middle Cambrian molassic rocks typical of the KFB.

The KFB developed from a Late Proterozoic to Early Palaeozoic pre-cratonic tectonic province, Middle Cambrian to Early Ordovician transitional tectonic province, and Devonian to Early Carboniferous complexes overlaping from the neighbouring Lachlan Fold Belt in the east. After the continent-wide Carboniferous Alice Springs-Kanimblan Orogeny the KFB behaved as a neocraton.

The Thomson Fold Belt

The Kanmantoo Pre-Cratonic Province probably continued farther north into Queensland, but this area is completely concealed by the post-Kanimblan cover and it is difficult to separate clearly the possible KFB complexes from subsequent Middle Palaeozoic ones. For this reason an all-embracing name, the Thomson Fold Belt (TFB) was introduced by Kirkegaard (1974). Recent seismic reflection data indicate that the crustal structure of TFB differs from that of the neighbouring fold belts (Finlayson et al., 1989).

In NSW the TFB occurs in the northern border region: in the Yantabulla Block (Scheibner, 1985b), where the Nebine Ridge continuing from Queensland appears to be terminated by cross faulting. To the south is a region which was affected by Early Devonian rifting and subsequent Middle Devonian deformation. This last zone is included in the Lachlan Fold Belt (Scheibner, 1988; Murray et al., 1989; Finlayson et al., 1989). The position of the Tibooburra and surrounding Milparinka, McDonalds Peak and Overflow Blocks (Scheibner, 1985b) is not completely clear. At present they are included in the TFB (cf. Thomson Regional Gravity Province of Murray et al., 1989). The above is a redefinition of the earlier (Scheibner, 1987) southern boundary of the TFB.

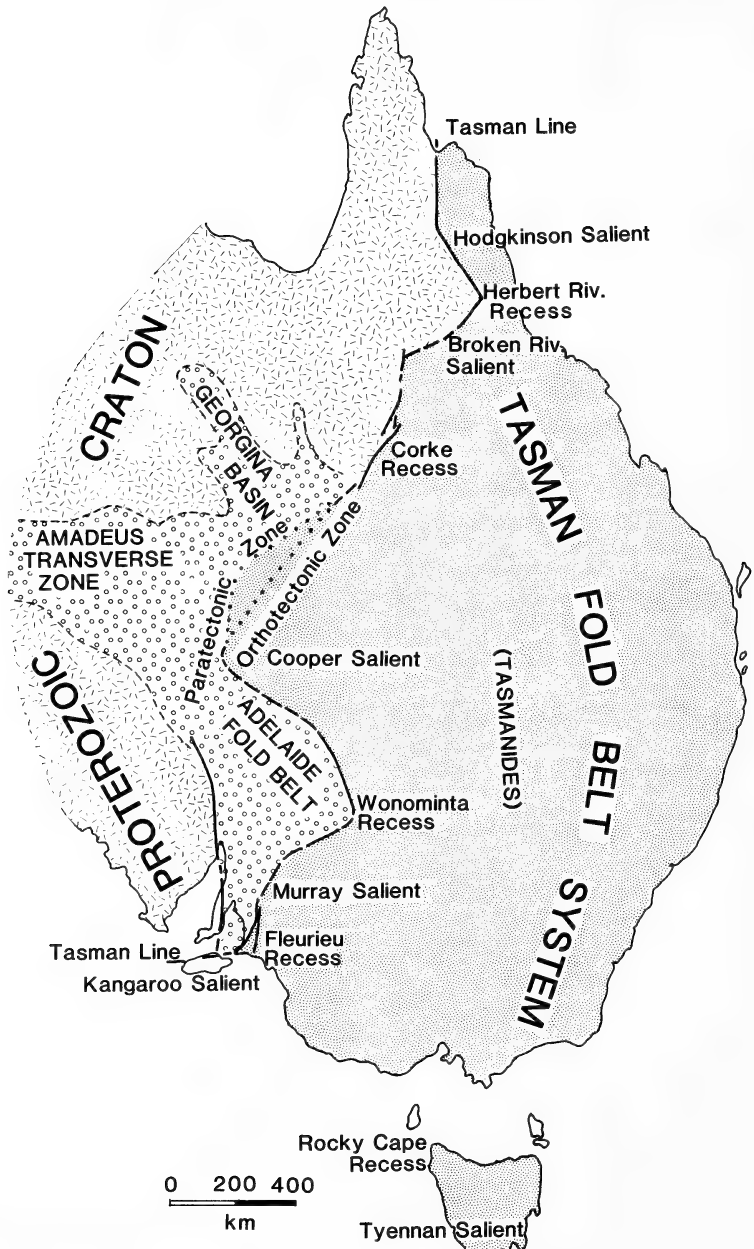

Figure 3. Schematic structural map of eastern Australia showing the Tasman Fold Belt System and para-tectonic belts. Modified from Scheibner (1987).

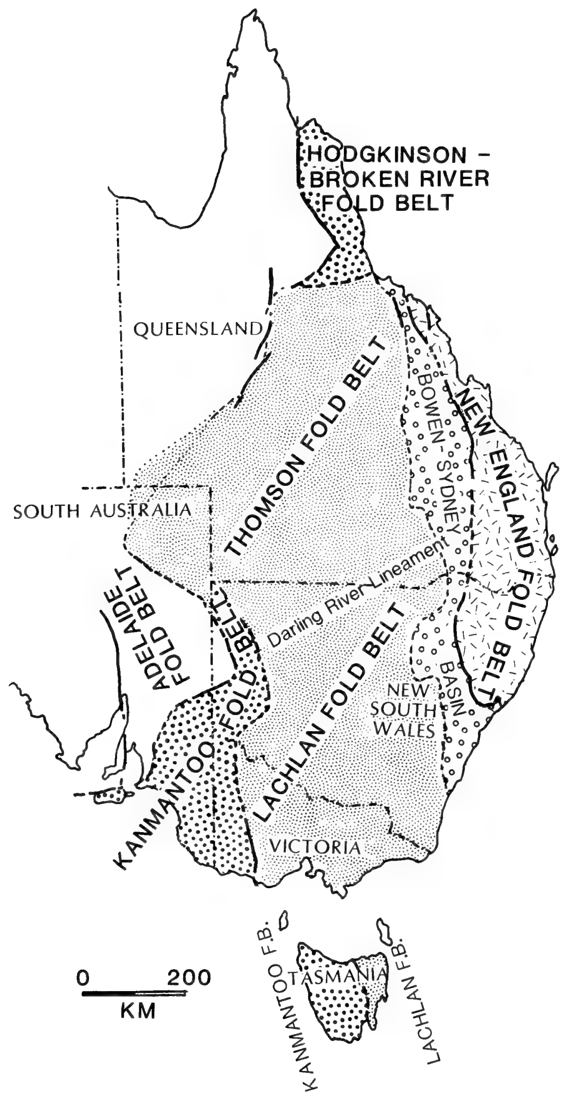

Figure 4. Schematic structural map of eastern Australia showing the fold belts. Modified from Scheibner (1987).

The pre-cratonic development of the TFB was terminated during a Middle to Late Ordovician episode of tectogenesis. The Devonian to Early Carboniferous Burdekin, Drummond and Adavale Basins represent transitional tectonic stage (Murray and Kirkegaard, 1978). After the Kanmiblan Orogeny the TFB changed into a neocraton.

The Lachlan Fold Belt

The Lachlan Fold Belt (LFB) (Scheibner, 1972b; an earlier synonym is the "Central and Southern Highland Fold Belt" of Packham, 1969) is a complex orogenic belt. There are no known outcrops of pre-Cambrian basement. The Cambrian history remains obscure (Ramsay and VandenBerg, 1986). The Early Palaeozoic history of a major part of the LFB culminated in a Late Ordovician to Early Silurian collisional belt during the Benambran Orogeny (Pogson, 1982; Scheibner, 1982), while elsewhere sedimentation continued uninterrupted, i.e. the Melbourne Zone (VandenBerg, 1978). Early-Middle Silurian extension affected the eastern half of the LFB followed by localized Late Silurian-earliest Devonian Bowning-Bindi deformation. The western half of the LFB was affected by extension during the latest Silurian-earliest Devonian. The Middle Devonian Tabberabberan Orogeny of variable intensity terminated the pre-cratonic developement, which was followed by Devonian to Early Carboniferous transitional tectonic complexes. The Kanimblan Orogeny converted the LFB into a neocraton.

The New England Fold Belt

The easternmost and youngest fold belt of the Tasmanides is the New England Fold Belt (NEFB)(Packham, 1969). It builds northeastern NSW (the New England Province), and southeastern Queensland (the Yarrol Province) (Day et al., 1978). It is separated from the orogenic belts to the west by its foredeep, the Bowen-Sydney Basin. The pre-cratonic development of the NEFB was complex and started in the Cambrian (Cawood, 1976). Its pre-cratonic development was punctuated by Middle Devonian and Carboniferous tectogenesis, followed by Early Permian reactivation, which resulted in pre-cratonic regimes in the east and transitional tectonic in the west. The pre-cratonic regime was terminated by the Middle Permian Hunter Orogeny (Leitch, 1974). The deformation of transitional tectonic complexes was spread over the Permian and Triassic Periods (Hunter-Bowen Orogeny, Day et al., 1978; Korsch and Harrington, 1981). The post-kinematic igneous activity lasted into Cretaceous time (Murray, 1986).

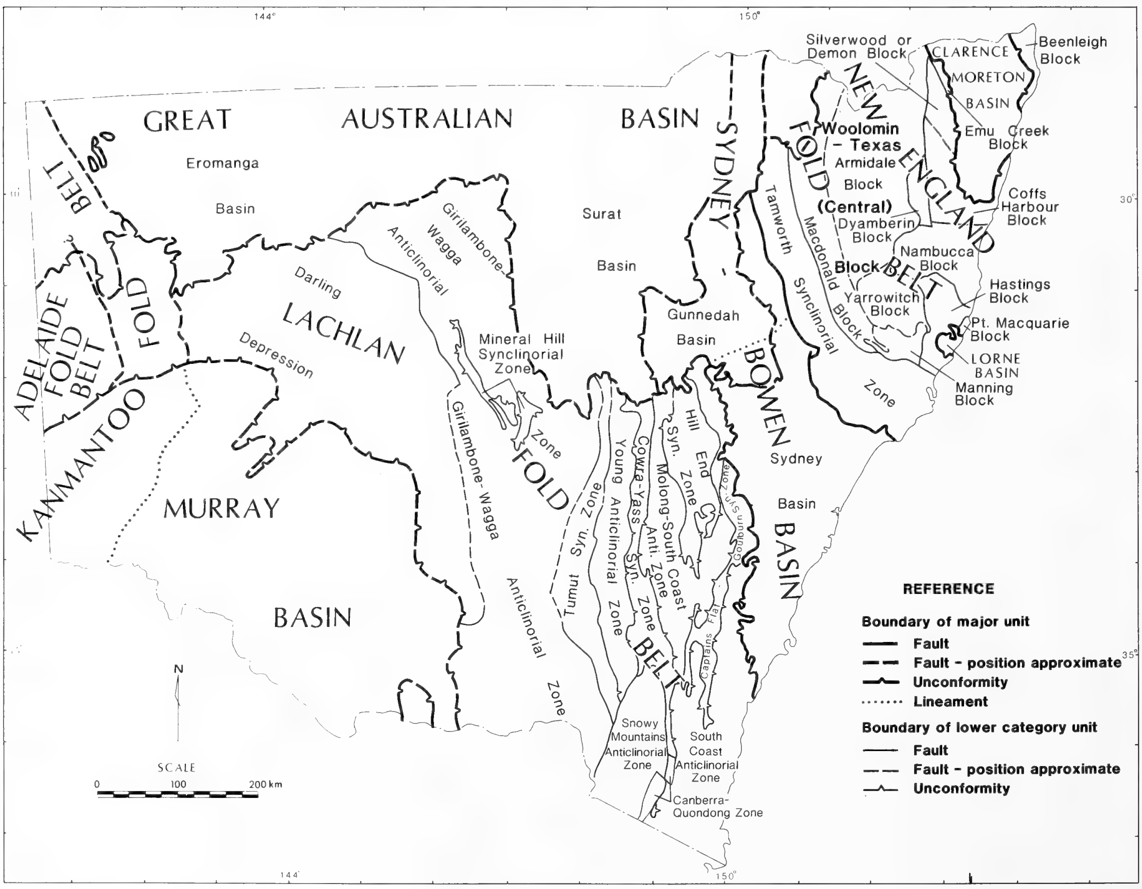

Figure 5. Schematic structural map of New South Wales. Modified from Scheibner (1985b).

The Sydney-Bowen or Bowen-Sydney Basin

The latest Carboniferous to Triassic Bowen-Sydney Basin is a foredeep of the NEFB and at the same time it represents a platform cover on older fold belts to the west. The NEFB was thrust over the inner deformed part of the Bowen-Sydney Basin along the Hunter-Mooki-Goondiwindi Thrust System and equivalent thrusts in Queensland.

Cratonic Cover and Passive Margin Related Complexes

Extensive areas of NSW are concealed beneath cratonic igneous and sedimentary cover sequences. Latest Carboniferous to Permian plus limited Triassic sediments fill infra-basins beneath the Murray Basin. The extent of Cretaceous sediments beneath the Cainozoic strata of the Murray Basin is less well known. Extensive regions of northern NSW are concealed by the Jurassic-Cretaceous sediments of the Great Australian (or Artesian) Basin (Hawke and Cramsie, 1984). In the New England area the Mesozoic Clarence-Moreton Basin conceals the older rocks. Elsewhere, a thin veneer of Quaternary sediments and deep weathering obscure the basement rocks.

Some of the cover sequences are related to the Mesozoic break-up of Gondwanaland and the developement of a passive margin (Veevers, 1984). Intra-plate igneous rocks of Jurassic-Cretaceous age are probably related to upper plate setting during rifting and break-up (Lister et al., 1986), whereas the Cainozoic ones, mainly the ubiquitous basalts, are probably mainly related to 'hot spots' activity (Sutherland, 1978).

Second Category Structural Units

The above-described major structural units can be further subdivided (figure 5). The outcrop regions of fold belts can be divided into structural zones (e.g. Gray, 1988) and structural blocks (e.g. Day et al., 1983). In NSW an attempt was made to recognize the tectonic style of structural zones, i.e. anticlinorial synclinorial zones (Scheibner, 1972b; 1976; revised in 1985b).

Anticlinorial zones are composite anticlinal or elevated structures composed of the oldest rocks in the region and the more deeply eroded intrusions and metamorphics, while the synclinorial zones are synclinal or depressed and composed of the youngest rocks in the region. The boundaries between structural zones can be hinge lines, regional faults, thrusts, reverse faults, igneous bodies, major unconformities, etc. (cf. Scheibner, 1972b; 1985b). A structural zone can have the character of a structural block or comprise several blocks (cf. Scheibner, 1985b). For that matter a structural zone can represent a tectonostratigraphic terrane (e.g. the Tamworth Terrane).

The usefulness of the recognition of structural zones and other lower category structural units lies in the fact that they are part of a quite objective structural framework and enable more precise description of tectonic and metallogenic models.

TECTONICS OF NEW SOUTH WALES

The time limitation does not allow a complete review of the tectonics of NSW. For this reason only selected topics will be addressed, especially those where new data lead to revision of earlier tectonic models, and also some aspects were not addressed previously. A new synthesis of of geology and tectonics of New Sout Wales is the subject of a New South Wales Geological Survey project which has just commenced.

Proterozoic Development

The Proterozoic tectonic development of eastern Australia east of the Tasman Line remains uncertain due to limited outcrop present as inliers in the Kanmantoo Fold Belt in Tasmania (Williams, 1978) and NSW (Leitch et al., 1987; Scheibner, 1987), and disputed occurrences in Queensland (cf. Murray, 1986). The existence of Precambrian basement elsewhere in the Tasmanides is controversial and opinions range from totally old continental basement (Rutland, 1976), through intermitent old basement (microcontinents) and young Palaeozoic ensimatic basement (Scheibner, 1974a; 1987) to exclusively Palaeozoic oceanic basement (Crook, 1980).

Proterozoic and even older isotopic ages have been recorded from old zircons in Palaeozoic granites (Williams et al., 1983; Williams, 1989), and similar zircons, however with a different frequency of distribution, occur in Ordovician sediments in the Southern Tablelands (Williams, 1989). Nd and Sr isotope studies indicate source rocks of about 1400 Ma for the Kosciusko and Berridale Batholiths (McCulloch and Chappell, 1982).

It is permissible to interpret these isotopic data as indicating: old heterogenous continental basement; subducted and tectonically underplated rocks; nd/or Palaeozoic source rocks with isotopes derived from terrigenous components.

Analysis of the paratectonic belt and deductions of the Early Palaeozoic development of the Tasmanides can help in the rationalization of the above problems.

Palaeoproterozoic-Mesoproterozoic Development in the Paratectonic Belt

The rocks in NSW which represent this time are described as the Willyama Supergroup intruded by post-kinematic granitoids (Stevens et al. 1988). They build basement inliers, the Broken Hill and Euriowie Blocks, in the paratectonic Adelaide Fold Belt (AFB), and were strongly affected by the Delamerian Orogeny. These blocks are adjacent to the concealed Curnamona Cratonic Nucleus of Thomson (1970) which apparently was not affected by the Delamerian deformation.

Based on the recent review by Stevens et al.(1988), the Willyama Supergroup consists of highly deformed metasedimentary schists, quartzo-feldspathic and lesser basic gneisses, and minor "lode" rocks. The estimated composite thickness is 7-9 km.

The original facies which were interpreted as shelf overlain by deeper water turbidites and minor contourites, have recently been reinterpreted as shallow marine, with the quartzo-feldspathic gneisses being fluvio-deltaic arkoses. The Broken Hill orebody is possibly of volcanic to sedimentary exhalative origin. A Rb-Sr model source age of 1820+60 Ma (Shaw, 1968) has been interpreted as the maximum age of deposition, however, according to R. Page (pers. comm., 1989) new isotopic data indicate 1690-1670 Ma, i.e. still a Palaeoproterozoic age. Multiple deformation coincident with prograde andalusite through sillimanite to granulite grade metamorphism has been dated at 1660+10 Ma (Harrison and McDougall, 1981; Gulson, 1984), however, again new data (R. Page, pers. comm., 1989) indicate 1600 Ma, close to the Palaeo-Mesoproterozoic boundary. Three episodes of Proterozoic deformation have been described, with the earliest resulting in recumbent folding and nappe structures

(Laing, in prep.) and the subsequent two causing refolding and further disruption (Hobbs et al., 1984). Some shear zones were formed during this early tectogenesis, but the numerous shear zones with strong retrogression are dated (Etheridge and Cooper, 1981) as Early Palaeozoic (520+20 Ma) and are related to the Delamerian deformation.

The allochthonous pile rests on autochthonous Proterozoic cover of an Archaean basement (Laing, in prep.). Seismic data (Branson et al., 1976) indicate that bodies with higher seismic velocity, possibly of igneous origin lie beneath the allochthous Willyama Supergroup, possibly in the Palaeoproterozoic cover. These could either be related to the original orogenic development (?rifting) or to Neoproterozoic and earliest Cambrian reactivation and rift-related igneous intraplating (meaning emplacement into the crust instead of emplacement at the sole of the crust during igneous underplating).

Stevens et al. (1988) interpreted the Willyama Supergroup as deposited in an epicontinental rift zone with thin crust. The basic gneisses are similar to some Fe-rich tholeiites of MORB affinity. The intense structural deformation could have resulted from some collisional event following subduction. However, apparently there is no direct evidence of oceanic crust or subduction.

The Willyama Supergroup is releated to the orogenic complexes of the Gawler Craton in South Australia and could be designated as the Gawler-Willyama Pre-Cratonic Province (Scheibner, 1974, Glen et al., 1977). It remains uncertain if it developed in active plate margin or intraplate setting. The second alternative would require more old crust in the east!

The southeasterly vergence of nappes in the allochthonous pile (Laing, in prep.), away from the cratonic interior, is interesting. The post-kinematic Mundi Mundi Granite (1490+20 Ma) in the Broken Hill Block and the Gawler Range Volcanics and associated granites (1590-1475 Ma) in the Gawler Craton could represent products of transitional tectonism (Geological Society of Australia, 1971; Plumb, 1979), or perhaps be related to reactivation tectonics (Scheibner, 1989), similar to the Basin-and-Range Province in North America, but this is a problem for South Australian geologists to resolve.

The older part of the Wonominta beds in the KFB is sometimes equated with the Willyama Supergroup (Leitch et al., 1987), but an other interpretation is preferred, see later.

Stevens et al. (1988), in a review of the distribution of Palaeoproterozoic to Mesoproterozoic rocks in NSW, concluded that there is no direct evidence for the existence of Willyama Supergroup rocks away from the Broken Hill region. This might be valid, but the proposed ensialic setting of the Willyama Supergroup, the southeasterly vergence of fold nappes, and the indication of a partly ensialic setting for the Late Proterozoic complexes in the east, indicate the presence of some pre-Neoproterozoic continental-type crust east of the Tasman Line. This crust, in the form of microcontinents, could have contributed to the basement of the Tasmanides, or it has been removed (shifted) in the processes of terrane dispersal. North-northwest-oriented lineaments west of the Kiewa Thrust were interpreted (Scheibner, 1973) as indicating old basement beneath the Murray Basin (Victorian Microcontinent, Scheibner, 1985a; 1987; see also Brown et al., 1988).

Neoproterozoic Development of the Para- and Orthotectonic Belts

The Late Precambrian is here understood as the time between 1000+100 Ma and 570 Ma (cf. Preiss, 1987) and is similar in time span to the Pan-African event (cf. Kroner, 1984; El-Gaby and Greiling, 1988). In the recently proposed subdivision of the Precambrian (Plumb, 1989) the Neoproterozoic starts from 1000 Ma.

In tectonic analyses and syntheses of the Tasmanides, usually only the Phanerozoic development is considered. However, the presence of turbiditic facies, ophiolites, and arc volcanics indicates that by earliest Cambrian time a well-developed active plate margin existed here (Oversby, 1971; Scheibner, 1972a, c; Solomon and Griffiths, 1972; Crawford and Keays, 1978; Crook, 1980; Powell, 1984b). If the Early Cambrian volcanic arcs (described later), were related to the subduction of oceanic crust, such oceanic crust probably was older by several tens of millions years as today it is unusual for subduction of young oceanic crust to take place. Hence, some break-up and sea-floor spreading associated with the separation of microcontinents could have occurred in late Precambrian time, prior to the distinctive episode of extension at the Cambrian/Precambrian boundary (Plumb, 1979; Veevers, 1984; von den Borch, 1980, and others). Direct evidence for earlier break-up is 187Os/186Os isotopic dating of ophiolites in Tasmania giving a 630 Ma age (Allegre and Luck, 1980).

During the Neoproterozoic, widespread platformal sedimentation occurred on the Australian Craton (Plumb, 1979). Extensive shallow-water to continental sediments and lesser intraplate volcanics accumulated in a wide region from Western Australia to western Tasmania. Of interest to the understanding of the Tasmanides are the rift zones, i.e. Adelaide, Amadeaus and Georgina, which are similar to aulacogens elsewhere (Olenin, 1967; Rutland, 1976; Scheibner, 1972c, 1974a; von der Borch, 1980). They are arranged discordantly to the eastern edge of the Craton and the subsequent Early Palaeozoic active margin. The remains of these rifts are located opposite salients in the Tasmanides, indicating deeper crustal relationships (Scheibner, 1987): the Adelaide Fold Belt is opposite the Murray Salient; the Amadeaus Transverse Zone (Rutland, 1976) and the Georgina Basin are opposite the Cooper Salient (Scheibner, 1987). Residual Bouguer gravity data indicate that a possible Neoproterozoic-Early Palaeozoic passive margin complex is concealed in the last region, along the Tasman Line (cf. Murray et al., 1989).

Thomas (1983) and other workers have suggested that salients of orogenic belts develop at sites of embayments formed at rifted continental margins. This situation may be complicated by accretion of microcontinental terranes, and this is possibly partly the case with the Murray Salient (Victorian Microcontinent).

Recently Preiss (1983) suggested that in the Adelaide Fold Belt the Early Adelaidean Callana and Burra Groups represent pre- and syn-rift deposits and the younger groups are post-rift sediments. The syn-rift Beda Volcanics have been dated at 1076+33 Ma (Webb et al., 1983) and this date is close to the world-wide extensional event around 1,000 Ma ago discussed by Sawkins (1978).

If we accept the modified continental margin and aulacogene model of von der Borch (1980) for the Adelaide Fold Belt, we can speculate that the prolonged Neoproterozoic rifting and basin formation (Rutland et al.,

1981) west of the Tasman Line were related to continental break-up farther east than the subsequent Cambrian break-up, which localized the ensimatic Kanmantoo Trough at the continental margin. The question which has to be posed is: did an active plate margin develop only during the earliest Cambrian, or did it start earlier as in some other regions of Gondwanaland, i.e. the Pan-African event (cf. El-Gaby and Greiling, 1988)?

Veevers (1984) postulated that the Early Palaeozoic continental break-up which lasted from 575 to 540 Ma was preceded by two stages of development: 1) from about 850 to 650 Ma the Precambrian Craton underwent extension concentrated along rift-valley complexes; 2) from 650 to 575 Ma regional dextral shear accompanied by extension and compression lead to marginal uplift. It can be added that perhaps the first stage started somewhat earlier, around 1,000 Ma.

The orthotectonic Kanmantoo Fold Belt in western Tasmania and northwestern NSW contains internal massifs of variably metamorphosed sedimentary and igneous basement rocks (Leitch et al., 1987).

According to Turner (1989) about one-fifth of Tasmania is underlain by rocks that are older than the polyphase Penguin Orogeny (700-750 Ma; somewhat older ages were recorded in the Tyennan Inlier). The predominant metasediments were deposited from about 1,100 Ma onwards (Raheim and Compston, 1977). Relatively unmetamorphosed shallow marine sediments occur in the Rocky Cape region, with deeper facies (turbidites) including minor mafic lavas towards the east. Farther east is the Arthur Lineament which is a belt of high-strain and greenschist to amphibolite facies metamorphism produced during the Penguin Orogeny. Lithologies include mafic extrusives and intrusives as well as ubiquitous deeper facies sediments. Further deeper facies rocks occur in the north coast region around Burnie. Stronger deformation and higher grade rocks occur in the Tyennan Inlier, where greenschists and up to eclogite facies rocks were probably juxtaposed by east-verging thrusting (Turner, 1989). Orogenic granites on King Island have been dated at 730-725 Ma (McDougall and Leggo, 1965).

These Late Proterozoic complexes in Tasmania are unconformably overlain by Eo-Cambrian-Cambrian sediments and volcanics, plus associated intrusives (Turner, 1989). Those in the Smithton Basin and western part of the Dundas Trough appear to be miogeoclinal shallow water with within plate rift-related volcanics (pillow basalts) and intrusives (Brown, 1989). The other volcanics farther east, mainly in the Dundas Trough, appear to have ocean floor affinities, and a special associated type are high-magnesium rocks. These two last groups of volcanics could be part of allochthonous sheets as suggested by Berry and Crawford (1988).

In NSW the older part of the Wonominta beds comprises multiply deformed metasediments of greenschist up to biotite grade facies, with uncommon limestone, more massive metaquartzite, metarhyolite and amphibolitic greenstone (Leitch et al., 1987). There is no direct isotopic age evidence for these rocks, but they are unconformable beneath a sequence of simply but tightly to isoclinally folded and cleaved slate, slaty sandstone, dolomite, limestone and quartzite. This sequence contains two horizons of often pillowed basalts higher up in the sequence, in a similar position to the Eo-Cambrian strata of the Smithton Basin.

Leitch et al. (1987) who have the credit for recognizing the composite nature of the Wonominta beds, correlated the oldest part with the Willyama Supergroup as has been done previously (Rose and Brunker, 1969; Packham, 1969), and the overlying deformed sequence with the Torrowangee Group (Adelaidean). There appears to be, however, more similarity with the Kanmantoo Fold Belt basement complexes in Tasmania then with the adjacent paratectonic region to the west. The overlying deformed strata with basalts are probably Eo-Cambrian. The correlation here favoured needs isotopic confirmation.

In conclusion, it is suggested that at the margin of eastern Gondwanaland an active plate margin existed from about 1100+100 Ma to 700-650 Ma, and it was converted into a Proterozoic orogenic belt similar in age to the pre-cratonic complexes of the Pan-African belts elsewhere in the Gondwanaland (e.g. Johnson et al., 1987). The pre-cratonic development of this relatively little known Late Proterozoic orogenic belt was terminated by the Penguin Orogeny in Tasmania and its correlatives elsewhere. It is possible to refer to this belt as the Penguin Fold Belt (figure 6). At present it is not clear if this fold belt was partly ensimatic, like elsewhere in the Pan-African belts, and if separation of microcontinents has taken place. Either these older elements or only the Penguin Fold Belt elements contributed to the microcontinents which appear to have existed during Eo-Cambrian-Cambrian time (Scheibner, 1987, Brown et al., 1988).

The Kanmantoo Pre-Cratonic Province would than start in the Eo-Cambrian, in post-Penguin Orogeny time, i.e. post 700 Ma, possibly as late as 630 Ma (Adams et al., 1985), and would have been superposed on the Penguin Fold Belt. This tectonic province started during the second Neoproterozoic stage of development according to Veevers (1984), from 650 to 575 Ma.

The possible earlier (1100+100Ma) Proterozoic break-up of the Australian Proterozoic Craton was followed by renewed Eo-Cambrian break-up and separation of microcontinents of unknown size. These were separated by one or more marginal seas possibly floored by oceanic crust. With time, such oceanic crust became gravitationally unstable and would have led to the formation of a new active plate margin (Scheibner, 1987).

Early Palaeozoic Development

To develop a model for NSW, again the rock record in the whole of the Tasmanides has to be considered. This record indicates that by earliest Cambrian time (figure 7) a well-developed Pacific-type convergent plate margin existed here, assuming that the present conceptual models are applicable. Stratigraphic and geochemical data (cf. Berry and Crawford, 1988; Brown, 1986, 1989; Burrett and Martin, 1989; Collins and Williams, 1986; Cook, 1982; Cooper and Grindley, 1982; Corbett and Solomon, 1989; Crawford, 1983; Crawford and Keays, 1978, 1987; Crawford et al., 1984; Crook, 1980; Leitch et al., 1987; Murray, 1986; Parker, 1986; Powell, 1984b; Williams, 1978, etc.) suggest the existence of Early Cambrian volcanic arcs.

The volcanic arc in NSW has been called the Mount Wright Volcanic Arc (Scheibner, 1972a,c). Aeromagnetic and gravity data (Brown et al., 1988; Murray et al., 1989), as well as sporadic bore-hole data south of the Broken Hill Block, indicate that the Mount Wright Volcanic Arc is probably continuous with the Padthaway Ridge (Parker, 1986) in South Australia, and these arcs comprise the hypothetical Mount Wright-Padthaway Terrane. The volcanics at Mount Arrowsmith are probably Eo-Cambrian (Leitch et al., 1987) and were erronously correlated with the Mount Wright Volcanics (Scheibner, 1972c). The volcanics at Mount Arrowsmith are within-

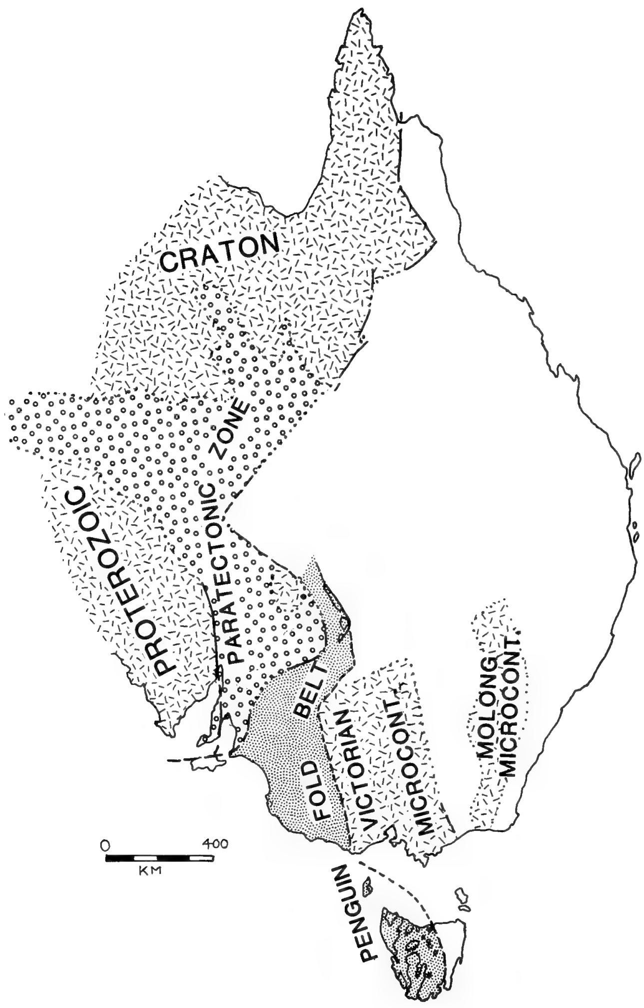

Figure 6. Distribution of the Penguin Fold Belt in eastern Australia.

plate alkaline basalts (Edwards, 1978), whereas the geochemistry of the Early Cambrian Mount Wright Volcanics has yet to be determined. Edwards (1978) analyzed only two samples which had alkaline to tholeiitic character.

There is little known about the Cambrian volcanics in the Padthaway Ridge area, but the recognition of boninites indicating arc - fore-arc setting is important (Foden et al., 1989).

The Mount Stavely Greenstone Belt (Ramsay and VandenBerg, 1986) in western Victoria, mainly the Mount Stavely Volcanic Complex, represents remnants of a calc-alkaline volcanic arc (Buckland and Ramsay, 1982). This belt is strongly expressed in aeromagnetic and gravity data (Dimboola Gravity-Magnetic Ridge) and can be followed towards the north-northwest, and, with some disruption in the Murray River area, it connects with the northeast-trending Lake Wintlow Ridge (Brown et al., 1988; Murray et al., 1989) to form the Stavely-Lake Wintlow Terrane. Sparse subsurface data from the area south and southeast of Scopes Ranges indicate that the coincidental gravity/aeromagnetic positive anomalies are caused by intermediate intrusives and felsic volcanics, probably of Early Palaeozoic age, here assumed to be Cambrian.

It is unclear at present if the above-mentioned Mount Wright-Padthaway Arc or Terrane represents a continuation of the Stavely-Lake Wintlow Arc or Terrane, and if their present distribution resulted from strike-slip displacement and doubling, or if they represent remnants of a split, wider volcanic arc, as is so often witnessed in the Western Pacific region. The gravity negative zone between the two positive ridges would than represent remanants of an inter-arc basin, perhaps filled by subsequent overlap sequences. Another possibility is that the depressed region formed during extension related to reactivation during Late Cambrian-Ordovician time. A- and M-type intrusions (Foden et al., 1989) emplaced during this extension contribute to the geophysical signature (Scheibner, 1988).

The Heathcote and Mount Wellington Greenstone Belts in Central Victoria (Ramsay and VandenBerg, 1986) have been interpreted by Crawford and Keays (1987) as representing fore-arc region boninites overlain by MORB rocks related to back-arc basin formation. Both these greenstone belts are allochthonous, and the andesites and boninites indicate a general volcanic arc related setting.

The Mount Read Volcanic Arc in Tasmania (Corbett and Solomon, 1989) is somewhat younger than the already discussed arcs. It appears to be of late Early to Middle Cambrian age. Geochemically, the bulk of the Mount Read Volcanics is high-K to medium-K calc-alkaline volcanics similar to Andean-type continental margin orogenic arches (Corbett and Solomon, 1989). The tholeitic basalts in the western part of the Mount Read Volcanic Arc have been interpreted by Corbett and Solomon (1989) as indicating a partly ensimatic setting.

In the area north of the Mount Wright Volcanic Arc, the Early Cambrian tuffs and volcanics in the "Circum-Denison Arc" of the Warburton Basin (Wopfner, 1972; Gatehouse, 1983) may represent a continuation of Early

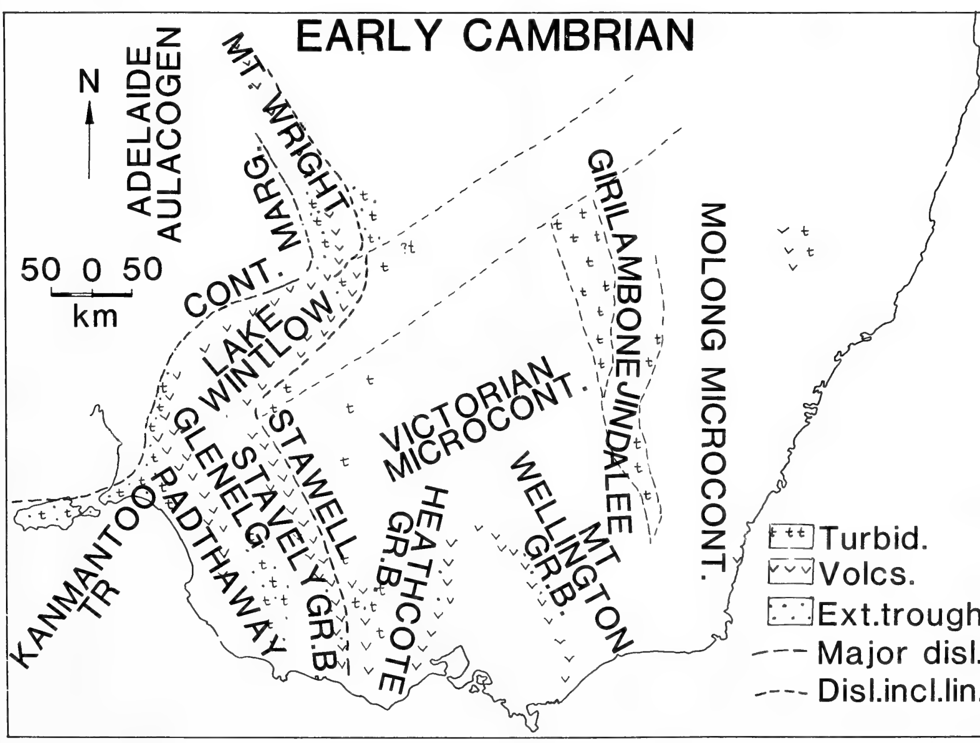

Figure 7. Schematic palaeogeographic (not palinspastic) map for Early Cambrian time.

Cambrian arcs at the Australian plate margin. Futher north, in the Thomson and Broken River Hodgkinson Fold Belts, calc-alkaline volcanic complexes (Mount Windsor Volcanics etc.) appear to be somewhat younger (of Cambro-Ordovician age) (Murray, 1986).

The westward convex shape of the Mount Wright-Padthaway and Stavely-Lake Wintlow Terranes has been interpreted by Brown et al. (1988) as indictaing eastward subduction beneath the arcs. Earlier, the widely distributed Cambrian volcanics and ophiolitic rocks in Central Victoria, which appear to be around the Victorian Microcontinent (basement of the Stawell-Bendigo and Melbourne Zones), were interpreted as indicating two Cambrian volcanic arcs, the western one (Stavely) developing by eastward subduction and the other hypothetical arc in the east by westward subduction (Scheibner, 1985a, 1987).

New unpublished and in press geochemical data (Foden et al., 1989; Gatehouse, 1988; Songfa Liu, pers. comm. 1988, Liu and Fleming, 1989) indicate that the Cambrian Kanmantoo Trough complexes were deposited at a passive margin on partly ensimatic (MORB) basement, and are now mostly in thrust contact with the para-autochthonous Adelaide Fold Belt (AFB). Only more detailed structural studies will establish if the Kanmantoo Trough complexes qualify as a terrane (Scheibner, 1985a). The foreshortening can not be assesed at present.

The presence of deformed turbidites west of the Wertago Terrane (K. Mills, pres. comm., 1985) indicate that Kanmantoo type complexes may be present beneath the Bancannia Synclinorial Zone.

It appears that the Mount Wright-Padthaway Terrane, plus possibly also the Stavely-Lake Wintlow Terrane and the Victorian Microcontinent, collided with the continental margin (Kanmantoo Trough) which in consequence collapsed and was inverted, and continent or foreland-directed thrusting resulted, giving the foreland fold and thrust structure of the AFB (Jenkins, 1989). The highest grades of regional metamorphism (high T/medium P) appear to define the point of first contact (collision). The continental margin (Kanmantoo Trough or Terrane) and the eastern edge of the continent itself (AFB) were intruded by syn-kinematic I-type granites and post-kinematic A- and M-type intrusives (Foden et al., 1989). The above collision, which can be described as terrane accretion, plus a general eastward rotation of the Australian Craton, was the cause of the tectogenesis which has been described by Thomson (1970) as the Middle Cambrian to Ordovician Delamerian Orogeny. The early Middle Cambrian deformation in western Tasmania (Corbett and Turner, 1989; Williams, 1978) is similar; the major effect of this deformation was the hypothetical thrust emplacement of mafic-ultramafic complexes related to the collision of a hypothetical volcanic arc from the east (Berry and Crawford, 1988).

The basement of the AFB, especially in the Broken Hill Block, was strongly affected by the Delamerian deformation; a thermal pulse at 520+40 Ma resetting isotopic ages was detected by Harrison and McDougall (1981). This tectogeny also caused the reactivation of old and the formation of new shear zones with strong retrogression dated at 520+20 Ma (Etheridge and Cooper, 1981). However, the geometry of these shear zones is difficult to decipher as at the surface they have steep disposition and cross cut each other, with some microstructures indicating formation at the brittle/ductile transition zone. It appears that this inlier was brought to the surface quite rapidly and the way this was achieved needs elucidation.

The orogenic belt (figures 5 and 8) which resulted from deformation of the Eo-Cambrian to Early Cambrian active plate margin has been referred to as the Kanmantoo Fold Belt (Scheibner, 1972a,c, 1987) which is distinct from the miogeoclinal paratectonic Adelaide Fold Belt, even if it was formed by the same deformation. Preiss (1987) preferred to refer to both of these distinctive belts as one Delamerian Fold Belt, whereas here emphasis is put on their different tectonic setting: ortho- versus paratectonic. In the orthotectonic belt at least the following terranes were accreted: Mount Wright-Padthaway, Stavely-Lake Wintlow, Wertago, Kayrunnera, and the composite terranes of western Tasmania (Scheibner, in prep.).

In Queensland the slightly younger complexes were consolidated by the Middle-Late Ordovician tectogenesis and formed the core of the Thomson Fold Belt (Murray and Kirkegaard, 1978; Day et al., 1983; Murray, 1986).

The first pulses of the Delamerian Orogeny were followed, during the Middle but mainly Late Cambrian to Ordovician, by relaxation and extension (perhaps related to some terrane dispersal) which caused subsidence of graben-like troughs in Tasmania and also on the present mainland. A- and M-type intrusions were emplaced during extension (Foden et al., 1989) and the upper parts of the Mount Read Volcanics might be related to such a setting. The new depressions were filled by molassic shallow marine to continental sediments on the mainland, with some deeper water facies, including turbidites in Tasmania (Dundas Trough, cf. Brown, 1989). The molassic Late Cambrian-Ordovician Dennison Group in Tasmania (Banks and Baillie, 1989), and the Cupala Creek Formation in northwestern NSW (Powell et al., 1982) are distinctly unconformable on the Eo-Cambrian to Cambrian complexes. From terrane analysis point of view, these molassic, transitional tectonic rocks represent overlap sequences.

The relationship of the Stawell Zone in Victoria to the Kanmantoo Fold Belt (KFB) is interesting. It appears to be formed by unfossiliferous, possibly Cambrian complexes (Ramsay and VandenBerg, 1986), which appear to be similar to rocks in the Morden Block in NSW (Pogson and Scheibner, 1971), where they are overlain by the Late Cambrian Cupala Creek Formation, but as yet there is no similar evidence available from Victoria. Perhaps in a stratotectonic sense the Stawell Zone is related to the KFB, but in a structural sense the deformation appears to be Benambran and younger, and also east verging, and considering all these features, related to the Lachland Fold Belt. The Stawell Zone appears to continue into NSW in the subsurface under the Murray Basin.

In a stratotectonic sense the Central Victorian greenstone belts were part of the active margin from which the KFB developed, these belts subsequently were incorporated into the LFB. Their structural relationship is still not clear. While the Heathcote Belt appears to be east verging, pre-1984 maps showed easterly dips on faults bounding the Mount Wellington Belt. Subsequently westerly dips were published, for example by Fergusson et al. (1986) and in the Geology of Victoria (1988). Aeromagnetic and also gravity data indicate that the two greenstone belts apparently join at the northern end of the Melbourne Zone, and this lead Brown et al. (1988) to suggest that they represent a west-verging thrust complex. The new ACORP proposal for a deep crustal seismic reflection survey will hopefully give a definitive ans' and end the frustrating controversy.

Ordovician Development of the Lachlan Pre-Cratonic Province

While during the Ordovician (figure 9) the region of the KFB became a continental shelf region (evidence in western NSW and western Tasmania, Cooper and Grindley, 1982), on the mainland in the adjacent region to the east the following stratotectonic units can be recognized: the Molong Volcanic Arc from eastern Victoria through central and eastern NSW up to the Cobar-Inglewood Lineament and possibly even farther north into southernmost Queensland; to the west of arc the Wagga Marginal Basin in eastern Victoria and central NSW up the Darling River Lineament; and to the east of the arc the Monaro Slope and Basin in eastern Victorian and southeastern NSW, which mostly appears to be a fore-arc region, with possibly an accretionary complex around Batemans Bay. Most authors (Oversby, 1971; Packham, 1973; Scheibner, 1972a, 1974a; Cas et al., 1980; Crook, 1980; Powell, 1983a,b,; 1984b) agree on the above model, with exception of Packham (1987) who suggested that the present distribution of the Ordovician volcanic arc and surrounding sediments was caused by Siluro-Devonian sinistral strike-slip displacement and tripling of an originally single volcanic arc and back-arc basin. This model deserves further testing, but the geometry of the volcanics and sediments, for example the eastward prograding Rockley Volcanics over Triangle Group, make it difficult to accept Packham's model uncritically, especially as no anomalous sedimentary transport has been noted in areas were large rotation of complexes is supposed to have happened.

Fergusson et al. (1986) suggested that the Bendigo and Melbourne Zone complexes formed in a partly ensimatic passive margin setting, whereas in the model of Brown et al. (1988) and Scheibner (1985a, 1987) the Melbourne Zone was autochthonous over the Victorian Microcontinent and the greenstone belts and the Bendigo Zone were allochthonous as suggested earlier by Cox et al. (1983). As mentioned already, only the deep seismic reflection survey will solve this controversy.

The Ordovician strata of eastern Tasmania appear to be similar to the above central Victorian ones (Baillie, 1985).

Geophysical data (Agostini, 1987; Murray et al., 1989) indicate that the Ordovician arc had a near-meridional direction and did not veer towards the northwest close to the Darling River as suggested by Cas et al. (1980). The Ordovician Mount Dijou Volcanics appear to be alkaline and of oceanic island affinity, and the mafic volcanics around Louth intersected in boreholes (Brunker, 1968) and encountered again subsequently during exploration (Degeling et al., 1986) are of probable Early Devonian age.

Molong Volcanic Arc.

Geochemical data (Wyborn, 1977; Owen and Wyborn, 1979; I. Clarke, pers. comm., 1985) indicate that the volcanism had a dominantly shoshonitic character, with minor tholeiitic basalts and island arc tholeiites in the southern part of the arc (Wyborn, 1977; Owen and Wyborn, 1979), and minor K-rich calc-alkaline andesites and basalts, minor trachytes in the northwestern part (I. Clarke, pers. comm., 1985).

Uncertainty about the origin of modern shoshonitic suites (cf. Johnson et al., 1978) has led to the reservations about the validity of a subduction model for the Molong Volcanic Arc (cf. Owen and Wyborn, 1979), and to the suggestion that these volcanics were related to Ordovician rifting and fracturing of continental crust in a marginal plateau environment (Wyborn, 1977). Recently D. Wyborn (1988) has suggested that the Ordovician volcanics formed by partial melting of subcontinental upper mantle after delamination of cold and dense subcontinental lithosphere and its foundering. To account for the relative Au and PGEs enrichment of these rocks he suggested that, firstly the subcontinental mantle was depleted in the basaltic component causing depletion of sulphur, and what sulphur was left behind became enriched in Au and PGEs. Secondly hydrous metasomatism followed causing enrichment in K, Ba, Sr and P. He admited that usually such metasomatism is explained as a consequence of subduction-related devolatization of subducted lithosphere (Pearce, 1983), but apparently the rather low Th, U and light REEs hint at some other process, but he does not explain what this is. Equally well the required mantle delamination, foundering and metasomatism could have been related to subduction. There is no way to differentiate between the two, considering how heterogeneous the mantle is. Wyborn (1988) is strongly relying on the data of Meen and Eggler (1987) from Montana, where these authors suggestedhat Late Cretaceous volcanism involved melting of old continental mantle, and not the suspected subducted plate as assumed previously. However, these authors did not

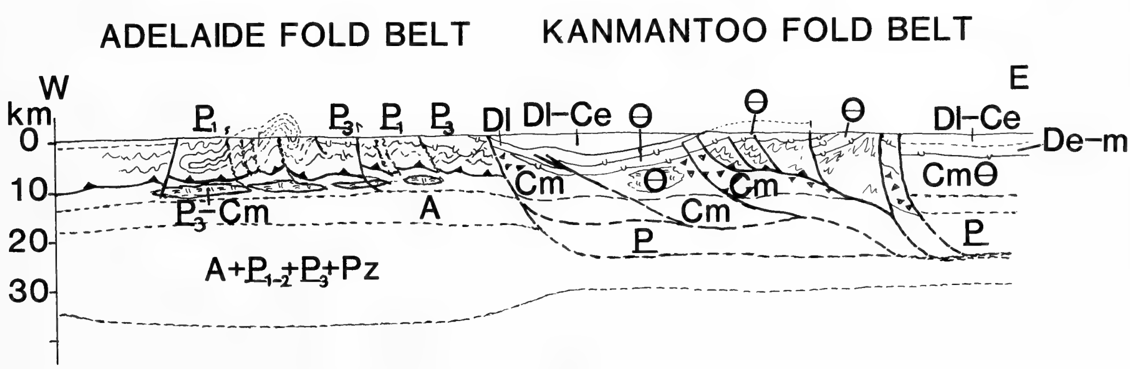

Figure 8. Hypothetical crustal section (adopted from Scheibner, 1989) showing the structure of the Adelaide and Kanmantoo Fold Belts in NW New South Wales. Structure of the Broken Hill and Euriowie Blocks based on Laing (in prep.).

explain why melting of the old mantle occurred and this is the crunch of the matter. Sure, the supposed mantle delamination can cause thermal disturbance, but so equally well can subduction. It has to be kept in mind that modern models of subduction-related igneous activity do not invisage partial melting of the subducted plate, but its devolatization and partial melting of the overlying asthenosphere. What Meen and Eggler (1987) and Wyborn (1988) suggested is that this asthenosphere formed by partial melting of subcontinental upper mantle. If deep mantle heat sources are available in such regions perhaps this is possible. What is needed is tectonic activation and subduction or rearrangement of plate rotations (interactions) that can provide the tapping of deep thermal sources.

Morrison (1980) discussed the tectonic setting of shoshonites and came to the conclusion that they occur in orogenic settings: in continental margin and volcanic island arcs, they can appear to be related to geochemical zonations indicating formation above deeper parts of subducted plates, to rearrangement or flips of subduction zones, to deep-faulted zones, to uplifts and areas of block faulting, etc. However, shoshonitic rocks occur also in intraplate settings, as members of alkaline suite rocks. The shoshonites cannot be taken in separation, but they have to be integrated with other data, and hopefully there is no doubt about the orogenic setting of Ordovician complexes in NSW!

The discovery of shoshonites in a nascent intra-oceanic volcanic arc in the northern Marianas (Stern et al., 1988) is important. Shoshonites were previously described from Fiji (Gill, 1981) as related to rifting of a young volcanic arc.

Stern et al. (1988) suggested that in the northern Marianas the shoshonites formed by melting of enriched mantle due to propagation of the Mariana Trough intra-arc basin spreading centre through the volcanic arc. It appears that what is really important in the generation of shoshonite magmas is that melting of "enriched" mantle occurs at a certain crustal depth, probably over 20 km (Coulon and Thorpe, 1981). In the northern Marianas this depth was provided by previoualy accreted island arc, in Papua New Guinea it was the edge of the Australian plate plus a collided volcanic arc under which the asthenosphere was tapped.

Why productive asthenosphere is present is crucial, and it appears that immediately related in time and space, or somewhat preceding the volcanism, subduction has occurred in the region. The chapter on the origin of shoshonites is obviously not yet closed ...!

Wyborn (1988) stated that the wide distribution of Ordovician shoshonitic volcanics in NSW favours his model (his figure 19). There are two points, however, which have to be stressed . The first is that Silurian basin formation caused extension of this region and dispersion of these volcanics, and the second is that if the model of Packham (1987) is correct about sinistral strike-slip doubling and tripling of the arc, then it was indeed very narrow originally. Another important point which needs clarification is the relationship of the PGEs-bearing circular gabbro-peridotite intrusions (Suppel and Barron, 1986) around Fifield and Tottenham to the Ordovician shoshonites. Wyborn (1988) suggested that they are time related and geochemically identical, whereas earlier isotopic and geological evidence (Pogson and Hilyard,

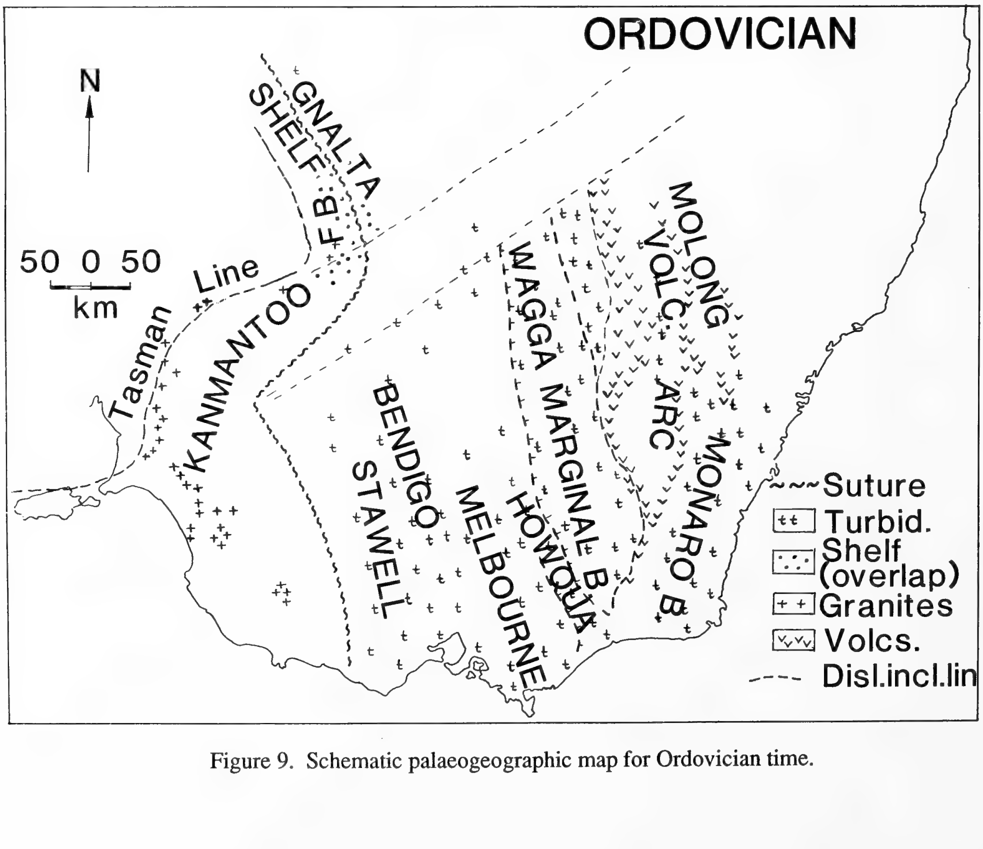

Figure 9. Schematic palaeogeographic map for Ordovician time.

1981) favours an Early Devonian age. Wyborn (pers. comm., 1989) indicated that iron microprobe dating of zircons from the Fifield complex gave an Ordovician age. The samples came from a monzonite and not from the gabbro-peridotite complex. The new data indicate that the intrusive history in the region is more complicated than originally thought (Suppel and Barron, 1986).

Considering the problems discussed above, the model favoured here is a covergent plate setting for the Molong Volcanic Arc, with the possibility that it developed over a microcontinental basement (Molong Microcontinent, Scheibner, 1982, 1987). Most authors envisage west-dipping subduction beneath the arc, but uncertainty is introduced by the apparent eastward-younging of the arc, with the oldest rocks on the west (Sherwin, 1979). If the conclusion of Dickinson (1973) about progressive migration of arcs away from the trench can be applied here, then subduction could have been towards the east. Also Wyborn (1977) noted an eastward progression of volcanics from tholeiitic through island-arc tholeiitic to shoshonitic in the souther part of the volcanic arc. This would support a model of eastward subduction at least for part of the development of the Molong Volcanic Arc.

Wagga Marginal Basin

To the west of the Molong Volcanic Arc a region of turbiditic basinal sedimentation is called the Wagga Marginal Basin (Scheibner, 1972a). Sedimentation started in earliest Ordovician time (Kilpatrick and Fleming, 1980). If westward subduction under the Molong Volcanic Arc did occur, then the Wagga Marginal Basin had a back-arc basin setting and as such could be expected to be partly floored by oceanic crust. However, there is no direct evidence for such crust, although it has been argued (Scheibner, 1987) that some Precambrian (Eo-Cambrian) oceanic crust could have been present between the Victorian and Molong Microcontinents as well as the younger oceanic crust formed in a back-arc basin setting.

The fill of the basin was converted into the Wagga-Omeo Metamorphic Belt during the Late Ordovician-Early Silurian Benambran Orogeny (figure 10). The belt is bounded by the Gilmore Suture on the east and the Kiewa Fault (Thrust or Suture) on the west, along which the high T/low P up to amphibolite grade Ordovician metamorphics intruded by synkinematic anatectic S-type granitoids are in contact with the little metamorphosed Ordovician strata of the Tabberabbera Zone (Ramsay and VandenBerg, 1986).

Fergusson et al. (1986) referred to the whole area east of the Melbourne Zone as the Benambra Terrane. The eastern boundary of the Melbourne Zone or Terrane is the wide Mount Wellington Fault Zone, which is shown as the eastern margin of east-verging Middle Devonian thin-skin thrusts. The Benambra Terrane is shown on their figure 4 as autochthonous on earlier Precambrian crust. Fergusson (1987) argued that the Wonnangata Line west of the Kiewa Fault is the important domain boundary, as west of it the rigidity and hence thickness of older basement increases. According to Scott (in Morand, 1988) the Kiewa Fault is a Benambran dextral strike-slip fault, with minor sinistral Tabberabberan displacement, and not a thrust (Beavis, 1962). It still needs to be explained how migmatites and gneisses were juxtaposed against lower greenschist facies Ordovician rocks along a strike-slip fault, separated by a mylonite zone up to 1.5 km wide.. The strike-slip displacement might not have been the only displacement along the Kiewa Fault. Also more research is needed to explain the structurally complex gneisses around Hume Lake, which according to Fleming et al. (1985) are an inlier of pre-Ordovician continental basement in the Wagga-Omeo Zone.

Fore-Arc Basin and Accretionary Wedge

Using the calculations of median volcanic arc size values of Dickinson (1973), and accepting that the minimum duration of the Molong Volcanic Arc was 65 Ma, the arc-trench gap should have been about 130-150 km wide, and the width of the arc over 80 km. This means that in the model of westward subduction the Monaro Slope and Basin sediments (Scheibner, 1974a) would mostly represent a fore-arc basin setting (Crook, 1980). Only in the South Coast region might we expect to find accretionary wedge rocks, and possibly the Wagonga Formation is a contender (Powell, 1983a, 1984b).

Ordovician-Early Silurian Tectonic Model

During the earliest Ordovician, and probably latest Cambrian time, west-facing Marianna-type, B-subduction developed east of the Molong Microcontinent. The Molong Volcanic Arc formed on this block. The back-arc basin (Wagga Marginal Basin) was partly floored by oceanic crust which formed during the subduction, and/or was a remnant from an earlier marginal sea between the Victorian and Molong Microcontinents. To the east was the fore-arc basin, Monaro Slope and Basin, and farther east the accretionary prism. During the later part of the Ordovician the Mariana-type boundary changed into a Chilean-type due to the arrival of a hypothetical Proterozoic intra-oceanic volcanic arc which was tectonically underplated up to the I-S line of Chappell and White (1974). This arc type protolith could have become the source for the subsequent I-type plutons. The subduction was relocated, i.e. flipped, and the partly oceanic basement of the back-arc basin underthrust the Molong Arc giving the mentioned eastward arc polarity. The Wagga Marginal Basin was inverted and finally the Ordovician volcanic arc and its microcontinental basement collided along the Gilmore Suture with the back-arc basin. The collision had a dextral transpressive component to it, with the point of possible first contact in the southern part of the Gilmore Suture (south of the Lachlan River), and with the amount of convergence decreasing northwards. The Gilmore Suture dips steeply west in the upper crust where the collision was intensive (area south of West Wyalong). Towards the north the Cambro-Ordovician Girilambone Group, possibly a separate terrane, is inserted between and beneath the western Goonumbla Segment of the Molong Volcanic Arc, and the back-arc basin complex. Gravity and aeromagnetic data and also the sporadic occurrence of rocks (Jindalee Group) in the Tumut district similar to the Girilambone Group (Basden, 1982) indicate that there could be a thrust relationship between the Girilambone Terrane and the Ordovician volcanic arc.

The deformation and thrust pile-up of the Wagga Marginal Basin fill (Pogson, 1982; Scheibner, 1982), plus heat contributed from the hypothetical spreading centre within the back-arc basin, resulted in high T/low P metamorphism, with areas of ultra-metamorphism leading to the formation of anatectic granites (Fagan, 1979). Subsequent granitic plutonism lasted through the Silurian for about 30 Ma (Fagan, 1979). The thrusts in the Wagga-Omeo Metamorphic Belt have northeast to north-northeast orientation in NSW (Pogson, 1982) and the Kiewa Fault is a parallel structure, and hence probably also a thrust, with a strong strike-slip component (cf. Scott in Morand, 1988). Another possible interpretation of the Kiewa Fault is that it represents a Silurian detachment fault with high-grade rocks forming a "core-complex". The dominantly S-type Silurian granitespost-date the main Benambran deformation, and granite emplacement was in a sinistral transtensional setting as indicated by the en-echelon arrangement of the plutons.

The Wonnangata Line of Fergusson (1987) may represent the junction of the back-arc basin with the Victorian Microcontinent. The Ordovician complexes west of this line were apparently thrust or reverse faulted westwards during subsequent, possibly Tabberabberan deformation (Fergusson, figures 14 & 15, 1987).

In an earlier model (Scheibner, 1982, 1985a, 1987) it was suggested that ultimately the Molong and Victorian Microcontinents came in contact and the compressional stresses were transmitted westwards, causing east-verging deformation and thrusting in the cover complexes in the Stawell and perhaps also the Bendigo Zones. In a modified model Brown et al., 1988) suggested west-verging thrusting involving emplacement of the Heathcote and Mount Wellington Greenstone Belts as one unified thrust unit, with subsequent faulting causing the present distribution.

Isotopic resetting during the Benambran Orogeny was noted in the region of the Kanmantoo Fold Belt (cf. Milnes et al., 1977). Fergusson et al. (1986) maintained that the fold and thrust structure of the Stawell-Bendigo Zones (Cox et al., 1983) is younger, being mainly of Middle Devonian age. The timing of thrusting is, however, of pre-Early Devonian granite emplacement age (Ramsay and VandenBerg, 1986). The solving of these problems in Victoria is of importance to us, as these zones continue in the subsurface into southwestern NSW.

Silurian to Middle Devonian Development

The Silurian rock record indicates that a major rearrangement of the active plate margin of eastern Gondwanaland followed the Late Ordovician-Early Silurian Benambran Orogeny. The changes (figure 11) south of the Darling River Fracture Zone, which today is expressed only as a lineament zone, were significant for the Lachlan region of NSW.

In the region west of the Gilmore Suture, Early to early Late Silurian sediments are absent in NSW, indicating probable dry land. Some subaerial volcanism accompanied intrusion of granites within the Wagga-Omeo Belt, as already mentioned, in a sinistral transtensional setting. South of the Murray River Lineament in the Melbourne Zone, sedimentation was continuous between the Ordovician and Silurian.

To the east of the Gilmore Suture, and along it, in the NSW Lachlan region, sedimentation in the Silurian, including thick turbidite sequences in some areas, occurred in the relatively narrow graben and half-graben-like troughs and somewhat wider basins. The following stratotectonic units can be defined: Tumut, Cowra and Hill End Troughs, the Captains Flat-Goulburn Trough or Ngunawal Basin, and the Murruin Basin, all interspersed with ridges.

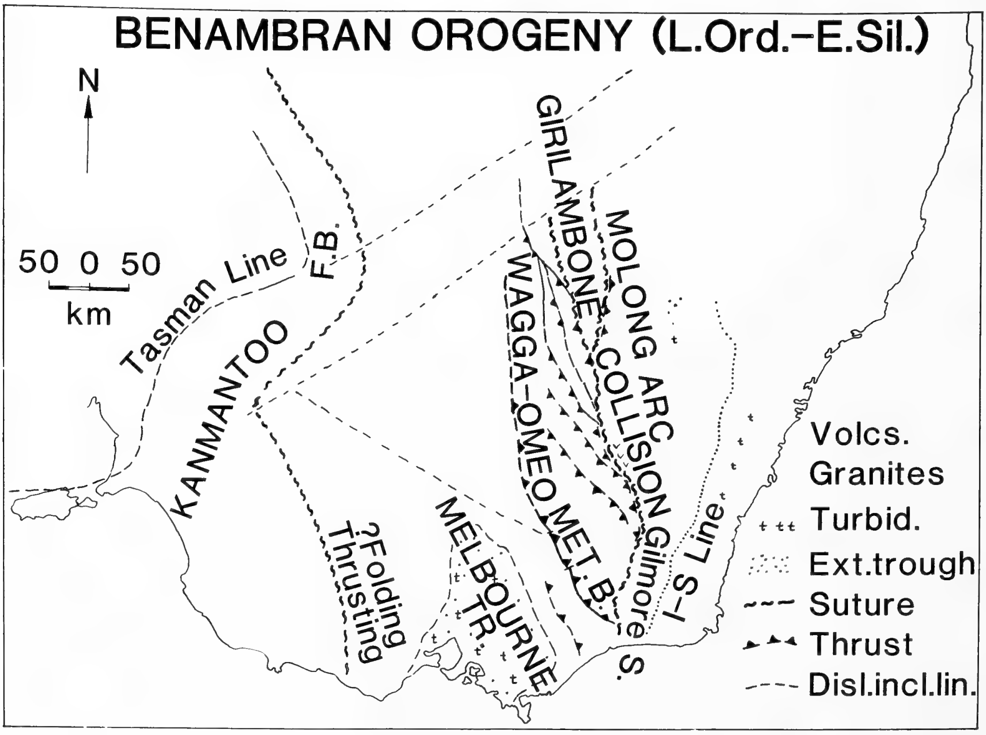

Figure 10. Schematic palaeogeographic map for Benambran Orogeny time.

Early Silurian sedimentation was limited and confined mainly to the Cowra Trough (Pickett, 1982). Regression accompanied the Quidongan Orogeny (Crook et al., 1973), and was followed in the Middle and Late Silurian by a transgression and widespread subaerial and submarine volcanism. This volcanism was related to rifting on the one hand (where volcanism was bi-modal though dominantly felsic) and to emplacement of granitoids on the other (where widespread volcanism was solely felsic). Rifting formed part of the processes of basin formation and the prevailing opinion has assumed that these troughs and basins formed due to general tension or transtension (oblique tension).

The cause of this general extensional setting in one model (Scheibner, 1974a; 1987) was the back-arc setting behind the frontal volcanic arc positioned somewhere outboard in the ancestral New England region. Oblique Mariana-type subduction would account for transtensional setting.

In another model (Powell, 1983a, 1984b) it was suggested that after the Benambran collision a dextral transform plate margin developed at the site of Ordovician subduction, and the consequent transtensional regime lasted from the Mid-Silurian until the Mid-Devonian. This transtensional regime was likened to the Basin-and Range Province of western North America (Cas, 1983; Powell, 1983a). However, there are quite distinctive differences between the Basin-and Range Province and Siluro-Devonian eastern Australia. The first region has exclusively continental facies, whereas in the second marine facies are dominant with the subsided regions filled with many kilometres of turbiditic, often deep-water facies rocks. The crust/lithospheric properties of the two regions must differ fundamentally. Also the related igneous activity differs, with absence of widespread late mafic volcanics in eastern Australia.

A different model was proposed by Bain et al. (1987)for the Captains Flat-Goulburn Trough. They suggested that it did not form as an extensional rift with accompanying rift-related volcanism and associated Kuroko-type mineralisation. This area was supposed to be part of a much wider basinal feature. This relatively shallow basin, which they called the Ngunawal Basin, formed in a region between rising granite batholiths and their comagmatic volcanic piles.

This proposal, however, needs further assessment, particularly with regard to the timing of basin formation, as this appears to precede emplacement of nearby batholiths. Also the Late Silurian marine sediments occur in down-faulted elongate zones, between high-strain zones. The above authors suggestedhat the high-strain zones formed during deformation and did not have syn-sedimentary precursors which is disputable considering the brittle behavour of the upper crust during basin formation, even if the basin formed by thee of shoulders, as the authors suggested.

In the hypothesis proposed by Packham (1987) the Silurian "troughs" were related to major sinistral strike-slip displacement of individual segments of the Ordovician arc, and formed on the frontal side of the arc as fore-arc regions. There is evidence that the Meandarra Gravity Ridge is a younger rift structure, and not a

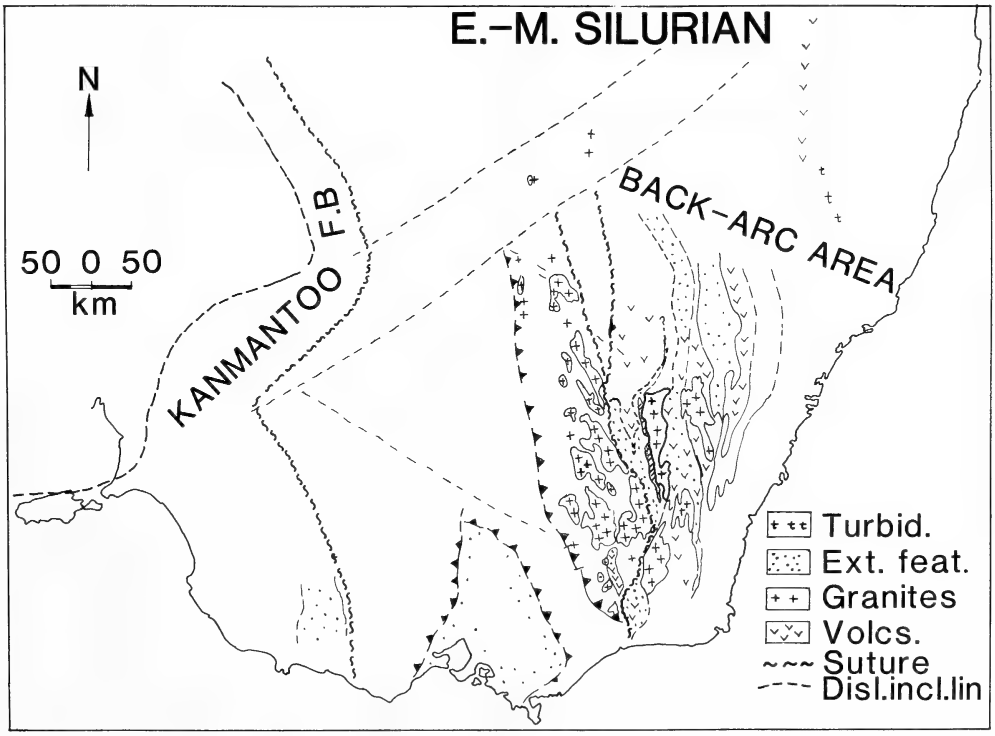

Figure 11. Schematic palaeogeographic map for Early-Middle Silurian time.

supposed outermost displaced segment of the Ordovician arc. A lot more detailed work has to be done to support Packham's model, and of course the sense of displacement has to be resolved, as an opposite direction has been suggested by Powell (1983a).

At least one of these troughs, the Tumut Trough, was partly floored by ophiolites (Ashley et al., 1979). Powell (1983a) suggested that these ophiolites were emplaced along leaking transform faults and hence of very limited extent. Other authors (Stuart-Smith, 1989) have casted doubt on the existence of ophiolites by separating the components as unrelated; however, the geochemistry of these rocks suggests otherwise (Ashley et al., 1979; Basden, 1982). Stuart-Smith (1987) has documented rifting in the ensialic part of the Tumut Trough along detachment faults, with the older basement forming core complexes. The metallogenic aspects of detachment faulting require attention.

The large thickness of sediments in the Hill End and Cowra Troughs (Packham, 1969; Cas, 1983) suggests that the continental-type crust there was extensively thinned, but there is no evidence for oceanic crust as suggested in very early models (Scheibner, 1972a, 1974a), even if mafic dykes are frequent low in the stratigraphic pile in the Hill End Synclinorial Zone. After an initial rift phase, the troughs were filled predominantly by turbidites which initially were quartz-rich and later became lithic and volcaniclastic (Packham, 1968; Cas, 1978a). Locally, deep-water emplacement of silicic lavas has been documented (Cas, 1978b). Marginal trough facies include olistostromes and slump deposits (Crook and Powell, 1976).

Between Temora and West Wyalong, Early to Middle Silurian andesitic volcanics along the Gilmore Suture are closely associated with monzodiorite (Suppel et al., 1986). These are either related to waning Ordovician arc activity or to rifting (Tumut Trough, cf. Suppel and Scheibner, in press).

The ridges, rises, or highs between the troughs were sites of shallow-water sedimentation, with some carbonates, and submarine to subaerial volcanism. Dominantly these volcanic piles were of S- and I-type (Owen and Wyborn, 1979; Wyborn et al., 1981) and were intruded by comagmatic granites. On the rises which had previously been the site of Ordovician arc volcanism, Siluro-Devonian porphyry-type mineralization was associated with felsic igneous activity (Bowman et al., 1983).

During latest Silurian-earliest Devonian time, Bowning-Bindi tectogeny affected the zone adjacent and between the Gilmore and Coolac-Narromine Sutures, plus a zone in thetern part of the Southern Tablelands. In NSW the Tumut Trough (Basden 1982) and in Victoria the Cowombat Rift (Ramsay and VandenBerg, 1986) were inverted. This deformation involved regional metamorphism and was followed by a regional heating event during which numerous granites were intruded in a wide belt across the Lachlan Fold Belt. According to Chappell and White (1985), while this intrusive episode was short lived at around 400 Ma ago, it was volumetrically the most important intrusive event. The various models for the Siluro-Devonian orogenic igneous activity will be addressed later.

The cause of the Bowning-Bindi tectogeny according to Powell (1983a) was continued dextral shear which by transtension created the Tumut Trough and by transpression inverted it. Packham (1987) saw the cause in the continued sinistral dismemberment of the Ordovician arc, to which the stiffening crust reacted by brittle deformation. In Scheibner's (1987) model the back-arc region would have yielded in a weakened zone, mainly between the major Gilmore and Coolac-Narromine Sutures, next to a more consolidated block (Wagga-Omeo Belt). It has to be pointed out, that at about the same time as contractional structures formed east of the reactivated Gilmore Suture, to west of it and along it extension occurred.

Outside the zone affected by the Bowning-Bindi deformation, deposition continued from the Silurian into the Devonian without interruption, for example in the Hill End and Cowra Troughs. The area along the Gilmore Suture and between it and the Parkes Thrust was one of shallow marine Silurian-Devonian sedimentation, and submarine to subaerial, dominantly felsic volcanism, related partly to rifting and partly to emplacement of I- and M-type plutons.

Basin formation during the earliest Devonian west of the Gilmore Suture resulted in the formation of the composite Darling Basin (figure 12). The rocks which were deposited in this stratotectonic feature, and the subsequent Late Devonian-Early Carboniferous Barka Basin, now comprise the Darling Depression. Most of this structural unit is concealed beneath the Cainozoic Murray Basin and its Late Palaeozoic to Mesozoic infra-basins. This hampers precise definition of the western and southern boundaries, but principally the Darling Basin could have onlaped on the Kanmantoo Fold Belt in the west and was separated by the Murray River Fracture Zone (lineament) from the central Victorian region. The Early Devonian sediments and volcanics which were deposited in the Darling Basin and adjacent shelves comprise the Cobar Supergroup. The eastern margin of the extended area is along the Rookery Fault where the basinal facies pass eastwards into the shallow-water facies of the Kopyje Shelf (Glen et al., 1985). In the area of the present Mineral Hill Synclinorial Zone, and also in the Buchan Zone in Victoria, the was a narrow zone of extension.

Faults and lineaments (representing zones of fracturing and or faulting) in the Darling Depression, appear to indicate the existence of a mosaic of blocks which can be used to construct a model for Devonian basin formation. During basin formation the degree of extension varied, so that while some blocks behaved in rigid manner, others were affected by crustal and/or lithospheric thinning. Detachment faults would have facilitated such extension. In blocks where crustal thinning was achieved by brittle fracturing and faulting of the upper crust and plastic flow in the lower crust, tectonic subsidence led to immediate sedimentation. Blocks which did not undergo crustal thinning remained in near isostatic balance, subsiding slowly in sympathy with neighbouring regions, leading to relatively shallow-water sedimentation (e.g. Walters Range Block). Under blocks where the hypothetical detachment faults penetrated into the lithosphere, thinning of lithosphere occurred to balance the related crustal extension. In such areas, upwelling of asthenosphere occurred causing uplift (cf. Wernicke, 1985). The thinned crustal blocks became sites of immediate sedimentation, whereas the uplifted blocks supplied detritus. The initial tectonic subsidence would have been followed by thermal subsidence of the whole region. It is possible that two episodes of extension occurred (Glen et al., 1985). The large thickness, over 7 km, of the Cobar Supergroup in the eastern part of the Devonian Darling Basin (Glen et al., 1985) and the relatively deep water turbidite facies support the thermal subsidence model.

As discussed, during the crustal thinning, which is accomplished by brittle faulting of the upper crust, the lower crust may have adjusted by plastic flow. Igneous emplacement of mafic magmas into the lower crust, dominantly in the form of sills (figure 13), would have partly compensated for the extension of the upper crust. Hopefully the deep seismic reflection survey being made around Cobar by a consortium headed by Bureau of Mineral Resources will image such sills, as they have been detected in many other similar basins in Australia and overseas. During the subsequent orogenic inversion of rifts and basins, crustal shortening resulted in an increase in the thickness of the lithospheric layers, with the zones with most basic (mafic) rocks in the crust causing positive Bouguer gravity anomalies. Thrusting (Glen, 1988) could have enhanced these anomalies. This created a geophysical paradox: namely, normally one would expect zones with large thicknesses of low-density sediments to cause relatively negative gravity anomalies (figure 13). But this is not so in some rifts and basins which developed by a variant of crustal thinning, a combination of pure and simple shear, as recently numerically modeled by Buck et al. (1988).

There appear to be differences in the amount of rifting along the north-south axis of the eastern part of the Darling Basin. Pre-existing lineaments, like the Lachlan River Lineament, appear to have functioned as transform faults (Scheibner, 1974b) or transfer faults (Gibbs, 1984), or accommodation zones (Bothworth et al., 1986). It appears that more extension occurred to the north in the Cobar Basin than in the south, in the Mount Hope and Rast Troughs. The differences in igneous activity north and south of this transfer structure have been pointed out previously (Scheibner and Stevens, 1974). It appears that basic magma emplaced into the less extended crust in the Mount Hope and Rast Troughs triggered crustal melting and igneous activity of a bimodal, dominantly felsic character (Barron et al., 1982). Another transfer structure was either along the Kerigundy Fault or the Darling River Lineament. To the north of this structure volcanism developed in the Louth Block area. More transfer structures in the Cobar Basin were identified by Glen (in prep.).

Isotopic dating (Glen et al., 1986) indicates that at least in the high-strain zone on the eastern side of the Darling Depression, deformation and metamorphism occurred at the close of the Early Devonian, as an early expression of the Tabberabberan Orogeny.

It has been suggested (Scheibner, 1987) that the enigmatic Owendale, Tout and other circular gabbro-peridotite or Alaskan type intrusions (Suppel and Barron, 1986) in the Fifield-Nymagee region are related to the Devonian basin formation to the west of the Gilmore Suture. It is speculated north of the Lachlan River this suture is steep, near vertical in the upper crust, but dips to the east at depth, and this deep part was reactivated as a detachment fault. The lithosphere thinned on this structure beneath the Girilambone Group between the Gilmore Suture and the Parkes Thrust. Under this region the asthenosphere welled-up and the M-type intrusions mentioned above were derived from it. It is possible that some melting of earlier continental upper mantle occurred in this region as suggested by Wyborn (1988), and also

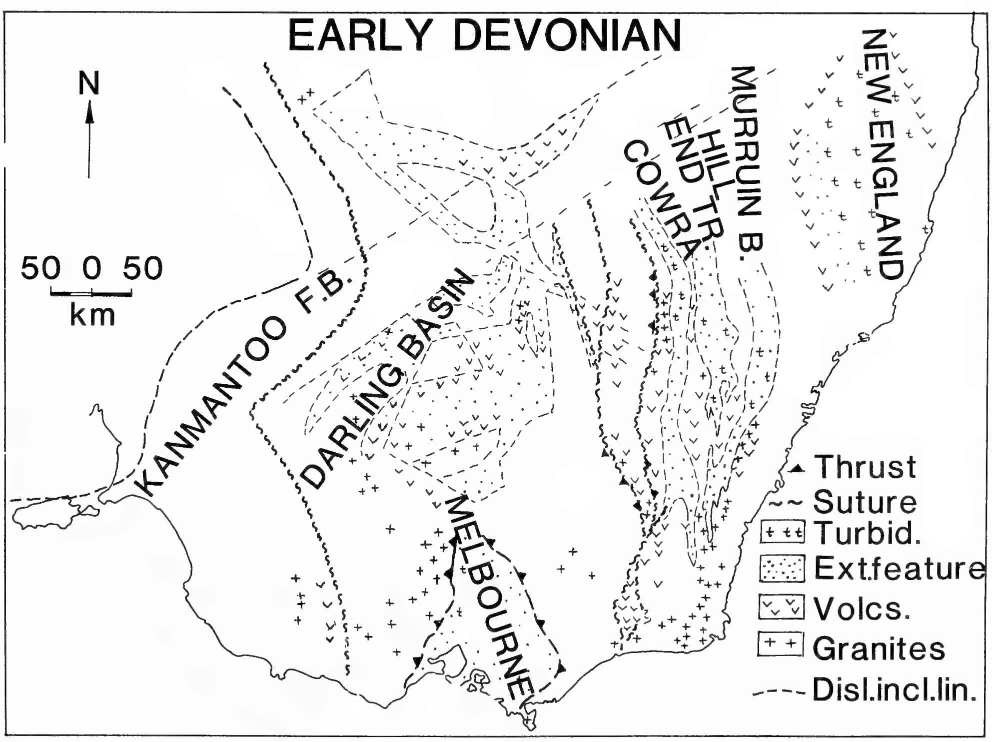

Figure 12. Schematic palaeogeographic map for Early Devonian time.

that shoshonitic igneous activity occurred in the same region during the Ordovician. Thinned lithosphere would explain the present day gravity high between the Gilmore Suture and the Parkes Thrust (Scheibner and Agostini, in prep.).

The Midde Devonian Tabberabberan Orogeny affected the Lachlan region with varying effects as documented by Powell and co-workers (Powell, 1984b). Even if in some areas only a paraconformable relationship exists with younger rocks, everywhere these diachronous deposits (figure 14) are developed in facies typical of a transitional tectonic setting (Scheibner, 1976).

Siluro-Devonian Magmatic Activity in the Lachlan Region

Before the next tectonic stage is discussed, it is necessary to address the problem of the widespread granitoid igneous activity. Powell (1983, 1984b) suggested that an eastward-migrating heat source, the original spreading centre in the Ordovician Wagga Marginal Basin, can explain the distribution of orogenic granitoids in the Lachlan Fold Belt. However, while the general easterly younging is valid for the eastern part of the Lachlan region, opposing trends are present in Central and Western Victoria and elsewhere. Chappell (1984) argued that because of the 800 km wide belt of Siluro-Devonian magmatism in the Lachlan region, and the lack here of calc-alkaline rocks typical today for subduction-related magmatic arcs, no subduction was involved. He suggested that high heat flow in this wide region caused crustal melting, but the source of this heat remains unknown.

Wyborn (1988) came up with a model for this hypothetical heat source by suggesting delamination and foundering of subcontinental lithosphere (its upper mantle component) in the Ordovician which led to upward flow of hot asthenosphereic mantle to replace it. It has been, however, already pointed out above that it is difficult to differentiate between such asthenosphere and that above the lower plate in a subduction zone. Wyborn (1988) sugested that initial breakage of lithosphere took place beneath the Wagga Metamorphic Belt. Apparently not a great deal of asthenospheric melting took place and it produced the rare Silurian tholeiitic gabbros, dolerite dyke swarms and basalts. The subsequent crustal heating was supposed to be by conduction. It took up to tens of millions of years for the high geothermal gradient to be established which led to the widespread crustal melting discussed by Chappell (1984) and his co-workerkers. Wyborn (1988) suggested that the high gradient spread eastwards from the Wagga Metamorphic Belt at a rate of about 10 km/Ma, in sympathy with the eastward-spreading asthenosphere. The timing and the presence of asthenosphere in Wyborn's (1988) model is the same as in Powell's (1983) model, and of course the same objection applies, namely that the distribution of granitoids does not everywhere follow the suggested path. For example a 410 Ma old group of granitoids occurs in a wide region from Tiboobura to Snowy Mountains, and the post-Bowning/Bindi granites across the whole of Victoria and the Central Victorian Magmatic Province with dates of around 365 Ma (Ramsay and VandenBerg, 1986) croscut earlier trends and continue into southern NSW perhaps as far as West Wyalong. Similar spatial complications occur in Tasmania, not to mention the rest of the Tasmanides, or Wyborn (1988) did not intended his model to apply to other areas than the southeastern corner of the Australian mainland?

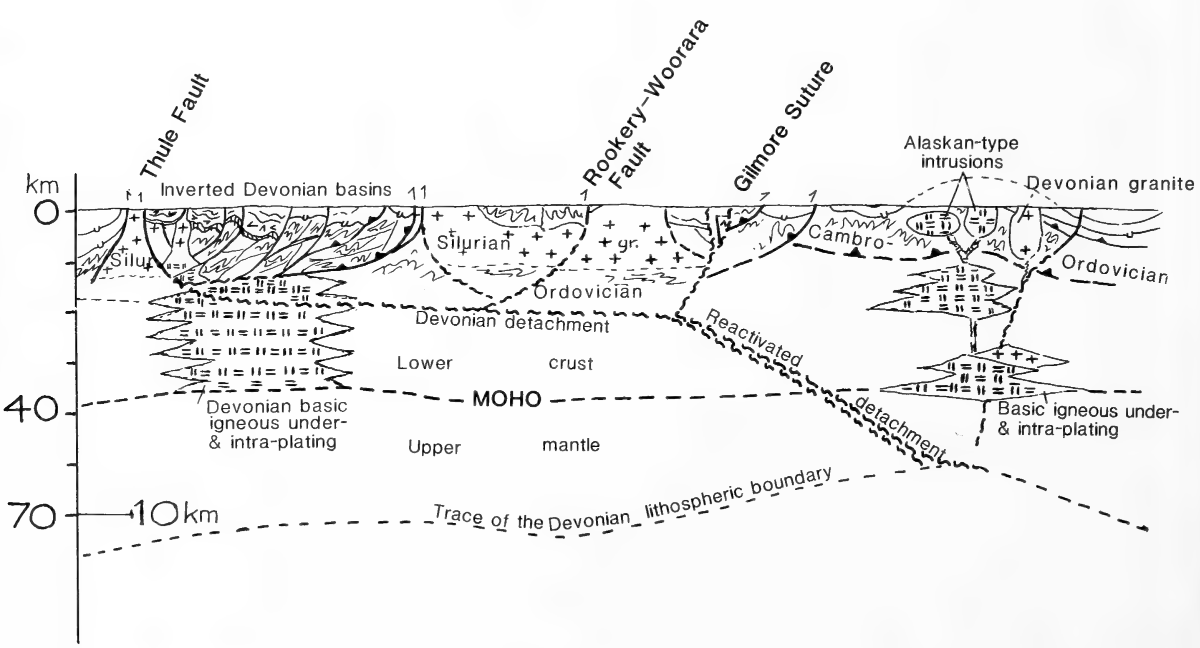

Figure 13. Schematic W-E crustal section through the Cobar region (after Scheibner, 1989). Thrust structure in the eastern side of the Darling Depression after Glen (1988).

Wyborn (1988) suggested that the Siluro-Devonian crustal melts rose to form great batholiths and ignimbrite sheets. This upward migration of magmas was compensated by downward flow in the crust. The Silurian basins were supposed to form above the downward flow in the crust. This process of crustal mass redistribution was termed "granite tectonics" by Chappell et al.(1987) and is similar in style to the "thermal convective halokinesis" of Jackson and Talbot (1986). It remains to be documented that such a model is applicable. The initiation of basins appears to precede emplacement of granite batholiths. In some batholiths (Wologorong and Wyangala) small hot gabbro to diorite bodies were emplaced before the onset of felsic activity. This could be interpreted as indicating heat transfer by mafic magmas and not conduction only. What is then needed is a tectonic process which could cause thermal perturbation. Subduction and extension in a convergent plate setting comes to mind. Wide areas of enigmatic felsic granitoid magmatism are confined not only to Mid-Palaeozoic eastern Australia, but occur elsewhere in space and time, for example the Mid-Palaeozoic magmatism in Central Europe, the wide Mesozoic magmatic igneous activity in Eastern Asia and Meso-Cenozoic North America.

In my early model (Scheibner, 1972a) it was envisaged that several small subduction zones existed in the Lachlan region and this has to be clearly abondoned in favour of an extensional back-arc setting in which igneous activity was related to subduction directly, an opinion also supported by Fergusson (1987), or indirectly, the cause being crustal extension affecting the whole lithosphere. Hopefully modern isotopic studies will supply the needed discriminants.

The New England Region

Cambrian-Ordovician and Silurian rocks occur in the New England Fold Belt (NEFB) in NSW only as small fault slivers and blocks close to the Peel Thrust (Korsch and Harrington, 1981), whereas in Queensland Late Silurian volcanic rocks occur in fault blocks as remnants of the so-called Calliope Volcanic Arc, which developed above a westwards subducting zone (cf. Murray, 1986). This arc was probably intra-oceanic, separated by a back-arc basin from the rest of the plate margin (Mardsen, 1972). The main development of this arc occurred during the Devonian. To the east of it was the Yarrol Shelf, a fore-arc basin. This feature appears to be continous with the Tamworth Belt in NSW, and similarly here, there was an andesitic arc (named the Baldwin Arc by Veevers, 1984)to the west of it. Residual Bouguer gravity data, however, indicate that the Tamworth Belt was thrust over its own adjacent arc probably during Late Carboniferous tectogenesis (Murray et al., 1989). Modern biostratigraphic (radiolaria) data (Ishiga et al., 1987; Atchison, 1988) indicate that the accretionary complex (Woolomin-Wandilla Slope and Basin, Day et al., 1978) which occurs to the east of the Tamworth-Yarrol Belt is mainly Devonian-Carboniferous and much less is Early Palaeozoic in age (only Silurian documented) than originally thought (Leitch, 1974; Scheibner, 1974a).

There appears to be a change in the arc from intermediate to felsic rocks with time (Crook, 1964), which probably reflects the maturation of this arc. Blake and Murchey (1988) suggested that the greenstones (including ophiolitic assemblage rocks) occurring east of the Tamworth Belt are part of the upper plate, i.e. basement of the arc and fore-arc region, and not as mostly interpreted part of the lower plate which was subducted westwards during Early-Middle Palaeozoic time.

A late Middle Devonian event, which correlates with the Tabberabberan event in the Lachlan region, affected the Calliope Volcanic Arc (Murray, 1986). The marginal sea which separated the New England pre-cratonic domain from the rest of the Tasmanides in the west was closed and inverted not only in Queensland (Marsden, 1972), but also in NSW (Murruin Basin). Some granitoides were emplaced in the Calliope Volcanic Arc. Local unconformities and disconformities (cf. Korsch and Harrington, 1981) are an expression of this event in the Tamworth Belt. In Queensland the volcanic arc was relocated westwards during the Late Devonian, and the Connors-Auburn Volcanic Arc, an Andean-type continental margin magmatic arc, came into existence (Day et al., 1978, Murray, 1986). The continuation in NSW is concealed and hard to asses. It appears that from the Middle Devonian onwards the New England region, a super-terrane, docked with the rest of the Tasmanides. Definitive Lachlan-derived clastic material occurs in the New England region from Early Carboniferous onwards (Leitch, 1974; Korsch and Harrington, 1981). While in the New England region the Mid-Devonian tectogenesis caused relatively minor changes in distribution of stratotectonic units, and also the pre-cratonic development continued into Late Carboniferous, in the rest of the Tasmanides the pre-cratonic tectonic setting was replaced by transitional tectonic or molassic.

Late Devonian-Carboniferous Development

The Middle Devonian (Tabberabberan) event which was diachronous and of variable strength (Powell, 1984b) may have been caused by collision of a hypothetical block, and a candidate is Lord Howe Block which separated from Australia during the Mesozoic. Solomon and Griffiths (1972) suggested that this block may have been a Precambrian microcontinent. Another candidate is the ancestral New England region. The collision resulted in the progressive emergence of wide regions of the Tasmanides, including the Lachlan region, and this gave rise to widespread subsequent diachronous molassic sedimentation. Progression was from west to east, from the foreland towards the zone of collision, suggesting that the convergent movement of the Australian plate played an active role in the collisional deformation. The transitional tectonic province commenced, especially in the eastern part of the Lachlan region, by extensional basin formation and rifting, the Eden-Comerong-Yalwal Rift (McIlveen, 1974). In this rift, bimodal volcanics are intercalated with continental and marine strata (Fergusson et al., 1979). A-type granitoids are associated with the rifting (Collins et al., 1982). The brief Late Devonian marine incursion from the east was replaced by widespread continental sedimentation (figure 14). The Barka, Hervey and Lambie Basins can be recognized from west to east in NSW. To some extent controversy still persists about these basins: whether they formed a continuous blanket, or separate basins and intramontane depressions. A large amount of volcanogenic detritus in the east was attributed by Powell (1983a,b, 1984b) to a volcanic arc which was supposed to be related to the New England region. Farther north in Queensland, however, a wide zone of magmatic activity appears to be separate and different from the Connors-Auburn Arc or Arch of the New England Pre-cratonic Province (Day et al., 1983). As mentioned earlier,here the convergent plate margin with a west-plunging subduction zone continued into Carboniferous time (Leitch, 1974; Day et al., 1978; Fergusson, 1982; Murray et al., 1987; Ishiga et al., 1988; Atchison, 1988).

Of special interest for NSW is the extension of the Central Victorian Magmatic Province characterized by an average 365 Ma date (Ramsay and VandenBerg, 1986) into southern NSW. This is indicated by new aeromagnetic data acquired by the NSW Geological Survey (Ross et al. in prep.). This igneous zone has a northeast diagonal trend, and continues as far east as West Wyalong, across the basement terrane boundaries of Chappell et al. (1988). Obviously more research is needed to explain this igneous zone.

The Kanimblan Orogeny during the late Early and Early Late Carboniferous caused metamorphism, folding and faulting and converted the Lachlan Fold Belt into a neocraton. The effects of this orogeny were discussed in detail by Powell (1984a). The eastern part of the LFB was intruded by post-kinematic early Late Carboniferous Bathurst-type granites (Facer, 1979), which according to S. Shaw (pers. comm., 1989) are geochemically similar to the Early Carboniferous volcanics in the Hunter Valley within the New England Fold Belt (NEFB). As mentioned earlier, a wide belt of Carboniferous magmatic activity occurs in Queensland west of the NEFB and also west of the Bowen Basin. So this spatial distribution of Carboniferous magmatic activity in eastern Australia needs more research.

Late Carboniferous to Triassic Platform Cover of the Tasmanides

Veevers (1984) has described in great detail the early Late Carboniferous continental and alpine glaciation which followed the Kanimblan-Alice Springs Orogeny. Subsequent deposition in the region west of the future Bowen-Sydney Basin had platformal character. Epi-cratonic basins were filled dominantly by continental deposits of Late Carboniferous-Early Permian and Permian-Triassic age. In NSW these rocks are part of the infrabasins beneath the Murray Basin.

NSW Portion of the Bowen-Sydney Basin

The Sydney, Gunnedah and southern part of the Bowen Basins comprise the NSW portion of the Bowen-Sydney Basin. In its present form this complex structural basin developed from a transitional tectonic or reactivation tectonic domain which was closely related to an active plate margin with which the ancestral New England region was associated.

Harrington (1982) reviewed the earlier tectonic theories for the origin of the Bowen-Sydney Basin (BSB); this review with the addition of critical remarks is repeated here, and some post-1982 models are discussed. However, it has to be mentioned that all these theories which try to explain the stratotectonic development of the BSB by a single causal reason bound to be wrong as this basin and its sub-basins i.e. the Bowen, Gunnedah and Sydney Basins, appear to be polycyclic, in other words they had a polyhistory (Kingston et al., 1985), and usually each cycle or episode had its own cause.

1) The hypothesis of Voisey (1959) that these basins formed as an exogeosyncline, besides the fact that the geosynclinal concept has lost its meaning and place in plate tectonics, depends on the timing of the inversion (deformation) of the "New England Eugeosyncline". In classic geosynclinal theory exogeosynclines (synonym parageosynclines) accumulate clastic sediments from inverted and uplifted eugeosynclinal (orthogeosynclinal) belts (Kay, 1947). If the tectonic development is protracted there could be some overlap in time between the internides (central parts of the deformed eugeosyncline) and externides (Auboine, 1965).

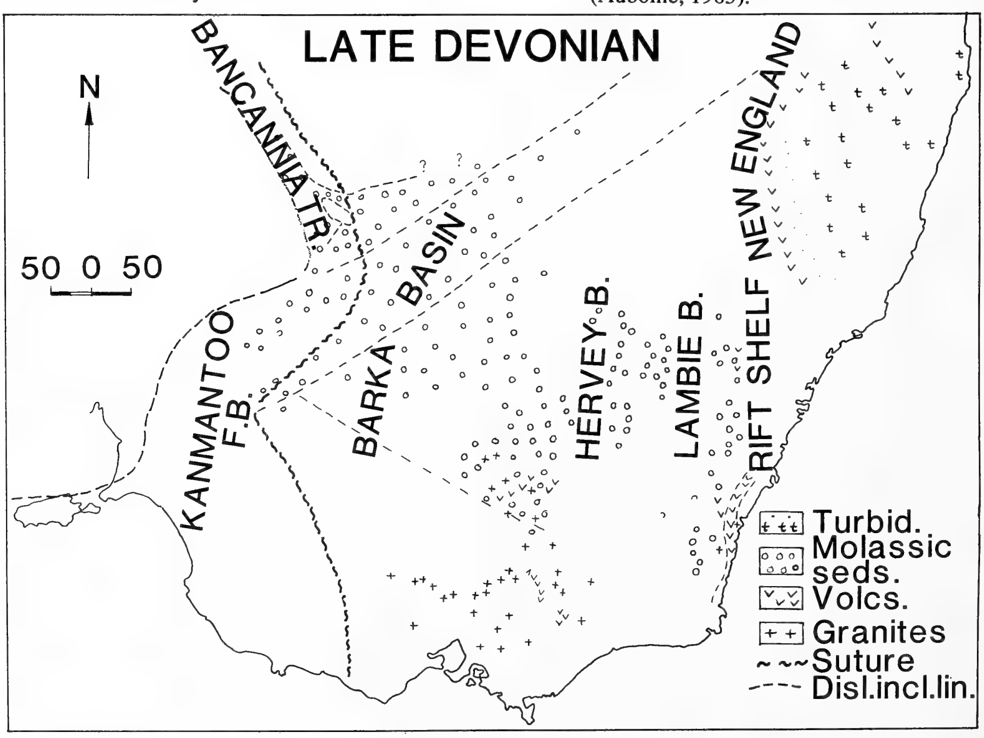

Figure 14. Schematic palaeogeographic map for Late Devonian time.

The discussed basin and sub-basins started to form in the latest Carboniferous to earliest Permian, and this was immediately preceded by an important orogenic deformation in the New England region. However, renewed orthogeosynclinal development followed in the New England region during the Early to Middle Permian, so the situation is more complex than Voisey's hypothesis envisages even within the geosynclinal context.

2) The hypothesis of Jones and McDonnel (1981) that these basins were fore-arc trough to a Late Permian arc in the New England region, similar to the relationship between the Aure Trough and the Papuan Peninsula, is of questionable validity. The Aure Trough may have been a combination of subduction zone and fore-arc basin, but there is no such indication for the BSB. The metal zoning in the Permian New England Magmatic Arch (Weber and Scheibner, 1977) indicates subduction from east to west, if subduction occurred at all at that time. The inner thrusts on the eastern side of the BSB may have started in the Middle Permian, but movement as young as Triassic occurred on them and so timewise they are contemporaneous with the igneous activity in the NEFB. These thrust at best could be classified as A-type subduction which could not have caused the Andean-style magmatic arch. If anything, the BSB was in a back-arc or retroarc basin postion as discussed by Murray (1985).

Harrington (1982) under this point also mentioned the foreland basin model of Conaghan et al. (1981), and Jones et al. in Veevers (1984) should be added. These authors paralleled the Papuan Basins's relationship with the New Guinea Orogenic Belt with the BSB's relationship with the New England Orogenic Belt, both basins being foreland basins. This is a modernized version of Voisey's (1959) model and is widely accepted for the time post-dating the Middle Permian deformation of the NEFB, but it does not solve the problem of the initial basin formation processes in the BSB and its tectonic setting during pre-Middle Permian time.

3) The "overthrust theory" which apparently was only discussed but not published. It assumes compression, i.e. thrusting and thrust piles from the New England orogenic region depressing the edge of the Lachlan Fold Belt; yet the early volcanics of the BSB indicate extension rather than compression. Thrusting did occur along the Peel Fault Zone during Late Carboniferous-Early Permian time, but no-one has as yet explicitly suggested that this was the cause of the BSB as a foreland basin at that time, even if Murray (1985) has discussed the possibily of early thrusting (see below).

4) The hypothesis that the basin was formed by rifting during the Earth's expansion (Carey, 1969) is difficult to asses, as no good criteria exist to evaluate such processes, but catastrophic expansion has been discounted on geophysical and other grounds.

5) Scheibner's (1974, 1976) tectonic analysis was the first which pointed to the polycyclic or polyhistory in the tectonic development of the BSB. While the existence of the foredeep character of this basin since the emergence of the NEFB is undisputed and is in agreement with the earlier ideas (Voisey, 1959; Diessel, 1970), the initial basin development is subject to controversy.

6) The explaination of the formation of the BSB as a precursor to the Mesozoic rifting and break-up of Gondwanaland has not been published and is difficult to assess. The hypothetical ensimatic Nambucca Basin could have been in the position of the two arms where break-up occurred, with the BSB being the failed arm, but there is no hard evidence for such a speculation.

7) The "thermal model" for the origin of the Sydney and Gunnedah Basins by Brownlow (1981) proposes the ad hoc intrusion of an asthenospheric diapir into the crust as the cause. Most available evidence indicates that upwelling of the asthenosphere occurs in response to tension in the lithosphere, e.g. during continental rifting as in the East African Rift Valley. If igneous activity is related to such asthenospheric upwelling it has mostly alkaline and peralkaline character and this is the consequence of the large thicknesses of involved lithosphere. In contrast, rifting in orogenic regions results in calc-alkaline to peralkaline igneous activity. In both orogenic and anorogenic environments, the rift related volcanism is usually bimodal. During the various types of basin formation processes involving thinning of crust and lithosphere, the lithospheric thinning is usually compensated by upwelling of asthenosphere. After the initial tectonic subsidence, thermal subsidence follows, and unless the basin fill is detached from its basement during the basin inversion, such a rifted basin is expressed in the Bouguer gravity data. The suggestion of Brownlow (1981) that the Carboniferous plutonism in NSW, i.e. the Bathurst granites in the northeastern part of the LFB, was caused by an asthenospheric diapir is not supported by the available geophysical data. This area does not have a regional gravity and aeromagnetic signature which would indicate the presence of a dense upwelled upper mantle, neither is the igneous activity bimodal nor alkaline, and the area did not subside subsequently due to thermal collapse as would be expected. The Late Carboniferous-Mesozoic sediments feather edge over this area as is observed in many other similar foreland regions around the world.

Some recent models of continental rifting (Mohr, 1987) envisage emplacement of asthenospheric material high into the crust and lithosphere, but this leads to uplift and arching, with rifting positioned in the crestal area which becomes the site of strongest thinning and subsequent tectonic and later thermal subsidence. In the model proposed by Brownlow (1981) the crest of the asthenospheric diapir has not subsided but the flanking area produced the Sydney and Gunnedah Basins. The basaltic volcanism (Werrie Basalt) hardly represents embryonic seafloor spreading (Brownlow, 1981, p.11); it appears to be part of bimodal volcanic activity.

8) The model of Harrington and Korsch (1985) is dependant on the existence of the hypothetical

Mooki-Lapstone Fault in latest Carboniferous and Early Permian time. As evidence for this fault they gave the dextral strike-slip displacement between the Bulgonnuna and "Kuttung" Volcanics. The Bulgonnuna Volcanics occur in the area of the Late Devonian-Carboniferous Drummond Basin, and according to Day et al. (1983) they are related to the "North Queensland Volcanic and Plutonic Province".According to Murray et al. (1987) their Late Carboniferous component was related to subduction north of the so-called Gogango-Baryulgil Transfrom Fault discussed below. The Bulgonnuna Volcanics have rhyolitic to dacitic character with minor andesites, and the volcanics are intruded and also comagmatic with the Late Carboniferous granites of this province. Roberts (in press) has pointed out that the "Kuttung" volcanics in the Tamworth Belt of the NEFB are closely related to the arc concealed beneath the Sydney Basin, with several igneous centres identified in the Hunter Valley area. The small granites mentioned by Harrington and Korsch (1985, p. 169) occur in this region at Winders Hill and Pokolbin Hills; one the Mount View Range Granodiorite, has a minimum age of 336 Ma (Brakel, 1972). Recently S. Shaw (pers. comm. October 1989) has determined that the Bathurst type granites in the LFB are geochemically similar to the "Kuttung" volcanics. This means that there was a wide belt of Carboniferous igneous activity west of the future Bowen Basin and west of the Connors-Auburn Arch, i.e. New England region proper, and that in NSW the possibly identical Carboniferous igneous belt was more closely associated with the New England region proper and crossed the region of the future Sydney Basin. Perhaps the same happened in Queensland, but either basin formation was more intensive in the Bowen Basin or such an igneous belt is deeply concealed beneath it. However, from the above it follows that there is no need for large transform displacement to explain the present distribution of Early Carboniferous igneous rocks in and close to the BSB.

The main objection to the Harrington and Korsch's (1979, 1985) model is based on the study of residual Bouguer gravity data (Murray et al., 1989) (see below).

Recently Harrington (1986) elaborated certain aspects of his earlier tectonic model for the BSB. He appeared to accept the foreland basin hypothesis expressed by several authors, notably Murray (1985), but this foreland basin in a back-arc position was supposed to have formed in a transform fault setting. The time of formation was given as the end of the Carboniferous to the beginning of the Permian, when the "Kuttung-Bulgonnuna Volcanic Arc" became extinct and dextral strike-slip displacement commenced. He accepted that the Werrie Basalt and associated volcanics are rift related.

9) Harrington (1984), in the chapter on "Tectonic Setting" in the compendium "Permian Coals of Eastern Australia", has discussed the BSB as "marginal basins", being marginal in respect to their closeness to the Permian coast, in contrast to "interior basins" that were distant from the Permian coast.

The term "marginal sea" or "marginal basin" denotes a type of "small ocean basin" of Menard (1964, 1967) which is characterized by oceanic crust and a position marginal to a continent and major ocean. For this reason it is misleading to use the term "marginal basin" in the sense suggested by Harrington (1984). The closeness of a sedimentary basin to a coast has no special significance; the relationship to the plate margin or plate interior is more important. The available evidence indicates that the determining factor in the tectonic setting of the BSB was the immediate influence of an active plate margin.

10) A modern tectonic synthesis of the Bowen Basin was made by Murray (1983, 1985). He concluded that the Bowen Basin fits the retroarc foreland basin setting (Dickinson, 1974, 1978). Based on Dickinson (1974, 1978), Beaumont (1981) and Miall (1984), he quoted eight features characteristic of retroarc basins.

a) Position behind magmatic arc: the Bowen Basin is behind the Camboon Volcanic Arc (Day et al., 1983), and Veevers (1984) suggested that the Sydney and Gunnedah Basins were behind his Innamincka Arc which is represented by the Hillgrove and Bundarra Plutonic Suites (Shaw and Flood, 1981). The Boggabri and Gunnedah Volcanics together with the Werrie Basalt may be related to rifting in the BSB, even if McPhie (1984) suggested that the felsic rocks are the final restricted product of the "Kuttung Arc". Murray (1985) pointed out that it is not typical for retroarc basins to form during the waning of arc activity.

b) Continental crust: all evidence points to an ensialic setting for the BSB and there is little evidence for the "embryonic sea-floor spreading" of Brownlow (1981) as already mentioned.

c) Foreland thrust belt loading: the BSB is bounded by thrusts on the east, and structural deformation increases as the eastern boundary is approached, but these thrusts post-date the BSB . The Tamworth Belt has a foreland thrust and fold structural style, but this formed during the Middle Permian orogeny (Leitch, 1969) and hence could not be the cause of foreland basin downwarping. Murray (1985) suggested that the early thrusts related to the formation of BSB have not been recognized or have been removed by erosion. As has already been mentioned, perhaps the thrusting along the Peel Fault Zone, and similar structures in Queensland, could represent the early thrusting. From the Middle Permian onwards, of course, the foreland basin model applies to the BSB (new data of Glen and Beckett, 1989). Early elastic bending of the lithosphere due to compression does not appear to be probable, neither the loading due to adjacent magmatic arc (Murray, 1985).

d) Transverse profiles across the BSB do comply with the model; they are all asymmetric, gradually deepening towards the adjacent fold belt.

e) The cratonic flanks do gradually merge with the adjacent cratonic cover as is common in other regions.

f) Characteristic sediments: according to Dickinson (1978), fluvio-deltaic deposits are most typical for retroarc basins and are definitely dominant along the western onlap margin of the BSB, but during certain episodes, namely the Early and Late Permian, shallow marine sedimentation occurred especially along the axial and eastern part of the BSB. Murray (1985) noted westward movement of the main axis of the Bowen Basin with time, this being consistent with the continued westward displacement of the thrust belt. Derivation of clastics is alternatively from the foreland and hinterland (NEFB). The general trend of upward transition from marine to non-marine strata is here well developed, as well as continental coal measures, the BSB containing the main coal resources in Australia (Harrington, 1984).

g) Coal rank variations are consistent with tectonic modelling (Murray, 1985), but also are dependant on the relationship to the early rift, which was the source of relatively high heat flow, and individual rift compartments could have a different maturation history (cf.Tadros, 1988).

h) Inversion: deposition in the BSB ceased at the end of the Middle Triassic. Harrington and Korsch (1985) attributed this deformation to the accretion of the Gympie Terrane, but Murray (1985) pointed out that the stratigraphic and structural evidence from the Gympie Province and the adjacent Esk Trough point to Early Triassic accretion of the Gympie Terrane. The reason for the discrepancy may be that there was possible progressive propagation of stresses westwards, or that the Middle Triassic compression was related to events farther east at the active plate margin of that time (New Zealand region).

11) Hammond (1987) and Mallet et al. (1988a) have applied the latest extensional tectonic models to the Bowen Basin and subsequently Mallet et al. (1988b) attempted the same for the Sydney and Gunnedah Basins. These attempts are commendable, but it is regrettable that these authors did not familiarize themselves with the earlier ideas on rifting (see discussion above). Transverse structures based on remotely sensed satellite and geophysical data have been recognized for some time, and also the fact that these transverse structures functioned as transform faults in the past (Scheibner, 1974b). A major transverse lineament was used to divide the Gunnedah and Sydney Basins (Bradley et al., 1985). The interpretation of residual Bouguer gravity data (Murray et al., 1989) resulted in the suggestion that the dominant northeast transverse lineaments represent transfer faults separating rift compartments. The model proposed by Hammond (1987) and Mallet et al. (1988a, b) could be improved by using residual Bouguer gravity data, aeromagnetic data, satellite imagery, and the results of deep seismic reflection and refraction data (Finlayson, 1989; in prep.; Murray et al., 1989, Tadros, 1988; Wake-Dyster et al., 1987).

All available evidence points to an epicontinental setting, with crustal thinning during basin formation. The long Meandarra Gravity Ridge can be interpreted as indicating a rift origin (figure 15) (Murray et al., 1989). The large length, over 1750 km, and the unusually high ratio, at least 24, of length to width of the Meandarra Gravity Ridge, indicate that rifting and basin initiation were caused by large-scale plate interaction, for example stepping out of the subduction zone. Pull-apart basins related to strike-slip or transform faulting have a ratio close to 3 independant of scale (Aydin and Nur, 1982), and the ratio in continental deformation is 5-10 (England et al., 1985).

Based on present knowledge the Bowen-Sydney Basin should be classified as a Late Carboniferous to Early Permian rift basin formed at a convergent, probably transtensional, plate margin, and it became a foreland basin only subsequently, possibly after mid-Permian diastrophism in the NEFB. This is contrary to the most widely accepted view that the basin developed initially as a foreland basin (Veevers et al., 1982; Murray, 1985), but is in agreement with an earlier view based on tectonic analysis (Scheibner, 1976). Throughout its development the Bowen-Sydney Basin was behind some type of orogenic igneous arc, i.e. in a retatroarc position (Murray, 1985), but hardly did it subside under the weight of the neighbouring arc. A more probable cause was overthrusting of the NEFB definitely from the Middle Permian onwards, but perhaps somewhat earlier (cf. Glen and Beckett, 1989).

Some volcanic activity in the Bowen-Sydney Basin region was related to rifting during basin formation, some was related to waning of the Devonian-Carboniferous frontal New England arc, in the west some was related to a wide region of magmatism the cause of which and precise relationship to the New England arc is not yet established, and some was related to a subsequent stepped out magmatic arc in the NEFB.

In summary, the Bowen-Sydney Basin, except for its rift inception, best fits a foreland basin or foredeep model as advocated repeatedly by many authors. In the west this basin represents cover over the older fold belts.

Late Carboniferous-Early Permian in the New England Region

The development in Queensland has been recently discussed by Murray (1986) and the development in NSW is similar, even if diachronous (Murray et al., 1987). Sedimentation in post-Kanimblan time continued in continental facies in the Ayr Basin (Scheibner, 1974a, 1976) or Werrie Basin (Evans and Roberts, 1980). According to Roberts and Engel (1980), during the Namurian the central part of the New England region was uplfited to form the New England Arch of Campbell (1969). This may mark the coupling of the lower and upper plates in this region.

According to Murray et al. (1987) the complicated structure of the NEFB resulted from a progressive change from oblique subduction to a dextral transform fault boundary. This change occurred first in the Yarrol Province of the NEFB and led to a westward jump of the transform boundary to a new site, the newly created Gogango-Baryulgil Fault Zone. At the same time subduction continued in the New England Province. The Yarrol Province was translated dextrally southwards for about 500 km, along the new transform fault, and this accounts for the observed doubling of arc - fore-arc - accretionary complexes in the NEFB. During this process the accretionary complexes were oroclinally bent to form the so-called Texas-Coffs Harbour Megafold of Fergusson (1982) and Flood and Fergusson(1984). Korsch and Harrington (1987) suggested another orocline in the Maning region. Subduction westwards recommenced north of the Gogango-Baryulgil Transform and explains the Late Carboferous igneous rocks in north Central Queensland.

Recent work by Blake (Blake and Murchey, 1988) corrected an earlier misconception, namely that the greenstones and associated ophiolitic rocks occurring now mostly along a late compressional structure, the Peel Thrust, are related to accretionary complexes (all previous authors). He suggested that these rocks are part of the upper plate and basement to the arc and fore-arc region, and that the contact between the arc and the ophiolitic rocks is the trace of the subduction zone. After coupling of the two converging plates leading to compressional deformation, the region, mainly the upper plate with its ophiolitic basement, was extended and thinned, and only after this new compression resulted in thrusting and formation of the Peel Thrust. This means that the Peel Fault Zone (Thrust) is not the first class suture as suggested by the authors until now, but that this principal suture is at the roof of the accretionary complexes of the NEFB.

Some authors (Leitch, 1974; Crook, 1980) have compared the Peel Thrust (obduction zone of Scheibner and Glen, 1972) to the Coast Range Thrust in California, but while similar stratotectonic elements are involved, the Peel Thrust is antithetic to the Coast Range Thrust. However, a closer analogy exists with obduction of the accretionary prism over the fore-arc and arc suggested by Kroenke and Dupont (1982) for the Three Kings Rise in the SW Pacific. Obduction in the Three Kings Rise region appears to have been caused by an oceanic plateau which collided with the rise and choked the subduction zone. Perhaps the needed collision was provided by the change of the converging margin suggested by Murray et al.(1987) and southwards transpressional translation of the Yarrol Province of the NEFB.

Permian-Triassic Development of the New England Region

Major changes took place during the Late Carboniferous-Early Permian, and Murray et al. (1987) narrowed it down to the Carboniferous-Permian boundary which they defined as the interval 300-295 Ma. As already discussed, the BSB formed at this time and it was pointed out that the style of rifting requires a new plate margin rearrangement, most probably the establishment of a new subduction zone in the east. The Camboon Volcanic Arc has been recognized in Queensland (Day et al., 1978), and Veevers (1984) suggested that the Bundarra and Hillgrove Plutonic Suites represent part of an arc. Crook (1980) and Shaw and Flood (1981) suggested the formation of these plutonic suites under the influence of a subducted spreading centre which would have provided the high heat flow for crustal melting in a relatively cold accretionary complex. The Bundarra Plutonic Suite is parallel to the Peel Thrust and could be related to thrusting along it (Shaw and Flood, 1981).

At the same time extensional basins formed; the Nambucca Basin was a possible marginal sea (Scheibner, 1974a; 1976), and further south in the Manning region several fault-bounded basins accumulated thick Early Permian diamictite sequences (Leitch, 1988). A similar short-lived, possibly ensimatic trough was formed in the Yarrol Province (Day et al., 1983; Murray et al., 1987).

Controversy exists in respect of dextral (Scheibner, 1976; Scheibner and Glen, 1972) versus sinistral (Corbett, 1976; Cawood, 1982) displacements in the southern part of the NEFB, mainly along the Peel Thrust. Murray et al. (1987) convincingly documented a dextral active margin up to 300 Ma. The Peel Thrust and the fundamental block structure of the NEFB probably formed at this time. The distribution of greenstones and associated ophiolitic rocks was probably related to the thrusting and blocks tectonics. The distribution of blocks and ophiolitic rocks was the basis for the suggestion of the dextral regime (Scheibner, 1976). Structural data (Corbett, 1976, and Offler and

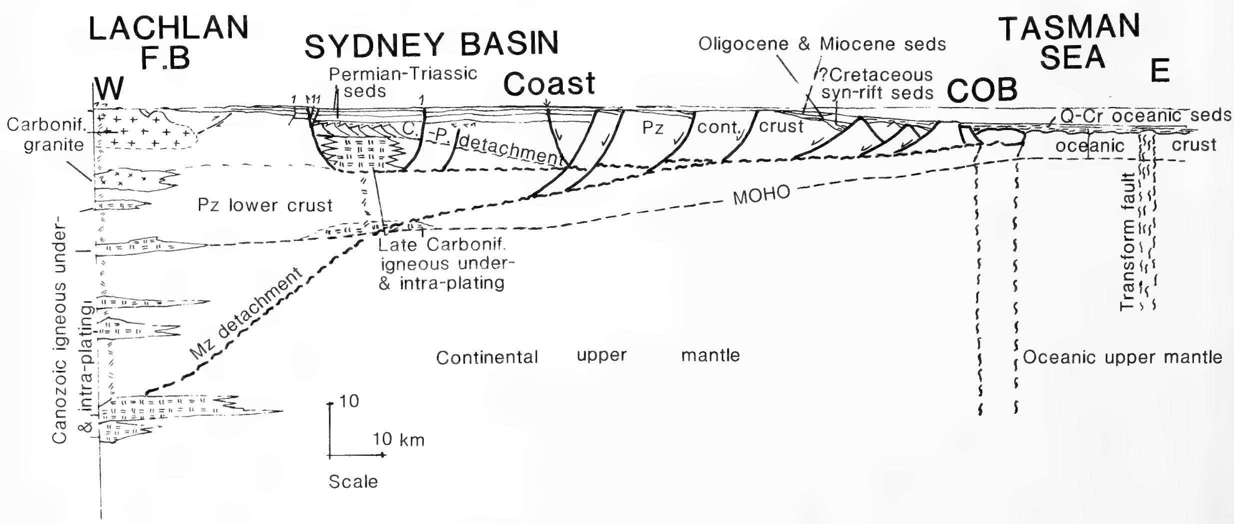

Figure 15. Schematic crustal section through the Sydney Basin, continental margin and adjacent oceanic crust (after Scheibner 1989). Offshore data after Colwell and Coffin (1989).

Williams, 1987), on the other hand, suggested sinistral transpression east of the Peel Thrust. Murray et al. (1987) suggested a change of direction in plate inter-action after 300 Ma resulting in the sinistral structures, which were further enhanced during subsequent Middle Permian deformation. So, perhaps both opinions are correct, but valid for certain time only, and thorough research could establish this.

During the mid-Early or Middle-Permian Hunter event the structure of the NEFB was further developed. The strongest deformation, including regional metamorphism occurred in the central part of the NEFB. Further movement possibly occurred on earlier thrusts and boundaries of blocks. The Tamworth Belt shows evidence of burial metamorphism which increases towards the Peel Thrust. The whole NEFB was thrust over the neighbouring BSB. The above event could have resulted from terrane collision and accretion in the region farther east, and recently Cawood (1984) tried to correlate the tectonic development of the NEFB and the Rangitata Orogenic Belt in New Zealand.

The subsequent tectonic development is characterized by the formation of a magmatic arch and by disruptive volcanic rifting and basins formation typical of transitional tectonism. The magmatic arch appears to show zoning of associated metallogenic provinces (Weber and Scheibner, 1977) similar to that described from subduction-related arcs, and Cawood (1984) argued for a close relationship with plate convergence in the New Zealand orogenic region, but this problem is far from solved.

Transitional tectonic basins having the character of an intra-montane depression, accumulated continental facies sediments (Lorne, Callide, Tarong and Ipswich Basins in NSW and Queensland).

The igneous activity and deformation appear to have migrated northward with time, suggesting an unstable migrating plate configuration, but no clear explanation is available yet. The Permian to Early Triassic clastic, volcanic and carbonate Gympie Terrane (Murray, 1986) was accreted possibly during the Early Triassic, and terminal deformation of the NEFB and its foredeep (BSB) occurred during the Late Triassic (Murray, 1986).

Obviously the NEFB is not a complete orogenic belt, and parts essential for tectonic interpretation remain hidden in marginal plateaus and microcontinents of the SW Pacific produced during the Late Mesozoic break-up of this region.

Meso-Cainozoic Passive Continental Margin and the Tasman Sea Crust

Calc-alkaline igneous rocks of Early Cretaceous age occur in Queensland (Day et al., 1983), and their tectonic seting is not yet satisfactorily explained. Similarly the Jurassic plutons in the Lorne Basin area need more elaboration.

The continental margin of eastern Australia adjacent to the Tasman Sea is extremely narrow compared with other passive margins. Off Sydney along an east-west transect there is 115 km between the shore and the 4 km isobath. Apparently Cretaceous rift sediments appear on the latest seismic data (Colwell et al., 1989) in half-graben and tilted blocks, followed by Paleogene sediments which in the shelf region appear to be of Oligocene age, and a distinct erosional break is followed by Miocene sediments (Falvey and Mutter, 1981). Quaternary sediments are thin (Thom and Roy, 1985). The thickness of the shelf and slope sediments is in the order of hundreds of metres, with exceptional thickness of over 3 km in some large half-graben structures. The thickness of basin sediments at the foot of the slope and farther away is over 1.5 km, in some areas over 2.5 km (Symonds, 1973; Colwell et al., 1989). The new seismic data indicate that rotated continental blocks occur beyond the perceived continental-ocean boundary (cf. Broken Hill-Sydney Geoscience Transect, Scheibner, 1989).

Development of the Australian or Tasman passive continental margin (Falvey and Mutter, 1981; Veevers, 1984) was heralded by Jurassic and Cretaceous intraplate, mostly alkaline, igneous activity (Sutherland, 1978). Emplacement of these rocks indicates that extension had affected the whole lithosphere. Many of these intrusions occur on east-northeast-oriented lineaments (Scheibner, 1979). In the coastal region these intrusions are opposite the Late Cretaceous-Paleogene transform faults in the Tasman Sea (Ringis, 1975). By the end of the Early Cretaceous, rifting took place between the Dampier Ridge and Lord Howe Rise (Mutter and Jongsma, 1978), which at that time were still attached to Australia. Lister et al. (1986) suggested that this rifting was governed by a major west-dipping detachment and that the eastern Australian margin was in the upper plate position. The final break-up occurred close to the present narrow shelf and slope and not in the axial region of the rift (Mutter and Jongsma, 1978). Sea-floor spreading started at about 85 Ma and terminated in the Tasman Sea at about 57.5 Ma at the end of the Paleocene (Hayes and Ringis, 1973).

CONCLUSIONS

The plate tectonic paradigm since its inception nearly thirty years ago has advanced considerably and new research adds to it constantly. The original simple conceptual models have been replaced by more advanced ones as the various processes are better understood. The application of plate tectonics to orogenic and also anorogenic regions, in our case the study of geology of New South Wales, has to take this into account.

The above discussion is only an abbreviated abstract of the revision of the "Geology of New South Wales" currently being undertaken by the NSW Geological Survey. It is quite obvious that even if enormous progress has been achieved in the last twenty years since the publication of the previous synthesis (Packham, 1969), there are still many unsolved problems and plenty of scope for research. The application of satellite remote sensing has brought with it an important change in perception and elevated earth scientists from small outcrops to large regions. It should be kept in mind that often the answer to a local problem is in the study of a larger region.

However, my experience is that the best understanding of geology is achieved during detailed geological mapping. Modern geochemical, geophysical and remote sensed data are useful only if integrated with a detailed knowledge of geology. Unfortunately the time when the whole of New South Wales will be covered by detailed geological maps is remote in the future. Perhaps the new "National Mapping Accord" will bring us closer to such a desirable situation.

The state of the art could be defined: "we now know where the problems are ..."

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I would like to acknowledge and express my great appreciation to the Royal Society of New South Wales for the invitation to present the 1989 Clarke Memorial Lecture, and also for the opportunity to have it published.

The ideas expressed in this lecture developed over long period and I was influenced not only by my own field observations and past geologic experience, but also by the results of field investigations, namely detailed geologic mapping of my colleagues at the New South Wales Geological Survey, and also outside this organization. The experience has shown that integrated earth science investigations bring meaningful results only when based on detailed field knowledge; this was best illustrated during the Cobar region study (cf. Glen et al., 1985). The lecture then presents a working model based on the work of many researchers, not all which could be acknowledged in the text. However, geologic observations, remotely sensed data, especially geophysical data, lend themselves to multiple, often contradictory interpretations, and here I was influenced by the latest ideas concerning all aspects of plate tectonics.

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REFERENCES

Adams,C.J., Black, L.P., Corbett, K.D., and Green, G.R., 1985. Reconnaissance isotopic studies bearing on the tectonothermal history of Early Palaeozoic and Late Proterozoic sequences in Western Tasmania. *Australian Journal of Earth Sciences 32*, 7-36.

Agostini, A., 1987. Walgett 1:25,000 sheet - a geological interpretation from regional aeromagnetic and gravity data. *N.S.W. Geological Survey — Quarterly Notes 66*, 21-31.

Allegre, C.J., and Luck, J-M., 1980. Osmium isotopes as petrogenetic and geologic tracers. *Earth and Planetary Science Letters 48*, 148-154.

Ampferer, O., 1906. Uber das Bewegungbild von Faltergebirge, Austria. *Geologische Bundesanstalt — Jahrbuch 56*, 479-503.

Anderson, R.N., 1981. Surprises from the Glomar Challenger. *Nature 293*, 261-262.

Argand, E., 1924. Late tectonique de l'Asie. IIIe Congress Geologique Internationale, Liege, Imprimerie Vaillant-Carmanne (translated and edited by A.V. Carrozi), New York, Hafner Press, 218 p.

Ashley, P.M., Brown, P.F., Franklin, B.J., Ray, A.S., and Scheibner, E., 1979. Field and geochemical characteristics of the Coolac Ophiolite Suite and its possible origin in a marginal sea. *Geological Society of Australia - Journal 26*, 45-60.

Atchison, J.C., 1988. Radiolaria from the southern part of the New England Orogen. In: Kleeman, J.D., ed., New England Orogen - Tectonics and Metallogenesis, University of New England, 49-60.

Atwater, T., 1970. Implications of plate tectonics for the Cenozoic tectonic evolution of western North America. *Geological Society of America — Bulletin 81*, 3513-3536.

Baillie, P.A., 1985. A Paleozoic suture in eastern Gondwanaland. *Tectonics 4*, 653-660.

Bain,J.H.C., Wyborn, D., Henderson, H.A.M., Stuart-Smith, P.G., Abell, R.S., and Solomon, M., 1987. Regional geologic setting of the Woodlawn and Captains Flat massive sulphide deposits, N.S.W., Australia. *Australasian Institute of Mining and Metallurgy, Pacific Rim Congress 87 — Proceedings*, 25-28.

Bally, A.W., and Snelson, S., 1980. Facts and principles of world petroleum occurence: Realms of subsidence. *Canadian Society of Petroleum Geologists - Memoir 6*, 9-94.

Banks, M.R., and Baillie, P.W., 1988. Late Cambrian to Devonian, *in* Burrett, C.F., and Martin, E.L., eds., Geology and Mineral Resources of Tasmania. *Geological Society of Australia — Special Publication 15*, 182-237.

Barrel, J., 1914. The strength of the Earth's crust. *Journal of Geology 22*, 28-48, 145-165, 209-236, 289-314, 441-468, 537-55, 655-683, 729-741.

Basden, H., 1982. Preliminary report on the geology of the Tumut 1:100,000 Sheet area, southern New South Wales. *N.S.W. Geological Survey — Quarterly Notes 46*, 1-18.

Beavis, F.C., 1962. The geology of the Kiewa area. *Royal Society of Victoria — Proceedings 75*, 349-410.

Benioff, H., 1954. Orogenesis and deep crustal structure - Additional evidence from seismology. *Geological Society of America — Bulletin 65*, 385-400.

Barron, L.M., Scheibner, E., and Suppel, D.W., 1982. The Mount Hope Group and its comagmatic granites on the Mount Allen 1:100,000 Sheet, New South Wales. *N.S.W. Geological Survey - Quarterly Notes 47*, 1-17.

Berry, R.F., and Crawford, A.J., 1988. Tectonic significance of Cambrian allochthonous mafic ultramafic complexes in Tasmania. *Australia Journal of Earth Sciences 35*, 523-533.

Bird, P., 1980. Continental delamination and the Colorado Plateau. *Journal of Geophysical Research 84*, 7561-7471.

Blake, Jnr. M.C., and Murchey, B.L., 1988. A California model for the New England Fold Belt. *N.S.W. Geological Survey — Quarterly Notes 72*, 1-9.

Bond, G.C., Nickeson, P.A. and Kominz, M.A., 1984. Breakup of a supercontinent between 625 Ma and 555 Ma: new evidence and implications for continental histories. *Earth and Planetary Science Letters 70*, 325-345.

Bothworth, W., Lambiase, J., and Keisler, R., 1986. A new look at Gregory's Rift: the structural style of continental rifting. *EOS 67* (No 29), 577 & 582-583.

Bowman, H.N., Richarson, S.J., and Paterson, I.B.L., eds., 1983. Palaeozoic island arc and arch mineral deposits in the central west of New South Wales. Part 1: tectonic, metallogenic, and economic discussion. *N.S.W. Geological Survey — Records 21*, 329-406.

Brackel, A.T., 1972. The geology of the Mt. View Range district, Pokolbin, N.S.W. *Royal Society of N.S.W. — Journal and Proceedings 105*, 61-70.

Branson, J.C., Moss, F.J., and Taylor, F.J., 1976. Deep crustal reflection seismic test survey, Mildura, Victoria and Broken Hill, N.S.W. *Australian Bureau of Mineral Resources, Geology and Geophysics — Report 1983*, 30p.

Brown, A.V., 1986. Geology of the Dundas - Mt Lindsay - Mt Youngbuck area. *Tasmania Geological Survey — Bulletin 62*, 221p., maps.

Brown, A.V., 1988. Eo-Cambrian-Cambrian., *in* Burrett, C.F., and Martin, E.L., eds., Geology of Tasmania. *Geological Society of Australia — Special Publication 15*, 47-83.

Brown,C.M., Tucker, D.H., and Anfiloff, V., 1988. An interpretation of the tecto-stratigraphic framework of the Murray Basin region of southeastern Australia based on examination of airborne magnetic pattern. *Tectonophysics 154*, 309-333.

Brunker, R.L., 1968. 1:250,000 Geological Series Explanatory Notes Bourke Sheet SH/55-10, 1st edition. N.S.W. Geological Survey, Sydney, 19 p.

Buck, W.R., Martinez, F., Steckler, M.S., and Cochran, J.R., 1988. Thermal consequences of lithopsheric extension: Pure and simple. *Tectonics 7*, 213-234.

Buckland, G.L., and Ramsay, W.R.H., 1982. The geological setting and mineral potential of the Mount Stavely Volcanic Complex, western Victoria. *Australian Institute of Mining and Metallurgy — Transactions 20*, 419-432.

Bullard, E.C., Everett, J.E., and Smith, A.G., 1965. The fit of the Continents around the Atlantic. *Royal Society of London — Philosophical Transactions A258*, 41.

Burrett,C.F., and Martin, E.L., eds., 1989. Geology and Mineral Resources of Tasmania. *Geological Society of Australia - Special Publication 15*, 574 p.

Campbell, K.S.W., 1969. Carboniferous System, *in* Packham, G.H., ed., The Geology of New South Wales. *Geological Society of Australia — Journal 16*, 245-261.

Carey, S.W., 1958. A tectonic approach to continental drift, *in* Continental Drift - A Symposium (ed., S.W. Carey). University of Tasmania, 177-355.

Cas, R.A.F., 1978a. Basin characteristics of the Early Devonian part of the Hill End Trough based on stratigraphic analysis of the Merrions Tuff. *Geological Society of Australia — Journal 24*, 381-401.

Cas, R.A.F., 1987b. Silcic lavas in Palaeozoic flysch-like deposits in New South Walesm Australia: behavious of deep subaquaeous silicic flows. *Geological Society of America - Bulletin 89*, 1708-1714.

Cas, R.A.F., 1983. A review of the facies patterns, palaeogeographic development and tectonic context of the Palaeozoic Lachlan Fold Belt of southeaster Australia. *Geological Society of Australia — Special Publication 10*, 104 p.

Cas, R.A.F., Powell, C.McA., and Crook, K.A.W., 1980. Ordovician palaeogeography of the Lachlan Fold Belt: a modern analogue and tectonic constraints. *Geological Society of Australia — Journal 27*, 19-32.

Cawood, P.A., 1976. Cambro-Ordovician strata, northern New South Wales. *Search 7*, 317-318.

Cawood, P.A., 1982. Structural relations in the subduction complex of the New England Fold Belt, eastern Australia. *Journal of Geology 90*, 381-392.

Cawood, P.A., 1984. The development of the SW Pacific margin of Gondwana: Correlations between Rangitata and New England Orogoens. *Tectonics 3*, 539-553.

Chappell, B.W., 1984. Source rocks of I- and S-type granites in the Lachlan Fold Belt, southeastern Australia. *Royal Society of London — Philosophical Transactions A310*, 693-707.

Chappell, B.W., and White, A.J.R., 1974. Two contrasting granite types. *Pacific Geology 8*, 173-274.

Chappel, B.W., and White, A.J.R., 1985. Granites and the Victorian lithosphere. *Victorian Lithosphere Symposium — Abstracts*, 10-11.

Chappell, B.W., White, A.J.R., and Hine, R., 1988. Granite provinces and basement terranes in the Lachlan Fold Belt, southeastern Australia. *Australian Journal of Earth Sciences 35*, 505-521.

Chappell, B.W., White, A.J.R., and Wyborn, D., 1987. The Importance of Residual Source Material in Granite Petrogenesis. *Journal of Petrology 28*, 1111-1138.

Clarke, W.B., 1848. On the Genera and Distribution of Plants in the Carboniferous System of New South Wales. *Geological Society of London — Quarterly Journal 4*, 60-63.

Clarke, W.B., 1860. Researches in the Southern Goldfield of New South Wales. Reading and Wellbank, Sydney.

Clarke, W.B., 1878 (4th ed.). Remarks on the Sedimentary Formations of New South Wales.

Collins, P.L.F., and Williams, E., 1986. Metallogeny and tectonic development of the Tasman Fold Belt System in Tasmania. *Ore Geology Reviews 1*, 153-201.

Collins, W.J., Beams, S.D., White, A.J.R., and Chappell, B.W., 1982. Nature and origin of A-type granites with partial reference to southeastern Australia. *Contributions to Mineralogy and Petrology 80*, 189-200.

Collwell, J.B., and Coffin, M.F., principal investigators, et al., 1989. Rig Seismic Research Cruise 13: Structure and stratigraphy of the northeast Gippsland and southern New South Wales margin - Intial Report. *Australian Bureau of Mineral Resources, Geology and Geophysics — Report 283*.

Coney, P.J., Jones, D.L., and Monger, J.W.H., 1980. Cordilleran suspect terranes. *Nature 288*, 329-333.

Cook, P.J., 1982. The Cambrian palaeogeography of Australia and opportunities for petroleum exploration. *The APEA Journal 22*, 42-64.

Cooper, R.A. and Grindley, G.W., eds., 1982. Late Proterozoic to Devonian Sequences of southeastern Australia, Antarctica and New Zealand and their Correlation. *Geological Society of Australia — Special Publication 9*, 103p.

Corbett, G.J. 1976. A new fold structure in the Woolomin Beds suggesting a sinistral movement on the Peel Fault. *Geological Society of Australia — Journal 23*, 401-406.

Corbett, K.D. and Solomon, M., 1989. Cambrian Mt Read Volcanics and Associated Mineral Deposits. In: Burrett, C.F., and Martin E.L., eds., Geology and Mineral Resources of Tasmania. *Geological Society of Australia — Special Publication 15*, 84-153.

Corbett, K.D., and Turner, N.J., 1989. Early Palaeozoic Deformation and Tectonics. In: Burrett, C.F., and Martin, E.L., eds., Geology and Mineral Resources of Tasmania. *Geological Society of Australia — Special Publication 15*, 154-180.

Coulon, C. and Thorpe, R.S., 1981. Role of continental crust in petrogenesis of orogenic volcanic associations. *Tectonophysics 77*, 79-93.

Cox, S.F., Ceplecha, J., Wall, V.J., Etheridge, M.A., Cas, R.A.F., Hammond, R., and Willman, C., 1983. Lower Ordovician Bendigo Trough sequence, Castlemaine area, Victoria - Deformational style and implications for the tectonic evolution of the Lachlan Fold Belt. *Geological Society of Australia - Abstracts 9*, 41-42.

Crawford, A.J., 1983. Tectonic development of the Lachlan Fold Belt and construction of the continental crust of eastern Australia. *Geological Society of Australia — Abstracts 9*, 30-32.

Crawford, A.J., Cameron, W.E., and Keays, R.R., 1984. The association of boninite-low Ti andesite-tholeiite in the Heathcote Greenstone Belt; ensimatic setting for the early Lachlan Foldbelt. *Australian Journal of Earth Sciences 31*, 161-177.

Crawford, A.J., and Keays, R.R., 1978. Cambrian greenstone belts in Victoria: marginal sea crust slices in the Lachlan Fold Belt of southeastern Australia. *Earth and Planetary Science Letters 41*, 197-208.

Crawford, A.J., and Keays, R.R., 1987. Petrogenesis of Victorian Cambrian Tholeiites and Implications for the Origin of Associated Boninites. *Journal of Petrology 28*, 1075-1109.

Crook, K.?A.W., 1964. Depositional environment and provenance of Devonian and Carboniferous sediments in the Tamworth Trough, New South Wales. *Royal Society of N.S.W. — Journal and Proceedings 97*, 41-53.

Crook, K.A.W., 1980. Fore-arc evolution in the Tasman Geosyncline: the origin of southeast Australian continental crust. *Geological Society of Australia — Journal 27*, 215-232.

Crook, K.A.W., Bein, J., Hughes, R.J., and Scott, P.A., 1973. Ordovician and Silurian history of the southeastern part of the Lachlan Geosyncline. *Geological Society of Australia — Journal 20*, 113-138.
Crook, K.A.W., and Powell, C.McA., 1976. Th evolution of the southeastern part of the Tasman Geosyncline. *International Geological Congress 25th Session — Excursion Guide 17A*.
Crough, S.T., and Jurdy, D.M., 1980. Subducted lithosphere, hot spots, and the geoid. *Earth and Planetary Science Letters 48*, 15-22.
Dietz, R.S., 1961. Continent and ocean basin evolution by spreading of the sea floor. *Nature 190*, 854-857.
Day, R.W., Murray, C.G., and Whitaker, W.G., 1978. The eastern part of the Tasman orogenic zone. *Tectonophysics 48*, 327-364.
Day. R.W., Whitaker, W.G., Murray, C.G., Wilson, I.H., and Grimes, K.G., 1983. Queensland Geology, A companion volume to the 1:2,500,000 scale geological map (1975). *Queensland Geological Survey — Publication 383*, 194p.
Degeling, P.R., Gilligan, L.B., Scheibner, E., and Suppel, D.W., 1986. Metallogeny and tectonic development of the Tasman Fold Belt System in New South Wales. *Ore Geology Reviews 1*, 259-313.
Dickinson, W.R., 1973. Widths of moderna arc-trench gaps proportional to past duration of igneous activity in associated magmatic arc. *Journal of Geophysical Rsearch 78*, 3376-3389.
Dietz, R.S., 1963. Collapsing continental rise: An actualistic concept of geosyn-clines and mountain building. *Journal of Geophysical Research 71*, 314-333.
Douglas, J.G., and Ferguson, J.A., eds., 1988. Geology of Victoria. Geological Society of Australia, Victorian Division, 664p.
Doutch, H.F., 1972. The concept of transitional tectonism in Australia. *Geological Society of Australia — Abstracts of Joint Specialists Groups Meeting*, E10-E11.
Du Toit, A.L., 1937. Our wandering continents. Oliver and Boyd, London.

Dziewonski, A.M., and Woodhouse, J.H., 1989. Three-Dimesional Earth Structure and Mantle Convection. *International Geological Congress 26th Session — Abstracts 1*, 427-428.
Edwards, A.C., 1978. Tectonic implications of immobile trace-element geochemistry of mafic rocks bounding the Wonaminta Block. *Geological Society of Australia — Journal 25*, 459-465.
El-Gaby, S., and Greiling, R.O., 1988. Introduction. In: El-Gaby, S., and Greiling, R.O., eds., The Pan-African Belt of Northeast Africa and Adjacent Areas. Friedrich Vieweg & Sohn, Braunschweig, 5-15.
Elam, R.M., and Hawkesworth, C.J., 1988. Is average continental crust generated at subduction zones? *Geology 16*, 314-317.
Elsasser, W.M., 1966. Thermal structure of the upper mantle and convection. In: Hurley, P.M., ed., Advances in earth science: Contributions. Massachussetts Institute of Technology, Cambridge, 461-502.
Etheridge, M.A., and Cooper, J.A., 1981. Rb/Sr isotopic and geochemical evolution of recrystallized shear (mylonite) zone at Broken Hill. *Contributions to Mineralogy and Petrology 78*, 74-84.
Etheridge, R.Jun., and Jack, R.L., 1881. Catalogue of works, palaeontology, mineralogy, mining and metallurgy, etc. of the Australian continent and Tasmania. London, E. Stanford, 196 p.
Elsasser, W.M., 1969. Convection and stress propagation in the upper mantle. In: Runcorn, W.K., ed., The Application of Modern Physics to the Earth and Planetary Interioprs, Wiley, New York, 223-246.
Evans, P.R., and Roberts, J., 1980. Evolution of central eastern Australia during the Late Palaeozoic and Early Mesozoic. *Geological Society of Australia — Journal 26*, 325-340.
Facer, R.A., 1979. New and recalculated radiometric data supporting a Carboniferous age for the emplacement of the Bathurst Batholith, New South Wales. *Geological Society of Australia — Journal 25*, 429-432.
Fagan, R.K., 1979. S-type granite genesis and emplacement in N.E. Victoria and its implications. *Australian Bureau of Mineral Resources, Geology and Geophysics — Records 1972/2*, 29-30.
Falvey, D.A., and Mutter, J.C., 1981. Regional plate tectonics and the evolution of the Australian passive continental margins. *BMR Journal of Australian Geology and Geophysics 6*, 1-29.
Fergusson, C.L., 1982. Structure of the Late Palaeozoic Coffs Harbour Beds, northeastern New South Wales. *Geological Society of Australia - Journal 29*, 25-40.

Fergusson, C.L., 1987. Early Paleozoic back-arc deformation in the Lachlan Fold Belt, southeastern Australia: Implications for terrane translations in Eastern Gondwanaland. In: Leitch, E.C., and Scheibner, E., eds., Terrane Accretion and Orogenic Belts. *American Geophysical Union — Geodynamic Series 19*, 39-56.
Fergusson, C.L., Cas, R.A.F., Collins, W.J., Craig, G.J., Crook, K.A.W., Powell, C.McA., Scott, P.A., and Young, G.C., 1979. The Upper Devonian Boyd Volcanic Complex, Eden, New South Wales. *Geological Society of Australia — Journal 26*, 87-105.
Fergusson, C.L., Gray, D.R. and Cas, R.A.F., 1986. Overthrust terranes in the Lachlan fold belt, southeastern Australia. *Geology 14*, 519-522.
Fleming, P.D., Steele, D.A., and Comancho, A., 1985. A probable Cambrian migmatitic basement to the Wagga Zone in North-east Victoria. In: Victorian Lithosphere Symposium - Abstracts 14-15.
Flood, P.G., and Fergusson, C.L., 1982. Tectono-stratigraphic units and structure of the Texas-Coffs Harbour region. In: Flood, P.G., and Runnegar B., eds., New England Geology, University of New England, 71-78.
Foden, J.D., Turner, S., and Morrison, R.S., 1989. Tectonic implications of Delamerian magmatism in South Australia and western Victoria. Geological Society of Australia, South Australian Division, B. Daily Memorial Volume.
Finlayson, D.M., Wake-Dyster, K.D., Leven, J.M., Johnstone, D.W., Korsch, R.J., and Murray, C.G., 1089. Crustal terranes across Phanerozoic Eastern Australia along the Eromanga-Brisbane Geoscience Transect. *International Geological Congress 26th Session - Abstracts 2*, p. 487.
Fryer, P., Ambos, E.L., and Hussong, D.M., 1985. Origin and emplacement of Mariana forearc seamounts. *Geology 13*, 774-777.
Fyfe, W.S., 1986. Fluids in deep continental crust. *American Geophysical Union — Geodynamic Series 14*, 33-39.
Fyfe, W.S., 1987. Granitea and thermal structure of the lithosphere. *Geologische Rundschau 76*, 15-22.
Fyfe, W.S., 1988. Granites and a wet convecting ultramafic planet. *Royal Society of Edinburgh — Transactions Earth Science 79*, 339-346.
Gatehouse, C.G., 1983. Stratigraphic units in the Warburton Basin in South Australia. *South Australia Geological Survey — Quarterly Geological Notes 86*,

5-8.
Gatehouse, C.G., Kanmantoo Filed Symposium, Excursion Guide. *South Australian Department of Mines and Energy — Report 88/35*, 89 p. (unpubl.).
Geological Society of Australia, 1971. Tectonic Map of Australia and New Guinea, 1:5,000,000 scale. Sydney.
Gill, J.B., 1981. Orogenic andesites and plate tectonics. Springer-Verlag, Berlin.
Gibbs, A.D., 1984. Structural evolution of extensional basin margins. *Geological Society of London — Journal 14*, 609-620.
Gilluly, J., 1971. Plate tectonics of magmatic evolution. *Geological Society of America - Bulletin 82*, 2387-2396.
Glazner, A.F., and Ussler III, W., 1989. Crustal extension, crustal density, and the evolution of Cenozoic magmatism in the Basin and Range of Western United States. *Journal of Geophysical Research 44*, B6, 7952-7960.
Glen, R.A., 1988. Basin inversion, thrusts,and ore deposits at Cobar, New South Wales: A preliminary report. *N.S.W. Geological Survey — Quarterly Notes 73*, 21-26.
Glen , R.A., in prep. Geology of the Cobar 1:100,000 Sheet, 8035. N.S.W. Geological Survey, Sydney.
Glen, R.A., Dallmeyer, R.D., and Black, L.P., 1986. Preliminary report on new isotopic evidence for, and implications of, an Early Devonian deformation at Cobar. *N.S.W. Geological Survey - Quarterly Notes 64*, 26-29.
Glen, R.A., Laing, W.P., Parker, A.J., and Rutland, R.W.R., 1977. Tectonic relationships between the Proterozoic Gawler and Willyama orogenic domains, Australia. *Geological Society of Australia — Journal 24*, 125-150.
Glen, R.A., MacRae, G.P., Pogson, D.J., Scheibner, E., Agostini, A., and Sherwin, L., 1985. Summary of the geology and controls of mineralization in the Cobar Region. *N.S.W. Geological Survey — Report GS 1985/203*, (unpubl.) 91p.
Gray, D.R., 1988. Structure and Tectonics. In: Douglas, J.G., and Ferguson, J.A., eds., Geology of Victoria. Geological Society of Australia, Victorian Devision, 1-36.
Gulson, B.L., 1984. Uranium-lead and lead-lead investigations of minerals from the Broken Hill lodes and mine sequence rocks. *Economic Geology 79*, 476-490.
Harland, H., 1971. Tectonic transpression Caledonian Spitsbergen. *Geological Magazine 108*, 27-42.
Harrington, H.J., 1974. The Tasman Geosyncline in Australia. In: Denmead, A.K., Tweedale, G.W., and Wilson, A.F., eds., The Tasman Geosyncline. Geological Society of Australia, Queensland Division, Brisbane, 383-407.
Harrington, H.J., 1982. Tectonics and the Sydney Basin. 16th Symposium for the Advancement in the Study of the Sydney Basin, Department of Geology, University of Newcastle, Proceedings 15-22.
Harrington, H.J., and Korsch, R.J., 1985. Tectonic model for the Devonian to middle Permian of the New England Orogen. *Australian Journal of Earth Sciences 32*, 163-179.
Hays, D.E., and Ringis, J., 1973. Seafloor spreading in the Tasman Sea. *Nature 243*, 454-458.
Hess, H.H., 1959. Nature of the great oceanic ridge. *International Oceanographic Congress (1st preprints)*, 33-34.
Hess, H.H., 1962. History of ocean basins. In: Engel, A.E., James, H.L., and Leonard, B.F., eds., Petrologic Studies: a volume in honour of A.F. Buddington Memorial Volume, Geological Society of America, 599-620.
Hess, H.H., 1965. Mid-oceanic ridges and tectonics of the sea-floor. In: Whittard, W.F., and Bradshaw, R., eds., Submarine geology and geophysics. Butterworth, London, 317-334.
Hilde, T.W.C., and Uyeda, S., 1983. Convergence and subduction. *Tectonophysics 99*, 85-400.
Hoffman, P.F., 1989. Speculations on Laurentia's first gigayear (2.0 to 1.0 Ga). *Geology 17*, 135-138.
Hubbert, H.E., and Sparks, R.S.HJ., 1988. The fluid dynamics of crustal melting by injection of basaltic sills. *Royal Society of Edinborough — Transactions Earth Sciences 79*, 237-243.
Hutton, D.H.W., 1988. Granite emplacement mechanisms and tectonic controls: inference from deformation studies. *Royal Society of Edinborough — Transactions Earth Sciences 79*, 245-255.
Isacks, B.L., Oliver, J., and Sykes, L.R., 1968. Seismology and the new global tectonics. *Journal of Geophysical Research 73*, 5855-5899.
Ishiga, H., Leitch, E.C., Watanabe, T., Naka, T., and Iwasaki, M., 1988. Radiolarian and conodont biostratigraphy of siliceous rocks from the New England Fold Belt. *Australian Journal of Earth Sciences 35*, 73-80.
Jackson, M.P.A., and Talbot, C.J., 1986. External shapes, strain rates, and dynamics of salt structures. *Geological Society of America — Bulletin, 97*, 305-323.
Jenkins, R.J.F., 1989. The Adelaide Fold Belt: a tectonic reappraisal. Geological Society of Australia, South Australian Division, B. Daily Memorial Volume.
Johnson, P.R., Scheibner, E. and Smith, A.E., 1987. Basement Fragments, Accreted Tectonostratigraphic Terranes, and Overlap Sequences: Elements in the Tectonic Evolution of the Arabian Shield. In: Leitch, E.C. and Scheibner, E., eds., Terrane Accretion and Orogenic Belts. *American Geophysical Uunion, Geodynamic Series 19*, 323-343.
Kasbeer, T., 1973. Bibliography of continental drift and plate tectonics. *Geological Society of America — Special Paper 142*, 96 p.
Kay, R.W., 1987. Mass flux at convergent plate margins. *EOS 68*, 1209.
Kay, R.W., and Kay, S.M., 1989. Crustal growth and crust-mantle recycling. *International Geological Congress 28th Session — Abstracts 2*, 162-163.
Kilpatrick, D.J., and Fleming, D.P., 1980. Lower Ordovician sediments in the Wagga Trough: discovery of early Bendigonian graptolites near Eskdale, north east Victoria. *Geological Society of Australia — Journal 27*, 69-73.
Kirkegaard, A.G., 1974. Structural elements of the northern part of the Tasman Geosyncline. In: Denmead, A.K., Tweedale, G.W., Wilson, A.F., eds., The Tasman Geosyncline - A Symposium, Geological Society of Australia, Queensland Division, Brisbane, 47-62.
Korsch, R.J., and Harrington, H.J., 1981. Stratigraphic and structural synthesis of the New England Orogen. *Geological Society of Australia — Journal 28*, 205-220.
Korsch, R.J., and Harrington, H.J., 1987. Oroclinal bending, Fragmentation and Deformation of Terranes in the New England Orogen, Eastern Australia. In: Leitch, E.C., and Scheibner, E., eds., Terrane Accretion and Orogenic Belts. *American Geophysical Union — Geodynamic Series 19*, 129-139.
Kroner, A., 1984. Late Precambrian plate tectonics and orogeny: a need to redefine the term 'Pan-African'. In: Klerkx, J., and Michot, J., eds., African Geology, Musee African centreau, Tervuren, 23-28.

Kroenke, L.W., and Dupont, J., 1982. Subduction-obduction: a possible north-south transitions along the west flank of the Three Kings Rise. *Geo-Marine Letters 2*, 011-016.

Laing, W. P, in prep. A tectonic model of the Willyama Supergroup, Australia.

Leitch, E.C., 1974. The geological development of the southern part of the New England Fold Belt. *Geological Society of Australia — Journal 21*, 133-156.

Leitch, E.C., 1975. Plate tectonic interpretation of the Paleozoic history of the New England Fold Belt. *Geological Society of America — Bulletin 86*, 141-144.

Leitch, E.C., 1988. The Barnard Basin and the Early Permian development of the southern part of the New England Fold Belt. In: Kleeman, J.D., ed., New Orogen - Tectonics and Metallogenesis. University of New England, Armidale, 61-67.

Leitch, E.C., and Scheibner, E., eds., 1987. Terrane Accretion and Orogenic Belts. *American Geophysical Union — Geodynamic Series 19*, 343p.

Leitch, E.C., and Scheibner, E., 1987. Stratotectonic terranes of the Eastern Australian Tasmanides. *American Geophysical Union — Geodynamic Series 19*, 1-19.

Leitch, E.C., Webby, B.D., Mills, K.J., and Kolbe, P., 1987. Terranes in the Wonominta Block, far western New South Wales. In: Leitch, E.C., and Scheibner, eds., Terrane Accretion and Orogenic Belts. *American Geophysical Union - Geodynamics Series 19*, 31-38.

Le Pichon, X., 1968. Sea-floor spreading and Continental Drift. *Journal of Geophysical Research 73*, 3661-3697.

Le Pichon, X., Francheteau, J., and Bonnin, J., 1973. Plate Tectonics. Elsevier, 300 p.

Lister, G.S., Etheridge, M.S., and Symonds, P.A., 1986. Detachment model for the formation of passive continental margins. *Geology 14*, 246-250.

Liu, Songfa, and Fleming, P.D., 1989. Amphibolites/ metadolerites and their tectonic implications from the Mt Lofty Ranges metamorphic belt, S.A. *Geological Society of Australia — Abstracts 24*, 89-90.

McCulloch, M.T., and Chappell, B.W., 1982. Nd isotopic characteristics of S- and I-type granites. *Earth and Planetary Science Letters 58*, 51-64.

Macdonald A.H., and Fyfe, W.S., 1985. Rates of serpentinization in seafloor environments. *Tectonophysics 116*, 123-132.

McDougal, I., and Leggo, P.J., 1965. Isotopic age determination on granitic rocks from Tasmania. *Geological Society of Australia — Journal 12*, 295-332.

McIlveen, G.R., 1974. The Eden-Comerong-Yalwal rift zone and the contained gold mineralization. *N.S.W. Geological Survey — Records 16*, 245-277.

McKenzie, D.P., 1967a. Some remarks on heat flow and gravity anomalies. *Journal of Geophysical Research 72*, 61-71.

McKenzie, D.P., 1967b. The viscosity of the Mantle. *Geophysical Journal of the Royal Astronomical Society 14*, 297.

McKenzie, D.P., and Parker, R.L., 1967. The North Pacific: an example of tectonics on a sphere. *Nature 216*, 1276-1280.

McLennan, S.M., and Taylor, R.S., 1980. Th and U in sedimentary rocks: Crustal evolution and sedimentary recycling. *Nature 285*, 621-624.

Meen, J.K., and Eggler, D.H., 1987. Petrology and geochemistry of the Cretaceous Independence volcanic suite, Absaroka Mountains, Montana: Clues to the composition of the Archean sub-Montana mantle. *Geological Society of America — Bulletin 98*, 238-247.

Milnes, A.R., Compston, W., and Daily, B., 1977. Pre- to syntectonic emplacment of early Palaeozoic granites in south-eastern South Australia. *Geological Society of Australia — Journal 24*, 87-106.

Morand, V.J., 1988. Omeo Zone. In: Douglas, J.G., and Ferguson, J.A., eds., Geology of Victoria. Geological Society of Australia, Victorian Division, 18-20..

Morgan, W.J., 1968. Rises, trenches, great faults and crustal blocks. *Journal of Geophysical Research 73*, 1959-1982.

Morley, L.W., and Larochelle, A., 1964. Paleomagnetism as a Means of Dating Geological Events. *Royal Society of Canada — Special Publications 9*, 4-51.

Morission, G.W., 1980. Characteristics and tectonic setting of the shoshonite rock association. *Lithos 13*, 97-108.

Murray, C.G., 1985. Tectonic setting of the Bowen Basin. In: Bowen Basin Coal Symposium. *Geological Society of Australia — Abstracts 17*, 5-16.

Murray, C.G., 1986. Metallogeny and tectonic development of the Tasman Fold Belt System in Queensland. *Ore Geology Reviews 1*, 315-400.

Murray, C.G., Fergusson, C.L., Flood, P.G., Whitaker, W.G., and Korsch, R.J., 1987. Plate tectonic model for the Carboniferous evolution of the New England Fold Belt. *Australian Journal of Earth Sciences 34*, 213-236.

Murray, C.G., and Kirkegaard, A.G., 1978. The Thomson Orogen of the Tasman Orogenic Zone. *Tectonophysics 48*, 299-325.

Murray, C.G., Scheibner, E. and Walker, R.N., 1989. Regional geological interpretation of a digital coloured residual Bouguer gravity image of eastern Australia with wavelength cut-off of 250 km. *Australian Journal of Earth Sciences 36*, 423-450.

Mutter, J.C., and Jongsma, D., 1978. The pattern of the Pre-Tasman Sea Rift System and Geometry of Breakup. *Australian Society of Exploration Geophysicists — Bulletin 9*, 70-75.

Nur, A., and Ben-Avraham, Z., 1977. Lost Pacific continent. *Nature 270*, 41-43.

Offler, R., and Williams, A.J., 1987. Evidence for Sinbistral Movement on the Peel Fault System in Serpentinites, Glenrock Station, N.S.W. In: Leitch, E.C., and Scheibner, E., eds., Terrane Accretion and Orogenic Belts. *American Geophysical Union — Geodynamics Series 19*, 141-151.

Olenin, V.B., 1967. The principles of classification of oil and gas basins. *Australian Oil and Gas Journal* February 1967, 404-446.

Oliver, J., and Isacks, B., 1967. Deep earthquake zones, anomalous structures in the upper mantle and the lithosphere. *Journal of Geophysical Research 72*, 4259-4275.

Oversby, B., 1971. Palaeozoic plate tectonics in the southern Tasman Geosyncline. *Nature Physical Science 234*, 45-48.

Owen, M., and Wyborn, D., 1979. Geology and geochemistry of the Tantangara and Brindabella 1:100,000 Shet areas, New South Wales and Australian Capital Territory. *Australian Bureau of Mineral Resources, Geology and Geophysics — Bulletin 204*, 52 p.

Ozima, M., Zashu, S., Mattey, D.P., and Pillinger, C.T., 1985. Helium, argon and carbon isotopic compositions in diamonds and their implications in mantle evolution. *Geochemical Journal 19*, 127-134.

Packham, G.H., 1968. The lower and middle Palaeozoic stratigraphy and sedimentary tectonics of the Sofala-Hill End-Euchareena region. *Linnean Society of N.S.W. — Proceedings 93*, 111-163.

Packham, G.H., ed., 1969. The geology of New South

Wales. *Geological Society of Australia — Journal 16*, 654 p.

Packham, G.H., 1983. A speculative Phanerozoic history of the south-west Pacific. In: Coleman, J.P., ed., The Western Pacific; Island Arcs, Marginal Seas, — Geochemistry. University of W.A., Perth, 369-388.

Packham, G.H., 1987. The eastern Lachlan Fold Belt of southeast Australia: A possible Late Ordovician to Early Devonian sinistral strike slip regime. In: Leitch, E.C., and Scheibner, E.,. eds., Terrane Accretion and Orogenic Belts. *American Geophysical Union — Geodynamics Series 19*, 67-82.

Parker, J.A., 1986. Metallogeny and tectonic development of the Kanmantoo Trough in South Australia. *Ore Geology Reviews 1*, 203-212.

Parkin, L.E., ed., 1969. Handbook of South Australia Geology. Geological Survey of South Australia, Adelaide.

Patchett, P.J., Kouvo, O., Hedge, C.E., and Tatsumoto, M., 1981. Evolution of Continental Crust and Mantle Heterogeneity: Evidence from Hf isotopes. *Contributions to Mineralogy and Petrology 78*, 279-297.

Pearce, J.A., 1983. Role of the Sub-continental Lithosphere in Magma Genesis at Active Continental Margins. In: Hawkesworth, C.J., and Norry, M.J., eds., Continental Basalts and Mantle Xenoliths, Shiva Geology Series,230-272.

Pickett, J.W., 1982. The Silurian System in New South Wales. *New South Wales Geological Survey — Bulletin 29*, 264 p.

Pitcher, W.S., 1987. Granites and yet more granites fourty years on. *Geologische Rundschau, 76*, 51-79.

Pitman, W.C., and Heirtzler, J.R., 1966. Magnetic anomalies over the Pacific-Antarctic ridge . *Science 145*, 1164

Plumb, K.A., 1979. The Tectonic Evolution of Australia. *Earth Science Reviews 14*, 205-249.

Plumb, K.A., 1989. A new Precambrian timescale. BMR Research Symposium 1989. Abstracts, Australian Bureau of Mineral Resources, Geology and Geophysics, Canberra.

Pogson, D.J., 1982. Stratigraphy, structure and tectonics: Nymagee-Melrose, Central Western New South Wales. *NSW Institute of Technology — M.App.Sc. Thesis* (unpubl.).

Pogson, D.J., and Hilyard, D., 1981. Results of isotopic age dating related to Geological Survey of New South Wales investigations, 1974-1978. *N.S.W. Geological Survey — Records 20*, 251-273.

Pogson, D.J., and Scheibner, E., 1971. Pre-Upper Cambrian sediments east of the Copper Mine Range, New South Wales. *N.S.W. Geological Survey — Quarterly Notes 4*, 3-8.

Powell, C.McA., 1983a. Tectonic Relationship between the Late Ordovician ad Late Silurian palaeogeographies of southeastern Australia. *Geological Society of Australia — Journal 30*, 353-373.

Powell, C.McA., 1983b. Geology of N.S.W., South Coast. *Geological Society of Australia — SGTSG Field Guide 1*, 118 p.

Powell, C.McA., 1984a. Terminal fold-belt deformation: Relationship of mid-Carboniferous megakinks in the Tasman fold belt to coeval thrusts in cratonic Australia. *Geology 12*, 546-549.

Powell, C.McA., 1984b. Uluru and Adelaide Regimes (f) Ordovician to earliest Silurian marginal sea and island arc. In: Veevers, J.J. ed., Phanerozoic Earth History of Australia, Oxford University Press, 290-303.

Powell, C.McA., and Edgecombe, D.R., 1978. Mid-Devonian movements in the north eastern Lachlan Fold Belt. *Geological Society of Australia — Journal 25*, 165-184.

Powell, C.McA., Edgecombe, D.R., Henry, N.M., and Jones, J.G., 1977. Timing of regional deformation of the Hill End Trough: a re-assesment. *Geological Society of Australia — Journal 23*, 407-421.

Powell, C.McA., and Fergusson, C.L., 1979. The relationship of structures across the Lambian unconformity near Taralga, New South Wales. *Geological Society of Australia — Journal 26*, 209-219.

Powell, C.McA., Fergusson, C.L., and Williams, A.J., 1980. Structural relationships across the Lambian unconformity in the Hervey Range-Parkes area, N.S.W. *Linnean Society of New South Wales — Proceedings* 104, 195-204.

Powell, C.McA., Neef, G., Crane, D., Jell, P.A., and Percival, G., 1982. Significance of Late Cambrian (Idamean) fossils in the Cupala Creek Formation, northwestern New South Wales. *Linnean Society of New South Wales — Proceedings 106*, 127-150.

Preiss, W.V., 1983. Depositional and tectonic contrasts between Burra Group and Umberatana Group sedimentation. *Geological Society of Australia — Abstracts 10*, 13-16.

Preiss, W.V., 1987. The Adelaide Geosyncline, Late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics. *Geological Survey of South Australia — Bulletin 53*, 438 p.

Raheim, A., and Compston, W., 1977. Correlations between metamorphic events and Rb-Sr ages in metasediments and eclogite from western Tasmania. *Lithos 10*, 271-289.

Ramsay, W.R.H., and VandenBerg, A.H.M., 1986. Metallogeny and tectonic development of the Tasman Fold Belt System in Victoria. *Ore Geology Reviews 1*, 213- 257.

Rast, N., 1969. Orogenic belts and their parts. In: Kent, P.E. et al., eds., Time and Place in Orogeny. *Geological Society of London — Special Publication 3*, 197-213.

Rickard, M.J., and Scheibner, E., 1975. The philosophical basis and terminology for tectonic nomenclature. *Geological Society of Australia — SGTSG Newsletter 4*, 16-29.

Ringwood, A.E., 1969. Composition and evolution of the upper mantle. In: The Earth's Crust and Upper Mantle. *American Geophyscial Union — Monograph 13*, 1-17.

Ringwood, A.E., 1972. Phase transformations and mantle dynamics. *Earth and Planetary Science Letters 14*, 233-241.

Roberts, J., and Engel, B.A., 1980. Carboniferous palaeogeography of the Yarrol and New England orogens, eastern Australia. *Geological Society of Australia — Journal 27*, 167-186.

Rose, G., and Brunker, R.L., 1969. The Upper Proterozoic and Phanerozoic geology of north-western New South Wales. *Australasian Institute of Mining and Metallurgy — Proceedings 229*, 105-120.

Rubey, W.W., 1951. Geological history of sea water. An attempt to state the problem. *Geological Society of America — Bulletin 62*, 1111-1147.

Rubey, W.W., 1955. Development of the hydrosphere, with special reference to probable composition of the early atmosphere. In: Poldevaart, A., ed., Crust of the Earth. *Geological Society of America — Special Papers 62*, 631-650.

Rutland, R.W.R., 1976. Orogenic evolution of Australia. *Earth Science Reviews 12*, 161-196.

Rutland, R.W.R., Parker, J., Pitt, G.M., Preiss, W.V., and Murrell, B., 1981. The Precambrian of South Australia.

In: Hunter, D.R., ed., Precambrian of the Southern Hemisphere, Elsevier, Amsterdam, 309-360.

Sawkins, F.J., 1978. Some aspects of metallogeny of continental rifting events. In: Neumann, E.-R., and Ramberg, I.B., eds., Petrology and Geochemistry of Continental Rifts. Reidel, Dordrecht. 51-54.

Scheibner, E., 1972a. Actualistic models in tectonic mapping. *International Geological Congress — 24th Session, Reports 3*, 405-422.

Scheibner, E., 1972b. The Kanmantoo Pre-Cratonic Province in New South Wales. *N.S.W. Geological Survey — Quarterly Notes 7*, 1-10.

Scheibner, E., 1972b. Tectonic concepts and tectonic mapping. *N.S.W. Geological Survey — Records 14*, 37-83.

Scheibner, E., 1973. ERTS-1 geological investigations of New South Wales. *N.S.W. Geological Survey — Records GS 1973/383* (unpubl.) 57 p.

Scheibner, E., 1974a. A plate tectonic model of the Palaeozoic tectonic history of New South Wales. *Geological Society of Australia — Journal 20*, 405-426.

Scheibner, E., 1974c. Fossils fracture zones (transform faults), segmentation, and correlation problems in the Tasman Fold Belt System. In: Denmead, A.K., Tweedale, G.W., and Wilson, A.F., eds., The Tasman Geosyncline - A Symposium in Honour of Dorothy Hill, Geological Society of Australia, Queensland Division, 65-96.

Scheibner, E., 1976. Explanatory Notes on the Tectonic Map of New South Wales. New South Wales Geological Survey, 283 p.

Scheibner, E., 1979. Geological significance of some lineaments in New South Wales. LANDSAT 79, Proceedings of the 1st Australian Remote Sensing Conference, Sydney, 318-332.

Scheibner, E., 1982. Some aspects of the geotectonic development of the Lachlan Fold Belt. *N.S.W. Geological Survey — Report GS 1982/069* (unpubl.).

Scheibner, E., 1983. Tectonic development of the southern part of the Cobar Trough in the Mount Hope area. *Geological Society of Australia - Abstracts 9*, 302-304.

Scheibner, E., 1985a. Suspect terranes in the Tasman Fold Belt System. In: Howell, ed., Tectonostratigraphic Terranes in the Circum-Pacific Region. *Circum-Pacific Council for Energy and Mineral Resources — Earth Science Series 1*, 493-514.

Scheibner, E., 1985b. Structural Map of New South Wales 1:1,000,000 Scale. N.S.W. Geological Survey, Sydney, (unpubl.).

Scheibner, E., 1987. Paleozoic tectonic development of Eastern Australia in relation to the Pacific Region. In: Monger, J.W.H., and Francheteau, J., eds., Circum-Pacific Orogenic Belts and Evolution of the Pacific Ocean Basin. *American Geophysical Union — Geodynamic Series 18*, 133-165.

Scheibner, E., 1988. Geophysical signature of terranes in eastern Australia. *4th Circum-Pacific International Tectonostratigraphic Conference — Provisional Abstracts*, Nanjing, China, 82-88.

Scheibner, E., 1989. Geoscience Transect Broken Hill to Sydney, New South Wales, Australia. *International Geological Congress 28th Session — Abstracts 3*, 42-43. (expanded handouts).

Scheibner, E., in prep. The status of terrane analysis in the Tasman Fold Belt System. In: Explanatory Notes to the Tectonic Map of the Tasman Fold Belt System. (early draft available as unpublished. *N.S.W. Geological Survey — Report GS 1987/065*).

Scheibner, E., and Agostini, A., in prep. Early Devonian rifting and basin formation in the Cobar region, Central New South Wales.

Scheibner, E., and Glen, R.A., 1972. The Peel Thrust and its tectonic history. *N.S.W. Geological Survey — Quarterly Notes 8*, 2-14.

Scheibner, E., and Stevens, B.P.J., 1974. The Lachlan River Lineament and its relationship to metallix deposits. *N.S.W. Geological Survey — Quarterly Notes 14*, 8-18.

Shaw, S.E., 1968. Rb-Sr isotopic studies of the mine sequence rocks at Broken Hill. In: Radmanovich, M., and Woodcock, J.T., eds., Broken Hill Mines. *Australasian Institute of Mining and Metallurgy — Monograph 3*, 185-198.

Shaw, S.E., and Flood, R.H., 1981. The New England Batholith, eastern Australia: geochemical variations in time and space. *Journal of Geophysical Research 86*, 10530-10544.

Sherwin, L., 1979. Age of the Nelungaloo Volcanics near Parkes. *N.S.W. Geological Survey — Quarterly Notes 35*, 15-18.

Sibuet. J.-C., 1989. Paleoconstraints during rifting of the northeast Atlantic passive margins. *Journal of Geophysical Research 94*, B6, 7265-7277.

Solomon, M., and Griffiths, J.R., 1972. Tectonic evolution of the Tasman Orogenic Zone, eastern Australia. *Nature Physical Science 237*, 3-6.

Stern, R.J., Bloomeer, S.H., Lin Ping-Nan, Ito, E.,and Morris J., 1988. Shoshonitic magmas in nascent arcs: New evidence from submarine volcanoes in the northern Marianas. *Geology 16*, 426-430.

Stevens, B.P.J., Barnes, R.G., Brown, R.E., Stroud, W.J., and Willis, I.L., 1988. The Willyama Supergroup in the Broken Hill and Euriowie Blocks, New South Wales. *Precambrian Research 40/41*, 297-327.

Stuart-Smith, P.G., 1987. Extensional structures in the Tumut Trough, southern N.S.W., Australia. BMR Research Symposium 87, Applied Extension Tectonics, *Australian Bureau of Mineral Resources, Geology and Geophysics — Record 1987/51* (unpubl.), 62-63.

Stuart-Smith, P.G., 1989. The fault history and emplacement of the Coolac Serpentinite, Lachlan Fold Belt, N.S.W. *Geological Society of Australia — Abstracts 24*, p.138.

Suppel, D.W., and Barron, L.M., 1986. Platinum in basic to ultrabasic intrusive complexes at Fifield: A preliminary report. *N.S.W. Geological Survey — Quarterly Notes 65*, 1-8.

Suppel, D.W., and Scheibner, E., in press. Lachlan Fold Belt in New South Wales - Regional Geology and Mineral Deposits. *Australasian Institute for Mining and Metallurgy — Monograph.*

Suppel, D.W., Warren, A.Y.E., Watkins, J.J., Chapman, J., Tenison Woods, K., and Barron, L., 1986. A reconnaissance study of the geology and gold deposits of the West Wyalong - Temora - Adelong District. *N.S.W. Geological Survey — Quarterly Notes 64*, 1-23.

Sutherland, F.L., 1978. Mesozoic-Cainozoic volcanism of Australia. *Tectonophysics 48*, 413-427.

Sykes, L.R., 1967. Mechanism of Earthquakes and Nature of Faulting on the Mid-ocean Ridges. *Journal of Geophysical Research 72*, 2131-2153.

Symonds, P.A., 1973. The structure of the north Tasman Sea. *Australian Bureau of Mineral Resources, Geology and Geophysics — Record 1973/167* (unpubl.), 8 p.

Tadros, V., 1988. Structural subdivision of the Gunnedah Basin. *N.S.W. Geological Survey — Quarterly Notes 73*, 1-20.

Thom, B.G., and Roy, P.S., 1985. Relative sealevels and coastal sedimentation in southeast Australia in the Holocene. *Journal of Sedimentary Petrology 55*, 257-267.
Thomas, W.A., 1982. Continental margins, orogenic belts, and intracratonic structures. *Geology, 11*, 270-272.
Thomson, B.P., 1970. A review of the Precambrian and lower Palaeozoic tectonics of South Australia. *Royal Society of South Australia — Transactions 94*, 193-221.
Turner, N.J., 1989. Precambrian. In: Burrett, C.F., and Martin, E.L., eds., Geology of Tasmania. *Geological Society of Australia — Special Publication 15*, 5-46.
Uyeda, S., 1981. Subduction zones and back-arc basins - A review. *Geologische Rundschau 70*, 552-569.
VandenBerg, A.H.M., 1978. The Tasman Fold Belt System in Victoria. *Tectonophysics 48*, 267-297.
Veevers, J.J., ed., 1984. Phanerozoic earth history of Australia. Oxford Geological Sciences Series 2, 418 pp.
Veevers, J.J., Jones, J.G., and Powell, C.McA., 1982. Tectonic framework of Australia's sedimentary basins. *The APEA Journal 22*, 283-300.
Vine, F.J., 1966. Spreading of the ocean floor: New evidence. *Science 154*, 1405-1415.
Vine, F.J., and Hess, H.H., 1970. Sea-floor spreading. In: The Sea, volume 4, part 2, John Wiley & Sons, New York, 587-622.
Vine, F.J., and Matthews, D.H., 1963. Magnetic anomalies over oceanic ridges. *Nature 199*, 947.
Voisey, A.H., 1959. Australian Geosynclines. *Australian Journal of Science 22*, 188-198.
von der Borch, C.C., 1980. Evolution of Late Proterozoic to Early Palaeozoic Adelaide Foldbelt, Australia: comparison with post-Permian rifts and passive margins. *Tectonophysics 70*, 115-134.
Webb, A.W., Coats, R.P., Fanning, C.M., and Flint, R.B., 1983. Geochronological framework of the Adelaide Geosyncline. *Geological Society of Australia — Abstracts 10*, 7-9.
Weber, C.R., and Scheibner, E., 1977. The origin of some Permo-Triassic metal zones in the New England region, New South Wales. *N.S.W. Geological Survey — Quarterly Notes 26*, 1-14.
Webby, B.D., 1978. History of the Ordovician continental platform shelf margin of Australia. *Geological Society of Australia — Journal 25*, 41-63.
Wegner, A., 1912. Die Enstehung der Kontinente. *Geologische Rundschau 3*, 276-292.
Wegener, A., 1929. Die Enstehung der Kontinente und Oceane. 4th edition, Vieweg, Braunschweig.
Wernicke, B., 1985. Uniform sense normal simple shear of the continental lithosphere. *Canadian Journal of Earth Sciences 22*, 108-125.
White, A.J.R., and Chappell, B.W., 1977. Ultra-metamorphism and granitoid genesis. *Tectonophysics 43*, 7-22.
White, A.J.R., and Chappell, B.W., 1983. Granitoid types and their distribution in the Lachlan Fold Belt, southeastern Australia. In: Roddick, J.A. ed., Circum-Pacific Plutonic Terranes. *Geological Society of America — Memoirs 159*, 21-34.
Williams, E., 1978. Tasman Fold Belt System in Tasmania. *Tectonophysics 48*, 159-205.
Williams. I.S., 1989. Iron probe dating of zircons from Australia. Public lecture for the Geological Society, A.C.T. Division, 1st September, 1989, on occasion of receiving Professor D.A. Brown Medal for excellence.
Williams, I.S., Compton, W., and Chappell, B.W., 1983. Zircon and Monazite U-Pb Systems and the Histories of I-type Magmas, Berridale Batholith, Australia. *Journal of Petrology 24*, 76-97.
Wilson, J.T., 1963. A possible origin of the Hawaiian Islands. *Canadian Journal of Physics 41*, 863-870.
Wilson, J.T., 1965a. A New Class of Faults and Their Bearing on Continental Drift. *Nature 198*, 925-929.
Wilson, J.T., 1965b. Evidence from oceanic islands suggesting movements in the earth. In: Blackett, O.M.S., Bullard, E., and Runcorn, S.K., eds., A Symposium on Continental Drift. *Royal Society of London — Philosophical Transactions 258*, 145-167.
Wilson, J.T., 1973. Continents Adrift; Readings from Scientific American, 172p.
Wopfner, H., 1972. Depositional history and tectonics of South Australian sedimentary basins. *South Australian Mineral Resources Reviews 133*, 32-50.
Wyborn, D., 1988. Ordovician magmatism, gold mineralisation, and an integrated tectonic model for the Ordovician and Silurian history of the Lachlan Fold Belt in NSW. *BMR Research Newsletter 8*, 13-14.
Wyborn, D., Chappell, B.W., and Johnston, R.M., 1981. Three S-type volcanic suites from the Lachlan Fold Belt, southeastern Australia. *Journal of Geophysical Research 86*, B11, 10335-10348.
Wyborn, L.A.I., 1977. Aspects of the geology of the Snowy Mountains region and their implications for the tectonic evolution of the Lachlan Fold Belt. *Australian National University, Canberra — Ph.D. Thesis* (unpubl.).
Zindler, A., and Hart, S., 1986. Chemical geodynamics. *Annual Reviews of Earth and Planetary Sciences 14*, 493-571.

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Doctoral Thesis Abstract: A new Approach to Transient Electrum Spin Resonance Spectroscopy

JUDITH M. DAWES

Transient electron spin resonance (esr) offers the most general method for the detection of short lived reactive free radicals, which are common chemical intermediates. It is currently limited to 10 to 100 ns time resolution by the lack of suitable high power short pulsed microwave sources, and by the dead time associated with cavity resonances of these sources. In this thesis, a new approach to overcome these problems is presented. A laser driven semiconductor device has been designed to produce subnanosecond microwave pulses, for use in time resolved esr experiments.

Microstripline technology has been adopted for both the sample cell and microwave detection as well as for the microwave pulse generator. This offers advantages of broad bandwidth, low loss and high power handling capability. It also enables access to the sample by a laser photolysis pulse. As the laser pulse is synchronized with the microwave pulse, it is possible to study the kinetics of reaction intermediates by optical pump - microwave probe spectroscopy.

Since the microwave pulse generator depends on semiconductor photoconductivity, some simple photoconductive devices were investigated experimentally. The charge carrier recombination, which governs the long time behaviour of these switches, was theoretically modelled in two and three dimensions for comparison.

The devices for microwave generation, absorption and detection were constructed using microlithography techniques. These devices were characterized and tested experimentally.

The lasers which were developed to drive the microwave generator are also described. A mode locked, Q-switched and cavity dumped laser operating with high power and stability at a repetition rate of up to 12 kHz, was used to pump a dye laser amplifier to provide short pulses of sufficient energy for microwave generation. Some pulse compression experiments using optical fibre were also performed to investigate the potential of chirped pulse amplification.

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M. Sc. Thesis Abstract: Rheological of Coagulated Colloidal Suspensions

DAVID EVERETT

Monodisperse spherical colloids were prepared (poly-styrene and poly-methyl methacrylate by emulsion polymerisation techniques and coagulated by the addition of cationic surfactant, cetyl trimethyl ammonium bromide (CTAB), or by compression of the double layer as a consequence of increasing the ionic strength. The elastic shear modulus (G) was measured on coagulated samples using a pulse shearometer and compared with viscous data obtained from a couette viscometer. Both elastic and viscous parameters were related to colloid chemical parameters such as particle radius, particle volume fraction and the zeta potential. Values for shear modulus were compared with a previously developed semi-empirical model based on viscous parameters, and some correlation was observed. A model was developed to predict the primary yield stress of a coagulated sol as a function of the zeta potential and volume fraction. Yield stress values from the model were in reasonable agreement with estimates obtained from viscous data, measured using a constant stress Deer rheometer.

Shear modulus was measured for different volume fractions and was found to be proportional to volume fraction to the power of 2.6 at constant zeta potential. This was explained by assuming the existence of regions of close packed particles within the internal floc structure of a coagulated sol. A model was developed to describe the increasing G values over time in terms of the kinetics of interparticle bond formation. This model enabled estimates to be made of the energy barrier to coagulation of the diffusion controlled process at different zeta potentials. Values obtained were of order 3 kT.

Rheological measurements were performed on coagulated kaolinite mineral suspensions as a function of pH and ionic strength. Time dependent shear modulus experiments were performed using the pulse shearometer, and the results were explained in terms of different charges on the kaolinite surface and the subsequent variations in aggregate structure.

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Doctoral Thesis Abstract: Transmembrane Chemical Shift Differences in the ^{31}P NMR Spectra of Erythrocyte Suspensions: Origins and Applications

KIARAN KIRK

Trimethyl phosphate, triethyl phosphate, dimethyl methylphosphonate, diethyl methylphosphonate, trimethylphosphine oxide and the hypophosphite, phenylphosphinate and diphenylphosphinate ions all contain the phosphoryl functional group. When added to a suspension of intact human erythrocytes at 20°C, seven of these eight compounds (the exception being triethyl phosphate) gave rise to intra- and extracellular ^{31}P NMR resonances that differed in their chemical shifts. Triethyl phosphate added to an erythrocyte suspension gave rise to only a single ^{31}P NMR resonance; the significantly different intra- and extracellular chemical shifts were averaged by the fast transport of the compound across the cell membrane. The intra- and extracellular chemical shifts of the phosphoryl compounds varied with the haematocrit, osmotic pressure and temperature of the suspension, as did the *difference* between the intra- and extracellular chemical shifts.

The transmembrane chemical shift differences could not be attributed to the operation of any single mechanism but, rather, resulted from a combination of different effects. For carbonmonoxygenated cells suspended in physiological saline, the magnetic susceptibility of the intracellular compartment was lower than that of the extracellular compartment, largely as a result of the diamagnetic susceptibility of intracellular haemoglobin. The corresponding difference between the bulk magnetic field in the two compartments was less than that calculated using a simple two-compartment model. It was sufficient to account for most (if not all) of the relatively small difference between the intra- and extracellular chemical shifts of trimethyl phosphate and triethyl phosphate, but the same was not true for the other six compounds of interest. Despite obvious structural similarities between the eight compounds, the transmembrane chemical shift differences for the phosphonates, phosphinates, phosphite and phosphine oxide were very much larger than that for the two phosphates and, therefore, larger than could be accounted for by magnetic susceptibility effects alone. For these other phosphoryl compounds an additional effect was operating to cause the intra- and extracellular chemical shifts to differ. The various intra- and extracellular solutes were shown to influence the ^{31}P NMR chemical shifts of these compounds to different extents by a susceptibility-independent mechanism. The largest such effect was that exerted by haemoglobin, which was therefore identified as being the agent primarily responsible for the transmembrane chemical shift differences. Lysozyme was shown to exert a similar (susceptibility-independent) effect on the phosphoryl chemical shifts; it therefore seems likely that the effect involves a property of proteins in general and not a property unique to haemoglobin.

In experiments with a range of different solvents, it was demonstrated that the ^{31}P NMR chemical shifts of trimethyl phosphate and triethyl phosphate were entirely insensitive to factors affecting the formation of hydrogen bonds at the phosphoryl oxygen atom. The same was not true of the other six compounds; their ^{31}P NMR chemical shifts decreased markedly in response to any disruption of hydrogen bonding. It was therefore proposed that haemoglobin exerted its susceptibility-independent chemical shift effects by perturbing the hydrogen bonding of the phosphoryl groups to solvent water. Such a hypothesis accounts for the lack of a significant susceptibility-independent effect of haemoglobin on the ^{31}P NMR chemical shifts of the two phosphates.

Irrespective of the origin of the transmembrane chemical shift differences, the phenomenon was shown to have a number of useful applications. The observation of separate ^{31}P NMR resonances for the intra- and extracellular populations of the hypophosphite ion allowed the estimation of the relative concentrations of hypophosphite in the intra- and extracellular compartments. Incorporation of the hypophosphite distribution ratio into the Nernst equation yielded an estimate of the membrane potential. The cell volume-dependence of the transmembrane chemical shift difference for dimethyl methylphosphonate was shown to provide a convenient means of monitoring cell volume changes using ^{31}P NMR spectroscopy. Furthermore, the separation of the intra- and extracellular resonances of dimethyl methylphosphonate allowed the application of the NMR saturation transfer technique to measuring and characterising the equilibrium exchange of the compound across the erythrocyte membrane. The results of the transport measurements were fully consistent with the hypothesis that the molecule crosses the membrane solely by a process of simple diffusion through the lipid bilayer.

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Annual Report of Council

MEETINGS

Nine general monthly meetings and the annual general meeting were held during the year. The average attendance was 28 (range 17 to 48). Abstracts of the addresses were published in the Newsletter. Seven meetings were held in the Lilac Room, the Australian Museum, and two were held at the University of Sydney.

The 26th Liversidge Research Lecturer in Chemistry was Associate Professor R.J. Hunter of the School of Chemistry, the University of Sydney. His lecture was entitled "High Frequency Transport Properties of Colloidal Dispersions" and was delivered on Thursday, 27 July, 1988, at Sydney University.

As the Society's contribution to the Australian Bicentennial Celebrations, a special Sir Joseph Banks Memorial Lecture was organized, in co-operation with the Royal Society of Tasmania. The lecture, entitled "Commemorating Sir Joseph Banks: Symbiosis and the Concept of Mutual Benefit", was delivered by Sir David Smith, F.R.S., Principal and Vice-Chancellor of the University of Edinburgh, and former Sibthorpian Professor of Rural Economy at Oxford University. 62 attended. In conjunction with the lecture a booklet produced by the Royal Society of Tasmania was distributed. The arrangements for Sir David and Lady Smith's Sydney visit were handled by Dr. D. J. Swaine. The financial assistance to the Royal Societies collectively by the Australian Bicentennial Authority, Qantas Airways Ltd. and Ansett Airlines, and to this Society by the Council of the City of Bankstown, the Royal Botanic Gardens, Sydney, the University of Sydney and Mr Alexander Boden is acknowledged with gratitude.

The Cook Medal for 1987 was presented to Dr. Philip G. Law at the Society's office on 18 May, 1988, taking advantage of a visit by Dr. Law to Sydney.

Eleven meetings of Council were held at the Society's office, 134 Herring Road, North Ryde. The average attendance was 11.

PUBLICATIONS

The Journal and Proceedings, Volume 120, Parts 3 and 4, were published in May, 1988, incorporating six research papers, the Clarke Memorial Lecture 1987, two abstracts of higher degree theses, and the Annual Report of Council for the year ended 31 March 1987. Volume 121, Parts 1 and 2, were published in October 1988, and incorporated four research papers, four abstracts of higher-degree theses and the Annual Report of Council for the year ended 31 March 1988. Council again thanks the voluntary referees who assessed papers submitted for publication. The assistance of Miss H. Basden in processing the printing is gratefully acknowledged.

Nine issues of the Newsletter were published. Council is most grateful to the authors of short articles and reviews, which are much appreciated by members. The item "News of Members" is also popular, and is especially helpful in publicising members' achievements.

MEMBERSHIP

The membership of the Society at 31st March, 1989, was:

Honorary Members	14
Life	26
Ordinary	233
Absentee	15
Associate	20
Total	308

During the year the deaths were announced with regret of the following members:

Colin Lachlan ADAMSON, on 10 August, 1988.
Charles Joseph MAGEE, on 2 February, 1989.
William Wreford MILLERSHIP, on 15 January, 1989.
David Benjamin PROWSE, on 28 February, 1988.

AWARDS

The following awards were made for 1988:

Clarke Medal: Barry Garth Rolfe

Plate 1. Participants in the Summer School on Biotechnology, January, 1989, at Macquarie University. On the far left is Mrs. M. Krysko v. Tryst, Convenor of the Summer School and Mr. Martin Dwyer from Prince Henry Hospital. On the right is Associate Professor D.E. Winch, President of the Society and Mr. J.A. Welch, a member of Council.

Edgeworth David Medal: Peter Andrew Lay
The Society's Medal: Ragbir Bhathal

SUMMER SCHOOL

A most successful Summer School on "Biotechnology" was held from 16th to 20th January, 1989, at Macquarie University. It was attended by 66 students and 15 speakers took part. The Summer School was organised by Mrs. M. Krysko. The Vice-Chancellor of Macquarie University, Professor D. Yerbury, welcomed students and speakers while Mr. Andrew Tink MP, Member of the Council of Macquarie University and Member for Eastwood Electorate, performed the opening ceremony. The speakers came from universities, government organisations, and private industry.

The Council's appreciation is extended to the speakers, to Mrs. Krysko and to Council members who assisted her. Council is grateful to Roche Products Pty. Ltd. for financial support. Council also expresses its special thanks firstly to Professor Keith Williams, Head of the School of Biological Sciences, Macquarie University, who helped with advice and arranged for the students to visit his laboratories, and secondly to Medtel Pty. Ltd., Lane Cove, for providing the venue for a half-day excursion.

OFFICE

The Society continued during the year to lease for its Office and Library a half-share of Convocation House, 134 Herring Road, on the southeastern edge of the Macquarie University campus. The University authorities were forced by their space problems to review the Society's tenure, and we are very grateful to the University to have been permitted to continue to lease the premises.

LIBRARY

Acquisitions by gift and exchange continued as heretofore, the overseas and some Australian material being lodged in the Royal Society Collection, Dixson Library, University of New England. Other Australian material was lodged in the Society's office at North Ryde. The cataloguing of the collection at Armidale has been completed and a catalogue is being prepared for printing. The Council thanks Mr. K. Schmude for his continuing care and concern in ensuring the smooth operation of the Collection.

Mrs Grace Proctor continued to supervise the North Ryde collection and to liaise with Mr. Schmude and other New England librarians when necessary. The Council is very grateful to Mrs Proctor for her continuing voluntary assistance.

NEW ENGLAND BRANCH

The New England Branch held four very well attended meetings during the year 1988/89. They were:

24 May, 1988: Associate Professor G. Woolsey, Dept. of Physics, University of New England: "Light and Colour in the Sky".

21 June, 1988: Dr. W. S. McKerrow, University of Oxford: "Palaeozoic biogeography - The use of fossils to determine the positions of old continents".

2 August, 1988: Dr. B. C. McKelvey, Dept. of Geology, University of New England: "The last trees in Antarctica".

29 September, 1988: Dr. David Malin, Research Photographer, Anglo-Australian Telescope: "Things to see and do in the Dark".

FINANCE

The accounts for the financial year, January-December, 1988, show a surplus from operations of $881, an improvement of $2062 over the previous year's result. The only significant change in the operating accounts was the reduction in income due to a fall in Journal subscriptions and donations of about $3000, which was balanced by reductions in Journal costs and salaries.

The net assets of the Society at the end of 1988 were $135,700, up $4600. They were principally represented by interest-bearing, Trustee-Act-authorised, investments of $123,500, up $2400. The Society is very appreciative of having been made a residuary beneficiary of the estate of the late Dr G.H. Briggs, a member for many years. An initial disbursement of $2000 was received during the year and was invested.

The Society receives no Government grants and must stand on its own feet financially. The Council is therefore especially appreciative of the numerous donations received during the year. Donations were made to the Library Fund, the Summer School and the Journal.

The professional assistance of Mr A. M. Puttock, F.C.A., in the conduct of the Society's finances is again acknowledged with gratitude.

ABSTRACT OF PROCEEDINGS

The 121st Annual General Meeting and eight General Monthly Meetings were held during 1988. All meetings except the 996th General Monthly Meeting on 27th July, 1988, were held in the Lilac Room at the Australian Museum. This Meeting was held in Lecture Theatre 2, School of Chemistry, University of Sydney, and was followed by the Liversidge Research Lecture for 1988. To commemorate the Australian Bicentennial Sir David Smith, Principal and Vice Chancellor of Edinburgh University delivered the Sir Joseph Banks Memorial Lecture on Tuesday, 6th September, 1988 at the Stephen Roberts Lecture Theatre, University of Sydney. The title of the Lecture was "Commemorating Sir Joseph Banks: Symbiosis and the Concept of Mutual Benefit".

Abstracts of the meetings are given below:

APRIL 6

992nd General Monthly Meeting. Location: Australian Museum. The President, Dr. F.L. Sutherland, was in the Chair, and 48 members and visitors were present. Hugh Moore Henry, Edmund Clarence Potter, Samuel Peter Chatfield and Matthew Peter Fewell were elected to membership.

The death of Dr. David Benjamin Prowse on 28.2.1988, was announced with regret.

121st Annual General Meeting. Following the 992nd General Monthly Meeting the 121st Annual General Meeting was held. The Annual Report of Council and the Annual Financial Report were adopted.

The following awards for 1987 were announced: Clarke Medal (Zoology): Dr. Antony James Underwood; Cook Medal: Dr. Phillip Garth Law AO CBE FAA; The Society Medal: Dr. George Studley Gibbons; and the Edgeworth David Medal: Dr. Andrew Cockburn.

Messrs. Wylie and Puttock, Chartered Accountants, were elected Auditors for 1988.

The following Office-Bearers were elected for 1988/89:

President:	Associate Professor D.E. Winch
Vice-Presidents:	Dr. F.L. Sutherland,
	Professor J.H. Loxton,
	Dr. R.S. Bhathal,
	Professor R.L. Stanton,
	Dr. R.S. Vagg
Hon. Secretaries:	Dr. D.J. Swaine,
	Mrs. M. Krysko v. Tryst
Hon. Treasurer:	Dr. A.A. Day
Hon. Librarian:	Miss P.M. Callaghan

Members of Council: Mr. G.W.K. Ford, Mr. H.S. Hancock, Mr. J.R. Hardie, Professor R.M. MacLeod, Dr. R.A.L. Osborne, Mr. T.J. Sinclair, Mr. M.L. Stubbs-Race, Mr. J.A. Welch.

The retiring President, Dr. F.L. Sutherland, delivered his Presidential Address entitled "Demise of Dinosaurs and other Denizens - by Cosmic Clout, Volcanic Vapours or other Means".

The incoming President, Associate Professor D.E. Winch, proposed a vote of thanks.

MAY 4

993rd General Monthly Meeting. Location: The Australian Museum. The President, Associate Professor D.E. Winch, was in the Chair, and 30 members and visitors were present. It was announced that Mrs. J.E. Ford had been elected to Associate Membership by Council on 27.4.88.

A talk on "Caving for Sport and for Science" was given Dr. Julia M. James, Senior Lecturer in the School of Chemistry, University of Sydney.

JUNE 1

994th General Monthly Meeting. Location: The Australian Museum. The President, Associate Professor D.E. Winch, was in the Chair, and 30 members and visitors were present. Aubrey Darnell Hosking was elected to membership.

Mr. Jim Frazier of Mantis Wild Life Films gave a talk on "Making Wild Life Films".

JULY 6

995th General Monthly Meeting. Location: The Australian Museum. The President, Associate Professor D.E. Winch, was in the Chair, and 22 members and visitors were present.

A talk on "You Show Me Your Shorthand, and I'll Show You Mine" was given by Mr. Bob Beale, Science Writer, Sydney Morning Herald.

JULY 27

996th General Monthly Meeting. Location: Lecture Theatre 2, School of Chemistry, University of Sydney. The President, Associate Professor D.E. Winch, was in the Chair, and 34 members and visitors were present.

The Liversidge Research Lecture for 1988 was delivered by Associate Professor R.J. Hunter, Head of the School of Chemistry, University of Sydney. The title of the Lecture was "High Frequency Transport Properties: a New Probe for Colloidal Systems".

OCTOBER 5

997th General Monthly Meeting. Location: The Australian Museum. The President, Associate

Professor D.E. Winch, was in the Chair, and 38 members and visitors were present.

Mrs. Mary E. White of the Australian Museum gave a talk on "The Greening of Gondwana".

NOVEMBER 2

998th General Monthly Meeting. Location: The Australian Museum. The President, Associate Professor D.E. Winch, was in the Chair, and 17 members and visitors were present.

A talk entitled "Towards an Australian Design" was given by Mr. John Holt, Director of John Holt Design.

DECEMBER 7

999th General Monthly Meeting. Location: The Australian Museum. The President, Associate Professor D.E. Winch, was in the Chair, and 17 members and visitors were present. Robert Lawrence McNamara was elected to membership.

Papers Read by Title Only: S.K. Singh: "Geology of Tillegra Dam Site, N.S.W."; R.J. Hunter (Liversidge Lecture, 1988): "High Frequency Transport Properties of Colloidal Dispersions".

It was announced that Emeritus Professor R.L. Stanton had been elected to Honorary Membership.

After a short talk members were taken on a donducted tour of the gallery "Tracks Through Time" by Dr. Alex Ritchie.

AUDITORS REPORT

In our opinion:

(a) the attached accounts, set out on pages 2 to 10 which have been prepared under the historical costs convention, are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society at 31st December 1988 and of the results of the Society for the year ended on that date; and

(b) the accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provisions of those Rules.

WYLIE & PUTTOCK
Chartered Accountants.

By ALAN M. PUTTOCK
Registered under the Public Accountants Registration Act, 1945 as amended.

BALANCE SHEET as at 31st December 1988

	RESERVES	
7310.57	Library Reserve (note 2(a))	7310.57
6676.36	LIBRARY FUND (note 2(b))	7276.14
19565.24	TRUST FUNDS (note 3)	20515.82
97560.31	ACCUMULATED FUNDS	100643.86
----------		----------
131112.48	TOTAL RESERVES AND FUNDS	135746.39
==========	=======================	==========

BALANCE SHEET as at 31st December 1988

	Represented by:			
	CURRENT ASSETS			
195.20	Petty Cash Imprest		187.58	
1707.95	Debtors for Subscriptions	1855.13		
1707.95	Less Provision For Doubtful Debts	1855.13		
8351.78	Other Debtors & Prepayments		8761.76	
2979.80	Cash at Bank		11661.42	
----------			----------	
11526.78				20610.76
	Less: CURRENT LIABILITIES			
14230.58	Sundry Creditors & Accruals		21227.87	
35.37	Life Members Subscriptions - Current Portion		35.37	
36.70	Membership Subscriptions Paid in Advance		66.57	
1562.82	Subcriptions to Journal Paid in Advance		1325.97	
----------			----------	
15865.47				22655.78
----------				----------
4338.69	NET CURRENT LIABILITIES			2045.02
	Add: FIXED ASSETS			
986.66	Furniture, Office Equipment, etc.- at cost less Depreciation		886.66	
13600.00	Library - 1936 Valuation (note 4)		13600.00	
10.00	Pictures - at cost less Depreciation		10.00	
----------			----------	
14596.66				14496.66
----------				----------
(10257.97)				(12451.64)
	Add: INVESTMENTS			
5400.00	Commonwealth Bonds & Inscribed Stock		3100.00	
100000.00	Loans on Mortgage		100000.00	
15698.73	Interest Bearing Deposits		20403.60	
----------			----------	
121098.73				123503.60
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STATEMENT OF ACCUMULATED FUNDS
For the Year Ended 31st December 1988

(1180.57)	OPERATING SURPLUS for the year		881.50
1285.68	Donations & Interest to Library Fund		801.83
0.00	Proceeds Estate Late Dr G.H. Briggs		2000.00
318.54	Transfer from Library Fund		202.05
98422.34	Accumulated Funds - Beginning of Year		97560.31
98845.99	AVAILABLE FOR APPROPRIATION		101445.69
1285.68	Transfer to Library Fund	801.83	
1285.68			801.83
97560.31	ACCUMULATED FUNDS Current Year		100643.86
(131356.70)			(135955.24)
	Less: NON-CURRENT LIABILITIES		
244.22	Life Members Subscriptions - Non-Current Portion		208.85
131112.48	NET ASSETS		135746.39

D.E. WINCH President

A.A. DAY Honorary Treasurer

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1988

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1988. Unless otherwise stated, such accounting policies were also adopted in the preceding year

(a) Basis of Accounting

The accounts have been prepared on the basis of historical costs

(b) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

Furniture	7.50%
Office Equipment	15.00%

2. MOVEMENTS IN PROVISIONS AND RESERVES

(a) Library Reserve

7310.57	Balance at 1st January		7310.57
7310.57			7310.57
0.00	Transfer to Accumulated Funds	0.00	
7310.57	Balance at 31st December		7310.57

(b) Library Fund

5709.22	Balance at 1st January		6676.36
1285.68	Add Donations and bank interest		801.83
6994.90			7478.19
318.54	Less Library purchases and expenses	202.05	
318.54			202.05
6676.36	Balance at 31st December		7276.14

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1988

3. TRUST FUNDS

	Clarke Memorial Fund - Capital			
5000.00	Balance at 1st January	5000.00		
5000.00	Balance at 31st December		5000.00	
	Clarke Memorial Fund - Revenue			
745.70	Revenue Income for Period	732.46		
1074.46	Less Expenditure for Period	98.42		
(328.76)		634.04		
404.44	Balance at 1st January	75.68		
75.68	Balance at 31st December		709.72	
5075.68				5709.72
	Walter Burfitt Prize Fund - Capital			
3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	
	Walter Burfitt Prize Fund - Revenue			
447.42	Revenue Income for Period	439.48		
680.15	Less Expenditure for Period	6.00		
(232.73)		433.48		
2833.49	Balance at 1st January	2600.76		
2600.76	Balance at 31st December		3034.24	
5600.76				6034.24
	Liversidge Bequest Fund - Capital			
3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	
	Liversidge Bequest Fund - Revenue			
447.42	Revenue Income for Period	439.48		
520.00	Less Expenditure for Period	1039.50		
(72.58)		(600.02)		
1056.65	Balance at 1st January	984.07		
984.07	Balance at 31st December		384.05	
3984.07				3384.05
	Olle Bequest Fund - Capital			
4000.00	Balance at 1st January	4000.00		
4000.00	Balance at 31st December		4000.00	
	Olle Bequest Fund - Revenue			
596.56	Revenue Income for Period	585.98		
1600.00	Less Expenditure for Period	102.90		
(1003.44)		483.08		
1908.17	Balance at 1st January	904.73		
904.73	Balance at 31st December.		1387.81	
4904.73				5387.81
(19565.24)	Total Trust Funds			(20515.82)

4. LIBRARY

During the 1983 year the Society gifted the serials collection component of the library to the University of New England. The Society has retained that section of the library which is of historical significance. At the 31st December, 1988 a current valuation of the library had not yet been obtained.

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31st December 1988

	INCOME			
	Membership Subscriptions			
6852.30	- Ordinary			7605.50
	Membership Subscriptions			
35.37	- Life Members			35.37
25.20	Application Fees			28.00
6912.87				7668.87
	Subscriptions and Contributions to Journal			
12080.91	Publication Costs			8673.32
	Total Membership and			
18993.78	Journal Income			16342.19
15495.38	Interest Received			15583.33
30.00	Sale of Reprints			25.50
39.20	Sale of Back Numbers			91.50
	Sale of Other			
20.00	Publications			40.00
392.22	Summer School Surplus			0.00
157.80	Other Income			7.10
35128.38				32089.62
	Less:EXPENSES			
1500.00	Accountancy Fees		1650.00	
750.00	Audit Fees		825.00	
	Bank Charges & Government			
29.95	Duties		34.70	
200.00	Branches of the Society		200.00	
115.00	Depreciation		100.00	
143.25	Entertainment Expenses		192.50	
65.44	Insurance		65.15	
	Journal Publication and Distribution Costs			
17700.16	Printing	13244.14		
2600.14	Wrapping & Postage	2344.92		
20300.30			15589.06	
318.54	Library Expenses		202.05	
168.80	Miscellaneous Expenses		197.04	
200.18	Monthly Meeting Expenses		400.00	
	Newsletter Printing &			
1825.37	Distribution		1978.61	
418.92	Postage		285.48	
	Printing & Stationery -			
358.13	General		285.81	
	Provision for Doubtful			
31.45	Debts		1140.18	
2000.00	Rent		2000.00	
322.50	Repairs & Maintenance		170.27	
7327.47	Salaries		5649.34	
0.00	Summer School Deficit		182.45	
233.65	Telephone		60.48	
36308.95				31208.12
(1180.57)	SURPLUS for the year			881.50

STATEMENT OF SOURCE AND APPLICATION OF FUNDS
For the Year Ended 31st December 1988

	SOURCE OF FUNDS		
	Operating surplus for the		
0.00	year	881.50	
	Add:		
	Items not involving the outlay of funds in the current period:		
	Depreciation of fixed		
0.00	assets	100.00	
	Provision for doubtful		
0.00	debts	1140.18	
	Funds derived from		
0.00	operations		2121.68
	Donations and interest to		
1285.68	library fund		801.83
2237.10	Trust fund income		2197.40
	Reduction in working		
3378.55	funds		0.00
	Proceeds Estate Late G.H.		
0.00	Briggs		2000.00
	Life Membership		
132.50	Subscriptions		0.00
7033.83			7120.91
	APPLICATION OF FUNDS		
	Operating deficit for the		
1180.57	year	0.00	
	Less:		
	Items not involving the outlay of funds in the current period:		
	Depreciation of fixed		
115.00	assets	0.00	
	Provision for doubtful		
(1351.55)	debts	0.00	
	Funds applied to		
2417.12	operations		0.00
	Reclassification of life members subscriptions in		
43.37	advance		35.37
698.73	Increase in investments		2404.87
3874.61	Trust fund expenses		1246.82
0.00	Increase in working funds		3433.85
7033.83			7120.91

AWARDS

THE CLARKE MEDAL

BARRY GARTH ROLFE

Dr. Rolfe is a dinstinguished Australian biologist who has concentrated on unravelling the relationship between plants and the microbial soil bacteria which so affect plant growth. He has embraced the new techniques and opportunities provided by modern molecular biology to study the crucial question of how plants recognise and restrict infection by microorganisms.

Dr. Rolfe is an enthusiastic supporter of science in Australia and places importance on nurturing young scientists, addressing Australian problems and maintaining our scientific expertise at the forefront internationally.

Over the past fourteen years Dr. Rolfe has established an outstanding international record in the fields of biological nitrogen fixation and the molecular analysis of plant-microbe interactions. He has built a strong, multi-disciplinary research group which has developed a series of specific plant assay systems, cloned and analysed significant genetic material from *Rhizobium* bacteria. These studies provided a range of biological probes which have enabled his group to initiate an investigation of the preformed and inducible defence mechanisms produced by a number of leguminous plants in response to pathogen attack, and thus a description of the molecular basis of how plants recognise and restrict infection by microorganisms.

The work of his group ranges from field experiments with supernodulating soybeans in northern New South Wales and southern Queensland, to the fine structure analysis at the DNA base pair level of genes involved in plant-microbe interactions. Several of the group's recent findings have significant implications for future studies into microbial-plant interactions. They have isolated and identified specific flavone compounds secreted by the roots of plants which directly affect gene expression in *Rhizobium.* As a result of these findings, Dr. Rolfe's group have now constructed *Rhizobium* strains that respond to signals secreted from the roots of non-leguminous plants such as wheat, rice and maize.

His innovative science has placed him at the forefront of an internationally, highly competitive field, and he is a worthy recipient of the Clarke Medal.

THE SOCIETY'S MEDAL

RAGBIR SINGH BHATHAL

The Society's medal for contributions to the progress of the Society and to Science is awarded to Dr. Ragbir Singh Bhathal, BSc (*Singapore*), Certif. Ed. (*Birmingham*), PhD (*Queensland*). Dr. Bhathal joined the Society in 1982, became President in 1984 and Vice President in 1985, serving the Society with great energy and enthusiasm.

Dr. Bhathal has published papers on science museums and on the history of science and astronomy. He is at present working with Dr. Orchison on a book on the history of astronomy in Australia. Dr. Bhathal organised a seminar on "The Preservation of the Scientific and Industrial heritage", which lead to a change in the NSW Heritage Act. He has also served on an advisory committee to the Federal Minister for Science, the Honourable Mr Barry Jones MP, concerning the establishment of the Australian Science and Technology Centre which opened in November 1988 in Canberra. Through his work at the Power House Museum, Dr. Bhathal is helping to present a very favourable image of science, its significance and its relevance to the community at large.

Dr. Bhathal's contributions to the Society and to science education make him a very worthy recipient of the Society's Medal.

EDGEWORTH DAVID MEDAL

PETER ANDREW LAY

The Society's Edgeworth David Medal for 1988 is awarded to Dr Peter Andrew Lay for his contributions to inorganic chemistry research.

Dr Lay graduated with first class Honours in Chemistry from the University of Melbourne in 1977, and followed this with a PhD from the Australian National University in 1981. After periods of post-doctoral research at Stanford, Michigan State, Deakin and Australian National Universities, and at the CSIRO Division of Applied Chemistry, he took up his present appointment as Lecturer in Chemistry at the University of Sydney in 1985.

Within the general theme of physical and synthetic inorganic chemistry Dr Lay's research interests have been quite diverse and prolific. They have been directed at an understanding of the energetics and mechanisms of inorganic reactions with a view to possible industrial and biological applications. These applications range from solar energy capture, through the destruction of harmful organochlorine wastes, to the role of chromium in the induction of human cancers. The work has been reported in more than fifty papers in primary research journals.

Dr Lay's scientific capabilities have been recognised through the award of a Union Carbide Prize, a Queen Elizabeth II Fellowship, and both the Bloom-Gutmann Prize and Rennie Medal of the Royal Australian Chemical Institute. The Edgeworth David Medal is awarded by the Society to young researchers who already have made a significant contribution to Australian science, and Dr Lay is indeed a worthy recipient.

CHARLES JOSEPH PATRICK MAGEE

1901 - 1989

Charles Joseph Patrick Magee, B.Sc.Agr.(Syd), M.Sc.(Wisc), D.Sc.Agr.(Syd), FAIAS, formerly Chief Biologist and Chief of the Division of Science Services in the New South Wales Department of Agriculture, died in Sydney on 2 February, 1989, in his 88th year, after a full and richly rewarding life and a very distinguished professional career.

Charles Joseph Patrick Magee (1901-1989)

A long-time member of the Royal Society of New South Wales, Dr. Magee joined the Society in 1947. He was a Council Member in 1948 and 1949, Honorary Treasurer in 1950 and 1951, President in 1952 and Vice-President from 1953 to 1957, inclusive.

It is fitting and proper that Dr. Magee's obituary be published in the Journal and Proceedings of the Society, to which he gave so generously of his services. It is no less appropriate that the opportunity thus presented be taken to place on record an appreciation of, and a tribute to the life and career of a quite remarkable man.

FAMILY BACKGROUND AND EARLY EDUCATION

The son of Charles Joseph and Mary Magee, Charles Magee was born on a farm at Lismore, N.S.W. on 17 November, 1901. He was the third son in a family of 4 boys and 3 girls. Tragically for the family, both parents died within 2 weeks of one another in 1908.

Charles, at the age of 7, thereupon went to live with an aunt at Newcastle, where he completed his primary school education. As a secondary level student, and a scholarship holder, he attended Sydney Boys' High School, representing the school in rowing and football and performing well academically.

UNIVERSITY AND PROFESSIONAL CAREER

In March, 1920, having completed his secondary education, gained another scholarship and been awarded a Department of Agriculture Cadetship, he enrolled in the Faculty of Agriculture in the University of Sydney. After a year at St. John's College, he boarded privately for the remainder of his time at the University.

Presaging the distinguished career that was to follow, Magee achieved excellent results at undergraduate level, as he had done at High School. He was awarded the Belmore Scholarship for Chemistry and Geology, and graduated with honours in 1924.

During University vacations agricultural cadets were required to undertake practical training at experimental farms attached to the Department of Agriculture. These on-farm assignments provided an opportunity to meet, live-in and socialize with fellow undergraduates. At times they led to the development of life-long friendships as was the case with Charles Magee and Bob (Dr. R.N.) McCulloch, in consequence of a first meeting at Yanco Experiment Farm in 1922.

Following graduation Magee was apponted to the position of Assistant Biologist in the State Department of Agriculture's Biology Branch.

Shortly thereafter, in May, 1924, he was seconded to a special purpose committee, set up by the Commonwealth Government to investigate the cause and to consider and recommend ways and means of countering the then highly destructive disease of bananas known as bunchy top.

As the biologist member of the investigational team, Magee made a monumental contribution to the overall study by determining the nature and cause of what he established as an aphid-transmitted viral disease. In so doing, he was one of the first, if not the first scientist to demonstrate conclusively the transmission of aplant pathogenic virus by an insect vector. Having thus established the fundamental nature and aetiology of banana bunchy top disease, Magee proceeded to devise a very practical and basically effective means of control involving the removal and destruction of infected plants. This approach to controlling the disease continues to be adopted to the present day and has served to save an important industry from what otherwise would almost certainly have been virtual extinction.

The successful implementation under field conditions of the control programme devised by Magee owed much to the support given it by a North Coast farmer and community leader of the day in the person of H.L. Anthony, later a Federal Government Member and Minister; and the father of one-time Deputy Prime Minister, J.D. (Doug) Anthony.

H.L. Anthony, convinced by Magee of the practical soundness and the potential merit of the control measures recommended proceeded in turn to convince his fellow growers to accept and adopt them in practice. Impressed by the leadership qualities thus shown by Anthony, Magee was later to suggest to him on a number of occasions that he should "consider going into politics".

Whether or not in response to Magee's urgings, the end result, as aforementioned, was that Anthony did in fact eventually enter politics, to succeed there, as he had done as a farmer, with his son following a similar course with comparable success.

Subsequent to his successful involvement in the banana bunchy top investigations, Magee was awarded a Ben Fuller Travel Scholarship in 1926. Under the terms of this award he pursued postgraduate studies on plant virus diseases at the University of Wisconsin, U.S.A., and visited selected research institutions in the U.S.A. and Europe. The studies involved led, in turn, to the award, in 1927, of a M.Sc. degree from Wisconsin, where he also successfully completed all preliminary examinations for registration as a Ph.D. candidate, without proceeding further in the matter, however, bacause of time limitations.

En route back to Australia in 1928, following the visits to European research centres, he obliged a request from the British Government to appraise and report on the banana disease situation in both Egypt and Ceylon.

Back in Australia, Charles Magee rejoined the Biology Branch towards the end of 1928 and, four years later, received permanent appointment to the position of Plant Pathologist. During the ensuing decade he engaged in investigational and advising work on a range of vegetable diseases including, in particular, leaf roll and other virus disorders of potatoes, potato scab and whiptail disease of crucifers. Over the same period, he also pursued his banana bunchy top studies; and helped lay the foundations of the N.S.W. Potato Seed Certificates Scheme, which has since served to reduce materially the incidence of disease in the State's potato industry.

In 1939 Magee joined a very select group when he was admitted by the University of Sydney to the Degree of Doctor of Science in Agriculture. His doctoral thesis, entitled "Studies on the Bunchy Top Disease of *Musa* spp.", was variously commended by his examiners as being "a highly meritorious piece of work" and "a notable contribution to economic biology".

The year after being awarded his doctorate, Charles Magee was promoted to the position of Senior Biologist. Further promotion followed in 1942 when he was appointed Chief Biologist and Head of the Biology Branch.

Subsequently, in July 1958, he was appointed Chief of the Department of Agriculture's Division of Science Services (made up of the Biology, Chemistry and Entomology Branches), whilst retaining *pro tem* the role and title of Chief Biologist.

Two years later, in a major departmental initiative, the three Branches involved were accommodated together, for the first time, in a single, separate laboratory, service and office complex at Rydalmere. Magee, who had been instrumental in instigating, and was largely responsible for implementing this particular development was confirmed as Chief of the newly consolidated Division. At the same time, he was given an additional role as officer-in-charge of the Rydalmere complex which was later named the Biological and Chemical Research Institute. Because of the extensive range and demanding nature of the duties involved, those associated with the position of Chief Biologist were relinguished, as was this particular title.

Until his retirement in 1966, Charles Magee discharged with admirable flair and great distinction and efficiency, the duties and responsibilities of administering the research and advisory service activities of the Biological and Chemical Research Institute. In the process he combined technical knowledge and expertise with administrative ability to mould the three component Branches of his Division into what was widely acknowledged as being one of the Department of Agriculture's most efficient and productive research and service units.

Additional to his intra-departmental activities Magee, during the course of his career, found himself called upon by the Australian and various foreign governments, and other instrumentalities and interests, on no less than 20 occasions, to undertake special overseas assignments of a wide-ranging nature. For the record, but without itemising the specific nature of each, these assignments, variously undertaken between 1926 and 1965, made him the most widely travelled of the Department of Agriculture's scientific officers, with visits to Canada, Egypt, Fiji, Malaysia, New Guinea, North Borneo, The Phillipines, Sri Lanka, Switzerland, the United Kingdom, U.S.A. and Western Samoa.

The purpose of these overseas visits ranged, for example, from investigations of the deterioration of armed service equipment and stores in New Guinea during World War II, city refuse disposal in the United Kingdom and the application of electrodialysis to the de-salination of sea and bore water in the U.S.A. to plant disease studies in Fiji, North Borneo and Western Samoa and attendance, as an official Australian representative, at various international conferences.

Such activities bear convincing testimony to the high professional standing enjoyed by Charles Magee, both locally and internationally, as well as to the exceptional scope of his scientific interests extending, as they did, well beyond his specialty field of microbiology.

To the range of overseas assignments identified above can be added notable contributions made locally in a diversity of activities including promotion of the mushroom and strawberry growing industries, early foreshadowing of the potential value and environmental implications of herbicide usage, studies on the relationship between particle size and biological efficiency in agro-chemicals, especially those with fungicidal properties, and commercialisation of legume inoculant production, with appropriate quality control safeguards.

Befittingly for such a talented and versatile scientist, Magee belonged to a number of scientific bodies and held membership of many committees.

His membership of, and executive-level connections with, the Royal Society of N.S.W. have earlier been noted. He was a foundation member of both the Australian Society of Dairy Technology and the Australian Institute of Agricultural Science, of which he was elected a Fellow in 1965, having earlier served a term as President of the N.S.W. Branch in 1946. He was also a member and Fellow of the Australian and New Zealand Association for the Advancement of Science.

His more important committee activities included the Chairmanship, from 1952 until his retirement, of the Registration Advisory Committee (Biological Products) of the National Association of Testing Authorities and membership of the State Committee of that body over the same period. For several years, following his initial appointment in 1952, he was a member also of the Technical Advisory Committee of the Department of Agriculture's Agricultural Research Institute, Wagga Wagga. Some years later he joined forces with Professor J.M. Vincent of the Faculty of Agriculture of the University of Sydney in planning committee activities which led ultimately to the establishment of a combined University-Department of Agriculture Laboratory Service (UDALS). This service has since functioned very successfully in maintaining pure culture stocks of legume rhizobia and in monitoring the quality of inoculants produced for distribution to farmers by commercial interests.

In his role as Chief of the Division of Science Services, Magee chaired or otherwise contributed to the deliberations of a range of technical and advisory committees established variously to deal with administrative aspects and the research and service functions of the Division. Magee had close rapport with the rural sector and, not infrequently, such meetings were convened in response to representations from rural producers and industry organisations.

PERSONAL CHARACTERISTICS AND PHILOSOPHIES; RELATIONSHIPS WITH STAFF

Charles Magee's record of achievement leaves no doubt that he was an extremely versatile and able team leader and administrator. His success, as earlier indicated, was attributable basically to technical knowledge and expertise combined with administrative and management ability. Personal and professional integrity of the highest order also played a part, as did a number of particular approaches and philosophies, espoused and practised by him throughout his career.

So it was that, from a team morale viewpoint, he appreciated the importance of identifying and remedying problems of creativity, communication and motivation; and of satisfying the related resource needs and the postgraduate aspirations of staff. No less importantly, he appreciated also, and stressed to staff, the desirability of establishing and maintaining effective contact with agribusiness interests, the universities, other government departments and instrumentalities and the practical farming sector. Additionally, he displayed in his team leadership role, a perceptive awareness of the fact that the direction of individual officers oftentimes called for careful appraisal of the extent to which control should or should not be exercised; and of what called for encouragement, on the one hand, and admonishment, on the other.

Accountability-wise, Magee as a governmental officer, was ever-mindful of his obligations to his employer, to industry and to the general public for satisfying what he referred to as the "expenditure-results achieved" equation. Accordingly, he was shrewdly critical, in a cost-benefit sense, of research proposals advanced by members of his staff. Once convinced, however, of the merits of particular projects he encouraged and supported their pursuance, whilst keeping a wary eye on operational costs. In this connection, it was his oft-expressed view that research, contributing to the advancement of science, "comes from the minds of innovative people, not from expensive equipment!" Somewhat unjustly, perhaps, he tended to identify requests for sophisticated and expensive equipment with a penchant, on the part of staff concerned, for producing what he viewed as pedantically erudite articles of marginal relevance to the practical solution of problems of the day. So it was that, when unconvinced of the need for additional costly equipment, the requisition orders for it were not infrequently dismissed on the grounds that "we are not here to write pretty papers!" In similar dismissive vein, he was once heard to pose the not unreasonable question "what's wrong with using jam tins?" when approached, at a time of budgetary constraints, for funds to purchase expensive containers in which to grow plants.

To a degree, the above observations and recollections can be interpreted as serving to explain why two of his favourite sayings were "waste not, want not" and "all things in moderation". Certainly in his own research endeavours and in his team leadership role, he adopted an applied research and development approach, based on practical and economic considerations and objectives, as distinct from the pursuance of basic research, regardless of cost, purely for the sake of adding to the store of scientific knowledge.

Consistent with the latter viewpoint, his approach to the recruitment of staff, in which he participated personally whenever possible, rested on the philosophy that is preferable to wait for the "right" person, rather than make an appointment solely for the sake of filling a vacancy. Following their appointment, he interested himself closely in the prfessional development of staff members - admonishing, criticising, enthusing, encouraging or counselling, as circumstances warranted, according to his assessment of each individual situation.

In the process, he persistently stressed the importance of the documentation and publication of research or other scientific data as a measure of scientific productivity. He himself was the author of a total of 42 scientific bulletins and articles, advisory leaflets and governmentally-commissioned reports.

On a quite different front, but still on the general theme of his relationships with staff, many, myself included, will ever remember with appreciation and be grateful for the innate kindliness with which he extended sympathy, comfort and advice in times of personal adversity.

As a person, Charles Magee was possessed of an imposing personality and presence which, together with the high regard in which he was held personally, and in scientific circles, inspired the deep respect of staff, professional colleagues and industry leaders alike.

He also inspired in staff, esteem and a lasting loyalty. This stemmed, in large degree, from his interest in and concern for them as individuals, but was also attributable, at least in part, to the unfailing courtesy with which he received and considered their representations as well as to the care and effort he devoted to maintaining contact with those of his staff who moved to other fields of employment and endeavour.

In other regards, Magee was a man of vision with a wide-ranging knowledge of and interest in science, as a whole. His curiosity was that of the true scientist, as was the objectivity with which he sought to unravel the nature and complexities of the particular problem at hand, whatever it happened to be.

In his private life, as in his scientific endeavours, he was practically-minded, self reliant, determined and tenacious, with an excellent sense of judgment. He was, too, a man of great charm; and the courtesy and innate kindliness, which characterised his dealings with staff, extend-always to others. To those who knew him well, he was possessed also of a wry humour and a sense of fun which helped, no doubt, to generate and enhance the particular empathy that he enjoyed with young people.

Recollections of Charles Magee would not be complete without reference to the fact that he was also a very forthright man of strongly held views and convictions. This was to result in him being seen, at times, as being over-dogmatic and even belligerent and unnecessarily argumentative. Certainly he could be adamant in maintaining a particular point of view. Confrontations sometimes resulted, not infrequently in consequence of representations forcibly made on behalf of and in the interests of members of his staff. By their very nature, confrontations arising from such representations were usually with Magee's peers in administration in the Department of Agriculture or with inspectorial staff of the State Public Service Board.

He showed greater forbearance, but was no less firm, in dealing with lesser mortals, like the departmental "efficiency expert" who arrived one day to announce that he proposed to overhaul the Biology Branch's filing system. Magee listened politely and then, gently but resolutely escorted the officer concerned from office to lift, informing him on the way that the existing system adequately met the needs of the Branch and, this being so, he was not going to have it changed, let alone dissected and dismantled!

At other times, depending on the circumstances, Magee was seen by some as being irascible and somewhat lacking in tolerance and patience. At no time, however, did he lose his dignity and somehow he seemed always to introduce a sense of decorum and propriety into the particular proceedings involved, however delicate and disputations they might be. It is a measure, indeed, of the man that he could do so!

FAMILY LIFE AND RETIREMENT

Family life proper began for Charles Magee towards the end of 1930 when he married Christina Kennedy Shearer. He and his Christina made a handsome couple, and were devoted to one another, as the both were to their daughter and only child, Elinor.

Their first home was at Rose Bay where Elinor was born in 1933. In the following year the family moved to a larger residence, with spacious garden surrounds at Roseville. Here Dr. Magee grew an extraordinarily wide range of fruit trees, vines, vegetables and ornamentals with such success that - to the benefit of neighbours - family needs were more than satisfied for the most part.

As was to be expected, he was often called upon by neighbours aware of his background to play the role of resident advisor on local gardening problems. He even turned his hand, with some success, to the hybridisation of ornamentals. Always an early riser, it was customary for him to spend at least an hour in the garden most mornings before leaving home for work.

Other recreational activities included reading, tennis, swimming, fishing and the occasional game of golf.

In the late 1930s and early 1940s, and again in the 1950s cottages bought at Terrigal and Palm Beach, provided the opportunity, particularly on weekends and during holiday periods, to relax from the demands of work-a-day pursuits by taking nature walks, gardening, fishing from the rocks or rowing boat and surfing.

Some two years after his retirement from the

Department of Agriculture in 1966, Dr. Magee moved, with his wife, from Roseville to take up permanent residence at Palm Beach, where the daily walk and swim became a ritual. Gardening remained a great interest, as did fishing and reading.

In the year of his retirement from the Department of Agriculture he accepted an invitation to join the Sydney-based firm of Root Nodule Pty. Ltd. as its Consulting Bacteriologist. In this role he supervised, for a decade, the firm's bacteriological work and legume inoculants production and distribution service, in an affiliated association with UDALS (University Department of Agriculture Laboratory Service), the rhizobia quality control organisation which he himself had played such a key role in establishing some years earlier.

Another major post-retirement interest was planning committee work associated with the establishment of Macquarie University.

During his latter years he was troubled by failing eyesight. Reading, perforce, became less and less a recreational option, as did television viewing. He turned increasingly, in consequence, to radio as a means of "passing the time", as he put it, and of keeping in touch with news and current affairs and such other broadcasts as were of interest to him.

He was devastated and disconsolate when his wife predeceased him in 1983, and was sorely perturbed by his eyesight troubles and their consequences, particularly as he lived alone after the death of Mrs. Magee.

Notwithstanding, he remained stoically independent and in basic good health and spirit, and was ever delighted and comforted by visits from and contacts with family members, friends and one-time colleagues and associates.

A richly gifted, highly esteemed and greatly respected individual, Charles Magee will be widely remembered with admiration and affection, especially by members of his immediate family and by those privileged to have worked with, and under him, in the N.S.W. Department of Agriculture.

ACKNOWLEDGMENTS

I am indebted to Dr. Magee's daughter, Mrs. Elinor Reynolds and to Mr. K.E. Hutton, Dr. R.N. McCulloch, Dr. T.B. Kiely and Dr. K.D. O'Neill for assistance given in the preparation of this obituary and biographical memoir.

F.C. Butler

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The Mt. Daubeny Formation: Arenite-Rich ?Late Silurian-Early Devonian (Gedinnian) Strata in Far Western New South Wales

G. Neef, A. C. Edwards, R. S. Bottrill, J. Hatty, I. Holzberger, R. Kelly and J. Vaughan

ABSTRACT. The 6 km-thick, nonmarine Mt Daubeny Formation, commonly pale-red in colour, crops out in far western New South Wales. It is largely composed of arenite with subordinate siltstone and rudite. A basal orthoquartzite, the Koonburra Creek Quartzite Member, is present in the south whereas in the north three horizons (~ 0.5 km, 2.5 km and ~4.5 km above basement) contain andesite flows. The central part of the outcrop contains common 6m-thick orthoquartzite beds which are interbedded largely with pale-red or grey arenite and siltstone. The sequence containing orthoquartzite beds is at least 775m thick in the west and it is ~ 690m thick in the east where it is overlain by a ~610m sequence composed of brown-red arenite and siltstone.

The upper part of the formation is Early Devonian (Gedinnian) in age, is dated by fossil plants. The base of the formation is probably ~ 4 m.y. older than the fossiliferous horizon and this basal part may be latest Silurian in age. An unknown thickness of the formation has been removed by erosion since it was deposited.

Palaeocurrents indicate that during the ?Latest Silurian-Early Devonian a mountainous terrain composed largely of Precambrian - ? Cambrian rocks lay west of the present outcrop area of the formation area and provided the sediment from which the formation was formed.

INTRODUCTION

The Mt Daubeny Formation has an outcrop distribution of ~230 km^2 in the remote Wertago area of far western New South Wales (Fig. 1). It is usually well exposed, especially in dry creek beds. The aim of this contribution is to describe this very thick (6 km) Latest Silurian-Early Devonian strata which form the Mt Daubeny Formation (new formation). The formation is illustrated by two geological maps (Figs 2 & 2a), six geological sections (Figs. 3 & 4), and two stratigraphic columns (Figs. 5 & 6).

All previous investigations of the Mt Daubeny Formation have been of a reconnaissance nature. Previous estimates of the age of the formation range from Proterozoic (Rose *et. al.*, 1964) to Early Devonian (Rose and Brunker, 1969) and Late Silurian (Evans, 1977). The latter estimate of age follows from the discovery of elements of the *Baragwanathia* Flora within the mid-upper part of the formation which indicates that this part of the formation was deposited in the Late Silurian and/or Early Devonian (Douglas and Lejal-Nicol, 1981). The Mt Daubeny Formation is of special interest as it represents the only exposed ?Late Silurian early Devonian strata within the Darling Basin.

The northern half of the Mt Daubeny Formation was mapped by J.H., I.H., R.K. and J.V. in July 1977 and the southern half and most of the northern half was subsequently mapped, and remapped, by G.N. Petrology is by A.C.E. and R.S.B

GEOLOGICAL SETTING

The Mt Daubeny Formation lies west of the important NNE-trending Koonenberry Fault. West of the fault the basement rocks (Cambrian-Precambrian rocks) have abundant magnetic anomalies, which are lacking east of the fault (Wilson, 1967; Stevens, 1985). Leitch *et al.* (1987) considered that there are three late Precambrian to ?Early Cambrian stratigraphic units west of the mapped area.

The Mt Daubeny Formation, largely composed of immature clastics (Warris, 1967; Neef and Bottrill, in prep.) was largely faulted and folded during the Mid Devonian Tabberabberan Orogeny. Deformation was moderate in the north and central regions whereas in the south deformation was relatively mild.

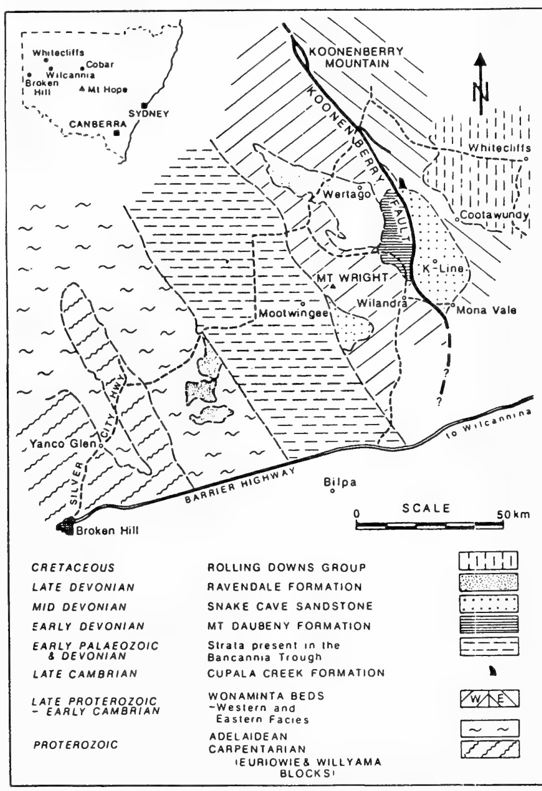

Fig. 1. Generalised geology of the West Darling.

During the orogeny feldspar porphyry dikes (commonly intruded parallel to NNE trending faults), plugs and sills (Wilson, 1967), and a few narrow basalt dikes, which are absent in younger strata, were intruded. The formation, which lacks marker beds

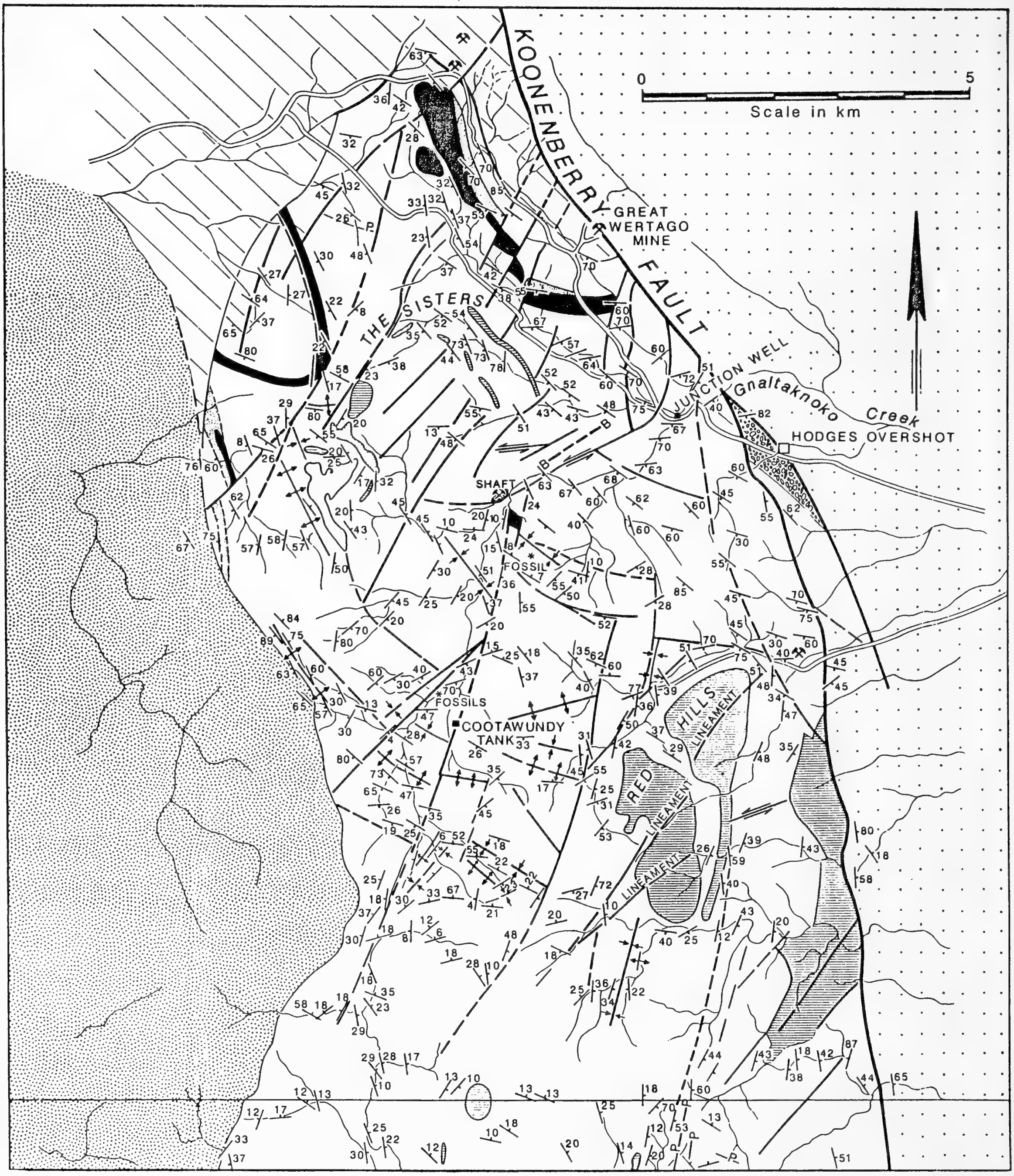

Fig. 2a Geological map of the northern part of the Mt Daubeny Formation.

(Warris, 1969),is dominated by lithic arenites, (with subordinate siltstone and minor rudite), andesite and volcaniclastic arenite (reported by Warris, 1967; and Rose, 1974) whereas carbonates are lacking. It lies unconformably on the mildly metamorphosed Late Precambrian rocks to the north and south, (Figs. 2a & 2b) and is overlain, locally with only slight (~10°) unconformity, by the Late Devonian, Ravendale Formation which is usually subhorizontal in attitude in the west (Warris, 1967). The eastern boundary of the formation is along the NNW-trending Koonenberry Fault and the northern boundary is also bounded by a north-east-trending fault which locally cuts the Ravendale Formation at section A-B. Adjacent to the Koonenberry Fault on its eastern side, there are outcrops of Mid Devonian, Snake Cave Sandstone, which are strongly folded, presumably during the Kanimblan Orogeny, (the character of the Snake Cave and Ravendale Formations has been described by Carroll, 1982),

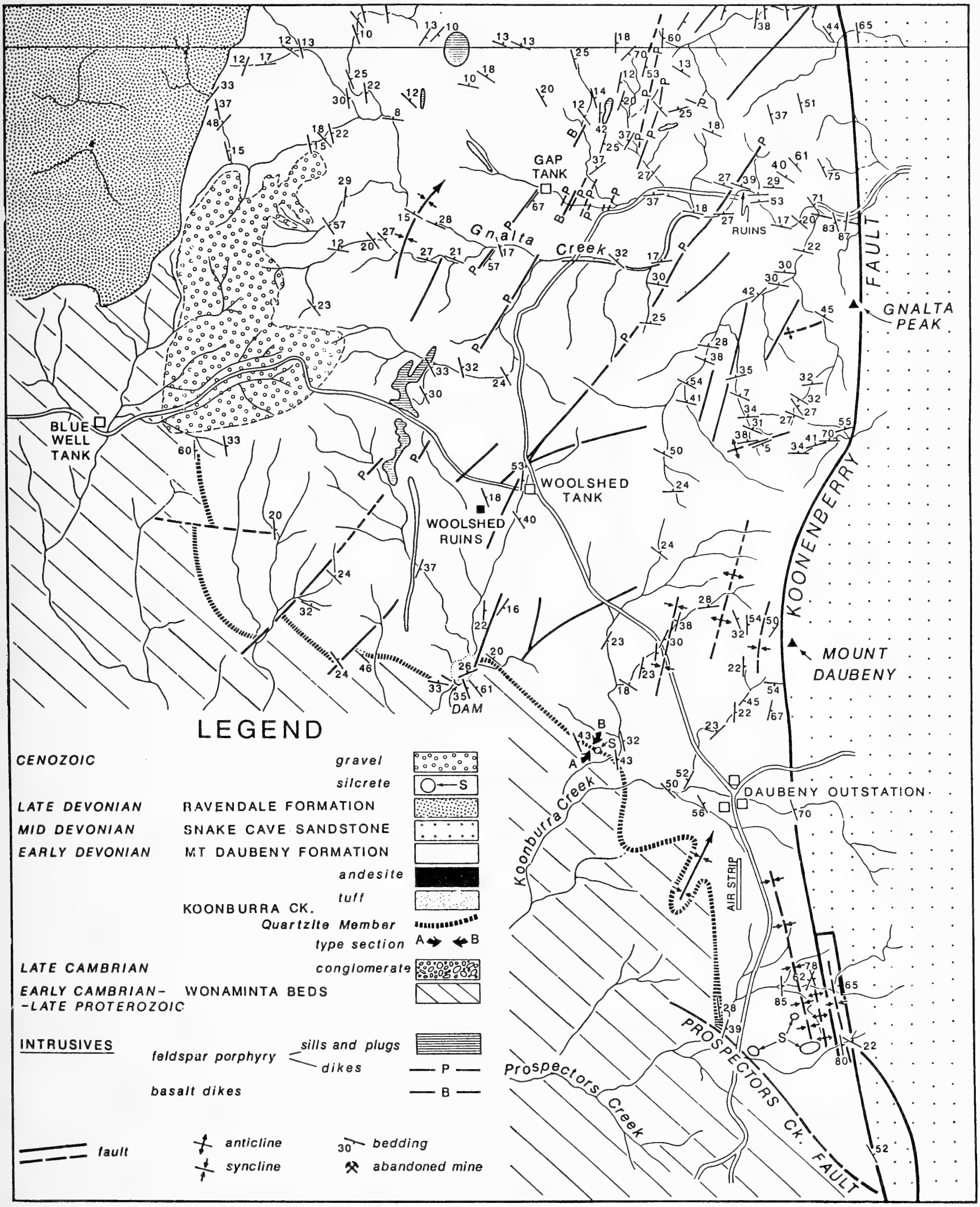

Fig. 2b Geological map of the southern part of the Mt Daubeny Formation.

whereas near Hodges Overshot there is conglomerate which is thought to be Late Cambrian in age (i.e. coeval with the conglomerates of Bilpa and Koonenberry Mountain, Powell *et. al.*, 1982).

Near Blue Tank in the south-west there is a 8 km^2 area which is overlain by Early Tertiary gravel and there are a few outcrops of silcrete (Fig. 2b).

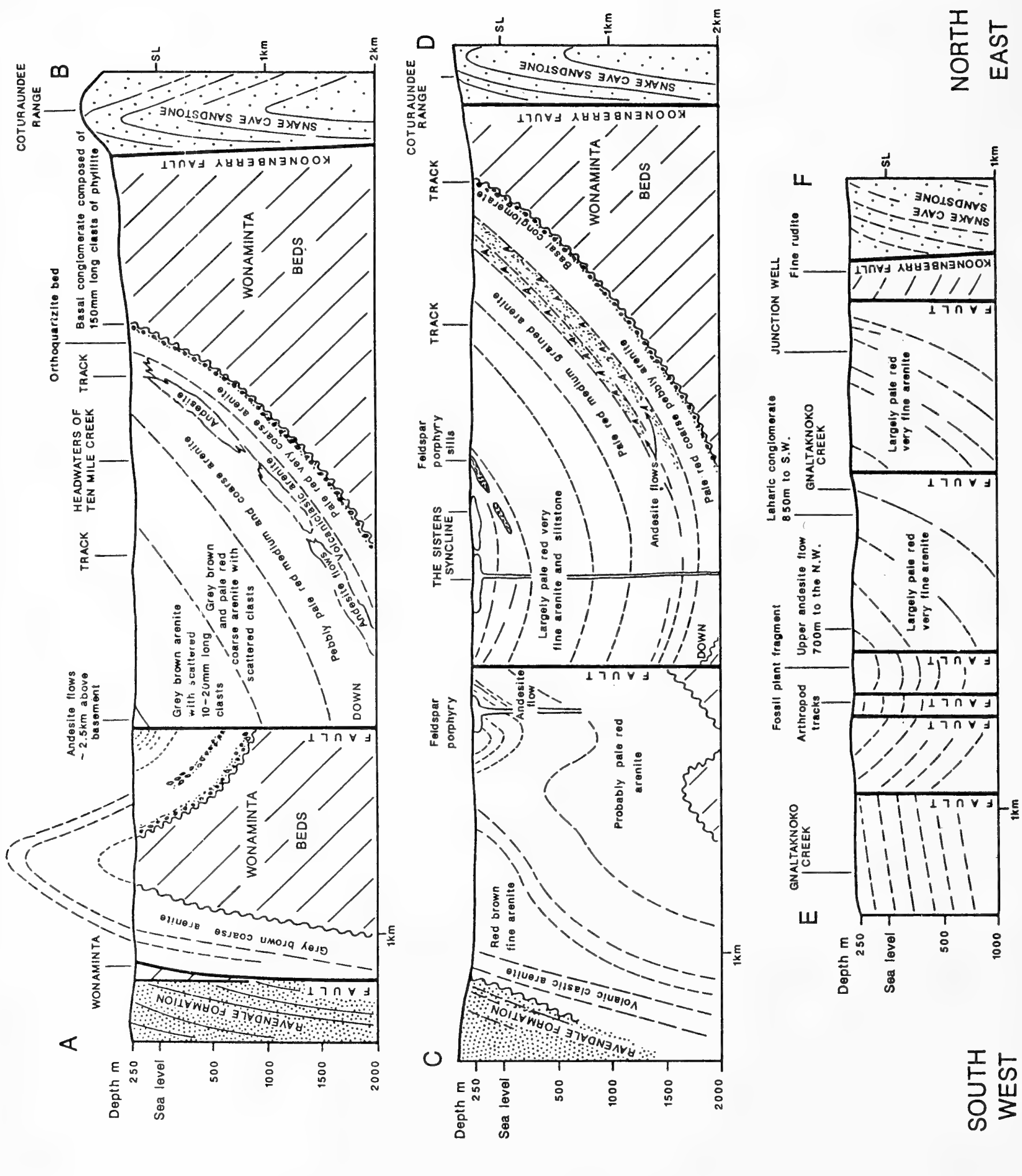

Fig. 3. Geological cross sections A-B, C-D, and E-F from the central and southern parts of the formation.

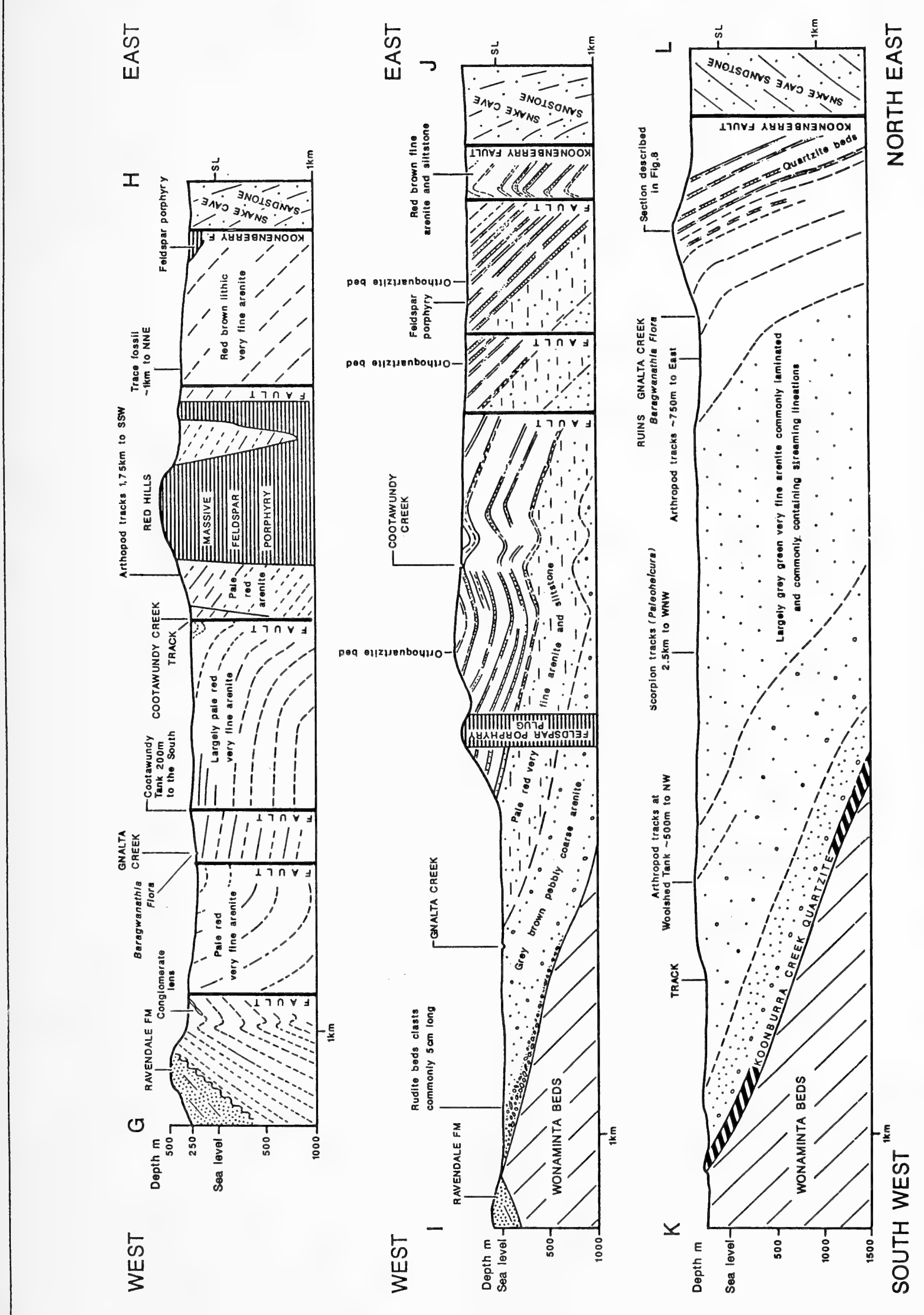

Fig. 4. Geological cross sections G-H, I-J and L-K from the central and southern parts of the formation.

KOONBURRA CREEK QUARTZITE MEMBER (new member)

Derivation of name: Koonburra Creek which flows southwards west of Daubeny Outstation)

TYPE SECTION: Near Koonburra Creek (GR 5719 1408, Wilcannia 1:250 000) (Frenda, 1965) (see A-B of Fig. 2b).

DISTRIBUTION AND STRATIGRAPHIC RELATIONS: The member, which is unconformable on the Wonaminta Beds, extends for 12 km from near Blue Tank in the north to Prospectors Creek in the south (Wilson, 1967; Warris, 1969).

CONTENT AND THICKNESS: The member, which suprisingly lacks a basal conglomerate, and body and trace fossils, forms a prominent ridge along its entire outcrop. It is fine grained, commonly tabular cross-stratified (in sets commonly ~0.3 m thick) and contains very rare clasts of vein quartz (and at least one clast of red arenite). A quartzite from the northern part of the outcrop has Q, F and L percentages of 95, 4 and 1 respectively. (Sample W11, Neef and Bottrill, in prep.).

It is thickest (75m) about 500 m northwest of Koonburra Creek; elsewhere it ranges from 14m to 36 m in thickness.

SOUTHERN PART OF THE MT DAUBENY FORMATION

The southern part of the Mt Daubeny Formation contains the type section which represents an unfaulted ~ 6 km thick sequence largely composed of grey-brown and grey-green arenite (Fig. 5). This sequence resembles the five unit sequence described by Warris (1967). About 1.5 km west of the type section an indurated pale-red 5R6/2, 25m-thick laminated fine quartzose pale red arenite having typical Q, F and L percentages of 78, 5 & 17 respectively (Sample W20, Neef and Bottrill, in prep.). Further west a ~ 250 m thick, very poorly exposed conglomerate contains 0.2m - long clasts of phyllite, basalt and vein quartz. Stratigraphically higher beds are characteristically coarse pebbly arenite, however conglomerate composed entirely of clasts 20-30 mm long of disc-shaped phyllite is present locally (for example at Woolshed Ruins, which lies 0.7 km southwest of Woolshed Tank, a 3m-thick fine conglomerate is composed of 30% phyllite clasts and 70% coarse arenite/fine conglomerate matrix). At Woolshed Tank slabs of fine grained lithic arenite (rich in lithic fragments and having typical Q, F and L percentages of 48, 6 & 46 respectively, sample W17;, Neef and Bottrill, in prep.) are flute and groove-casted and contain arthropod tracks thought by Warris (1967) to be trilobite tracks but are here interpreted to be non-marine arthropod traces (Neef in prep.). Northwest of Gap Tank the basal sequence is represented by 590m of pebbly, grey-brown coarse arenite followed by ~525m of pale-red siltstone and arenite (Section I-J, Fig. 4).

Beds of grey orthoquartzite beds are present locally west of the Koonenberry Fault near Mt Daubeny and adjacent to the fault in Prospectors Creek. In the east, the Gnalta homestead (now in ruins), which lies along the type section, was constructed from local green-grey (5GY6/1) and less common grey-brown (5YR3/2) micaceous and lithic-rich very fine arenite having typical Q,F and L percentages of 34, 13 and 53 respectively and siltstone (Sample W93) and 47, 10 and 43 respectively (Sample W94) (Neef and Bottrill, in prep.) Bedding is medium (maximum thickness is 1 m) and current lineations, ripple marks and cross bedding are present locally, whereas soft sediment deformation is lacking. Nearby sediment is brownish-grey (5YR4/1) or light-grey (N6) in colour. Oxidized facies (red-brown or pale-red) is rare, perhaps forming only 5% of the strata near the ruins.

A 0.43 m thick, green siltstone containing a little malachite is present 1 km southwest of Gnalta ruins in the south bank of Gnalta Creek.

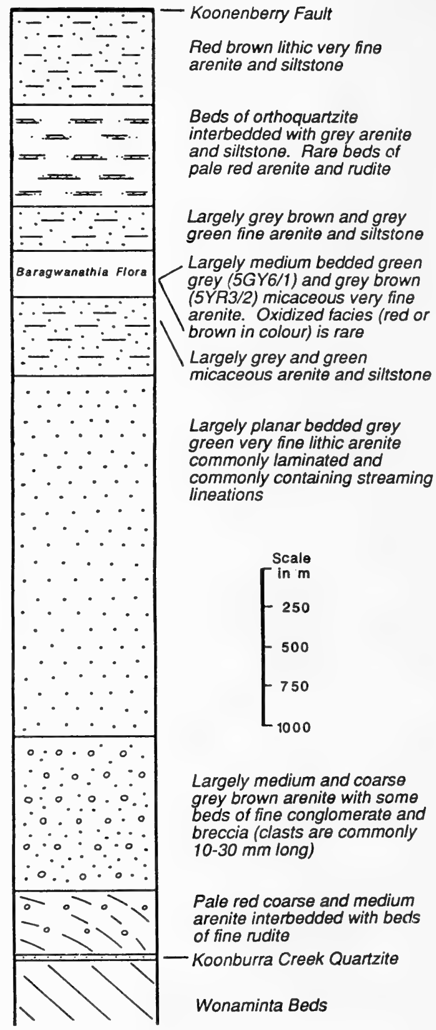

Fig. 5. Composite columnar section of the type-section of the Mt Daubeny Formation (L-K).

In the type section the thick quartzite beds which are characteristic of the central region are present ~4.7 km above the base of the formation whereas west of Gap Tank thick quartzite beds outcrop only ~ 1.1 km above the base of formation (Section 1-J, Fig. 4). This data is consistent with the depth contours to magnetic basement pattern of Wilson (1967, fig. 5), and it shows that deposition rates northwest of Gap Tank were much less than those characteristic of the type section.

NORTHERN PART OF THE MT DAUBENY FORMATION

The northern part of the Mt Daubeny Formation is largely unfossiliferous and was much more oxidized (shortly after it was deposited) than the southern part of the formation being, invariably, pale-red in colour. Basal conglomerates are commonly present and there are three horizons where andesite flows and tuffs may be developed. These andesites occur ~ 0.5 km ~ 2.5 km, and ~ 4.5 km above the basal unconformity. The northern part of the formation is illustrated in geologic cross sections A-B, C-D, and E-F (Fig. 3) (the latter section being almost central) and by a stratigraphic column (Fig. 6).

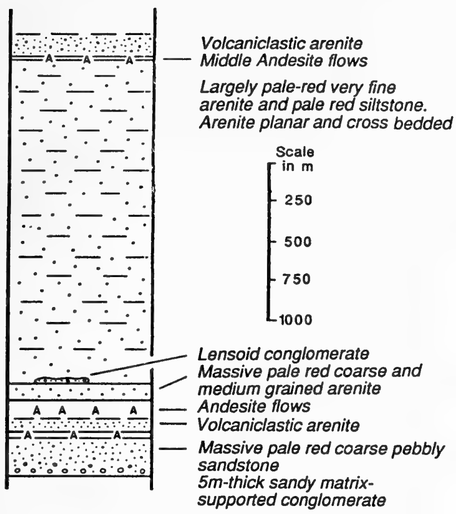

Fig. 6. Composite columnar section of strata in the north.

The basal conglomerates are usually only a few metres thick except in the northwest where locally conglomerates are ~ 20m thick (see section A-B). Above the conglomerate lies a 220 m thick pale-red coarse arenite commonly containing scattered clasts (Fig. 6). However between these northern sections a lensoid 60m-thick conglomerate contains well rounded to sub-angular clasts (max. length 0.41m).

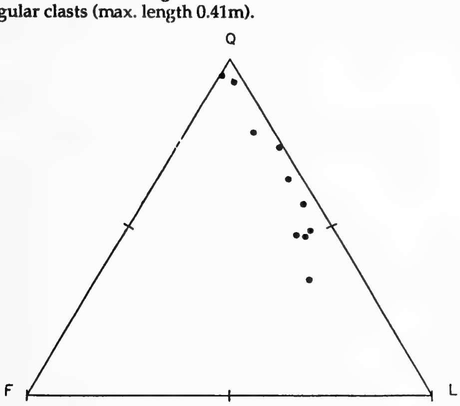

Fig. 7. Q, F and L Diagram of arenites point counted.

The lower andesite is lenticular having a maximum thickness of 440 m (south of section A-B) and it is composed of numerous flows each several metres thick. Southwards the andesite thins and individual flows are interbedded with arenite and conglomerate. Near Section C-D (Fig. 3) a volcanic-rich, arenite which separates two andesite flows, has typical Q, F and L percentages of 47, 8 and 45 respectively, W87, (Neef and Bottrill, in prep.). Further south a section contains at least 8 flows aggregating 61m in thickness within a 210 m-thick sequence (Fig. 8). To the northwest thick andesite masses, possibly representing small volcanic cones, or the infill of Early Devonian or Late Silurian valleys, are present. At one locality beneath the andesite flows a 0.7 m wide thick vertical feeder dike trends NNE (013^{o}) and it can be traced for ~100 m towards the Koonenberry Fault.

The lower andesite is also present on the western limb of a northwest-trending anticline (see section A-B), (Fig. 3).

In thin section the andesites are fine-grained pervasively altered rocks, with relic igneous textures ranging from

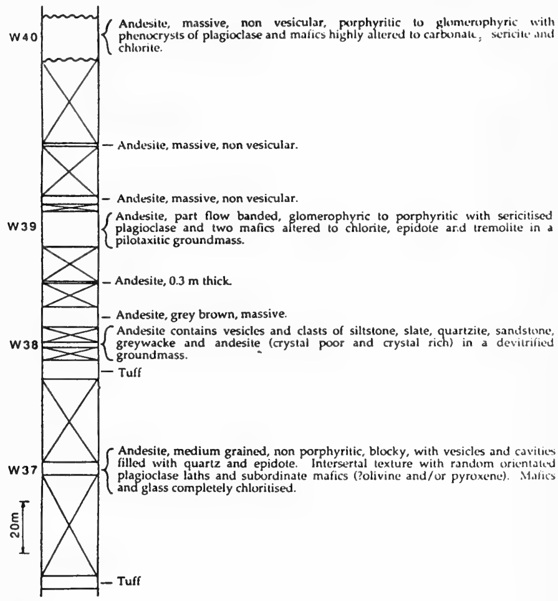

Fig. 8. The andesitic sequence in the northern part of the Mt Daubeny Formation, located 1.3 km southwest of the Great Wertago Mine.

microporphyritic-trachytic to equigranular intersertal. Sub-greenschist metamorphism has resulted in the albitization of the groundmass plagioclase laths, and produced assemblages of chlorite, epidote, sphene and magnetite (weathering to limonite) in the interstices. Chlorite and carbonate with minor epidote or prehnite form inclusions within the albitised plagioclase laths. Relict microphenocrysts (1.0 to 1.5 mm long) comprise up to 20% of the rock and include: albitised plagioclase laths containing fine grained aggregates of carbonate with minor prehnite and epidote; clinopyroxene altering to chlorite $\pm$ epidote; and euhedral pseudomorphs of chlorite and carbonate after clinopyroxene. Irregular shaped amygdules (0.5 to 3.0 mm) are common and are mantled by plagioclase-free zones containing fine grained chlorite and arborescent quench textured magnetites. The amygdules contain assemblages which include quartz, calcite, chlorite and epidote.

Overlying the lower andesite flows is a ~ 80 m thick medium to coarse-grained pale-red (5R 6/2) planar, medium to thickly bedded arenite which is overlain by ~ 2 km pale-red, fine and very fine grained, planar and cross bedded lithic-rich arenite (Section A-B, Fig. 3). Pale-red (5R6/2) rippled siltstone is rare. Within this sequence are four lensoid, 10-20 m thick coarse grained conglomerate beds. The rudite depicted on the columnar section (Fig. 6) has a strike length of 80 m. It is composed of about 50% clasts which have a maximum length of 0.2 m and are part rounded and part angular. The clasts are largely of metasediment and vein quartz, with rare clasts of andesite. The uppermost part of the rudite is matrix-supported, and it has a crude bedding, and contains two 0.5m thick arenite lenses.

The central andesite flows (maximum thickness 50 m) are not as well developed as the lower andesite flows. However they are recognised in geological sections A-B and C-D (Fig. 3) (at two localities in the latter). Locally the flows are underlain, or overlain, or wedge out into dark-green coloured volcaniclastic arenite.

Strata which lie > 2.5 km above the basement are present in Gnaltaknoko Creek (section E-F, Fig. 3) where the sequence is cut by several faults. Here the beds are generally very fine grained, pale-red (5R6/2) arenite, occasionally containing rip-up clasts of siltstone and soft-sediment-deformed beds. These beds are largely planar-bedded, commonly rippled, and occasionally cross-bedded. A sheet-like fine rudite bed (see section E-F, Fig. 3) which represents a laharic conglomerate (Neef and Bottrill, in prep.), has a maximum thickness of 2.6 m.

A 16m-thick andesite flow, thought to lie ~ 4.5 km above basement (see section E-F, Fig. 3) is present near the abandoned shaft adjacent to Gnaltaknoko Creek (4.5 km W.S.W. of Hodges Overshot). Strata which overlie it are largely pale-red, fine arenite with subordinate grey-brown and grey-green beds. Fossils, although very rare, are present at several localities (see section E-F & G-H, Figs. 3 & 4).

CENTRAL AREA

In the central part of the outcrop area of the formation, a 4.5 km-wide, east-trending belt contains strata like that of the northern part of the formation except that orthoquartzite beds up to 6m thick, which commonly have strike lengths of 1-2 km, are present. These strata, which are unfossilferous and virtually lack beds of rudite, are at least 775 m thick in the hills north of Gap Tank and they are ~ 690 m thick in the type section (Fig. 5). The orthoquartzite beds are medium light grey (N6) and light brownish-grey (5YR/61), and are well sorted, fine grained (rarely medium grained) and invariably lack clasts. The basal parts of the beds are commonly laminated with prominent current streaming lineations. Locally flute casts are present at the base of some of the beds. The middle to upper parts of the beds are

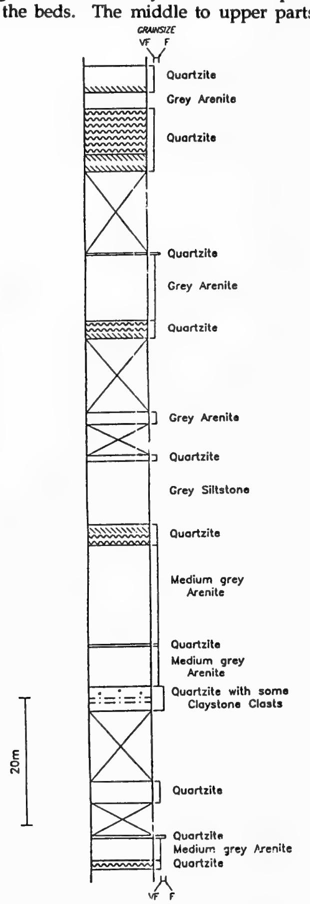

Fig. 9. A stratigraphic sequence containing eleven quartzite beds present 1.2 km ENE of the Gnalta Creek Ruins.

commonly plane and trough cross stratified and these bedforms are commonly soft sediment- deformed sometimes containing water escape structures. A quartzite near the Koonenberry Fault has Q, F and L percentages of 93, 2 and 4.5 respectively (W2, Neef and Bottrill, in prep.).

The quartzites are interbedded with varicoloured arenite and siltstone (which are usually pale-red in the north and west and grey in the east) (see Fig. 9 for an eastern example). In the type section and section I-J the uppermost part of the formation is represented by ~ 610 m of red-brown fine lithic arenite and siltstone.

THICKNESS OF THE MT DAUBENY FORMATION: Because the formation is deformed (Neef, in prep.) and because of the rarity of marker beds in much of the formation, its thickness is difficult to estimate. Wilson (1967) estimated the Late Silurian-Early Devonian strata to be more than 12,000 ft (3,660 m) thick. However, in the type section (Fig. 5) between Koonburra Creek-Gnalta ruins-Koonenberry Fault a thickness of is ~6 km is estimated by the authors and thicknesses of ~ 5 km are probable in the north. Such thicknesses are consistent with the greenschist metamorphism of the andesite in the north (such a metamorphic grade indicates a cover of up to 10 km and a palaeotemperature range of 200-330^{o}c; Winkler, 1974).

PALAEONTOLOGY AND AGE: Fossils present within the formation include primitive vascular plants (the *Baragwanathia* Flora), a bivalve (now probably misplaced, B. Webby, pers. comm., 1983) and there are at least sixteen localities mostly in the central part of the formation, containing trace fossils (G. Neef, in prep.).

Fossil vascular plants of the *Baragwanathia* flora were first reported by Brown (in Freeman, 1966) and were also collected by Dr. S. Shaw (pers. comm. 1967). Shaw collected his samples from near the mouth of a dry creek bed near its confluence with Gnalta Creek (about 200 m downstream of the Gnalta ruins). Subsequently, one of the authors traced the bed to Gnalta Creek (120 m downstream of the ruins) where a thinly bedded, 0.7m-thick green siltstone overlies a 1.5m-thick olive-grey pebbly arenite. Species present at the two localities are: *Sporongonites* sp., *Psilophyton* sp. (axes with minute pitting, spines) *Zosterophyllum* sp., (axes with pronounced knees at forks and transverse connections between adjacent axes), *Hostimella* sp. (smooth axes, pers. comm. Mary White). Another floral locality was discovered 600 m northeast of Cootawundy Tank along the west bank of Gnaltaknoko Creek where a well lithified 5 m by 3 m sized outcrop of quartzose arenite contains numerous impressions of unidentified small fossil plants (see Fig 2a for location).

The *Baragwanathia* Flora (previously described from Victoria) is the most primitive flora of Australia (Gould, 1975) ranging from Late Silurian (Ludlovian) to Early Devonian (Pragian) in age (Douglas and Legal-Nicol, 1981). More recent work suggests that the Mt Daubeny Flora is not a typical representative of the *Baragwanathia* Flora and the width of the standard axes of *Zosterophyllum* suggests a Gedinnian, or later age (D. Edwards pers. comm. 1983).

The Gnalta Ruins fossils lie ~ 4 km above the base of the formation and it could be argued that the lower part of the formation is signficantly older than the upper part. However, the trace fossils from the Woolshed Tank horizon (which crops out only ~ 1 km above the base of the formation) are identical to the trace fossils from the upper parts of the formation and they are clearly coeval with the Devonian and latest Silurian trace fossils of the northern hemisphere described by Pollard and Walker (1984). Sediments below the Woolshed Tank horizon are like those above and these underlying strata are also assumed to be Gedinnian or Latest Silurian in age. Also the presence of the unconformity below the Koonburra Quartzite is correlated with reflector A of Evans, (1977) which represents a regional latest Silurian-Early Devonian unconformity in the Darling Basin (Evans, 1977).

The Mt Daubeny Formation lacks unconformities and shows many features indicating very rapid deposition. Rates of deposition for alluvial fans have been estimated to range between 0.1 to 1m/1000/yr (Blatt *et al.*, 1980) although rates as high as 11 m/1000 yr have been deduced for Neogene alluvial fan deposition in California (Crowell, 1974). On this basis, assuming that deposition rates on terminal fans are like those on alluvial fans, the time taken to deposit the Mt Daubeny Formation within a rapidly subsiding basin may have been as little as half a million years although a more likely period of deposition is ~ 5 m.y. Thus the formation may be entirely Gedinnian (~ 10 m.y. long, Veevers, 1984) in age, or alternatively, the youngest and oldest parts of the formation may be Siegenian and latest Silurian respectively.

ENVIRONMENT OF DEPOSITION

Deposition within a non-marine environment is deduced from the presence of vascular plants and the red coloured (oxidized) nature of much of sediment and the lithofacies present (Neef and Bottrill, in prep.). This is confirmed by the trace fossils of the *Scoyenia* Ichnofacies which are characteristic of a non-marine environment (Seilacher, 1967).

Planar cross beds within the Koonburra Creek Quartzite show that it was deposited from currents flowing to the southwest apparently derived from the Gnalta Peak area (Neef and Bottrill, in prep.). Thinning of the quartzite westwards is consistent with a north-eastern source. Deposition within sand-bed braided streams is inferred from the tabular cross beds which suggest deposition from a variety of flat top bars (Smith, 1978). Their distribution suggests braid-plain deposition above a well developed peneplain (reflector A of Evans, 1977). The overlying red quartzose arenite is also thought to be derived from the north or northeast.

Subsequently the Koonburra Creek Quartzite was buried by thick sediments derived from the west indicating a considerable change in tectonic style with rapid uplift to the west (representing the Bowning Orogeny) to form a mountain chain. From this progressively uplifted mountain chain sand with minor silt and gravel was carried eastwards. Palaeocurrents, largely streaming lineations and planar cross beds, suggest that sediment was deposited on a number of convex-upward structures which are interpreted to be terminal fans (Neef and Bottrill, in prep.) (terminal fans form distal of alluvial fans, Friend, 1978, and others). This interpretation is consistent with the planar and cross bedded strata found within the formation and also with the presence of rare trace fossils of the non marine Scoyenia Ichnofacies of Seilacher (1967).

The strata contain twelve lithofacies (Neef and Bottrill, in prep.) and several of these represent sheet flood deposition (for example the orthoquartzite beds of the central area resemble the 1965 sheet flood deposits of Bijou Creek, Colorado, [McKee *et al.*, 1966]. Also present are fluvial deposits (the latter representing small streams which flowed across the fans). In the north and the west sedimentation was almost entirely within the oxidizing zone and the strata are characteristically pale-red or red-brown in colour. However in the east (south of Red Hills) such pale-red sediment is much rarer (e.g. the type section K-L, Fig. 4) and much of the strata are grey-green or grey-brown and were deposited within a reducing or partially reducing environment.

Two principal sediment sources are recognised: a nearby source of unconsolidated rhyodacitic ash, and a more distant source of quartz-rich metasediment and sediment (Neef and Bottrill, in prep.). Late Silurian-Early Devonian acid volcanics are known south of Cobar at Mt. Hope (Rose and Brunker, 1969) (Fig. 1), but are supposedly absent elsewhere west of the Wagga Metamorphic Belt (Powell, 1984, p. 311). The abundance and angularity of the grains derived from rhyodacitic tephras indicates a local volcanic source which, because there is an apparent absence of airfall tephra, was probably emitting frequently during relatively gentle eruptions and redeposited during subsequent floods. Also present in the arenite are grains of schist, garnet, microcline and tourmaline which are thought to be derived from the oldest Precambrian terrane recognised by Leitch *et al.* (1987).

It is likely that erosion of metasediment, especially phyllite, to the west was similar to recent erosion of this metasediment producing much sand-sized detritus but few pebbles and cobbles. Some of the quartz grains within the formation are probably reworked from the extensive tracts of quartz-rich Late Cambrian strata (such as the > 1000 m thick Cupala Creek Formation, Powell *et al.*, 1982) which may have overlain the Wonaminta Beds during the Late Silurian and Early Devonian and were subsequently removed by erosion. Also there may have been present tracts of Late Cambrian conglomerate (such as those near Hodges Overshot, Koonenberry Mountain, and at Bilpa Station). Boulders of quartzite, thought to be Adelaidean in age, are present in the south (Warris, 1967) and they may also be second cycle deposits.

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REFERENCES

Blatt, H., Middleton, G., Murray, R. 1980. ORIGIN OF SEDIMENTARY ROCKS. Prentis Hall, New Jersey. 782 pp.

Carroll, N.F., 1982. Geology of the Devonian rocks of Mootwingee. *MSc thesis, Univ. of N.S.W. (unpubl.).*

Crowell, J.C. 1974. Sedimentation along the San Andreas Fault, California. in MODERN AND ANCIENT GEOSYNCLINE SEDIMENTATION, pp. 190-204. R.H. Dott Jr. and R.H. Shaver (Eds.). *Society of Economic Palaeontologists and Mineralogists, Special Publication* 22.

Douglas, J.C. and Lejal-Nicol, A., 1981. Sur les premieres flores vasculaires terrestres datees Silurien: Une comparaisson entre la "Flore a *Baragwanathia*" d' Australia et la "Flore a *Psilophytes* et *Lycophytes*" d Afrique du Nord. *Comptes Rendus des Seances de L'academie des Sciences, 292,* 685-688.

Edwards, A.C., 1978. Tectonic implications of the immobile trace-element geochemistry of mafic rocks bounding the Wonaminta Block. *Journal of the geological Society of Australia, 25,* 459-465.

Evans, P.R., 1977. Petroleum geology of western New South Wales. *Australian Petroleum Exploration Association Journal, 17,* 42-49.

Freeman, R.N., 1966. The Lake Frome embayment area. *Australian Petroleum Exploration Association Journal, 6,* 93-99.

Fenda, G.A., 1965. Wilcannia, 1:250,000 Geological Map Series (1st Ed.) Geological Survey of New South Wales.

Friend, P.F., 1978. Distinctive features of some ancient river systems. *in* FLUVIAL SEDIMENTOLOGY, pp 531-542. A.D. Miall (Ed). *Memoir Society of Petroleum Geologists, Calgary.*

Goddard, E.N., Trask, P.D., De Ford, R.F., Rove, O.N., Singewald, J.J. and Overbeck, R.M., 1970. Rock colour chart. Distributed by *Geological Society of America,,* Boulder, Colorado.

Gould, R.E., 1975. The succession of Australian pre-Tertiary megafossil floras. *Botanical Review, 41,* 453-483.

Kenny, E.J., 1930. Geological survey of the West Darling District with special reference to the resources of sub-surface water. *New South Wales Department of Mines Annual Report,* pp 93-98.

Leitch, E.C., Webby, B.D., Mills, K.J. and Kolbe, P., 1987. Terranes of the Wonaminta Block, far western New South Wales. *in* TERRANE ACCRETION AND OROGENIC BELTS, pp 31-37. E. C. Leitch & E. Scheibner (Eds). *Geodynamics Series Vol. 19.* American Geophysical Monagraph Board.

McKee, E.D., Crosby, E.J. and Berry Hill, H.C., 1966. Flood deposits, Bijou Creek Colorado. *Journal of Sedimentary Petrology, 37,* 829-851.

Pollard, J.E. and Walker, E.F., 1984. Reassessment of sediments and trace fossils from Old Red Sandstone (Lower Devonian) of Dunure, Scotland, described by John Smith (1908) *Geobios. 17,* 567-576.

Powell, C. Mc A., Neef, G., Crane, D., Jell, P.A. and Percival, I.G., 1982. Significance of Late Cambrian (Idamean) fossils in the Cupala Creek Formation, northwestern New South Wales. *Proceedings of the Linnean Society of New South Wales, 106,* 127-150.

Powell, C. Mc A., 1984. Silurian to mid Devonian dextral transtensional margin. *in* PHANEROZOIC EARTH HISTORY OF AUSTRALIA, pp 309-329. J.J. Veevers (Ed). Clarendon Press, Oxford.

Rose, G., 1974. Explanatory notes on the White Cliffs 1:250,000 Geological Map Series. *Geological Survey of New South Wales,* 48 pp.

Rose, G., Louden, A.G., and O'Connell, P. 1964. White Cliffs, 1:250,000 Geological Map Series (lst edn.) *Geological Survey of New South Wales.*

Rose, G. and Brunker, R.L., 1969. The Upper Proterozoic and Phanerozoic geology of northwestern New South Wales. *Australian Institute of Mining and Metallurgy Proceedings 229,* 105-120.

Scheibner, E., 1978. Tasman fold belt system in New South Wales - General Description. *Tectonophysics, 48,* 207-216.

Seilacher, A., 1967. Bathymetry of trace fossils. *Marine Geology, 5,* 413-428.

Smith, N.D., 1978. Braided-stream deposits *in* THE ENCYCLOPEDIA OF SEDIMENTOLOGY, pp 82-84. F.W. Fairbridge and J. Bourgeois (Eds.). Dowden Hutchinson & Ross, Stroudsberg.

Stevens, B.P.J., 1985. Preliminary interpretation of regional basement geology in northwestern New South Wales. *New South Wales Geological Survey - Quarterly Notes,* 9-22.

Veevers, J.J., 1984. PHANEROZOIC EARTH HISTORY OF AUSTRALIA. Clarendon Press, Oxford. 418 pp.

Warris, B.J., 1967. The Palaeozoic stratigraphy and Palaeontology of northwestern New South Wales, *Ph.D. thesis, Univ. of Sydney (unpubl.).*

Warris, B.J., 1969. The Mt. Arrowsmith area. *in* THE GEOLOGY OF NEW SOUTH WALES. *Geol. Soc. Aust. J. 16,* 69-72.

Wilson, R.B., 1967. Geological appraisal of the Mootwingee area, New South Wales. *Australian Petroleum Exploration Association Journal, 7,* 103-114.

Winkler, H.G.F., 1974. PETROGENESIS OF METAMORPHIC ROCKS. Springer Verlag, Berlin. 320 pp.

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The Scientific Work Of Tenison Woods
A Symposium

CONTENTS

Journal and Proceedings, Royal Society of New South Wales, Vol. 122, p. 108, 1989
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Introduction

DAVID BRANAGAN

Julian Edmund Tenison Woods, Catholic priest, geologist, biologist, and historian, died in Sydney on 7 October, 1889. Author of more than 200 scientific papers, written in the 'spare' time of a busy missionary priest, Tenison Woods made major contributions to science during his working life in Australia over a period of more than thirty years,.and was active in many of the scientific societies of his day.

Because of his contributions to Catholic education, particularly through the founding of several religious orders, his centenary has been remembered by the Church in various ways. In every state of the Commonwealth.meetings have been held and papers written discussing his work.

To re-examine his contributions to Australian science a mini-symposium was organised by the Earth Sciences History Group of the Geological Society of Australia Inc.in Sydney.

The Symposium was strongly supported by the Sisters of St. Joseph, who gave generous financial assistance, by The Australian Museum, which allowed the use of the Hallstrom Theatre for the occasion, and by The Royal Society of New South Wales, which helped to publicise the event.

Through this help speakers were brought to Sydney for the symposium held at the Australian Museum on 14 September 1989, and a successful, well-attended meeting was held, although unfortunately the airline strike was on at the time, and one invited speaker, Dr. Michael Fitzgerald, was unable to come from Adelaide. The title of his talk was to have been 'Geological observations in South Australia, principally in the district south-east of Adelaide, and the Taal Volcano--then and one hundred years later'. Some aspects of these topics are covered in Anne Player's expanded paper which follows.

The following papers cover the topics discussed at the symposium. Although wide-ranging, they touch upon only a few of the vast range of interests that Tenison Woods had in science. Perhaps their publication will encourage others to study facets of the work of this pioneer scientist, and others of his generation, who laid the groundwork for so much of the science of today which we take for granted.

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Julian Tenison Woods, Scientist, 1832 - 1889

ANNE PLAYER

INTRODUCTION

In the last decade of his life Julian Tenison Woods was certainly not without recognition of his achievements as a scientist. At its meeting on 14 December 1887 the Council of the Royal Society of New South Wales, `on the motion of Mr. Hunt, seconded by Dr. Leibius, unanimously resolved to award the Clarke Medal' for 1888 to Woods, for his services to Australian science. The following May, C.S.Wilkinson, Government Geologist and President of the Society, in his anniversary address to the members declared that a more appropriate award could not have been made for:

> During the last thirty-one years the Rev. Tenison-Woods has been well known as a writer upon the Natural History of Australasia. Of his 157 works published since the year 1857 no less than 74 are upon his favourite branch of Science - Geology ... wherever I have travelled I have found his name a household word, so wide an influence have his writings exercised among all classes (Wilkinson,1889).

Woods, the eleventh recipient of the medal, joined a distinguished company. He shared the award with Sir Richard Owen, George Bentham, Professors Thomas Huxley, Frederick McCoy and James Dwight Dana, and with Baron Ferdinand von Mueller, Alfred R.C. Selwyn, Sir Joseph Dalton Hooker, Professor L.G. De Koninck and Sir James Hector. These men currently held or had formerly occupied government scientific posts. Woods alone of the group had no official appointment and his designation of Union Club, Sydney fitted ill with such descriptions as: Director of the Royal Gardens, Kew; Director of the Geological and Natural History Survey of Canada, Ottawa; Government Botanist, Melbourne; the Royal School of Mines, London; University of Liege, Belgium and so on. (Royal Society of New South Wales,1887)

WOODS AND THE AUSTRALIAN MUSEUM

Seven years earlier, on 2 November 1880, when the Board of Trustees of the Australian Museum met in Sydney James C. Cox, doctor and conchologist, Charles Moore of the Botanical Gardens, and Robert Hunt of the Sydney Mint nominated the Reverend Julian Tenison Woods as a Trustee of the Museum `on account of his scientific.....attainments' (Cox et al, 1880). The secretary of the Board wrote to Woods on 9 December informing him of his election. After a second letter had been sent in March 1881 the priest replied from Rockhampton explaining he had not received the first notification. He thanked the Trustees for the honour, declaring he would be happy to serve as an elective trustee if they considered he could assist the interests of the Museum. At the same time he reminded them that while his duties as priest often took him away from Sydney he expected, after his return from Queensland, about 15 May, that his future absences would not be for extended periods of time (Woods, 1881a).

The illness of Bishop James Quinn of Brisbane delayed Woods, and in his letter to E.P. Ramsay, Curator of the Museum, on 21 June he expressed concern that he had assured the Trustees he `would be down in May' and requested Ramsay to mention the matter to them (Woods 1881b). Woods was too late. When the Board met on 7 June the chairman declared the priest's position vacant on the grounds that he had been absent from meetings for six consecutive months without leave. By 21 June the date of Woods's letter to Ramsay the Hon. P.G. King MLC had been nominated in his place.

Near the time of his election to the Board Woods prepared his `President's Address' for the Linnean Society of New South Wales. At the Society's annual meeting in Sydney on 27 January 1881, however, the vice-president, not the president, delivered the address. Woods was busy conducting an `eminently successful mission' in Bundaberg `where the little chapel was well filled at each service, especially at night, the well known eloquence of Father Woods drawing many of all sorts to hear him' (Australian, 1881).

WOODS'S EARLY SCIENCE

Born in London in 1832, Julian Woods from his earliest years had shown an interest in natural history, and with his brothers had collected and preserved butterflies, beetles, shells, fossils and rocks (Woods, 1889a). His boyhood coincided with the `heyday of natural history' in England when the pursuit of natural science became almost a `national obsession' (Barber, 1980). Science was regarded as `part of the intellectual culture of mankind into which all might enter and from which all might profit' (Lucas, 1979). Thus `the naturalist might be anyone from Darwin down to the lowliest Sunday bug-hunter' (Barber,op cit) Science fascinated the young man and he made the most of any opportunity to increase his knowledge and skill. Thus while teaching English and pursuing his theological studies at the Marist College at Toulon in the south of France in 1854 he also took part in drawing, natural philosophy, natural history and chemistry classes, and in laboratory sessions. (Barber, 1980). When the College closed in the mid-year as a result of a cholera outbreak he returned to England and while there he attended a short course of lectures on scientific subjects (Woods, 1889a).

Woods arrived in Hobart with Bishop Robert Willson in January 1855. Two of his brothers had already settled in Australia and as his goal of ordination as a Catholic priest had eluded him for the second time he had accepted Willson's invitation to act as a lay chaplain to the convicts of Tasmania. Before the end of the year, dissatisfied with his work, he joined his brother James in Adelaide and some months, later under the patronage of the local bishop, Francis Murphy, he resumed his studies for the priesthood. After his ordination on 4 January 1857 Murphy appointed him as priest in charge of the vast mission of the south east of South Australia centred on Penola.

SOUTH AUSTRALIA AND WIDER VIEWS

His isolation in Penola proved an impetus to his interest in science and the priest used his frequent trips on parish work to observe and to note the natural history of the region. By the close of the year he had contributed articles on the extinct volcanoes, Mt. Gambier and Mt. Schank, to the *South Australian Register* (Woods, 1857a & b), and had established contact with Ferdinand von Mueller in Melbourne. With the botanist's advice and encouragement, he published his first formal paper, `Observations on Some Metamorphic rocks in South Australia' in the *Transaction of the Philosophical Institute of Victoria* (Woods, 1857c). His investigations during his years in Penola (1857-67) showed him to be a perceptive and careful observer, conversant with the scientific literature of the day and, as befitted one who came from a family of journalists, an excellent writer.

Scientific workers in Australia in the early 1860s faced the problem of a lack of local journals in which to publish their investigations. As Woods did not engage in scientific pursuits for interest alone the questions of the right of authorship and priority of discovery, as determined by date of publication, concerned him no less than they worried fellow scientists, Robert Ellery, government astronomer in Victoria, Frederick M'Coy and others (Royal Society of Victoria, 1864). In 1863 when for the third successive year the Royal Society of Victoria failed to publish the papers he submitted he had protested by refusing to pay his membership subscription(Woods, 1863). Initially he fared no better with the Philosophical Society of Adelaide in his quest for publication (Philosophical Society of Adelaide, 1861). Certainly he did not go to the lengths of John Brazier, the conchologist, who wrote a short paper in 1880 to prove his right of priority over George Angas in the naming and description of three shells (Brazier, 1880). Nonetheless, as late as 1880, in his `President's Address' to the members of the Linnean Society Woods regretted that `a few species of Brachiopods, Pectens and Echini' which he had described in the mid 1860s had been redescribed by `foreign authors' because of the insignificant circulation of the *Transactions of the Philosophical Society of Adelaide.* (Woods, 1880)

With the publication in 1862 of his first book, *Geological Observations in South Australia*, Woods became well known as a scientist, The *Edinburgh Review*, the *Quarterly Review* and other British periodicals as well as the colonial press praised the book's style and its content, and the *Border Watch* published extracts from the various reviews. (*Border Watch*, 1863). The *South Australian Register*, in an editorial in May 1863, declared it knew of no other book by an Australian which would bear comparison with *Geological Observations* for it contained so much useful matter for men of science and so much the ordinary reader could understand. Woods had wished the book to be of use to a wide audience and for that reason he had deliberately `entered more into detail and given more explanation than he would have done had the Work been intended only for men of Science' (Woods, 1862). He firmly believed that the goal of a complete geological history of the colony would be materially advanced if scientists encouraged amateurs to report what they knew of the geology of their local area (Woods, 1865a). In *Geological Observations* he provided a model for the general reader and so made such contributions a possibility.

Though the observations concentrated on the south east of South Australia, the area which Woods traversed time and again as he ministered to the Catholics of the district, *Geological Observations* did not degenerate into a simple parochial work. Woods carefully situated the local area into the wider context of the geology of the Australian continent. As a first attempt at a systematic examination of the geology of South Australia, the book marked a noteworthy achievement in the history of such endeavours in the colony (Corbett et al, 1986).

During his relatively short life Woods wrote about 200 scholarly and popular scientific papers and a close look at them reveals a concern with taxonomy. Yet he did not engage in this work for the sake of naming species after species. To him taxonomy was always a tool, a means to help unravel problems and to arrive at comparisons and generalisations. In the South East the age of the local Tertiary deposits interested him and he sent fossil material overseas to the experts. Charles Lyell proved the most helpful of Woods's contacts for he suggested the means by which the young naturalist could work on the problem independently. In 1859 he wrote to Woods in Penola:

> What I should advise you to do is to make yourself thoroughly acquainted with the marine zoology of South Australia. Without troubling yourself with specific names, collect wherever you can and examine collections of marine objects. Compare them with the fossil forms you know. By such means you will soon be in a position to tell more of the age of your tertiary[sic] beds than the most learned of our Palaeontologists in Europe could tell you. You will add in a valuable degree to the store of scientific knowledge, and for a young Geologist I cannot well conceive a more inviting position. (Lyell, 1859).

From his Penola days Woods studied and named animals, living and fossil, as a means to determine the ages of the local Tertiary deposits (Woods, 1866a). In a letter to Frederick McCoy in Melbourne in June 1864, for example, he begged to communicate an accidental discovery which might `be of some importance in determining the age of the Murray Cliffs'. He described coming across some unusual nodular ironstone composed of fragments of fossils. On examination he found that these fossils matched, at species level, specimens he had at home in his cabinet from Muddy Creek Hamilton. He gave his reasons for believing that the gravel rested above the Murray Cliffs and hence the cliffs would be older than the Miocene (Woods, 1864).

Not even the snub offered Woods by the *Geological Magazine* in London caused him to deviate from his course. When it reviewed his *Report on the Geology and Mineralogy of the South-Eastern District of the Colony of South Australia* in 1867 it remarked that the pamphlet would have been of more use if Woods `had omitted his favourite discussion on the discrimination of Upper Miocene from Lower Pliocene' (Geological Magazine, 1867) It continued `how can a single amateur geologist in one corner of South Australia dictate to the Geological Survey in Victoria and decipher aspects of the Tertiary which had baffled the experts in Europe'. Undeterred, Woods continued to work on the lines suggested by Lyell (Woods, 1880).

BARREN YEARS FOR SCIENCE

Bishop Sheil, the new bishop of Adelaide, transferred the priest to the capital city in 1867. The people of the South East appreciated Woods and he left Penola with their gift of 100 guineas to buy scientific books or instruments (*Border Watch,* 1867). Before taking up his new appointment he visited Melbourne, and at the annual conversazione of the Royal Society of Victoria on 4 March read a paper, `On the Glacial Period in Australia' (Woods, 1867a). This occasion marked his last contribution to a scientific journal for seven years.

In Adelaide, in spite of library facilities, the possibility of personal interaction with members of the Adelaide Philosophical Society and many other advantages, Woods, as a scientist, simply disappeared from the colonial scene and from public literary life. As director of education he became immersed in working for the establishment of a Catholic education system and, with Mary MacKillop, founding and forming a group of religious women, the Sisters of St. Joseph, to staff the schools and provide other social services. His years in the city carried their measure of failure. When he finally left the diocese in 1872 his projects for education and the alleviation of social distress carried heavy debts. While he had been praised as a good and zealous priest, he had been found wanting in prudence in his direction of the Sisters. He had encouraged a group of self-proclaimed mystics among them. Nevertheless he and Mary MacKillop had responded innovatively to pressing colonial needs and their work survived.

In 1979 Max Harris, the columnist, wondered what bishops could do with a priest like Woods: an eloquent preacher, effective in recruiting young women to join the Sisters of St. Joseph and, though not robust in health, possessing unbounded energy. Harris provided a perceptive answer: `It's a Big Country - Keep 'em moving. Ride on Stranger'.(Harris, 1979). So from 1871 to 1883 Woods was continually on the move working as a mission preacher in a number of dioceses - Sydney, Bathurst, Maitland, Tasmania and Queensland. This constant travelling provided him not only with work in the Church which utilised his talents but presented him with unique opportunities for scientific observations and comparisons.

Bishop Murphy of Hobart persuaded Woods to visit Tasmania in 1874 to give a series of missions, and both Murphy and Bromby, the Anglican Bishop, as well as the local press attest to his zeal in his work as priest (*Mercury*, 1875). Tasmania also offered Woods the opportunity to re-establish his links with Australian science. He had been elected a corresponding member of the local Royal Society in April 1865 but only in July 1874 repaid the honour by reading a paper on the physical and zoological relations between the island and the mainland (Woods, 1874). The following year, 1875, decisively marked his return to involvement in science when he began to contribute an increasing number of papers to the Royal Society of Tasmania.

RENEWING SCIENTIFIC LINKS

So while Woods criss-crossed various parts of Tasmania (and in later years the other colonies) giving missions, he fitted in his investigations and writings in science. He always revelled in beating the constraints of time. At Penola in 1865 he declared that he would not give a fig for the excitement of his work unless always rushed for time and struggling. He believed that literary and scientific work for the rich who had plenty of time and money must be dreadfully tame (Woods, 1865b).

Even after an absence of more than seven years from serious involvement in science Woods in Tasmania found Lyell's early advice still relevant. As the priest pointed out- the generalisations made on the age of the Australian tertiaries in England by P. Martin Duncan in the early 1870s proved unreliable for two reasons: Duncan lacked familiarity with the country and consequently confused widely separated formations; moreover, because of the imperfect state of the knowledge of Australian fauna, his comparisons between fossil and living fauna were of little value. So during his three years in Tasmania Woods worked on the taxonomy of the molluscan fauna of the island to supply data from which more accurate conclusions could be reached (Woods, 1880). At the August 1875 meeting of the Royal Society, he further justified his opting for such an approach. In preliminary remarks to his paper on the `Freshwater Shells of Tasmania', he gave a practical example of the use of taxonomy, which clearly illustrated the import of such work for him. He explained that in the early history of science the study of freshwater molluscs did not attract much attention from naturalists until its utility was strikingly demonstrated. A young French naturalist specialised in the study of such shells and recorded the `habits of life' of many species. When the eminent French scientist Cuvier set out to determine the age of the fossil bones found at Montmatre, Paris, the earlier work on the freshwater shells proved a boon. A close study of the shells found with the bones, showed them to be freshwater ones and already described. This association enabled Cuvier to explain the conditions under which the extinct animals of the beds existed. Woods also pointed out that `much light had been thrown on the conditions of life in the coal formation from the freshwater and land shells found embedded in it' (Woods, 1875).

Before he returned to Sydney in February 1877 Woods enjoyed membership in both the Linnean and Royal Societies of New South Wales. In a move to boost its contributing members, the Royal Society at its meeting on 4 August 1875 conferred honorary membership on a group of well-known colonial scientists: von Mueller, McCoy and Robert Ellery from Victoria; James Hector and Julius von Haast from New Zelaland and, in a supplementary list, the explorer Augustus Charles Gregory, F. D. Waterhouse and Woods (Royal Society of New South Wales, 1875). Woods responded to the honour by sending in 1876 a paper on the fossil polyzoa and naming a species for Rev. W.B. Clarke, the vice-president of the Society, and one for Archibald Liversidge, its secretary (Woods, 1876). The newly-formed Linnean Society followed a different system from the Royal Society, and in July 1876, after receiving from Woods a copy of one of his Tasmanian papers, the secretary announced that the Council had elected him a corresponding member. Within a few months he had forwarded the first of many papers which the Linnean Society would published over the next thirteen years.

Though occupied in 1877 in giving Missions in the Sydney, Maitland and Bathurst dioceses Woods strengthened his ties with the two local scientific societies. To the Linnean Society, however, he submitted the bulk of his papers, some ten of the eighteen published that year (three papers were submitted to each of the Royal Societies of New South Wales and Tasmania and two to the Royal Society of Victoria). Because its *Proceedings* admitted scientific papers only, and promptly published the account of the monthly meetings and the papers read, it suited Woods. Such a policy not only enhanced the chance of securing priority of discovery but made for prestige. In 1878, in the context of a description of the various colonial societies, he remarked

> The Linnean Society of NSW publishes more real matter than the Royal Society, all of A[sic] high class, and although not a popular Society yet takes a position amongst all kindred Societies at home and on the continent (Qld. Phil. Soc.,1878).

In addition Woods shared ideas with William Macleay, the Society's president. Both men believed Australian science to have an inadequate base of knowledge on which to make generalisations, and so they promoted the necessity of descriptive work on the local fauna as an initial priority. Macleay, a wealthy grazier and Parliamentarian, exerted a strong influence in the affairs of the Linnean Society and a minute of the Council meeting in January 1884 showed him suggesting changes in the rules of the Society and also giving a list of persons whom he considered should be proposed as Office-Bearers and members of Council for the ensuing year. Among other things these moves by Macleay enabled Woods to continue as one of the vice-presidents. There can be little doubt too that the priest owed his elections as president of the Society for the years 1879-80 to the support of Macleay, after his election as an ordinary member in November 1878

Woods's interests ranged wide. When his friend Ralph Tate in his anniversary address to the Adelaide Philosophical Society on 8 October, 1878 gave an account of the general progress of Natural History knowledge in South Australia he mentioned Woods's work in geology, palaeontology, the mollusca, polyzoa, sea urchins, corals and even in comparative anatomy. Though he criticised some aspects of the census of Tasmanian molluscs by Woods, Tate wrote of his work on corals, `We have to thank Mr. Woods for throwing light on the subject, and science is deeply indebted to him for what he has effected in this and other departments of Australian Natural History' (Tate, 1878).

BOTANICAL RESEARCHES

One of the areas in which Woods received no mention from Tate in 1878 was in botany. He had collected plants for von Mueller in Penola and later in Tasmania, and while on the island worked with the Rev. William Spicer, a competent botanist (Woods, 1876b). His comeback paper, "Notes on the Physical and Zoological Relations of Australia and Tasmania", in 1874, dealt with some botanical aspects. In June 1878 he had made a special trip from Parkes to Sydney to read before the Royal Society his ideas on `Tasmanian Forests: their Botany and Economical Value' (Woods, 1878a). This paper was one of the earliest attempts to stress the importance of conservation in Tasmania, and Woods's final words have a contemporary ring:

> The only way to prevent the wholesale destruction of the timber will be by proclaiming reserves or State forests as has been done in Victoria.....The matter is one which the Legislature should deal with promptly or the forests of Tasmania, peerless and priceless as they once were will soon be things of the past.

Woods spent 1873 in Queensland and made the acquaintance of botanist Frederick Bailey. He returned to that Colony in November 1878 for one month, and in March 1879 he and Bailey jointly published an extensive list of the Flora of Brisbane (Bailey & Woods, 1879). An impressive essay, by Woods, on the relation of the Brisbane flora to other plant zones in Australia introduced their census paper. A year later the pair co-operated to `furnish a contribution to Australian Mycology (fungi), and so far as possible to popularise the subject with a view to stimulate enquiry'. They gave short notes on the genera and more remarkable species so that naturalists could recognise specimens without having to consult an extensive library (Woods & Bailey, 1880). But Woods in Botany was far more than a Bailey collaborator. His series of five articles on `Botanical Notes on Queensland' in 1882 clearly showed his capability. It illustrated also that for him the naming of species contributed only the first step in the scientific process. He wrote:

> Now that the grand work of describing and cataloguing has been accomplished by the illustrious botanists Bentham and Mueller, humbler laborers may step in to add to the account of knowledge: This is the purpose of the present notes.

His accounts formed one of the first written on the vegetation of Queensland, and highlighted his outstanding powers of observation, his methodical manner of working and his attempts to explain and understand what he saw (Johnston, 1988).
Von Mueller(1890), while he expressed doubts as to Woods's reliability as a plant taxonomist also remarked that it would be unjust `to expect from him accurate knowledge of all native plants, his real strength being geology'. But the priest did have strengths in botany and he contributed significantly to botanical knowledge in Australia and later in Malaysia.

ARTESIAN WATER AND SANDSTONES

At times it seemed as if the scope of Woods's involvement knew no limits. Sometimes his interests touched on matters of possible economic significance. In the conclusion of his paper `On the Relations of the Brisbane Flora', for example, he stressed the utility of pursuing investigations into the useful qualities, industrial and medicinal, of that flora, and suggested lines of enquiry. Years earlier he had written too on the possibility of finding underground water supplies in arid areas. Though the first well in the Great Artesian Basin was only sunk in 1878, in February 1867 Woods had argued that if, as he believed, the springs of the interior resulted from underground drainage, then the `the whole of the Lower Darling, the country about the Barcoo, Danbury Ranges, Sturt's Desert etc., could be *splendidly watered by means of artesian wells*'.

W.E. Abbott, a grazier from Wingen, proposed (correctly, as it proved) in 1882 that the extensive clays overlying the artesian water had been deposited in a sea. Woods precipitated a controversy when he demanded fossil evidence of such a sea:

> Great oceans don't come and go, and leave no traces behind them. It is such figments which have retarded, and still retard, geology. We have no more right to presume that an ocean existed in any place without positive geological evidence of its former presence than we have to assent that there have been cities in the interior(Syd. Morning Herald,1882).

In his second and final letter Woods rather patronisingly referred Abbott to his forthcoming paper on the `Hawkesbury Sandstone' and trusted that the gentleman would `see in it something that will assist him in forming sound views of the origins of those deposits which cover the underground waters of the Darling'. Abbott, in his replies supposed that all knowledge would be summed up in the priest's coming paper to the Royal Society and promised:

> Of course I will read, and endeavour to derive from it all the hoped for advantages, but in anticipation of the eventful day on which is to be brought forth the result of the labour of so many years, I may say that unless it throws more light on the formation of the Hawkesbury sandstone than the aerial dust theory does on that of the Darling watershed, I shall have to remain in a state of blissful ignorance.

Abbott's taunt highlighted a practice of Woods. He often claimed legitimacy for his conclusions on the grounds of the time spent investigating a problem and/or on the number of specimens he had examined. Thus his explanation of the geological history of the south east of South Australia was the fruit of years of observations, of the sifting of data and of a comparison of his results with the findings of the geological survey of Victoria(Woods, 1866b). His case for no recent glaciation in Australia, as initially outlined to the members of the Royal Society of Victoria in 1867, rested on the evidence of thousands of fossils and shells which had passed through his hands over a period of more than two years. Then when he advocated a reduction of from eight to four species of the genus Risella in 1876 he reasoned on the basis of `some hundreds, ...nay thousands of shells' which he had examined over many years, not only from Tasmania, but from all colonies. Similarly, in his paper on the Hawkesbury Sandstone in 1882 when discussing one line of evidence for his argument in favour of an eolian origin for the deposit, Woods asserted that he had microscopically examined `all sands from all the rivers and creeks' he had come across(Woods, 1882a).

The Catholic *Freeman's Journal* (1882) described the `Hawkesbury Sandstone' as one of the most important contributions to colonial geology to appear in recent years, and published verbatim Woods's fourteen points on the origin of the deposits. It believed the accounts given by Woods in the paper of `long experiments and microscopic examinations of sand', the references to works and authorities in France, Germany and Great Britain and the scope of the paper, all bespoke a long study and commitment on the part of the author.

`Altogether', the report concluded, `the paper ... had a wonderful effect in stirring up geologists generally, and the Royal Society in particular, into life and activity'. The following week at the adjourned meeting of the Royal Society 40 members attended and heard both C.S. Wilkinson and Professors Stephens and Liversidge respond to the ideas presented in the paper and Woods's reply to their objections.

Christopher Rolleston, the Society's president, at the General Meeting in May 1883 acknowledged that Woods had contributed the most important papers of the 1882 session and singled out the one on the geology of the Hawkesbury Sandstone:

> which from the novelty of its conception, the variety of facts and observations by which his theory was supported, the clearness with which the facts were set forth and the masterly ease which characterised the treatment of the theory propounded, is a most interesting and valuable contribution to the Society's Transactions.

GOVERNMENT CONTRACTS AND ASIAN TRAVELS

As Woods's reputation as a geologist grew, governments in South Australia, Queensland and New South Wales engaged his services. In Queensland he surveyed the tin fields at Herberton in 1881 and wrote on the Colony's coal resources in 1883. South Australia had made use of his expertise in his Penola days and again, on his return from Asia in 1886, employed him to investigate mineral resources in the Northern Territory. His book, *Fish and Fisheries of New South Wales*,(1882b) which he wrote for the New South Wales government, won a diploma at the Fisheries Exhibition in London and a gold medal in Amsterdam in 1883.

Sir Frederick Weld, Governor of the Straits Settlement, and a friend of Woods, invited him in 1883 to investigate the mineral resources of the Malay Peninsula. This invitation arrived at an opportune time, for Woods's main source of financial support was not so readily available to him. The coming to Australia of religious orders, such as the Redemptorist priests(in 1882), devoted to preaching parish missions, made bishops independent of the services of priests such as Woods. So with prospects for mission work declining Woods gladly accepted Weld's offer and sailed from Brisbane for Singapore on 14 August 1883. Though he only expected to be away about six months he stayed almost three years in South East Asia.

During those three years Woods (1884a)wrote on his travels for the *Sydney Morning Herald*, and some short pieces for the London journal, *Nature*,(Woods,1884b), as well as a few papers for the Straits Branch of the Royal Asiatic Society (Woods,1885), but he contributed only one article to the Australian scientific periodicals. The Linnean Society published his `Report on the Geology and Physical Geography of the State of Perak' in December 1884. His many other observations made in Malaysia, Japan, Borneo, the Philippines and other places, and copiously recorded in his notebooks, had to await his return to Australia for processing.

LAST YEARS AND AN ASSESSMENT

The end of his scientific career at 533 Elizabeth Street Sydney, paralleled its beginning at Penola. In Penola, physical distance and isolation made him dependent on colleagues. Deteriorating health from 1887 proved even more of a constraint for not only did he require the help of others for specimens and books, but also for the physical act of writing. His letter of 3 January 1888 to William Archer in Melbourne summed up his situation:

> I have been an invalid for now nearly a year having almost lost the use of my hands and feet ... It seems to me that my active work is done ... I am ... employing my time when well enough in revising my notes of travel, writing a little on the same subject in the Herald beside a few scientific papers and trying to prepare a work on the Malay Archipelago which the government is to aid in publishing. This as you may imagine fills up my time pretty well but I need hardly say my working hours are not long nor always to be depended on.

Though he worked on, his promise of a second part to `Geographical Notes in Malaysia and Asia' never eventuated. The publication of lengthy papers on the non-marine mollusca and the vegetation of Malaysia as well as on the fisheries of South East Asia in the *Proceedings of the Linnean Society on New South Wales* (1888b&c) gave recognition to the fact that the proposed book on the Malay Archipelago would not be written. The Royal Society, too, received its share of his efforts. He submitted an essay in 1888 on the mollusca of Australia and won the Society's Medal and prize of 25.pounds. A few months later, his controversial paper `The Desert Sandstone' appeared in its journal.

Woods died on 7 October 1889. He was a scientist of 19th century dimensions, almost a Renaissance type, and true to that type his involvements ranged wide, and he often carried on his investigations with a broad sweep approach. The various scientific societies lamented his death for he was a prolific contributor to their proceedings. Professor Ralph Tate(1890) of Adelaide University summed up the sentiments of many of the tributes paid to Woods:

> No heavier loss has this year befallen the Scientific Societies of Australasia than the death of this naturalist. Not only was he one of the foremost Australasian naturalists, but to very many of us he was far more as a dear personal friend, a delightful companion, and a skilled adviser. ... Though at all times a scientific enthusiast, he was nevertheless the devoted priest, and as a preacher he was acknowledged to be singularly earnest and powerful - his fine presence and elocutionary power intensifying his influence. As a scientist his life became a part of the scientific progress and history of Australasia, labouring with equally good results in Geology, Botany, Palaeontology and Zoology.

One unidentified obituarist believed that `if young Australia possessed any aspirations beyond the development of brawn and the deification of sport', then the memory of Woods's life and achievements would be acknowledged and esteemed by all for many a year to come. Yet the memory of Julian Tenison Woods slipped into oblivion and not even the attempt of Richard Helms to immortalise him by naming, in 1896, a peak in the Snowy Mountains, Mount Tenison Woods, succeeded, for the name fell into disuse.

At the conclusion of *Geological Observations in South Australia*, his pioneer geological work, Woods spoke of the great enterprise called Geology (`science' could validly be substituted for `geology') and likened its pursuit to the construction of a building. The following Symposium papers consider some of the building blocks which Julian Tenison Woods, 100 years ago and more, fashioned, from the materials he had at hand, to add his contribution to the edifice of science.

Words he wrote in 1878 stand true not only for his time but for today and for the future and put all endeavours into perspective:

> It is a great temptation to young observers to glorify themselves at the expense of the mistakes of their predecessors, or on the superior knowledge which has accumulated since their time. But they little realise how very large is the debt that we owe to these men, and how their labours, incomplete or faulty as they may have been, represent an amount of care, study, industry, and zeal that we cannot easily command at the present.

So without falsifying history by either an uncritical adulation of the past or by dismissing parts of the past as irrelevant this mini-symposium explores something of science's debt to Julian Tenison Woods, priest and scientist, 1832-1889.

REFERENCES

Australian(Brisbane),1881. 12 Feb. issue.

Bailey, F.M., & Woods, J.E.T. 1879. A census of the flora of Brisbane. Proc. Linn. Soc. N.S.W. IV,137-204.

Barber, L., 1980. *The heyday of natural history*. New York.

Border Watch, 1863. 3 April issue.

Border Watch, 1867. 16 Feb. issue.

Brazier, J., 1880. Remarks on some recently redescribed Australian shells. *Proc. Linn. Soc. N.S.W.* V,630-631.

Corbett, D.W.P., Cooper, B.J. and Mooney, P.M., 1986. 'Geology' in C.R.Twidale, Tyler,M.J. and Davies, M. (eds.) *Ideas and endeavours-the natural sciences in South Australia*, Adelaide,36-37.

Cox, J.C., Moore, C. and Hunt, R., 1880. Letter to Trustees. Australian Museum Archives.

Freeman's Journal, 1882. 20 May issue.

Freeman's Journal, 1884. 26 Jan. issue.

Geological Magazine, 1867. Reviews on Australian geology, vol.IV,77.

Harris,M., 1979. *Weekend Australian Magazine,* 11-12 Aug. issue.

Helms, R., 1896. The Australian Alps or Snowy Mountains. *Jour. Roy. Geog. Soc. Aust.* IV(4),82.

Johnston, R., 1988. Letter to A.Player, 4 Oct.

Lucas, J.R., 1979. Wilberforce and Huxley: a legendary encounter. *The Historical Journal*,22(2),330.

Lyell, C., 1859. Letter to J.E.T. Woods. See Woods,1880.

Maitland Mercury, 1882. 29 April.

Mercury (Hobart), 1875. 15 Feb. issue.

Mueller, F.von, 1890. Letter to R.Tate. University of Adelaide Archives.

Philosophical Society of Adelaide, 1861. Minute Book 1856-1861, Mortlock Library.

Queensland Philosophical Society, 1878. Special Meeting,25 Nov. Minute Book 1868-1883. Society Archives.

Rolleston, C.S., 1883. Anniversary address. *Jour. and Proc. Roy. Soc. N.S.W.*,XVII,2.

Royal Society of New South Wales, 1875. Minute Book,1867-1876. Society Archives. MacQuarie University.

Royal Society of New South Wales, 1887. *Jour. and Proc.*,XXI.,xlviii.

Royal Society of Victoria, 1864. Minute Book,Society Archives.

South Australian Register, 1863. 8 May issue.

Sydney Morning Herald, 1882. 30 March, 5 April.

Tate, R., 1878. Anniversary address. *Trans.Proc.Phil.Soc.Adelaide*,29.

Tate, R., 1890. *Trans. and Proc. Roy. Soc. Sth. Aust.* XIII,253.

Wilkinson, C. 1889. Anniversary address. *Jour. and Proc. Roy. Soc. N.S.W.* XII,9.

Woods, J.E.T., 1857a. The Mount Gambier Volcano. *South Australian Register*, October.

Woods, J.E.T., 1857b. Mount Schank. *South Australian Register*, 31 December.

Woods, J.E.T., 1857c. Observations on some metamorphic rocks in South Australia. *Trans. Phil. Institute Vict.*. II,168-176.

Woods, J.E.T., 1862. *Geological observations in South Australia*. London.

Woods, J.E.T., 1863. Letter to W. Archer,28 Nov. Archer Papers, University of Melbourne Archives.

Woods, J.E.T., 1864a. Letter to F.McCoy,28 June. State Museum, Victoria, Archives.

Woods, J.E.T., 1864b. *North Australia: its physical geography and natural history*. Adelaide.

Woods, J.E.T., 1865a. *The geology of Portland*. Melbourne,2.

Woods,J.E.T., 1865b. Letter to W. Archer,5 Sept. Archer Papers, University of Melbourne Archives.

Woods, J.E.T., 1866a. The Tertiary rocks of South Australia,introduction. *Trans. Phil. Soc. Adelaide.*

Woods, J.E.T., 1866b. *The geology of the south-east.* Trans. Phil. Soc. Adelaide.

Woods, J.E.T., 1866c. *Report on the the geology and mineralogy of the south-east district of the colony of South Australia.* Adelaide.

Woods, J.E.T., 1867a. On the glacial period in Australia. *Trans. Roy. Soc. Vict.*VIII,43-47.

Woods, J.E.T., 1867b. The physical structure of our continent. *Australasian*, 2 Feb..

Woods, J.E.T., 1874. Notes on the physical and zoological relations between Australia and Tasmania. *Papers and Proc. Roy. Soc. Tas*,42-52.

Woods, J.E.T., 1875. Minutes, *Papers and Proc. Roy. Soc. Tas*,20.

Woods, J.E.T., 1876a. On some Tertiary Australian Polyzoa. *Jour. and Proc. Roy. Soc. N.S.W.*X,147-150.

Woods, J.E.T., 1876b. Letter to W. Archer,6 Jan. University of Melbourne Archives.

Woods, J.E.T., 1876c. Observations on the genus Risella. *Proc. Linn. Soc. N.S.W.* I,244.

Woods, J.E.T., 1878a. Tasmanian forests: their botany and economical value. *Jour. and Proc. Roy. Soc. N.S.W.* XII,17-28.

Woods, J.E.T., 1878b. On Bulimus Defresnii. *Proc. Linn. Soc. N.S.W.* III,82.

Woods, J.E.T., 1879 On the relations of the Brisbane flora. *Proc Linn. Soc. N.S.W.* IV,117-137.

Woods, J.E.T., 1880. President's address. *Proc. Linn. Soc. N.S.W.*V,645-648.

Woods, J.E.T., 1881a. Letter to E.P. Ramsay,21 June, Ramsay Papers, Mitchell library, MSS 2169.

Woods, J.E.T., 1881b. *Report on the Wild River and Great Western tin mines near Herberton.* Govt. Printer, Brisbane.

Woods, J.E.T., 1882a. The Hawkesbury Sandstone. *Jour. and Proc. Roy. Soc. N.S.W.* XVI,64.

Woods, J.E.T., 1882b. *Fish and fisheries of New South Wales.* Govt. Printer, Sydney.

Woods, J.E.T., 1882c. The Hawkesbury Sandstone-discussion. *Jour. and Proc. Roy. Soc. N.S.W.* XVI,91-116.

Woods, J.E.T., 1883. *The coal resources of Queensland.* Govt. Printer, Brisbane.

Woods, J.E.T., 1884a. A journey through Java. 20 letters Syd. Morning Herald, Feb- Oct.

Woods, J.E.T., 1884b. Physical geography of the Malayan Peninsula. *Nature.* 31,152-154.

Woods, J.E.T., 1885. A journey to the summit of Gunong Buba. *Jour. Straits Branch Roy. Asiatic Soc.* 14,275-285.

Woods, J.E.T. 1884. Report on the geology and physical geography of the state of Perak. *Proc. Linn. Soc. N.S.W.* IX,175-203.

Woods, J.E.T., 1888a. Letter to W.Archer,3 Jan.. Archer Papers, University of Melbourne Archives.

Woods, J.E.T., 1888b. Geographical notes in Malaysia and Asia. *Proc. Linn. Soc. N.S.W.* III(second series),557-650.

Woods, J.E.T., 1888c. Fisheries of the oriental region. *Proc. Linn. Soc. N.S.W.* III(second series),165-255.

Woods, J.E.T., 1888d. On the anatomy and life history of the mollusca peculiar to Australia. *Jour. and Proc. Roy. Soc. N.S.W.* XXII,106-157.

Woods, J.E.T., 1888e. The Desert Sandstone. *Jour. and Proc. Roy. Soc. N.S.W.* XXII,290-335.

Woods, J.E.T., 1889a. Memoirs of Reverend J.E.Tenison-Woods. Ms. Archives Sisters of St. Joseph, Goulburn.

Woods, J.E.T., 1889b. Malaysian land and freshwater mollusca. *Proc. Linn. Soc. N.S.W.* IV,9-106.

Woods, J.E.T. & Bailey, F.M., 1880. On some fungi of New South Wales and Queensland. *Proc. Linn. Soc. N.S.W.*V,51.

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J. E. Tenison Woods: His Contributions to the Tertiary Geology of South Eastern Australia

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A portion of the prodigious energy of the Rev. Julian Edmund Tenison Woods was directed to science (Player,1989), and in particular to the understanding of the palaeontology, stratigraphy and correlations of the Tertiary sedimentary sequences of southeastern Australia. While his contributions to Australian geology were by no means restricted to writings on Tertiary geology, it was problems of Tertiary stratigraphy and stratigraphy that dominated much of his scientific work.

Woods' contributions to Tertiary geology span the colonies (as they then were) of South Australia, Victoria and Tasmania; he was familiar with deposits and collections from Aldinga, Mount Gambier, the Murray cliffs, (South Australia) the southern coast, Hamilton (Victoria)and Table Cape(Tasmania).
He firmly believed in the value of descriptive palaeontology. Charles Lyell had advised Woods in 1859 to study both fossil and living forms in order to solve the problems of the ages of the Tertiary successions (Player, opcit). Not surprisingly,therefore, Tenison Woods' palaeontological work includes a series of papers on Tertiary bryozoans, corals, brachiopods, echinoids and molluscs. Many of his taxa have survived the subsequent century of study. For example Darragh (1970) lists some 20 species of Bivalvia and 120 species of Gasteropoda named by Woods from Tertiary strata of which only 3 and 7 respectively have not survived.

Only rarely have Tenison Woods' taxa caused confusion. One example concerns the echinoid Lovenia forbesii. The specific name forbesii was first published, in passing, by Woods in 1959 and 1860.(Tenison Woods 1859,p.91; 1860,p.256). He apparently copied the name from specimens so named by Frederick McCoy in the National Museum of Victoria(McCoy, 1879,p.39), although he later could not recall where he had seen the name(Tenison Woods,1866,p.2). In 1862 Woods figured specimens (pp.75,83), that shown on page 83 being a redrawn copy of a fossil illustrated by Charles Sturt (1833,plate 3, figure 10). This validated the specific name and, because McCoy's name was omitted, Woods became the author of the species forbesii. Duncan (1864) fully described the species and hence claimed joint authorship with Woods-a claim he accepted . However Tenison Woods is now accepted as the sole author of the species despite McCoy's claims in 1879. McCoy had originally proposed the name on the basis of a crude illustration of a 'Melbourne specimen' illustrated by Edward Forbes(1852,p.50). Forbes' specimen, probably from Beaumaris, southeast of Melbourne, is almost certainly a representative of Lovenia woodsii (Etheridge,1875), a closely related species to forbesii. Forbes did not identify his specimen to species level, whereas Sturt had much earlier referred his specimen to a European species. Copies of the the three illustrations by Sturt, Forbes and Tenison Woods are shown here for comparison (Figure 1).

Woods was convinced of the value of fossils for correlation and age determination, and strongly cautioned against correlation by rock type. Writing on the Tertiary limestones and flints of Port McDonnell he noted (1862,p.67) 'physical properties may produce the same results in strata vastly remote from each other' and 'fossils alone should be relied upon' for correlation. He remained a cautious man concerning the wider implications of his palaeontology. He discussed and was well aware of what would now be referred to as palaeoecological and palaeoclimatological implications of his observations (eg Tenison Woods,1862). However he was clearly aware of the limitations of his data, as when considering the Hamilton Miocene fauna he noted the relationships 'will be seen when the whole of the palaeontology of the beds has been dealt with'(Tenison Woods, 1879,p.2).

Despite his caution, Woods made 'provisional' attempts, 'with hesitation' to date and correlate his fossils. While aware of 'expert' opinions, such as those by T.Rupert Jones in England and McCoy in Melbourne, he contradicted them if the evidence suggested alternatives. Jones considered that the foraminiferans from the Mount Gambier were Pliocene (see Tenison Woods 1860, 1862), but Woods drew attention to the Lower Miocene and Upper Eocene character of many of the macrofossils from the same deposit (Tenison Woods,1862).

McCoy began publishing his views on the ages of the Tertiary deposits in southeastern Australia in 1861 (see Singleton,1941 for a review of how McCoy's ideas evolved), and Woods (1865) published a 'provisional' correlation scheme(Table 1) with variations on McCoy's opinions. Although he referred the Hamilton beds to the 'Upper Eocene' he noted the 'Miocene' character of the corals from both Hamilton and Schnapper Point (Mornington) in Victoria, again attesting to his awareness of independent data.

Woods prepared a firm foundation for the Tertiary palaeontology of southeastern Australia. Although his efforts were to be eclipsed by those of Ralph Tate of Adelaide, Woods's contributions are remarkable given the remainder of his contributions to humanity (Player, op cit).

Table 1 Subdivision of Tertiary strata as recognised by Tenison Woods

Newer Pliocene	Bed near Adelaide; Government House Quarry
Older Pliocene	Mount Gambier, Portland
Upper Miocene	Murray Cliffs
Lower Miocene	Murray Flats, Geelong, Cape Otway
Upper Eocene	Hamilton (later accepted as Miocene)
Middle Eocene	Schnapper Point Port Phillip (Mornington)

References

Darragh, T.A.,1970. Catalogue of Australian Tertiary Mollusca (except chitons). Memoirs of the National Museum of Victoria,31: 125-212.

Duncan, P.M.,1864. A description of some fossil corals and echinoderms from the South-Australian Tertiaries. The Annals and Magazine of Natural History Series 3, 14:161-168, plates 5&6.

Etheridge, R.(Jnr.)1875. Description of a new species of the genus Hemipatagus Desor, from the Tertiary rocks of Victoria, Australia, with notes on some previously described species from South Australia. Quarterly Journal of the Geological Society of London 31:444-450, plate 21.

Forbes, E.,1852. Our knowledge of Australian rocks as derived from their organic remains,in Lectures on Gold for the instruction of emigrants about to proceed to Australia. Delivered at the Museum of Practical Geology. David Bogue, London, pp.39-67.

McCoy, F.,1879. Prodromus of the Palaeontology of Victoria. Decade 6: 42pp. Melbourne, Geological Survey of Victoria.

Player,A., 1989. Julian Tenison Woods- Priest and Scientist. The Australasian Catholic Record 66(3):279-294.

Singleton, F.A., 1941. The Tertiary geology of Australia. Proceedings of the Royal Society of Victoria 53(1): 1-125.

Sturt, C., 1833. Two expeditions into the interior of Southern Australia, during the years 1828,1829,1830 and 1831. Smith,Elder and Co., London, 2 volumes.

Tenison Woods, J.E., 1859. Remarks on a Tertiary deposit in South Australia. Transactions of the Philosophical Institute of Victoria 3: 85-94.

Tenison Woods, J.E., 1860. On some Tertiary rocks in the Colony of South Australia. Quarterly Journal of the Geological Society of London 16: 253-260.

Tenison Woods, J.E., 1862. Geological observations in South Australia: principally in the district south-east of Adelaide. Longman,Green, Longman, Roberts & Green, London. xv & 404pp.

Tenison Woods, J.E., 1865. The Tertiary rocks of South Australia. No.1-Introduction. Adelaide Philosophical Society. Andrew, Thomas & Fisher,Adelaide,3pp.

Tenison Woods, J.E., 1866. The Tertiary rocks of South Australia. Part iv-Fossil Echinidae. Adelaide Philosophical Society. Andrews, Thomas & Clark, Adelaide, 2pp, 1 plate.

Tenison Woods, J.E., 1879. On some Tertiary fossils. Proceedings of the Linnean Society of New South Wales 4: 1-20, plates 1-4.

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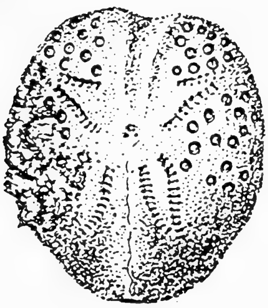
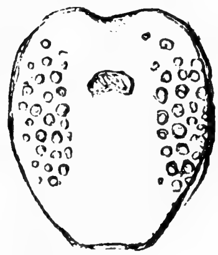
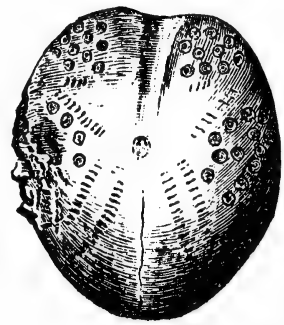


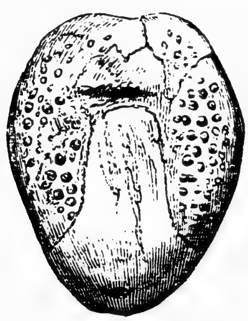


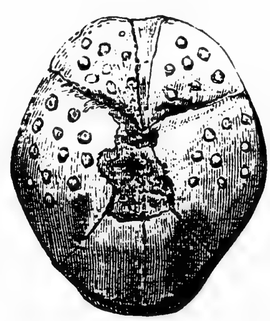


A. Copy of Plate 3, figure 10 of Sturt (1833), identified by Sturt as 'Spatangus Hoffmani Goldfuss' (Copy is x1.6).

B.Copy of figure by Forbes(1852,p.50), identified by Forbes as 'Spatangus' (Copy is x2).

C. Copy of figure by Tenison Woods (1862,p.83), identified by Woods as 'Spatangus Forbesii', and apparently a redrawn copy of Sturt's illustration (Copy is x1.7).





D,E. Copy of figures by Tenison Woods(1862,p.75) identified by him as 'Spatangus Forbesii (Copy is x1.8)

Note Figure A,C, D and E are true Lovenia forbesii(Tenison Woods) in modern terms. Figure B is almost certainly a representative of Lovenia woodsii(Etheridge).

Figure 1

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Father Julian Tenison Woods and The Hawkesbury Sandstone

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ABSTRACT

Tenison Woods' paper "The Hawkesbury Sandstone" presented to the Royal Society of NSW in 1882 bears clear testimony to his considerable stature as a scientist and pioneer Australian geologist. His interpretation of the Hawkesbury Sandstone as a wind-blown formation is supported by his observations of its geometry, lithology, sedimentary structures and fossil content; by comparison with aeolian and other formations in Australia and in various other parts of the world, either through the literature or by personal observation; by experiments he conducted with wind-blown sand, and by personal observation of aeolian processes in the field. Although his interpretation of the origin of the Hawkesbury Sandstone as a whole is not accepted today (he did not have available to him the detailed knowledge we now have of the processes and products of fluvial and other environments) his method was sound and his competence undoubted.

INTRODUCTION

Julian Tenison Woods' paper "The Hawkesbury Sandstone" (1882: *J.Proc.Roy.Soc.N.S.W.,16*,52-116) was read before the Royal Society of N.S.W. on 10 May, 1882. As published it covers 36 pages of text in the Journal and Proceedings, together with an appendix of two pages. The ensuing discussion (contributions by Mr Wilkinson, Professor Stephens and Professor Liversidge) and the reply by Tenison Woods occupy a further 26 pages.

Given the length of the reporting, the diversity of views expressed and the forcefulness of the arguments, it was obviously a major contribution to the Society's publication, and to the development of geological thought about the Sydney region. The aim of the present paper is to furnish an assessment of Woods' competence as a scientist, as evidenced by his Hawkesbury Sandstone paper.

THE HAWKESBURY SANDSTONE

The Hawkesbury Sandstone is the flat-lying Triassic quartz sandstone that dominates the landscape within a 100km radius of Sydney. It is particularly well exposed in coastal cliffs north and south of Sydney Harbour. It has an extent of approximately 20,000 km^2 and a maximum thickness of 250m.

It should be pointed out that the term Hawkesbury Sandstone, as used by Tenison Woods, included some sedimentary rocks which are regarded today as being not part of this formation.

The origin of the Hawkesbury Sandstone has been a matter of interest and study since Charles Darwin speculated about it on his visit to Sydney in 1844. Since then, various workers have interpreted it as having been formed in the sea (with or without the influence of ice), in lakes, by the wind or by rivers. It is only in very recent times that we have arrived at an understanding of present- day rivers which enables us to explain satisfactorily many of its puzzling features.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS

The approach to interpreting the environment of deposition of a sedimentary rock is through comparison of various features of the rock with those of the sediments being deposited today in a range of environments.

The features found to be most helpful are:

Geometry: the overall shape of the sedimentary deposit. This is particularly useful in the recognition of channels.

Lithology: the texture and composition of the sediment. Grainsize and grain-shape provide information about the method of transport and deposition; composition is largely a function of the source rock.

Sedimentary structures: bedding and other structures resulting from physical or biological action. These are particularly useful, assemblages of structures often being characteristic of particular environments; cross-bedding is especially important in indicating the kind of environment and the direction of transport of sediment.

Palaeocurrent patterns: overall patterns of transport of sediment interpreted from cross-bedding and other directional indicators. These require a considerable areal spread of data but can distinguish between different large-scale environments.

Fossils: the remains of animals or plants preserved in the rocks. These are important indicators of depositional environment as most living things are restricted to particular habitats.

Because the present is the key to the past it is obvious that detailed knowledge of large-, medium- and small-scale features of the sediments accumulating in the whole range of sedimentary environments on the earth at the present time is needed if we are going to be able to interpret the origin of sedimentary rocks with confidence.

DEPOSITIONAL ENVIRONMENT OF THE HAWKESBURY SANDSTONE

Geologists today would in general agree that the Hawkesbury Sandstone is essentially of fluvial origin. Its features can be explained by regarding it as the product of a large, low-sinuosity river system characterised by periodic strong current flow, comparable with the Brahmaputra River of the present day (Conaghan & Jones, 1975). Both channel and floodplain environments are represented in the Hawkesbury Sandstone.

In the light of Tenison Woods' interpretation to which we will turn next, the following quote from Conaghan and Jones is of interest: *"Although wind transport cannot be excluded on the basis of bedding characteristics, it seems unlikely to be the dominant process considering the angularity, size and sorting of the constituent grains of the Hawkesbury Sandstone"* (*op.cit.* p.278).

TENISON WOODS' INTERPRETATION

The purpose of Tenison Woods' paper was to establish the origin of the Hawkesbury Sandstone as aeolian, although he readily acknowledged that *"We must not suppose that in an immense deposit like the Hawkesbury rocks one explanation will suffice for all the appearances met with"* (Tenison-Woods, 1882, p.72.). His main conclusion was that *"the Hawkesbury sandstone is a wind-blown formation, interspersed with lagoons and morasses, with impure peat"* (*op. cit.* p.87).

In support of this interpretation he marshalled evidence under all the headings given above, with the exception of palaeocurrent patterns:

Geometry: the Hawkesbury Sandstone is an essentially horizontal sheet of great areal extent, subdivided into large irregular undulating layers; it shows no evidence of having been uplifted, so has been formed above sea level. Tenison Woods placed great stress on this *"non-upheaval"* of the sandstone and regarded it as conclusive evidence of its aeolian origin. The following evidence however he described as *"quite as significant"*.

Lithology: the absence of thin alternating beds of sand, clay and/or limestone argues against formation in rivers, estuaries or lakes; the quartz grains in the sandstone are rounded and abraded whereas fine water-borne sand he believed to be always angular; also present is fine aeolian dust; the small rounded pebbles present could have been carried by wind; larger pebbles in conglomerates mainly near the base of the deposit represent residual deposits left when the sand originally with them was blown away.

Sedimentary structures: the sandstone layers are cross-bedded, *"subdivided by laminae with every kind of dip and direction, rarely exceeding 23^{o}. this structure only belongs to eolian rocks"* (*op.cit.*p.63).

Fossils: in the sandstone itself there are no marine fossils or fresh water shells; plant fossils indicate a terrestrial origin and the presence of well preserved fern fronds argues against formation by rivers.

TENISON WOODS' RESEARCH METHOD

It is apparent from the above that Tenison Woods had a sound grasp of the principles of interpretation of sedimentary rocks in terms of their environment of deposition, and that his approach was comprehensive and thorough.

In addition he had a wide knowledge of studies of sediments in other parts of the world and showed an extensive knowledge of the literature. In the course of his paper he made reference to occurrences in Arabia, Bermuda, China, Egypt, France, India, Mexico and Switzerland. Closer to home he cited the Pliocene aeolian sands along the Victorian-South Australian coastline, the dunes and unconsolidated sandy deposits on the edge of the Murray desert, and the desert sandstone west of the main range in Queensland, all of which he had examined personally.

In studying the origin of cross-bedding he even adopted an experimental approach, designing and carrying out small-scale experiments using variously coloured sand.

Most significantly of all, Tenison Woods made personal observations of aeolian processes at work in the field, and made direct comparisons between the effects he observed and the features of the Hawkesbury Sandstone. He quoted his observations on the stratification of sand dunes at Wide Bay, Queensland, and on the movement, grain size and stratification (including the relationship between the dip of the cross-laminae and velocity of the wind) of loose drift-sand in the bed of the Burdekin River, Queensland. At Low Island, inside the Great Barrier Reef, he studied the movement and lamination of a particular sand dune under varying wind conditions. He drew also on his knowledge of the processes he saw operating in the stony deserts of Central Australia.

On the basis of his research therefore Tenison Woods wrote of the Hawkesbury rocks: *"Do these sandstones correspond in every particular with exposed sections of aerial sands? This I have answered by showing from many actual instances that they do"* (*op.cit.*p.111).

EVALUATION

Tenison Woods' study of the Hawkesbury Sandstone was extraordinary in its scope and detail. He was a competent and careful researcher with acute powers of observation, was well acquainted with the principles of interpretation of sedimentary rocks, and combined field observations with an experimental approach. He was familiar with the work of his contemporaries and with work on similar geological phenomena around the world. He pursued large-, medium- and small-scale aspects of his research problem, offering evidence at the sedimentary basin, outcrop and sand grain levels of scale. He had the ability to handle large quantities of information, to assess its validity and relevance, and to integrate it into a convincing explanation for his observations.

His method was sound. Why then did Tenison Woods reach a conclusion about the origin of the Hawkesbury Sandstone as a whole which is not accepted today? Before attempting to answer this it is worth noting in passing that many of the views of his contemporaries are not accepted today either: Clark and Daintree thought that the Hawkesbury Sandstone was formed in a fresh water lake; Darwin, Wilkinson, Liversidge and others believed it to be the result of deposition in a shallow sea; Wilkinson in particular held that ice action was also involved and was responsible for the boulders and conglomerates.

I suggest that what Tenison Woods and the other geologists of his day lacked was a detailed knowledge of the wide range of sedimentary environments on the earth at the present time. Aeolian environments and their deposits are much more accessible and easier to study than are subaqueous ones. It is only in the last 30 years or so that data from a wide range of modern environments has become sufficiently abundant and detailed for interpretations of ancient sediments to be made with confidence. Technological advances in areas such as echo-sounding, aerial and underwater photography, laboratory studies of hydrology and sedimentation, underwater sampling, scuba diving and the like have all played a part.

Tenison Woods did not have available to him the knowledge we now have of fluvial processes and their products. If he had, his conclusions may well have been different. What he did was to integrate a great amount of information from many and diverse sources into a coherent and persuasive model for the origin of the Hawkesbury Sandstone. The model fulfilled the main functions of any scientific model in providing a defensible explanation for the data and in successfully generating debate and further research. What he did was to apply his considerable gifts in a masterly way to the unravelling of a geological problem of great complexity - a problem on which, one hundred years later, the last word has certainly not been said.

REFERENCES

Conaghan, P.J. & Jones, J.G. 1975: The Hawkesbury Sandstone and the Brahmaputra: a depositional model for continental sheet sandstones. *J.Geol.Soc.Aust.,22,* 275-83.

Tenison-Woods, J.E., 1882: The Hawkesbury Sandstone. *J.Proc.Roy. Soc.N.S.W.,16,* 52-116.

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The Botanical Work of the Reverend J. E. Tenison-Woods

PETER MARTIN

In scientific circles, Tenison-Woods is mostly remembered as a geologist, invertebrate zoologist and palaeontologist.. He was, however, a highly competent botanist. His published papers on modern and fossil botany would, by themselves, have been sufficient to establish him as a significant figure in the annals of Australian science.

These things which come to mind when one attempts to summarise the nature of his botanical work are (1) his enormous erudition, (2) the extent of his journeyings in Tasmania, the rest of Australia, and South-East Asia, and (3) his astonishing facility for making comparative observations.

The botanical contributions of the Reverend Mr. Tenison-Woods were mainly communicated in formal botanical papers, but many of his publications on other subjects, as well as his 'letters' to newspapers, contain some botanical comments. His interests embraced both higher and lower plants, and included the botanical aspects of agriculture, forestry and horticulture. His papers were always interetingly written, occasionally being enlivened with controversial statements which,even if subsequently proved wrong, had the great merit at the time of challenging the assumptions inherent in the received opinions (e.g. the age of tall Eucalypts in southern Tasmania).

Unlike most of the botanists of his time, Tenison-Woods was not especially interested in the search for new species; as far as I can make out he did not describe any new species of living plants, being happy to leave the naming of any novelties that he came across to his numerous associates in herbaria in Australia and Europe. (He did, however, describe a number of new species of fossil plants). Rather, he used his special gifts and advantages to become the first Australia-based author to publish serious comparative observations of the vegetation (as distinct from the flora) of the various regions with which he was familiar.

In the formation of his intellectual approach to vegetation, he seems to have been much stimulated by Sir Joseph Hooker's Introductory Essay to the 'Flora Tasmaniae'(1860). Hooker stressed the need to identify the various 'geographic elements" in the make up of a flora as the key to its history, and Tenison-Woods seems to have developed this to an awareness that certain 'geographic elements' are as readily characterised by the overall form of their assemblages as by the names of the component species. This led him to recognise that particular types of vegetation have a degree of structural constancy which is not dependent upon the presence of a given group of species. Regrettably, his death at the early age of 57 cut short his studies of vegetation before he had time to formulate a definite methodology and set of descriptive terms.

An examination of his comparative studies of vegetation in Australia and in the Malayan region provides clear evidence that he was, in the 1870s and 1880s, looking at vegetation in a way which was not to gain scientific currency until its emergence as plant ecology in the first decade of the century. Tenison-Woods deserves, without question, a much higher place in the history of botany in the Australo-Malayan region than he has hitherto enjoyed.

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Speech by His Excellency Rear Admiral Sir David Martin, K.C.M.G., A.O., Governor of New South Wales at Annual Dinner and Presentation of Medals Royal Society of New South Wales 14th March, 1990

The main purpose of the Royal Society seems to be to encourage people to ask questions and to keep asking. Before I go any further, you may be interested to know what I say as Governor of New South Wales when people ask me questions Yes, my wife and I are enjoying the job very much indeed and it is certainly a team effort, with both of us working on our own and together. I mention to people the three "C's" explaining the community and ceremonial activities and the one part where my wife cannot really share the work (but which is, after all, the reason for having the Governor) i.e. the constitutional role. I enjoy (usually) the Executive Council meetings and find that the business of keeping in touch, politically, is stimulating, if not always a pleasure. It seems important to me that Ministers see the Governor not as a rubber stamp and not just as the Queen's representative, but as their conscience, as the representative of the people of the State, and as the custodian of the Constitution.

I make a point of reminding people that the Governor does not report to the Governor-General, nor does he keep in touch with any person or office in the British Government. Certain communications are sent by the Governor, or on behalf of the Government, to Her Majesty in her capacity of the Queen of Australia.

What do I say when I stand in front of a crowd? Probably I assert the obligation of people to set an example and exert influence. I talk about the problems we have seen, felt, experienced, and discussed since I became Governor: usually, lost children, the battered and bruised environment, the need for a united multicultural Australian society, road carnage, and the bad attitudes in industrial disputes. I mention our own obligation to influence, (and even to inspire if possible), and to follow the example of our predecessors in seeking to raise the stature of the office of Governor while also showing the warmth we feel for people.

Being here is a pleasure and a privilege, and a chance for us to broaden our horizons and be introduced into another family - in this case, an admirable, interesting group of people with an exciting past and a great future. The Society was started in the days of the sixth Governor, Sir Thomas Brisbane, and incorporated at the time of the 15th Governor, Rt. Hon. Lord Augustus Loftus. Last week I was in some despair as I came upon a series of examples of our shallow society - in so many ways superficial, insincere and casual, (as illustrated by much of our journalism). It is in many ways a veneer - glossy but not attractive. Too many of our so called problem-solvers look only at today's data, assembled for them by some trick of "computery" or word processing, addressed and solved by clever modern techniques. All too often so-called research leads to solutions involving images, sleight of hand, new slogans, jargon and buzz words, changed procedures, short cuts, and fast bucks, change for change sake - "slicks and quicks".

Tonight I am reassured to be with members of a Society which actually encourages people to think, stretch the mind, search for truth, unravel puzzles, inquire, wonder, and which has rules for discipline and honesty and procedures for logic organisation.

You have adopted codes of manners, and you have well defined means of presentation. This is not necessarily so in the rest of society, where rules are broken, conventions trampled upon, manners cast aside and codes discarded all too easily. You have discovered and perpetuated something that Australians can do very well indeed - our scientists can hold up their heads anywhere in the world with pride. In my own career I have seen many examples of that.

Also, it is good to see that you do not sit on your laurels - I am stimulated by your efforts to review the role and activities of the Society. I am sure you won't lose sight of "the encouragement of studies in science, art, literature and philosophy". Every scientist benefits from his or her efforts to extend horizons, to dig for deeper meaning, to search for new insights, to scratch and to go back again and again to chip away at some impregnable surface, behind which you think there is a secret. You are doing wonderful work with your Summer School. I believe that most young Australians are reaching out for guidance - you are providing it.

The important point to me is that it is not just the scientist who benefits but the whole of our society, and perhaps all of mankind. You help the corporate world (while also getting a bit of help from them). Also you can form part of a type of large-scale multi-national operation.

Please do not lose track of the need to encourage others to do the same, to inspire and teach those with whom you work and to stimulate and challenge others who may be novices. And please do your best to see that the fruits of your labours do not sit on the shelves or in your Journals, but provide succour for the world.

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AWARDS OF THE CLARKE MEDAL

Established in memory of
the Revd. WILLIAM BRANWHITE CLARKE, M.A., F.R.S., F.G.S.
Vice-President from 1866 to 1878

The Clarke Medal is considered annually for distinguished work in the natural science done in, or on, the Australian Commonwealth and its territories.

1980	No award
1981	W. Stephenson
1982	N.C.W. Beadle
1983	K.A.W. Crook
1984	Michael Archer
1985	H.B.S. Womersley
1986	D.J. Groves
1987	Anthony James Underwood
1988	Barry Garth Rolfe
1989	J. Roberts

CLARKE MEMORIAL LECTURESHIP

The lectureship is awarded every second year for the purpose of the advancement of Geology. The practice of publishing the lectures in the Journal began in 1936.

1981	R.W.R. Rutland
1983	R.H. Vernon
1985	R.L. Stanton
1987	J.J. Veevers
1989	E. Scheibner

THE SOCIETY'S MEDAL

The Society's Medal with a money prize of $25 was awarded for published papers up to 1896. After 1943 the Medal only was awarded to a member of the Society for meritorious contributions to the advancement of science, including administration and organisation of scientific endeavour and for services to the Society.

1980	M. Krykso v. Tryst
1981	William Eric Smith
1982	William B. Smith-White
1983	Nil
1984	Robert S. Vagg
1985	Dalway John Swaine
1986	Sydney Charles Haydon
1987	George Studley Gibbons
1988	Ragbir Bhathal
1989	John Harold Loxton

AWARDS OF THE JAMES COOK MEDAL

The James Cook Medal is awarded at intervals for outstanding contribution to science and human welfare in and for the Southern Continent.

1980	Robert J. Walsh
1981	Nil
1982	Nil
1983	Nil
1984	Ronald Lawrie Huckstep
1985	Donald Metcalf
1986	Nil
1987	Phillip Garth Law
1988	Nil
1989	Nil

THE EDGEWORTH DAVID MEDAL

The Edgeworth David Medal is awarded for distinguished contributions by young scientists under the age of 35 years for work done mainly in Australia or its territories or contributing to the advancement of Australian science.

1980	Michael Anthony Etheridge
1981	Martin Andrew Green (Applied Physics)
1982	Nhan Phan-Thien (Mechanics)
1983	Denis Wakefield
1984	Alan James Husband (Pathology)
1985	Joint Award: Simon Charles Gandevia (Clinical Neurophysiology) and Brian James Morris (Molecular Biology)
1986	Joint Award: Leslie David Field (Chemistry) and Peter Gavin Hall (Statistics)
1987	Andrew Cockburn (Zoology)
1988	Peter Andrew Lay (Inorganic Chemistry)
1989	Trevor William Hambley (Chemistry)

WALTER POGGENDORFF MEMORIAL LECTURE

The Memorial Lecture was established under the terms of a bequest to the Society by Walter Hans Poggendorff , whose pioneering efforts in plant breeding aided the development of a vigorous Australian rice industry.

1987	McDonald, D.G.

LIVERSIDGE MEMORIAL LECTURESHIP

The lectureship is awarded at intervals of two years for the purpose of encouragement of research in Chemistry. It was established under the terms of a bequest to the Society by Professor Archibald Liversidge. The lectures are published in the Journal.

1980	S.R. Johns
1982	D.P. Craig
1984	D.H. Napper
1986	B.G. Hyde
1988	R.J. Hunter

POLLOCK MEMORIAL LECTURES

The Pollock Memorial Lectureship is sponsored by the University of Sydney and the Royal Society of N.S.W. in memory of Professor J.A. Pollock, DSc., F.R.S., Professor of Physics in the University of Sydney (1899-1922) and Member of the Royal Society of N.S.W. for 35 years.

1980	Nil
1981	Edwin E. Salpeter
1982	Nil
1983	Nil
1984	R.S. Pease
1985	Nil
1986	Nil
1987	Nil
1989	Nil

THE WALTER BURFITT PRIZE

The Walter Burfitt Prize is awarded at intervals of three years to the worker in pure or applied science, resident in Australia or New zealand, whose papers and other contributions published during the past six years are deemed of the highest scientific merit. It was established as a result of generous gifts to the Society of Dr. and Mrs. W.F. Burfitt.

1980	H.A. Buchdahl (Physics)
1983	W.S. Hancock (Biochemistry)
1986	B.N. Figgis (Inorganic Chemistry)
1989	Nil

ARCHIBALD D. OLLE PRIZE

The Archibald D. Olle Prize is awarded from time to time at the discretion of the Council to the member of the Society who has submitted the best paper in any one year. The Prize was established under the terms of a bequest by Mrs. A.D. Olle.

1980	not awarded
1981	Helene A. Martin
1982	not awarded
1983	Joint Award: David S. King Nicholas R. Lomb
1984	Joint Award: R.A.L. Osborne and Terence J. Goodwin
1985- 1986	Robert S. Vagg and Peter A. Williams
1987	Joint Award: S.J. Riley and H.M. Henry
1988	Nil
1989	Nil

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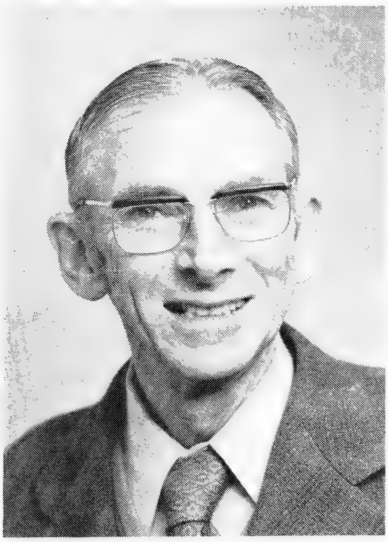
Biographical Memoirs



ADRIEN ALBERT

Adrien Albert was born in 1907 to a Swiss father and an Australian mother, who alas did not survive many years. Young Adrien was brought up by a loving aunt and he attended the Scots College in Sydney where he developed a passion for science. On matriculation, he was strongly urged to enter the family music-publishing business but his sights were set on a career in chemistry: as a compromise, he undertook training in pharmacy but after graduation he found that life in a chemist's shop involved too much commerce and too little science. He returned to Sydney University, completed a science degree, and promptly departed for London where he commenced research for the PhD degree under the guidance of W.H. Linnell at the College of the Pharmaceutic Society, a part of London University. It was there that he developed an interest in the acridine antiseptics and this eventually led to his life-long fascination with the role of heterocyclic compounds in chemotherapy and medicine.

Because he was forced to live on his meagre savings, supplemented only by a minute income from some part-time dispensing work in London, his meals became irregular and inadequate: this, combined with long hours at the bench, led inevitably to stomach ulceration, haemorrhage, and perforation. Emergency surgical intervention was carried out by a junior registrar at a London hospital in the middle of the night: although his life was saved thereby, he was left with an appalling legacy from which he suffered grievously for the rest of his life, despite later highly skilled reparative work.

Albert returned to Australia shortly before the outbreak of World War II and held several non-tenured teaching posts at the University of Sydney where he undertook valuable war work on antiseptic and antimalarial drugs for the Australian Army.

Eventually his research was noticed by the embryonic National Health & Medical Research Council who funded him to establish a loosely knit chemotherapy group within the University of Sydney, essentially to continue fundamental work on acridine and related antiseptics in collaboration with the late S.D. Rubbo and his colleagues in Melbourne. In 1948, Albert was about to join the Wellcome Foundation in London as a permanent senior research worker when Sir Howard Florey (later Lord Florey) induced the new Australian National University to offer Albert its foundation Chair of Medical Chemistry, an invitation he accepted with alacrity.

Because no building was available in Canberra, he promptly established his Department in hired laboratories in London and began research in purine and pteridine chemistry, an area then pregnant with possibilities following the introduction of mercaptopurine and methotrexate as anti-neoplastic drugs and the recognition of an essential place for the folic acid group in biochemistry. In 1956, the whole Department moved to new laboratories in Canberra where Albert further developed experimental research and his creative correlative thinking on biologically active chemicals. In 1972 he retired officially but work continued unabated, first in the Research School of Chemistry and later in the Department of Chemistry at Canberra, with frequent periods in the Department of Pharmacological Sciences at the State University of New York, Stony Brook. Late last year his health began to fail and he died on 29th December 1989, ironically of a condition resulting from a long-standing Staphylococcal infection which had become totally resistant to antibiotics and other antibacterial agents.

Albert was perhaps best characterized by the value he set on time: he never deliberately wasted one minute of his long life and many of his colleagues will remember his oft-repeated phrase to extricate himself (and others) from any overly long tea break conversation, "Oh well, back to the bench". He had a phenomenal memory even in old age, a deep knowledge and love of music, considerable skill as a pianist, and an unexpected ability in imaginative draftsmanship; he enjoyed travel, providing it led to scientific contacts, and he visited almost every corner of the world in which chemotherapeutic or heterocyclic chemical research flourished. He never married nor is he survived by any close relatives. His numerous friends, some dating from childhood, will remember him as a thoughtful and kindly person, a stimulating conversationalist, and a logical thinker whose head always ruled his emotions.

Among the more prestidigeous honours accorded Albert were the Order of Australia (1989), a Fellowship of the Australian Academy of Science (1958), the inaugural Royal Society of Chemistry Lectureship (Australia) (1960), the Liversidge Research Lectureship for 1964 (Royal Society of N.S.W.), the naming of an endowed biennial Adrien Albert Lecture (1985) and the Olle Prize for 1989 (Royal Australian Chemical Institute), the E.E. Smissman Award for 1981 (American Chemical Society), and a (posthumous) Doctorate of Science h. c. (1990: The University of Sydney).

Albert's experimental research is recorded in more than 200 research papers, mostly in the *Journal of the Chemical Society:* these covered many novel aspects of heterocyclic chemistry, mainly within the acridine, quinoline, pteridine, purine, and azapurine systems. He discovered and formulated the important phenomenon of covalent hydration, he introduced π-excessive/π-deficient concepts into the classification of heterocyclic systems, and it was he who first emphasised the importance of ionization constants on the physical and biological properties of heterocyclic derivatives. He summarized much of this work in his books entitled *The Acridines* (2nd Edition, 1966), *Ionization Constants* (3rd Edition with E.P. Serjeant, 1984), *Heterocyclic Chemistry* (2nd Edition, 1968), and a yet untitled version of the last which was aimed at undergraduate teaching and remained unfinished at his death.

The seminal thoughts and writings of Adrien Albert on how and why drugs act the way they do, were based firmly on experimental data, albeit of others. He introduced the concept of selective toxicity in a remarkable series of lectures given at University College London in 1948 and he subsequently formalized and gradually expanded these thoughts progressively in no less than seven editions of his book *Selective Toxicity* (the physico-chemical basis of therapy) from 1951 to 1985. This became essential reading for generations of practical pharmacologists and medicinal chemists throughout the world and each edition was translated into several languages to facilitate its use in teaching. In 1987, he published his last book, *Xenobiosis* (food, drugs, and poisons in the human body), a work already acclaimed as a masterpiece by life-scientists and intellectual lay-people alike.

Adrien Albert was elected to membership of the Royal Society of New South Wales in 1938 and subsequently became a Life Member.

D.B.

ARTHUR SINCLAIR RITCHIE

Arthur Sinclair Ritchie, scholar, author, gentleman, friend and mentor to countless geology students died in his 78th year in September 1989. Born at Richmond, N.S.W. he attended Parramatta High School from which he won a scholarship to Sydney Teacher's College and later studied at Sydney Technical College.

In 1938 he came to Newcastle, where he taught science in high schools and became a part-time lecturer in diploma classes in Geology and Mineralogy at the Newcastle Technical College. In 1947 he became a full-time lecturer at the College and later became supervising lecturer in the School of Mining Engineering and Applied Geology. With autonomy, he continued on the full-time staff of the University of Newcastle, obtained his M.Sc. degree and went on to attain the position of Associate Professor in Geology.

Arthur published in Australian and international scientific journals, contributed chapters in textbooks and achieved a first with his book "chromatography in Geology", which was subsequently translated into Russian.

His former students and the geological profession have much to thank him for as one who successfully spent much of career preparing others for their role in life.

He is survived by his wife Jean, a daughter and two sons.

S. St. J. W.

ILSE ROSENTHAL-SCHNEIDER

Dr. Ilse Rosenthal-Schneider - student and long-time friend of Albert Einstein - died in Sydney recently. She was 98.

Well known as a scientist, philosopher and author, she was born in Finsterwalde, Germany, but studied at Berlin University.

It was there that she met Einstein. One day after his public lectures on the theory of relativity, which she attended, he saw her in a tram and waved to her to sit beside him. It turned out they caught the same tram every day to the university.

It was at Einstein's lectures that she decided to put aside her ambition to be a famous scientist and to devote herself to explaining his theories so that they could be understood by the average intelligent student.

She studied philosophy and completed a master's degree in the comparison of ancient and modern Greek. She completed her doctorate in 1918, after working as a laboratory assistant in a military hospital during the war, and published her first book on Einstein's theory and relativity.

She and Einstein became close friends and often attended afternoon discussions. Dr. Rosenthal-Schneider was at Einstein's home when he received the telegram announcing that the theory of relativity had been confirmed by the British astronomer Sir Arthur Eddington in 1919.

Dr. Rosenthal-Schneider asked Einstein: 'What would you have said if there had not been such a confirmation?' Einstein replied: 'I would have been sorry for our dear God. He would have made a mistake.'

Three years later, she married Hans Rosenthal, who died in 1969. Growing anti-semitism forced Einstein to flee to Princeton University in the United States and Dr. Rosenthal-Schneider to Sydney. In 1939, she and her husband settled in Vaucluse, a suburb of Sydney.

She corresponded with Einstein until his death in 1955.

References from Einstein assisted her in obtaining lecturer position at the University of Sydney, where she taught scientific German and the philosophy of science. Throughout her life, she continued to write and her final publication - *Reality and Scientific Truth* - was published in 1983 at the age of 91.

A member of the Royal Society of N.S.W. since 1948 and since 1979 an Honorary Member - Dr. Rosenthal-Schneider is survived by her only child, Stephanie Van de Weyer, who taught at Sydney Grammar Preparatory School.

By courtesy of:
Australian Jewish Times
(Reporter W.S.)

COLIN LACHLAN ADAMSON

The death of Colin Lachlan Adamson occurred on 10th August 1988, aged 68 years. Col was elected a member of the Royal Society of New South Wales on 7th June, 1944 and was Honorary Treasurer in 1958/59 and Vice President in 1964/65. He was consistently supportive of the Society for the greater part of his life.

Col was born in Sydney in 1920 and was educated at North Sydney Boys High School and the University of Sydney, graduating Bachelor of Science majoring in geology and chemistry. Although geology remained his lasting love, he was first employed during World War II in the Department of Munitions, Victoria, in the field of chemistry. Subsequently, Col entered the Geological Survey of New South Wales as a Geologist. Memories of mapping in the Snowy Mountains in the late forties always lay close to his heart. There, many months were spent in rigourous field work under the initial guidance of Len Hall, for whom Col held a deep respect.

Col's love of the high places was expressed in diverse ways - but to me most memorable was when he induced me to accompany him on a 60 km circuit from near Jagungal to the Summit area and return as a brisk, so-called recreational, week-end break from our normal fieldwork.

Among other interesting activities was Col's jaunt, in younger days with a small group of friends, by bicycle from Burragorang up the Gingra Range to Kanangra.

Always an amiable companion, Col nevertheless had strong views on many aspects of camp life. An enthusiastic cook, he saw fit to dismiss some items from the menu - fried eggs made the plates too messy and oranges were "too much mucking about". In camp, he was a great constructor, always quick to establish the water supply - whether by excavation or a complex system of races and flumes.

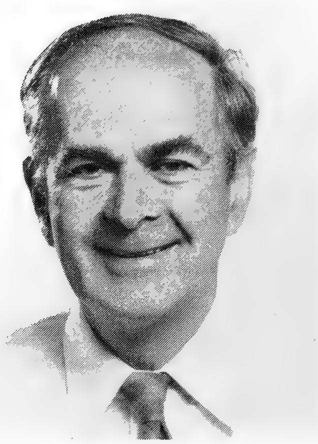
In the mid-sixties, Colin Adamson was appointed Assistant Director of the Geological Survey. He was widely experienced in most fields of geology, although his later activities were centred on engineering geology and industrial minerals. Coalfield geology and regional geology were also prominent.

Colin Adamson was a foundation member of the Geological Society of Australia and past Chairman of the N.S.W. Division. He was a moving force in establishing the Australian Institute of Geoscientists in 1981, devoting much energy to the aims of that body of which he was President at the time of his death.

I suspect Col would wish to be remembered as a friendly and a simple man who sewed his own canvas, made his own skis and loved snow daisies, snow grass and snow gums and all outdoors. For all of us who mourn his loss, we would add our recall of a gentle gentleman of total integrity, concerned, conscientious and caring.

There will only ever be one Colin Lachlan Adamson.

C.Mc.E.



A.N. CARTER

With the sudden death of Dr Alan Norval Carter in November 1989 the Royal Societies of New South Wales, Victoria and South Australia as well as the Australian Marine Sciences Association lost a scientist who had and was still making a valuable contribution to the geology of Australia and the Pacific Region.

Born in Melbourne, he attended Scotch College and later the University of Melbourne where he graduated B.Sc in 1951 majoring in Geology and Zoology. During the years 1951 to 1959 he was employed in the Geological Survey of Victoria; at the same time he completed his M.Sc thesis for the University of Adelaide and in 1959 his Ph.D thesis for the University of Melbourne. All his research work at the time was concentrated on the tertiary foramiferm and stratigraphy of the Aire District and of Gippsland.

In 1960 he accepted appointment to the Geology Department of the University of New South Wales where he remained until his retirement as Senior Lecturer in 1987. He initiated courses in stratigraphy and palaeontology and was also in charge of the field programme. An increasing involvement in marine geology lead to the teaching of Marine Geology in 1965 and finally to the course in Marine Science. He initiated the teaching of Oceanography in the degree course at the Royal Australian Naval College, Jervis Bay. Various study leaves in America, England and New Zealand were used in furthering his knowledge in the above mentioned areas of expertise. His stratigraphical classification of the Gippsland Basin lead to the discovery of the Bass Strait oilfield which produces a major portion of Australia's petroleum needs.

He participated in Phases I and II of The Tripartite marine Geoscience Programme, jointly contributed by the Governments of Australia, New Zealand and United States of America, for off-shore exploration for petroleum and minerals for the benefit of the South-West Pacific Region, chiefly Tonga, Fiji, Vanuatu and the Solomon Islands. His research work has been recorded in numerous publications over the years.

Alan Carter was a very caring, sincere person who always had time for friendship and fellowship; he was always available to his family and ever ready to offer them help and advice when the occasion demanded it. Leisure time was frequently spent at Pittwater where he could enjoy the bushland and sailing. Here, too, he involved himself with the Volunteer Fire Brigade and the Community Association.

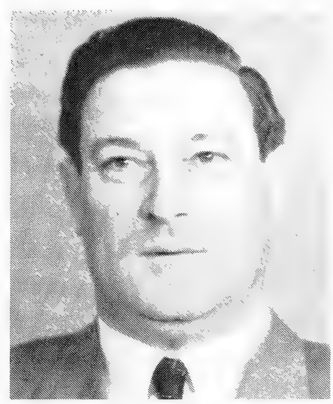
A.W.

MICHAEL DUHAN GARRETTY

Michael Duhan Garretty was born in Sydney on 23rd February 1914, and died in Melbourne on 21st November 1989. He entered the Faculty of Science at the University of Sydney in 1931 and graduated with First Class Honours and the University Medal in Geology in 1936. He was awarded the first Slade Prize for Geology in 1933, the Deas-Thomson Scholarship (Undergraduate) in 1934, and the Deas-Thomson Scholarship (Postgraduate) in 1935. He was also awarded the Science Research Scholarship (NSW Government Grant) in 1935 which enabled him to continue research and graduate with the M.Sc. in 1937. Publications of his early research included *Introductory account of the general geology of the Lake George District.* Part i General Geology. Proc. Linn. Soc. N.S.W., LXI, 186-207 (1936); *Some notes on the physiography of the Lake George region, with special reference to the origin of Lake George.* J. Proc. Roy. Soc. N.S.W., LXX (for 1936) 285-293; *Geological notes on the country between Yass and the Shoalhaven River.* Ibid. 364-374.

In 1947 Duhan Garretty was awarded the D.Sc. by the University of Sydney for his thesis *Mineralisation of the orebodies at Broken Hill N.S.W.* Duhan Garretty's progress as a geologist in industry was as spectacular as it was at University. Initially he worked as geologist in association with Dr Loftus Hills in Fiji in 1936, with Mr H.J. Connolly at Bendigo, at the time when Bendigo was being intensely explored by Western Mining Company.

In 1937 he joined Dr J.K. Gustafson and H.C. Burrell to undertake the Central Geological Survey. This was the first time that all the mines at Broken Hill were mapped in an effort to solve the geology and mineralisation of the orebodies. The final report was submitted to Zinc Corporation in 1939 (unpublished), by Dr Gustafson. This was to



be the interpretation that would influence the exploration of the orebodies by all Broken Hill companies for the next fifteen years. Arising out of this survey were a number of published papers including Gustafson J.K., Burrell H.C., and Garretty M.D., *Geology of the Broken Hill Deposit, Broken Hill N.S.W.,* Geol. Soc. Am. Bull. 1950, 61, 1369.

Duhan Garretty joined the staff of North Broken Hill as Chief Geologist in 1939, and remained with that company until 1950. During this time he conducted not only the exploration and mining geological programme at North Mine, but he was also responsible for North Broken Hill's exploration programme throughout Australia, especially on the West Coast of Tasmania, in a joint venture with South Broken Hill.

During the war Duhan Garretty was commissioned by the Department of Industry to carry out a survey of the occurrences of Piezo-electric quartz in Australia, and this was published in 1947 as B.M.R. Bulletin 17. After Duhan Garretty left North Broken Hill in 1950 he operated as a consultant geologist and company director from his Melbourne office. He formed the geological consulting company Mining and Prospecting Services (MAPS) in 1952, and I had the opportunity to work as senior exploration geologist with this company.

Duhan was an excellent leader, a person of great vision and professional expertise. His geological concepts lead to the formation of companies to explore in all states of Australia, and with Mineral Ventures NL he sought to explore the potential for oil in off-shore Gippsland. His belief and enthusiasm for the potential of the Tennant Creek field, and his early association with John Proud (later Sir) with Peko NL laid the foundation for a very successful mining venture. Exploration can be as frustrating as it can be rewarding, and Duhan Garretty bore the rewards and the frustrations with equal dignity and courage. He was a generous person who never sought favours.

Duhan married Miss Joyce Agassiz in February 1936. Joyce died in 1976, leaving three children, Peter, John and Helen, who live in Melbourne. Duhan Garretty joined the Royal Society of New South Wales in 1935, and was elected to life membership by the Council in 1979.

K.R.G.

IVOR VICKERY NEWMAN

Friends and colleagues were saddened to learn of the death of Ivor Vickery Newman, M.Sc. (Sydney), Ph.D. (London), F.L.S., F.R.M.S., on 5 May, 1987, at the age of 84.

The son of a Methodist Minister, Ivor Newman was born at Balmain in 1902. He attended Sydney Grammar School and subsequently the University of Sydney where he graduated Bachelor of Science with Honours in Botany in 1926. He was awarded a Government Science Research Scholarship and carried out valuable work on the life history of *Doryanthes excelsa* (the Giant or Gymea Lily) which earned him the degree of M.Sc. in 1928. He proceeded to King's College, University of London, in 1929, to work towards the degree of Ph.D. under the supervision of Professor R. Ruggles Gates, gaining the degree in 1931 for a thesis on aspects of the reproductive biology of certain Australian *Acacia* (wattle) species. Returning to Australia, he took up a Linnean Macleay Fellowship in Botany in the Botany Department, University of Sydney, where he conducted extensive researches on the ecology, cytology and reproductive biology of a range of *Acacia* species, making important contributions to our understanding of *Acacia baileyana,* the Cootamundra Wattle.

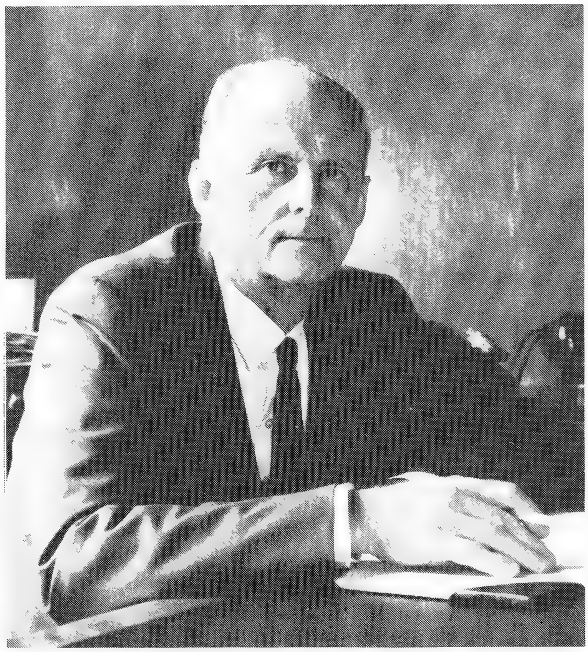
In 1937 he went to New Zealand to become lecturer in charge of Botany at the Wellington (Victoria) University College of the then University of New Zealand, leaving in 1949 for three years in Colombo as Professor of Botany at the University of Ceylon. He then returned to Australia, spent a few years as a Senior Research Scientist with the CSIRO Division of Forest Products, and then from 1954 to 1967 served as Senior Lecturer in Botany at the University of Sydney. Immediately upon retirement his assistance was sought by the newly established Macquarie University, and in 1968 he conducted the first advanced courses in plant morphology at that institution. An active member of many groups and societies, he was President of the Linnean Society of N.S.W. in 1960/61. I.V. Newman became a member of the Royal Society of New South Wales in 1932 (elected 6.7.1932) and in later years a life member.

It was the work of R.H. Cambage on *Acacia* seedlings, published in this journal as a series of thirteen papers between 1915 and 1928, which first attracted Dr. Newman to the Society. Soon after his election as a member in July, 1932, he produced an annotated and interpretative catalogue of Cambage's work on the subject, which, unfortunately, remains unpublished. Although never losing his enthusiasm for the wattles, after 1950 Dr. Newman became more and more interested in fundamental aspects of plant development, and by the time of his retirement was an internationally recognised authority on the apical meristems (growing points) of coniferous trees.

He is fondly remembered by a large circle of post-graduate students (including many from developing countries) for the patience and care with which he supervised their work and for his unfailing but unobtrusive interest in their personal welfare. His undergraduate lectures were notable for the pains he took in preparing them and the detailed blackboard diagrams with which he illustrated points of structure. However, his greatest pleasure in teaching came from his laboratory classes, particularly the advanced morphology classes, in which, to use his own words "the opportunity to be rewarded by mastering intricate structure, the opportunity to be satisfied in observing the fitness of harmonious activities" were best exemplified.

A man of wide interests, he rendered significant services to the peace movement, the Methodist Church (later the Uniting Church) and the nature conservation movement. He maintained his interest in all these activities, as well as his botanical work, to the last. He is survived by his wife Rewa, and by sons Ian and Keith and daughter Ruth, to whom the Society extends its deepest sympathy.

P.M.



SIR PHILIP BAXTER

John Philip Baxter, KBE, CMG, PhD, Hon. DSc, FRACI, FTS, FAA, who died on 5 September, 1989, was best known as the first Vice-Chancellor of the University of New South Wales -- an unenviable task. The new university did not have sufficient land or funds for its buildings, and had very little support from the community, most of whom believed that one university was all that each State needed. He pushed and prodded and coaxed the (then) New South Wales University of Technology into rapid growth both in size and in stature against considerable opposition, some even within the University; the rate of growth was too fast for some of the academics. When Professor J. P. Baxter became Vice-Chancellor in 1955, the University had 4034 students; when he retired from the University of New South Wales in 1969, there were 15,988.

John Philip Baxter was born on 7 May, 1905, in North Wales, attended school in Hereford and graduated in chemistry from Birmingham University. He was then awarded the James Watt Research Fellowship which he used in order to read for a Ph.D. in mechanical engineering. Thus a chemical engineer was created. He obtained a position with the newly-formed company ICI (Imperial Chemical Industries) and worked his way up to become Research Manager of the General Chemical Division at Widnes. During the war he was invited to the USA to advise the Oak Ridge Laboratories in Tennessee. The work there was mainly concerned with the atomic weapons programme, and Baxter's research concerned the separation of isotopes. Thus he became familiar with nuclear reactors.

In 1949 Baxter was appointed Foundation Professor of Chemical Engineering by the N.S.W. University of Technology, one of its first professors. He became Director in 1953; this title was changed to Vice-Chancellor in 1955. He proved himself to be a great educational administrator. During his regime he supervised the move to Kensington, the creation of new faculties, such as Medicine and Arts, and the extablishment of university colleges in Newcastle and Wollongong. One of his pioneering creations, in 1959, was Unisearch Ltd., the university's research and development company to link the university with industry. He was then much criticized for such practical applications of university research but by now every major university in Australia has established such an organization.

It appears from this account that Professor Baxter was a very busy man, yet he undertook many other responsibilities. He had a tremendous capacity for work. His secret was good organization, extensive delegation, and a clear view of the objectives to be achieved and of the means to achieve them. In 1953 he became Deputy Chairman, and in 1957 Chairman, of the Australian Atomic Energy Commission. Although he spent, on the average, only half a day per week on this task, he had a profound influence on the developments at Lucas Heights. His aim was the creation of a nuclear power plant in Australia; although a site was chosen at Jervis Bay and considerable site works were carried out, the Australian Government ultimately shelved this project. This must have been a great disappointment for Baxter but he continued in the chairmanship, full-time from 1969, until he retired in 1972.

Baxter had a great interest in the arts. In his younger days, and even when he became Vice-Chancellor, he acted in amateur theatrical productions; it was on one such occasion that he met his future wife, Lilian May Thatcher, in 1931. It is this interest which caused him to support the foundation of the National Institute of Dramatic Arts and to offer it a home in Kensington. The University provided NIDA with buildings and facilities; the buildings were only old huts but ultimately they were replaced by the present magnificent complex, still on ground owned by the University. NIDA proved to be an outstanding success: many of our best actors, directors and theatre designers are graduates of NIDA.

His interest in the arts may also have been partially responsible for his appointment as the first Chairman of the Sydney Opera House Trust (1968-1975). The logistics of running the multifarious activities of this cultural centre were worked out under Sir Philip's guidance.

Baxter was knighted in 1965 and was awarded the Kermot Medal in 1970. He was amongst the first scientists elected to the Australian Academy of Science in 1954; he was also elected a fellow of the Academy of Technological Sciences and Engineering. He was elected a member of the Royal Society of New South Wales on 7 June, 1950, and Honorary Member of the Society on 23 February, 1972.

His last years in retirement were marred by a progressive debilitating disease. He was bedridden when Lady Baxter, his beloved Lilian, died after a short illness in 1989. Sir Philip died five weeks later. He is survived by two sons and a daughter.

S. J. A.

ADDENDUM

Volume 122, page 77

In Volume 122, page 77 the title of Mr. D. Everett's thesis abstract should read:-

M.Sc. Thesis Abstract (University of Sydney): Rheological Properties of Coagulated Colloidal Suspensions.

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Some Natural and Unnatural Indoles*

David St. C. Black

ABSTRACT. New reactions of specially-activated indoles provide methods by which structures related to natural products can be produced. Various 4,6-dimethoxy-substituted indoles exhibit a variety of reactions, predominantly at C7, but others at C2 or C3 instead of C7. The general increase in nucleophilic character of these indoles allows the discovery of reactions which have not been observed for other indoles. These reactions include electrophilic substitution, and addition to aldehydes and ketones. Tri-indolyl macrocycles, pyrrolo[a]indoles, cyclopentano[b]indoles and indolocarbazoles can be produced. Furthermore, new ring-fused indoles can be prepared by intramolecular nitrone 1,3-dipolar cycloaddition reactions between N1 and C2 or N1 and C7. In the latter case, similar structures can be achieved by aldol-type or organometallic reactions. The use of N-aroylindoles enables some known pyrrolophenanthridone alkaloids and some of their unknown analogs to be synthesized effectively.

INTRODUCTION

The indole alkaloids form an enormous class of important natural products, which in many cases show potent biological activity. As a consequence of this, synthetic studies related to indoles in general and the indole alkaloids in particular continue to be explored by many groups.

Our own work has focussed on activation at C7, which has been achieved by methoxyl group substitution at C4 and C6. Not only does this substitution activate C7 in particular, but it enhances the general reactivity of the indoles, so that new reactions can be observed. Given suitable substitution patterns, reaction can occur at C7 alone, C2 and C7, N1 and C2, C2 and C3, and N1 and C7. Thus new ring-fused indoles can be formed. The main aim of our research is to establish routes to new classes of indoles, rather than to known alkaloid structures. We are especially interested in reaching structures similar to but different from the natural products. However, from time to time, our methods also enable us to achieve effective syntheses of some important indole alkaloids.

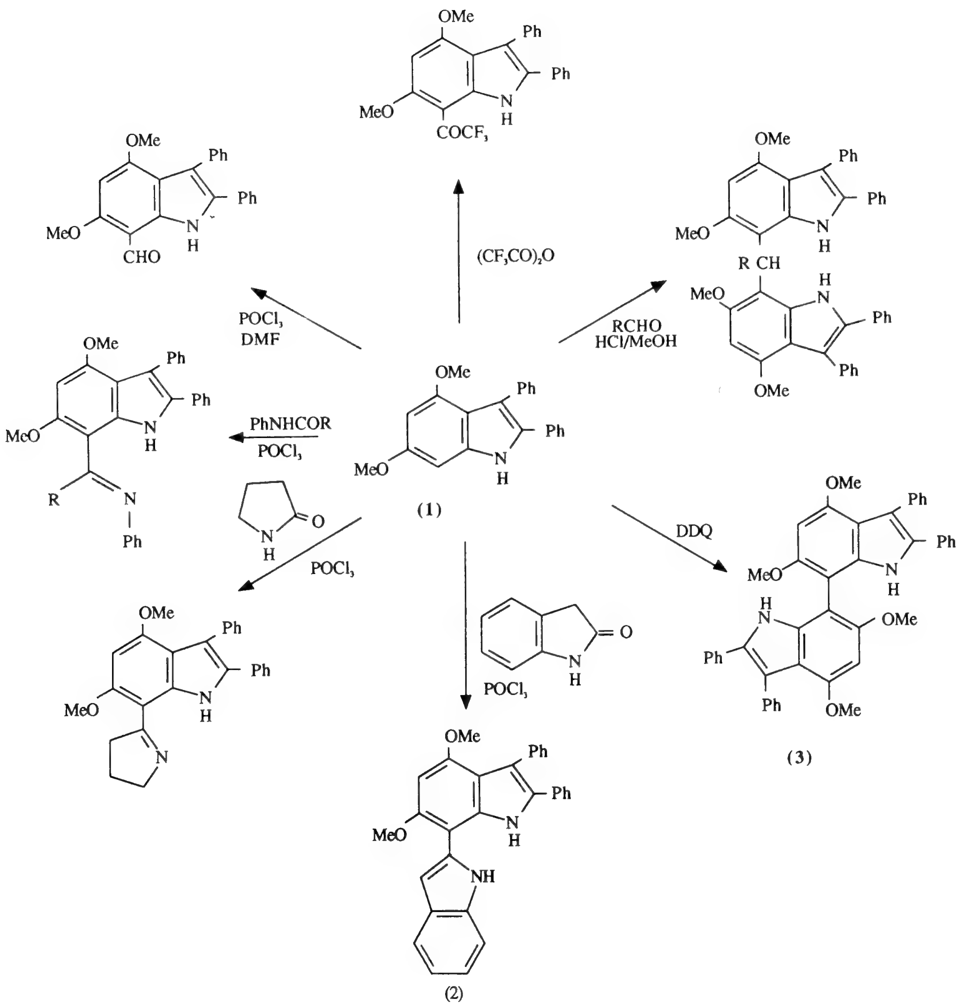
* Liversidge Research Lecture delivered before the Royal Society of New South Wales, September 5th, 1990, at the University of New South Wales.

C7 SUBSTITUTION

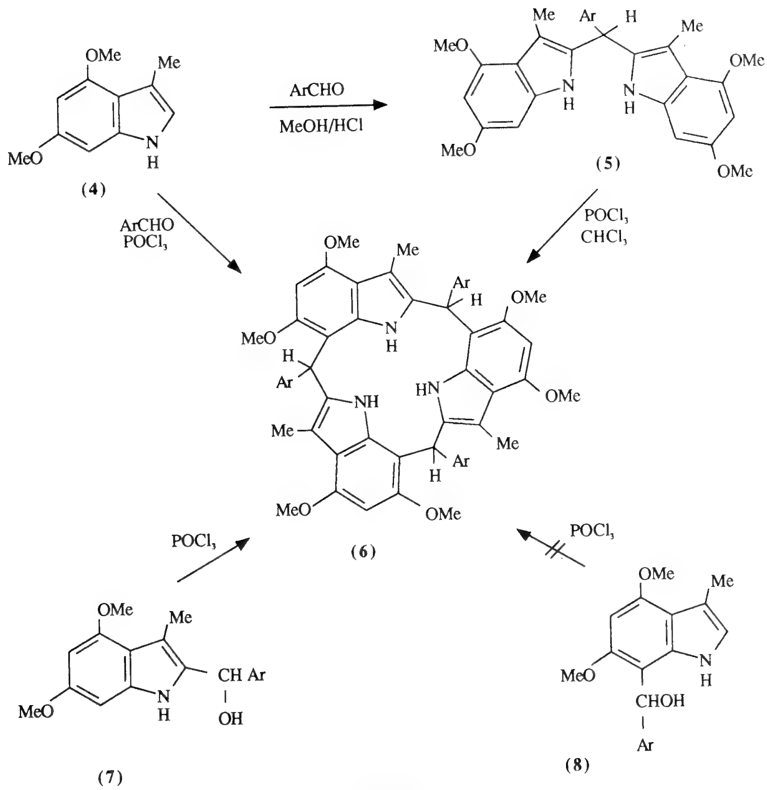
4,6-Dimethoxy-2,3-diphenylindole (1), prepared from benzoin and 3,5-dimethoxyaniline (Black *et al.*, 1986a), undergoes formylation (Black *et al.*, 1986b), acylation and acid-catalysed addition to aldehydes or α, β-unsaturated ketones, all at C7 (**Scheme 1**). Furthermore, the Vilsmeier formylation technique can be modified to attach imines at C7. In particular, the 2,7'-bi-indolyl (2) can be prepared from indolone and phosphoryl chloride (Black and Kumar, 1984). The general reactivity of the indole (1) is such that it readily undergoes oxidative dimerisation at C7 to give the 7,7'-bi-indolyl (3) (Black *et al.*, 1989a).

C7 AND C2 SUBSTITUTION

In contrast to the indole (1), 4,6-dimethoxy-3-methylindole (4) (Black *et al.*, 1983) undergoes formylation at both C7 and C2. However, addition to aldehydes occurs preferentially at C2 to give 2,2'-di-indolylmethanes (5). Either these or the initial indole (4) can allow formation of a remarkable group of macrocycles (6) under conditions involving phosphoryl chloride (Black *et al.*, 1989b) (**Scheme 2**). The parent compound (from benzaldehyde) has been shown by X-ray crystallography to have a very twisted structure, unlikely to provide any driving force for its formation (**Fig. 1**).


(CF$_3$CO)$_2$O
POCl$_3$
DMF
RCHO
HCl/MeOH
PhNHCOR
POCl$_3$
POCl$_3$
DDQ
POCl$_3$
(1)
(2)
(3)

Scheme 1



Scheme 2

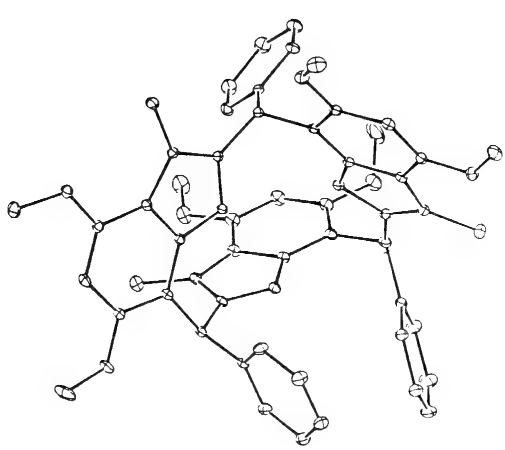
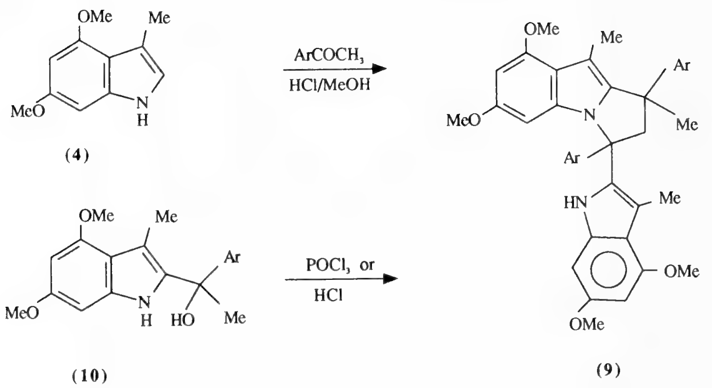


Fig.1 X-ray crystal structure of macrocycle (6: Ar = Ph)



Scheme 3

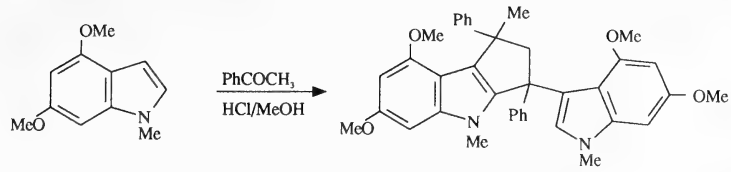
The macrocycle (6: Ar = 4Cl - Ph) can also be formed quantitatively from phosphoryl chloride and the 2-substituted alcohol (7), but not the 7-substituted alcohol (8). This implicates an intermediate which is nucleophilic at C7 and electrophilic at the C2 methyl carbon.

Formation of the macrocycles (6) is similar to the synthesis of porphyrins from pyrrole and aryl aldehydes. However, in the latter case, the corresponding macrocyclic tetrapyrrole undergoes rapid oxidation to produce the highly stable aromatic porphyrin structure. A similar situation cannot arise in the case of macrocycles (6).

N1 AND C2 SUBSTITUTION; C2 AND C3 SUBSTITUTION: FORMATION OF PYRROLO-INDOLES AND CYCLOPENTANO-INDOLES

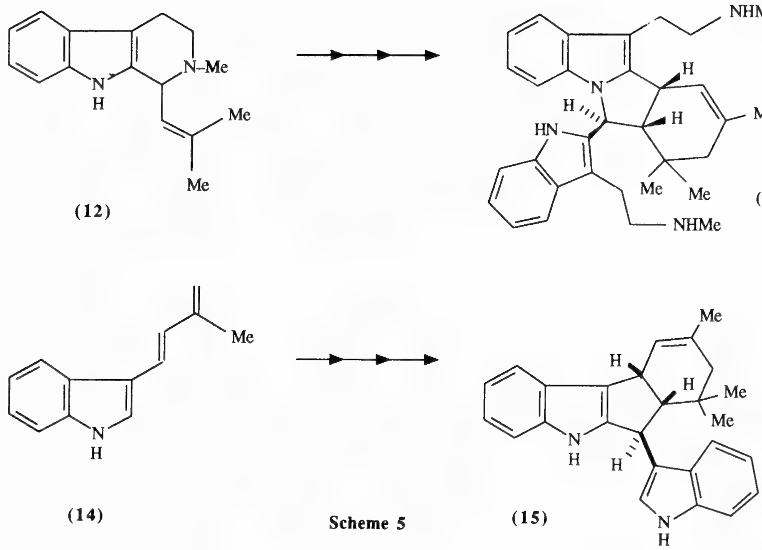
In an attempt to extend this reaction from aryl aldehydes to ketones, the indole (4) was reacted with several acetophenones. Conditions using phosphoryl chloride gave intractable mixtures but methanolic hydrogen chloride allowed the surprising formation in good yields of the pyrrolo [a] indoles (9) instead of di-indolylmethanes or macrocycles (**Scheme 3**). Again the same products could be formed from the related 2-substituted tertiary alcohols (10). The products (9) were obtained as a mixture of diastereomers, and the structure of the parent (Ar = Ph) confirmed by X-ray crystallography.

It is believed that dehydration of the tertiary alcohols (10) would yield 2-vinyl indoles (or related carbocations) capable of dimerization to give the products (9). One important aspect of this reaction is the absence of any attack at C7 and the methoxyl groups appear to play only a general activation role. For example, no reaction occurs between acetophenone and 3-methylindole, whilst 1-methylindole gives a 3,3'-di-indolylmethane. 4,6-Dimethoxy-1-methylindole reacts with acetophenone in a manner analogous to the 3-methyl compound (4) to give a cyclopentano [b] indole (11), again as a mixture of diastereomers (**Scheme 4**).



(11)

Scheme 4



(12) (13) (14) (15)

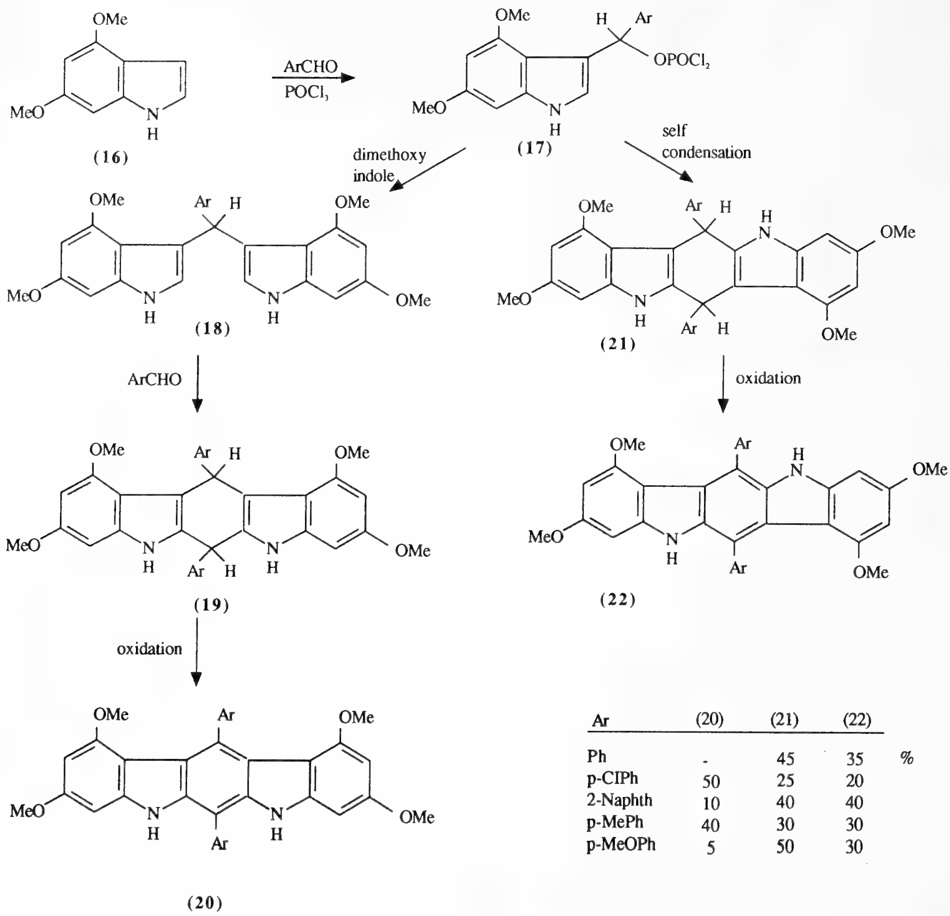
Scheme 5

Formation of compounds (9) and (11) are of interest in relation to the natural indoles isoborreverine (13) and yuehchukene (15) respectively. Isoborreverine is a minor constituent of *Borreria verticillata* and *Flindersia fournieri* and has been shown to arise by dimerization of borrerine (12) in a biomimetic synthesis (Tillequin *et al.*, 1978) (**Scheme 5**). The more important anti-fertility agent yuehchukene (15), from *Murraya paniculata* (Kong *et al.*, 1985) has been synthesised biomimetically from 3-isoprenylindole (14) (Cheng *et al.*, 1985; Wenkert *et Al.*, 1988) (**Scheme 5**).

C2 AND C3 SUBSTITUTION: FORMATION OF CARBAZOLES

The reaction of the 3-methyl indole (4) with aryl aldehydes and phosphoryl chloride gave macrocyclic structures as the result of reaction at the two available sites, C2 and C7. 4,6-Dimethoxyindole (16) has three available reaction sites, C3, C2 and C7. It was found that reaction with aryl aldehydes and phosphoryl chloride gave indolo-carbazoles (20) and (22), together with the dihydro-analog (21) (**Scheme 6**). In this instance reaction has occurred at C3 and C2, but not at C7. Again indole itself does not undergo this reaction, so that the two methoxyl groups provide increased general reactivity, without selectively activating C7. Clearly the formation of a six-membered ring between C3 and C2, and its subsequent aromatization provide effective driving forces in this reaction.

The respective product yields are shown in **Scheme 6**. In all cases except for *p*-chlorobenzaldehyde there is a predominance of products arising from the self-condensation of the presumed intermediate (17) over those arising from the 3,3'-di-indolylmethane (18). It is noteworthy that none of the dihydro compound (19) could be detected, being presumably more readily oxidised to the indolocarbazole (20) than dihydro-compound (21) is oxidised to its related aromatic structure (22). The indolocarbazoles (20) and (22) offer new structures which are of interest because of the succession of five fused aromatic rings. They are reminiscent of some indole alkaloids (such as ellipticine) which show anti-tumour activity by their ability to intercalate into the DNA chain. There is clearly an opportunity to develop the chemistry of these new structural types.



Ar	(20)	(21)	(22)	
Ph	-	45	35	%
p-ClPh	50	25	20	
2-Naphth	10	40	40	
p-MePh	40	30	30	
p-MeOPh	5	50	30	

Scheme 6

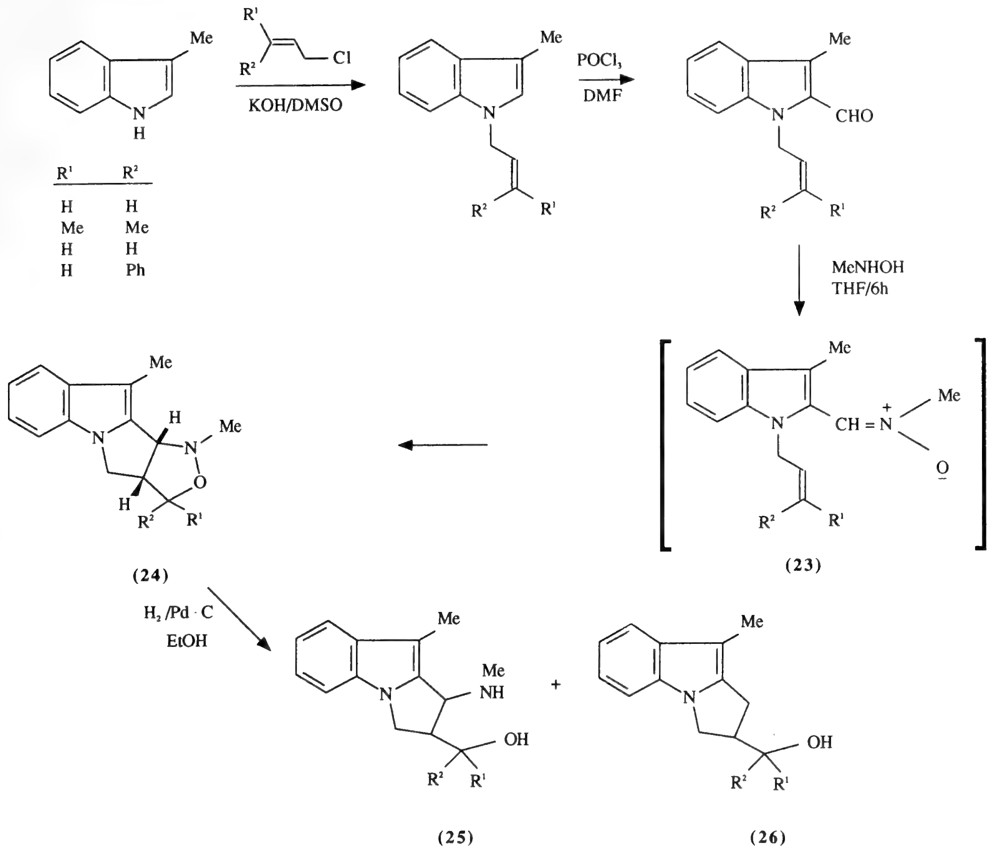
N1 AND C2 SUBSTITUTION: FORMATION OF PYRROLO-INDOLES

The previously-described strategy of methoxyl group activation is not the only one able to build a five-membered ring between N1 and C2. A more direct approach simply involves a suitable intramolecular reaction between pre-arranged substituents at N1 and C2. We have chosen to investigate such an approach using intramolecular nitrone 1,3-dipolar cycloaddition. Thus a 3-methyl N-allyl indole can be formylated at C2, such that subsequent reaction with N-methylhydroxylamine affords the cycloadduct (24), presumably via an intermediate nitrone derivative (23) (**Scheme 7**).

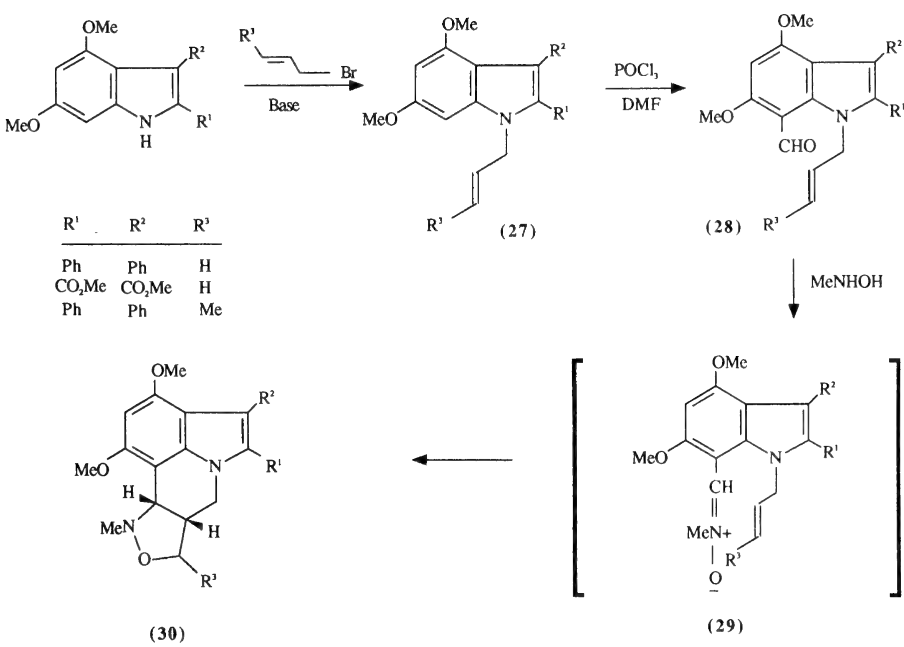
The cycloadducts (24) can be hydrogenolysed to give the amino-alcohols (25) as the major products, together with traces of some alcohols (26), which are the products of further reaction. Although we have not yet maximised yields, it is clear that either product could be obtained reasonably selectively, by an adjustment of reaction conditions.

N1 AND C7 SUBSTITUTION

The intramolecular nitrone cycloaddition strategy can also be applied to cyclization between N1 and C7. Here, however, 4,6-dimethoxy activation is again required for substitution at C7. Thus formylation of the N-allyl indoles (27) gives the 7-formyl compounds (28) which undergo reaction with N-methylhydroxylamine to give the cycloadducts (30) in high yield, again presumably via a nitrone derivative (29) (**Scheme 8**).

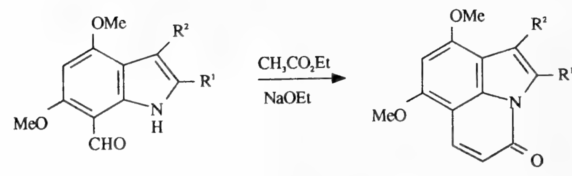


Scheme 7



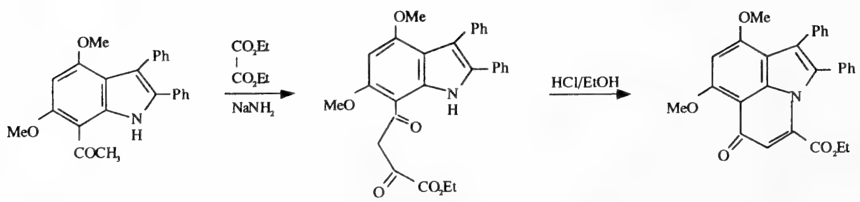
Scheme 8

R^1	R^2
H	H
Ph	Ph
Ph	H
p- BrPh	H
H	Me
–(CH$_2$)$_4$–	



(31) (32)

Scheme 9



(33) (34) (35)

Scheme 10

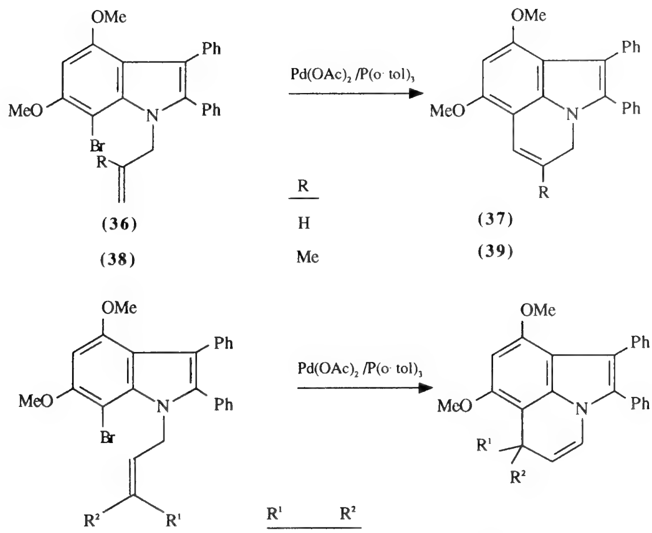
The cycloadducts (30) have yet to be submitted to further transformations.

Numerous possibilities arise for cyclization between substituents at N1 and C7 especially for the formation of pyrroloquinoline derivatives (Black and Kumar, 1990). For example, the 7-formyl compounds (31) can be reacted with ethyl acetate and sodium ethoxide to give excellent yields of the pyrrolo-quinolin-4-ones (32) (Black *et al.,* 1989c) (**Scheme 9**).

Alternatively, the pyrroloquinolin-6-one (35) can be prepared easily by acid-catalysed cyclization of the glyoxylic ester (34) derived in turn from the 7-acetyl indole (33) and diethyl oxalate in the presence of sodamide (**Scheme 10).**

A more effective and general route for the formation of a six-membered ring between N1 and C7 involves the palladium-catalysed cyclization of a 7-bromo-N-allyl indole. The initial example involved the 7-bromo-N-allyl indole (36) which was generated by allylation of the related 7-bromo-indole: bromination of the related N-allyl indole could not be achieved. On treatment with palladium (II) acetate, tri-o-tolylphosphine and triethylamine in acetonitrile, indole (36) afforded a quantitative yield of the pyrroloquinoline derivative (37) (**Scheme 11**). This reaction was extended to the substituted allyl indoles (38), (40), (42), (44) which in turn yielded compounds (39), (41), (43), (45) respectively (**Scheme 11**). Double bond migration was observed to give both compounds (41) and (43). However, both products (39) and (45) were unstable and rapidly decomposed to tars, although spectroscopic evidence could be obtained for the proposed structures.

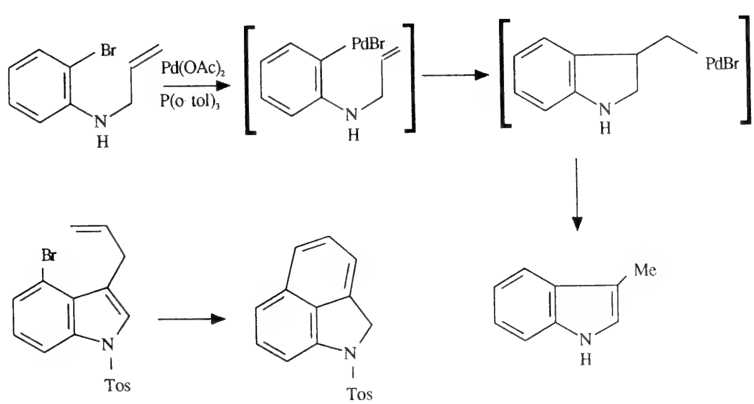
It is significant that only six-membered ring formation occurred in these examples of peri-cyclization. This type of organopalladium cyclization was developed by Hegedus *et al.,* (1978) as a 3-methyl indole synthesis from o-bromo-N-allylaniline via an aryl palladium intermediate (**Scheme 12**). More recently however, a similar reaction of the peri-substituted 3-allyl-4-bromo indole also gave selective six-membered ring formation (Harrington and Hegedus, 1984) (**Scheme 12**).



Substrate	R	Product
(36)	H	(37)
(38)	Me	(39)

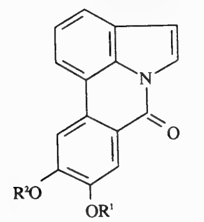
Substrate	R1	R2	Product
(40)	H	Me	(41)
(42)	Me	Me	(43)
(44)	H	Ph	(45)

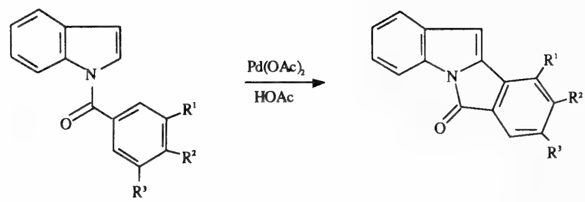
Scheme 11



Scheme 12

R¹	R²	
$-CH_2-$		(46)
Me	H	(47)
H	Me	(48)
Me	Me	(49)





	R¹	R²	R³		
(50)	H H	H		(51)	30%
(52)	MeO	MeO	MeO	(53)	70%
(54)	H	$-OCH_2O-$		(55)	30%

+ C2 regioisomer 30%

Scheme 13

The success of this type of organometallic cyclization to give pyrroloquinolines led us to consider related methods for the synthesis of benzo-analogs such as the pyrrolophenanthridones, which form a small but interesting group of natural products from several *Amaryllidaceae* species. Examples are hippadine (46), pratorimine (47), pratorinine (48) and pratosinine (49).

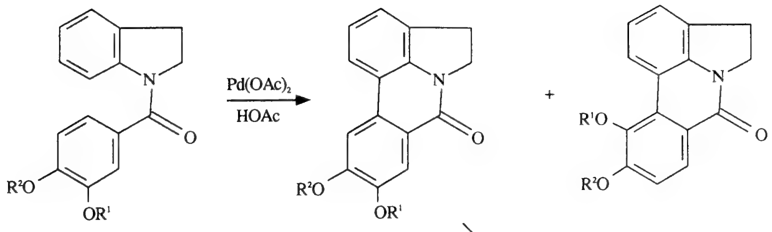
Hippadine shows strong anti-fertility activity in rats and is under further biological investigation. Before our work commenced, hippadine had already been synthesised by two groups in very poor yields after very lengthy sequences (Hayakawa *et al.*, 1987; Prabhakar *et al.*, 1987).

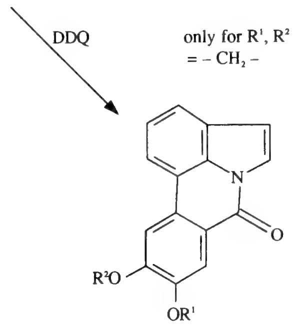
Itahara (1979) had also shown that N-benzoylindole (50) underwent cyclization at C2, on treatment with a stoichiometric amount of palladium (II) acetate in acetic acid, to give product (51) in 30% yield. We then found that the oxygenated benzoyl indoles (52) and (54) gave higher yields of cyclized products (53) and (55) respectively, but still showed regioselectivity for C2 cyclization: no cyclization to C7 was observed (**Scheme 13**).

Since cyclization of the N-aroylindoles occurred at C2, we removed this possibility by moving to the corresponding dihydroindoles. Indeed, palladium (II) acetate effected cyclization of the dihydroindoles (56 - 59) exclusively at C7, to give the phenanthridones (60 - 63), which could be oxidised by dichlorodicyanoquinone to the related indoles (Black *et al.*, 1989d). The choice of substituents was such that hydrogenolysis of benzyl groups afforded syntheses of pratorimine (47) and pratorinine (48) whilst hippadine (46) and pratosinine (49) were formed directly (**Scheme 14**).

The dihydropyrrolophenanthridone (63) (formed in 60% yield) is also a known alkaloid, oxoassoanine (Llabres *et al.*, 1986). The hippadine precursor (56) was the only one to give a mixture of regioisomers. Although the yields are only modest and the key reaction has not yet been made catalytic, the route is very direct and certainly the most effective so far, despite a more recent synthesis involving intermolecular coupling (Siddiqui and Snieckus, 1990).

In view of our success with C7 activation by methoxyl substitution at C4 and C6, we investigated related cyclizations of N-aroyl-4,6-dimethoxyindoles (64). These were particularly successful, showing regioselectivity for C7 cyclization and also giving good yields (60-80%) of pyrrolophenanthridones (65) (**Scheme 15**).

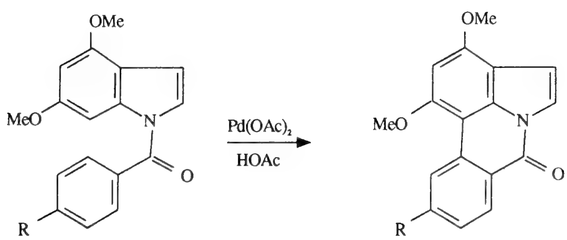




only for R^1, R^2 = – CH$_2$ –

	R^1	R^2		Yield %
(56)	– CH$_2$ –		(60)	15 + 10
(57)	Me	PhCH$_2$	(61)	25
(58)	PhCH$_2$	Me	(62)	25
(59)	Me	Me	(63)	60

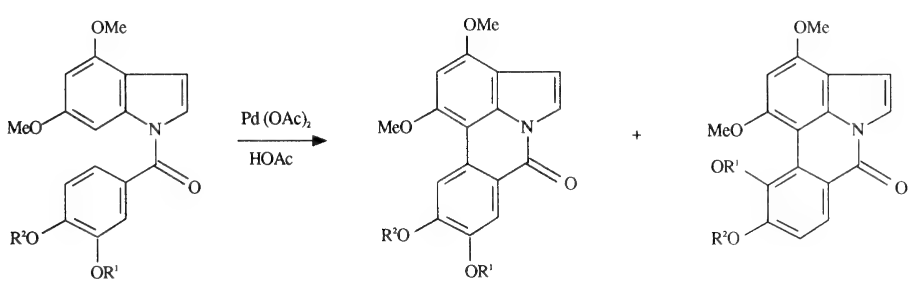
Scheme 14



(64) (65)

R = H, Me, Cl, OMe

Scheme 15



only for R^1, R^2 = – CH$_2$ –

R^1	R^2
–CH$_2$–	
Me	PhCH$_2$
PhCH$_2$	Me

Scheme 16

This approach was followed up in order to make the dimethoxy analogs of some of the pyrrolophenanthridone alkaloids. Here the yields were lower (30%) and again the methylene dioxy compound gave a mixture of regioisomers (**Scheme 16**).

It remains to be seen whether any of the dimethoxy compounds will emerge as natural products and it will also be of interest to see what effect the methoxyl groups have on the biological activity of these new analogues.

In summary, a wide range of new indole reactions has been discovered, by the use of 4,6-dimethoxy substitution. In some cases, this results in regioselective reaction at C7, our initial goal. However, the general increase in indole activity has led to the observation of quite new and exciting structures as a result of more conventional reaction at C3 and C2. Although our work has led to effective syntheses of some naturally-occurring indoles, it is more significant for the deliberate and accidental generation of totally unnatural products. We shall continue to investigate the chemistry of these new systems as well as the wider development of the reactivity of other highly activated indoles.

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REFERENCES

Black, D.St.C., Choy, A., Craig, D.C., Ivory, A.J. and Kumar, N., 1989a. Formation of 7,7'-bi-indolyls by oxidative dimerization of 4,6-dimethoxy-2,3-diphenylindole. *Journal of the Chemical Society, Chemical Communications,* 111-112.

Black, D.St.C., Craig, D.C. and Kumar, N.,1989b. Synthesis of a new class of indole-containing macrocycles. *Journal of the Chemical Society, Chemical Communications*, 425-426.

Black, D.St.C., Ivory, A.J., Keller, P.A. and Kumar, N., 1989c. A ready synthesis of 4-oxo-4H-pyrrolo[3,2,1-ij]quinolines. *Synthesis*, 322-323.

Black, D.St.C., Keller, P.A. and Kumar, N., 1989d. A direct synthesis of pyrrolophenanthridone alkaloids. *Tetrahedron Letters*, **30**, 5807-5808.

Black, D.St.C. and Kumar, N., 1984. A general strategy for the synthesis of 2,2'-, 2,3'-, and 2,7'-bi-indolyls. *Journal of the Chemical Society, Chemical Communications*, 441-442.

Black, D. St. C. and Kumar, N., 1990. Pyrroloquinolines. *Organic Preparations and Procedures International,* in press.

Black, D.St.C., Kumar, N. and Wong, L.C.H., 1986a. Synthesis of 4,6-dimethoxyindoles. *Australian Journal of Chemistry,* **39**, 15-20.

Black, D.St.C., Kumar, N. and Wong, L.C.H., 1986b Synthesis of 2-(7-indolyl)-benzimidazoles via 7-formylindoles. *Synthesis* , 474-476.

Black, D.St.C., Rothnie, N.E. and Wong, L.C.H., 1983. Metal template reactions. XX.. Macrocyclic metal complexes derived from 4,6-dimethoxy-3-methylindole-2,7-dicarbaldehyde and some primary diamines with additional donor atoms. *Australian Journal of Chemistry,* **36**, 2407-2412.

Cheng, K.F., Kong, Y.C., and Chan, T.Y., 1985. Biomimetic synthesis of yuehchukene. *Journal of the Chemical Society, Chemical Communications*, 48-49.

Harrington, P.J. and Hegedus, L.S., 1984. Palladium - catalyzed reactions in the synthesis of 3- and 4-substituted indoles. Approaches to ergot alkaloids. *Journal of Organic Chemistry,* **49**, 2657-2662.

Hayakawa, K., Yasukouchi, T. and Kanematsu, K., 1987. A new approach to pyrrolophenanthridone alkaloids via allene intramolecular cycloaddition : total synthesis of hippadine. *Tetrahedron Letters*, **28**, 5895-5898.

Hegedus, L.S., Allen, G.F., Bozell, J.J. and Waterman, E.L., 1978. Palladium - assisted intramolecular amination of olefins. Synthesis of nitrogen heterocycles. *Journal of the American Chemical Society,* **100**, 5800-5807.

Itahara, T., 1979. Intramolecular ring closure of 1-aroylindoles by palladium acetate. *Synthesis,* 151-152.

Kong, Y.C., Cheng, K.F., Cambie, R.C. and Waterman, P.G., 1985. Yuehchukene : a novel indole alkaloid with anti-implantation activity. *Journal of the Chemical Society, Chemical Communications*, 47-48.

Llabres, J.M., Viladomat, F., Bastida, J., Codina, C. and Rubiralta, M., 1986. Phenanthridine alkaloids from *Narcissus assoanus*. *Phytochemistry,* **25**, 2637-2638.

Prabhakar, S., Lobo, A.M. and Marques, M.M., 1987. A new synthesis of the Amaryllidaceae alkaloid hippadine. *Journal of Chemical Research (S),* 167.

Siddiqui, M.A. and Snieckus, V., 1990. Concise syntheses of the Amaryllidaceae alkaloids ungerimine and hippadine via the Suzuki aryl-aryl cross coupling reaction. *Tetrahedron Letters,* **31**, 1523-1524.

Tillequin, F., Koch, M., Pousset, J.L. and Cavé, A. 1978. Biomimetic synthesis of borreverine and isoborreverine. *Journal of the Chemical Society, Chemical Communications*, 826-828.

Wenkert, E., Moeller, P.D.R., Piettre, S.R. and McPhail, A.T., 1988. Yuehchukene analogues. *Journal of Organic Chemistry,* **53**, 3170-3178.

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Imbrication of a Reference Section: Re-evaluation of the Adaminaby Beds at El Paso, Dalgety, New South Wales

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ABSTRACT. Re-examination of a reference section through the Adaminaby beds at El Paso, west of Dalgety in southern New South Wales, does not support the conventionally held belief that rocks here form a simple Upper Ordovician homoclinal sequence which dips and youngs to the west. Rather, there has been thrust interleaving of a Lower Ordovician turbidite-chert sequence with an Upper Ordovician black shale sequence. The El Paso area thus lies in a thin-skinned thrust belt which was first recognized in the Delegate area 60 km to the south and which also extends north and east of Dalgety. Recognition of this thrust style of deformation at El Paso has led to the redefinition of the stratigraphic section here, which contains only a single Upper Ordovician black shale, the Warbisco Shale, and a single Lower Ordovician sequence which is redefined as the Adaminaby Group.

INTRODUCTION AND BACKGROUND GEOLOGY

Granitoids and Ordovician metasediments constitute the major elements of the southeastern part of the Lachlan Fold Belt between Canberra and the Victorian coastline (Fig. 1a). In contrast to the vast amounts of data collected on the granitoids, there are few data available on the Ordovician metasediments which go under a variety of formal and informal stratigraphic names such as "coastal greywacke facies", "inland facies", Mallacoota beds, Foxlow beds, Adaminaby beds, Nungar beds. This paper focuses on low-grade Ordovician metasediments in the greater Snowy Mountains area, stretching from Canberra southwards through Dalgety and Delegate to the Victorian coast (Fig. 1a), and presents new structural and palaeontological data which clarify stratigraphic and structural relations through a critical part of the Adaminaby beds.

Ordovician sedimentary rocks of the greater Snowy Mountains region are particularly poorly known. In northeastern Victoria, a sequence of Ordovician turbidites and black shales is known merely as "undifferentiated Ordovician", (e.g., on the TALLANGATTA 1:250,000 sheet). Across the border in New South Wales, the name Adaminaby beds has been used for a similar sequence of turbidites, black shales and cherts. The name Adaminaby beds was first used by Adamson in 1951, superseding the name Stony Creek-Barney's Range sediments of Mulholland (1941), but was only introduced into the literature by Fairbridge (1953). Adamson (1953) subsequently used the name as well. Graptolitic black shales were used to assign a Late Ordovician age to the unit (e.g., Hall 1952), but lithological and age relations were incompletely known. Although a type section has never been defined for the Adaminaby beds, the name was presumably taken from the old township of Adaminaby which was inundated by Lake Eucumbene in the late 1950s.

More recent mapping of the Adaminaby beds has been carried out by White et al. (1977) and by Owen and Wyborn (1979). Although White et al. (1977) concentrated on details of the granitoids on the BERRIDALE 1:100,000 sheet, they did report (p. 19) that in the El Paso area "a section [of turbidite, chert and black shale] which has escaped strong deformation and in which a chert bed occurs slightly higher in the succession than a prominent black slate horizon". It was only in this area of "overall simple structure" (p. 95) — in the west-dipping limb of a north-plunging anticline (see Fig. 1b) — that they were able for the first time to define a stratigraphic section for the Adaminaby beds.

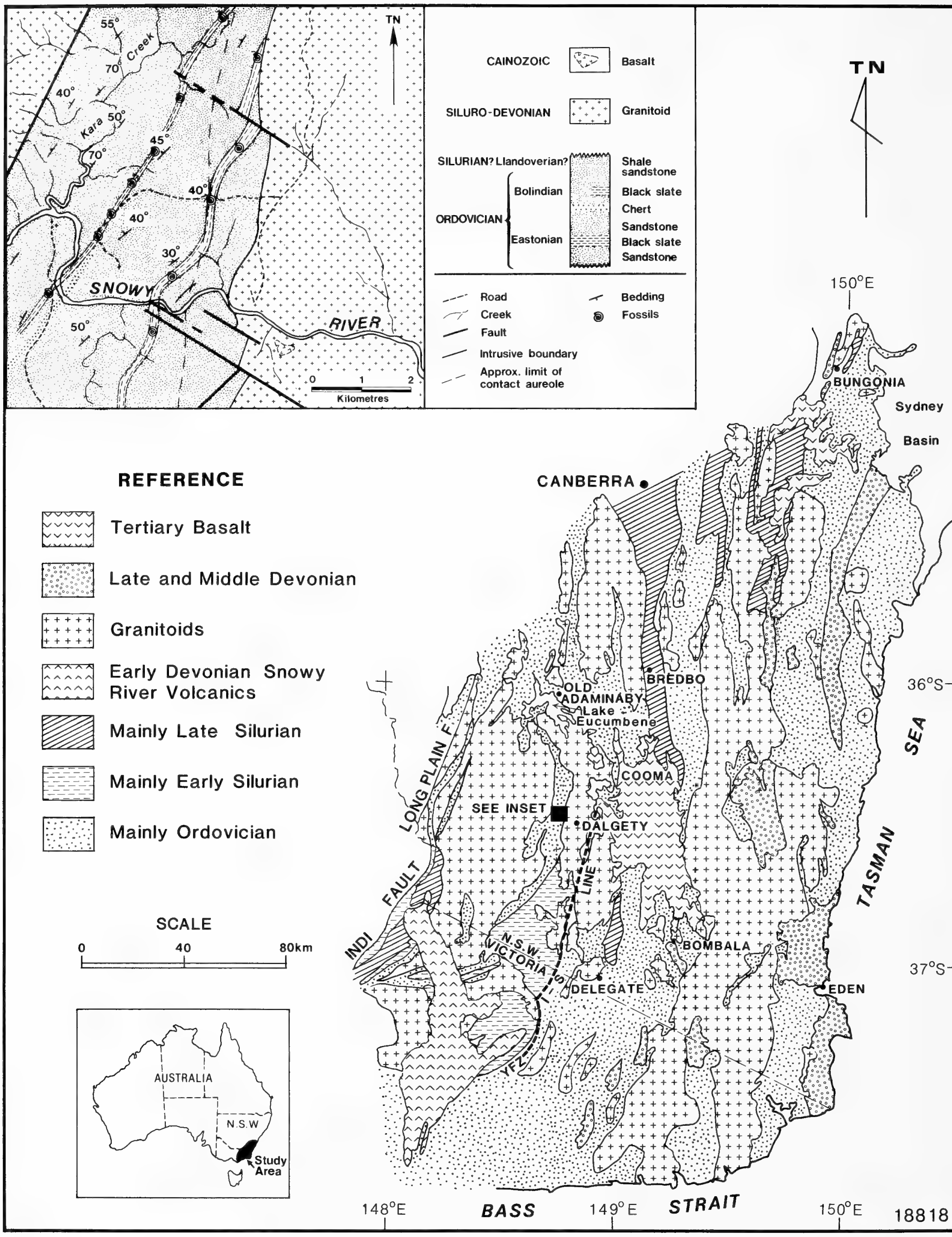


Figure 1.a. Regional geological map (modified and much simplified from Pogson 1972 and VandenBerg 1988) showing major geological elements in the southeastern part of the Lachlan Fold Belt. Note that faults have not been shown and that the southern part of the I-S Line is shown, where it corresponds with the Yalmy - McLaughlin Creek Fault Zone (YFZ). The location of the El Paso area is shown by the hatched box.

b. Map of the El Paso area from White et al. (1977).

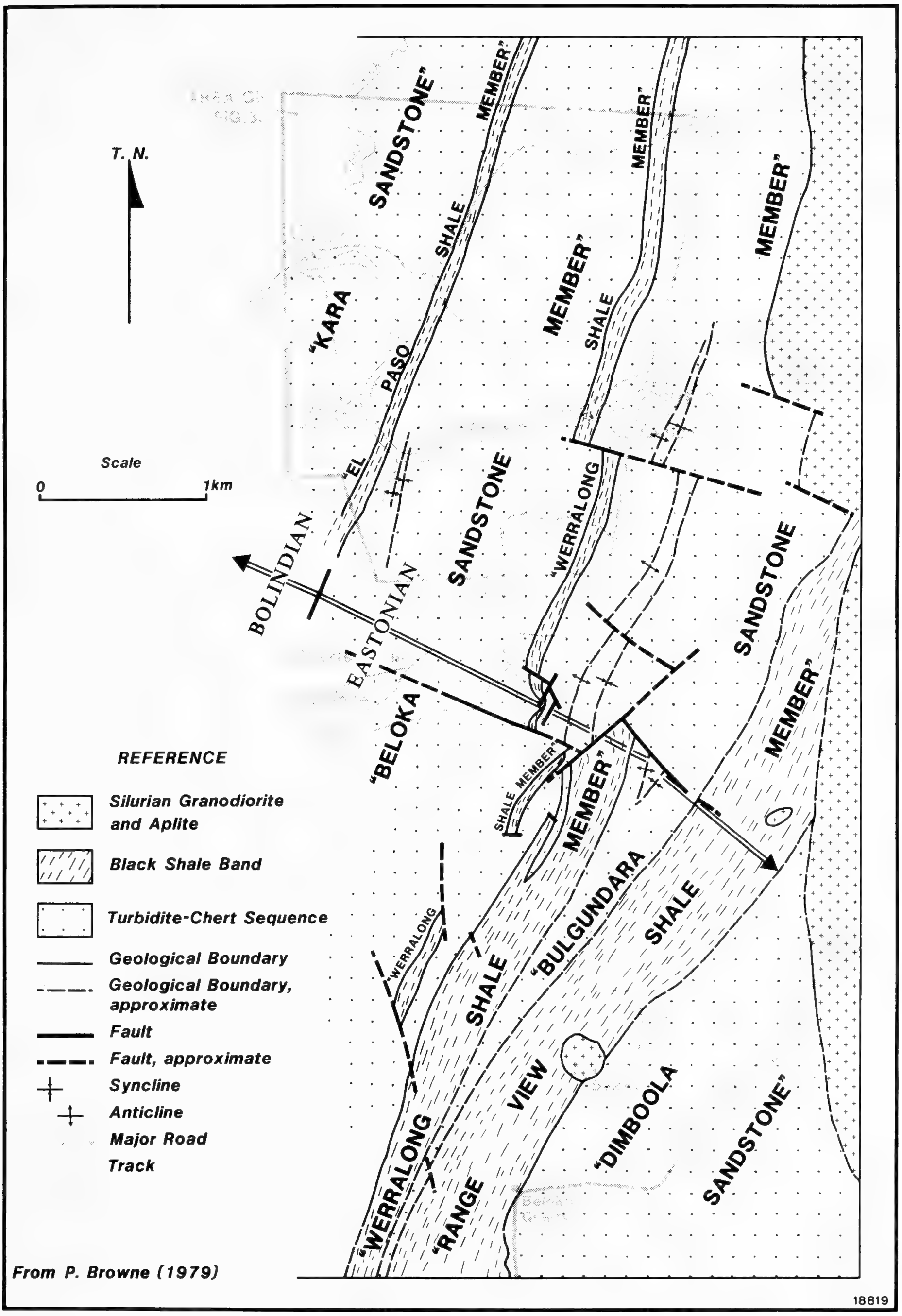
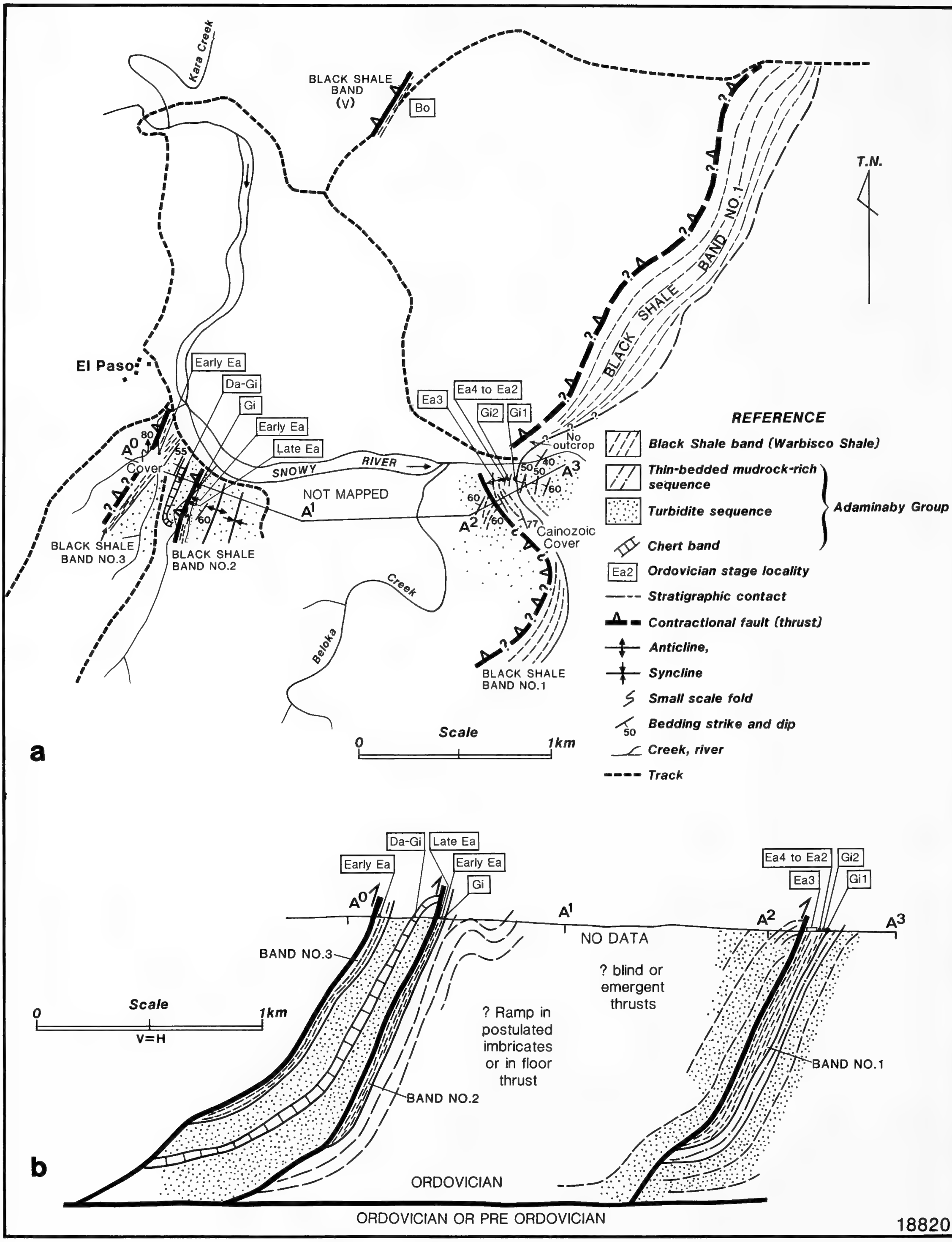


Figure 2. Map of the El Paso area from Browne (1979) showing his subdivision into three separate "stratigraphic" black shale units separated by turbidite - chert units. See text for discussion. Location of figure 3 is indicated by box.


Kara Creek
BLACK SHALE BAND (V)
Bo
T.N.
BLACK SHALE BAND NO.1
El Paso
Early Ea
Da-Gi
Gi
Early Ea
Late Ea
Ea3
Ea4 to Ea2
Gi2
Gi1
No outcrop
A0
80
55
Cover
SNOWY RIVER
NOT MAPPED
A1
A2
A3
60
50
40
77
Cainozoic Cover
BLACK SHALE BAND NO.3
BLACK SHALE BAND NO.2
Creek
Beloka
BLACK SHALE BAND NO.1
REFERENCE
Black Shale band (Warbisco Shale)
Thin-bedded mudrock-rich sequence
Turbidite sequence
Adaminaby Group
Chert band
Ea2 Ordovician stage locality
Stratigraphic contact
Contractional fault (thrust)
Anticline,
Syncline
Small scale fold
Bedding strike and dip
Creek, river
Track
Scale
0
1km
a
Da-Gi
Late Ea
Early Ea
Early Ea
Gi
Ea4 to Ea2
Gi2
Ea3
Gi1
A0
A1
A2
A3
NO DATA
? blind or emergent thrusts
BAND NO.3
Scale
0
1km
V=H
? Ramp in postulated imbricates or in floor thrust
BAND NO.2
BAND NO.1
b
ORDOVICIAN
ORDOVICIAN OR PRE ORDOVICIAN
18820

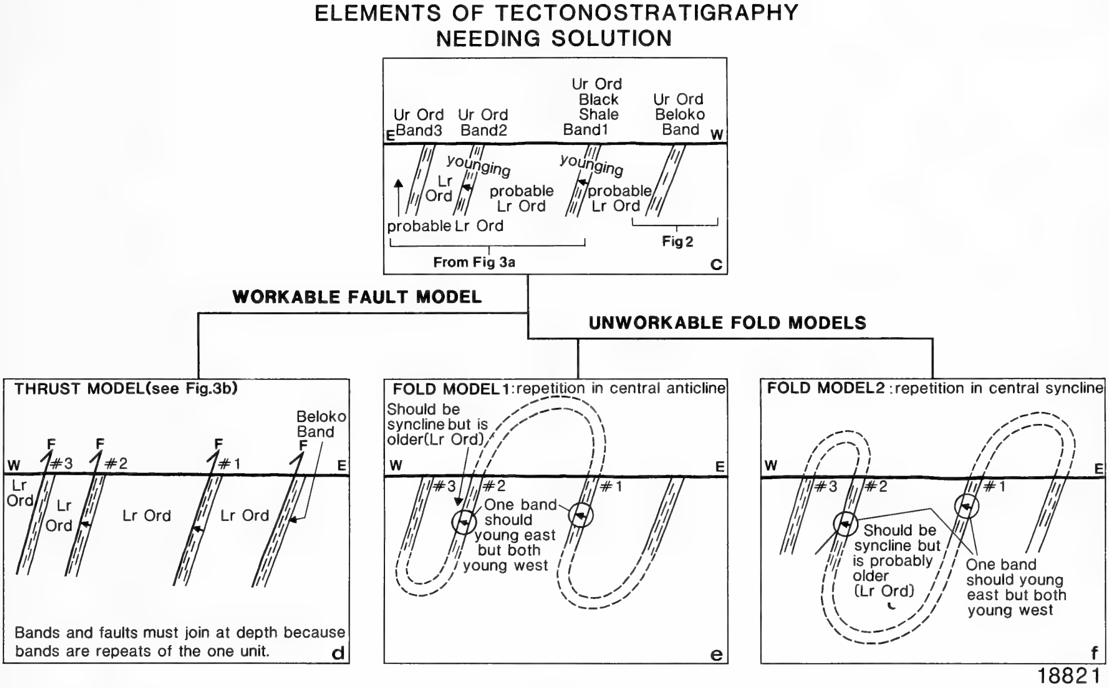


Figure 3. Map (Fig. 3a) and section (Fig. 3b) showing reinterpretation of part of the El Paso area along the Snowy River in terms of an imbricate splay system involving the Upper Ordovician Warbisco Shale and the Lower Ordovician Adaminaby Group. Stage names in the Upper Ordovician are as follows: Gi = Gisbornian; Ea = Eastonian; Bo = Bolindian. In Fig. 3b, position of floor thrust is uncertain. See text for explanation. Figs 3c-3d explain derivation of the structural model, starting from Fig. 3c which presents the raw field data. Fig. 3d is workable. As explained in the text,Figs 3e and 3f are not.

On the TANTANGARA 1:100,000 sheet further north, Owen and Wyborn (1979) concluded that, despite their recent mapping, the Adaminaby beds was still incompletely unknown and they did not formalize the name. Poor outcrop and faulting prevented them from defining a type section around Lake Eucumbene (close to the original type locality of the unit), but they suggested a 150 m — thick reference section along the southern bank of the Murrumbidgee River, some 6 km east of the township of New Adaminaby.

The thinness of Owen and Wyborn's section — only 150 m — precludes it from serving as a representative section for the widely outcropping Adaminaby beds. As a result, and in the absence of a properly defined type section, the El Paso area figured by White et al. (1977) has become the only reference section through the Adaminaby beds,as it were,a *de facto* type section. Further work was done on this section by Browne (1979) (see below), who like White et al. (1977, Fig. 16), interpreted this El Paso section to young and dip to the west (Fig. 1b).

Because of its importance, the El Paso reference section was examined by us in 1989 as part of the remapping of the BEGA 1:250,000 sheet being carried out by the Geological Survey of New South Wales. This re-examination took place in the light of two recent advances in the understanding of the geology of southeastern Australia. The first was work which indicated that large areas of so-called Ordovician rocks in the Snowy Mountains area and northeastern Victoria had been reassigned to the Early Silurian (Owen and Wyborn 1979, VandenBerg 1981, Glen et al. 1987). The second was the recent documentation of a thin-skinned, thrust style of deformation south and west of Delegate where Silurian rocks are interleaved with Upper Ordovician black shales (Glen and VandenBerg 1987).

This recent re-examination of the El Paso section indicates major differences from the simple interpretation of White et al. (1977) and Browne (1979), and the rocks are here instead interpreted as lying in an imbricate thrust system, part of the thrust belt recognised to the south by Glen and VandenBerg (1985,1987).

PREVIOUS INTERPRETATION OF THE EL PASO SECTION

The El Paso section is centred just east of the confluence of Kara Creek and the Snowy River, and lies some 10 km west of Dalgety on the BERRIDALE 1:100,000 sheet. The stratigraphy here was first described by White et al. (1977) and subsequently by Browne (1979). White et al. (1977) described the stratigraphy in this area as consisting of three turbidite-chert sequences separated by two black shale bands (Fig. 1b). They used graptolite identifications by Sherrard (in Hall 1956) and Wain (unpublished) to assign ages to these units. The eastern turbidite sequence plus the eastern black shale band were assigned to the Eastonian (middle Late Ordovician) and the western black shale plus the western turbidite sequence, extending west to the Barneys Range Fault, to the Bolindian (upper Late Ordovician) and ?Llandovery (Early Silurian).

Subsequent mapping and study of the graptolites by Browne (1979) refined the previous stratigraphy and the age control in the El Paso area. Browne mapped out the two black shale bands and the three turbidite-chert sequences of White et al. (1977). In addition, he recognised an additional black shale further east in the Beloko area (Fig. 2). These three black shale bands and the intervening turbidite-chert sequences were regarded as separate stratigraphic units and were given member status. From his graptolite identifications, Browne also concluded, like White et al. (1977), that these rock units form part of a west-dipping and — younging sequence in the Adaminaby beds. He suggested that the Bolindian part of the sequence extends from the "El Paso Shale Member" westwards to the Barneys Range Fault, and that the underlying Eastonian part of the sequence comprises three turbidite-chert members ("Beloko Sandstone Member", "Bulgundara Sandstone Member", "Dimboola Sandstone") interbedded with the eastern two of his black shale bands ("Range View Shale Member" and "Werralong Shale Member").

RESULTS OF THE PRESENT STUDY

Our present interpretion of the geology of the El Paso area is summarized in Fig. 3, and is based upon reconnaissance mapping and fossil collecting along the

Snowy River, as well as examination of most of Browne's collected material. Although additional work still needs to be undertaken, our studies are sufficiently detailed to demonstrate that major problems exist with the previous interpretations of the geology in this area. In presenting the results of our own work below, we refer to the black shale bands in the area shown on figure 3 by number, counting from east to west. This is because one of our conclusions is that the black shale bands are structural repeats of a single stratigraphic unit, and therefore should not be given different stratigraphic names.

Black Shale Band No 1 and Adjacent Turbidites

Black shale band No 1 corresponds to the eastern black shale of White et al. (1977) and the "Werralong Shale Member" of Browne (1979). It consists of two portions, both of which are hornfelsed: a lower part, several decametres thick, of siliceous shale and chert, and an upper part, greater than 300 metres thick, of low-outcropping black to grey shale with perfect lamination and fine parting. Dips are steep to subvertical and strikes swing from 340° in the south to 020° in the north adjacent to the Snowy River. Mesoscopic folds of uncertain geometry are also present.

To the east, black shale band No 1 grades downwards into a thin-bedded, non-carbonaceous siltstone-shale sequence which dips and youngs west (e.g. 020°/50°W) and which itself passes downwards into a strongly jointed and hornfelsed sandstone sequence which also dips and youngs to the west. The western (upper) boundary of black shale No 1 is faulted (Fig. 3). This boundary fault lies generally parallel in strike to bedding in the footwall black shale, but in the immediate hanging wall in the turbidite sequence to the west, the fault cuts across an anticlinal hinge defined by rotated beds of poorly sorted sandstone and mudrock.

Numerous fossils occur in black shale band No 1 and whilst preservation is very poor because of hornfelsing, it is sufficiently good to permit identification of the most diagnostic species. The thin siliceous portion at the base of the band contains abundant *Pygodus serra* and *Pygodus anserinus* conodonts which is an unusual association since ranges of these two species do not normally overlap. The only other place where this association occurs is in the *Nemagraptus gracilis* Zone (lower Gisbornian, Gi1) in central Victoria (Cas and VandenBerg 1988). Late Gisbornian graptolites (Gi2) occur low in the black shale proper (*Dicranograptus ramosus, Climacograptus bicornis bicornis, C. b. tridentatus, Orthograptus calcaratus acutus*), and are followed several decametres higher by early Eastonian graptolites of Ea1 or Ea2 age (*Dicranograptus hians, Climacograptus caudatus*). The thick upper part of black shale band contains the Ea3 index fossil *Dicranograptus kirki* in addition to mainly long-ranging or unidentifiable graptolites.

Black Shale Bands Nos. 2 and 3 and Adjacent Sequences

Black shale band No 2 occurs as scree fragments on the south bank of the Snowy River, but forms low, grey to black outcrops some 100 m to the south between two gullies (Fig. 3a). Laminations have steep to subvertical dips with a regional 040°-050° strike. Steeply plunging tight to isoclinal folds, some with faulted hinges, are present at decametre scale, and show eastward vergence. The eastern, basal margin of black shale band No 2 appears to be conformable with an underlying sandy turbidite sequence, the upper part of which dips and youngs to the west above an east-vergent fold pair (cf Browne 1979). In contrast, the upper or western boundary of this shale band is a fault. The best evidence for faulting is seen in the truncation of a prominent chert band in the hanging wall turbidite-chert sequence which trends 030°-040°/50°W just south of the Snowy River, but becomes disrupted farther south as it rotates eastwards into an anticlinal hinge which is cut off at the western contact of the black shale band (Fig. 3a).

Although black shale band No 2 is locally tightly folded, graptolites indicate a relatively thin and incomplete Upper Ordovician section which youngs to the west and which overlaps with band No 1 in age (Fig. 3a). Siliceous siltstone along the eastern part of band No 2 is Gisbornian in age — it contains *Climacograptus bicornis bicornis*. Early Eastonian graptolites (*Dicranograptus hians, Climacograptus caudatus*) occur about 15 m higher up in black shale, and Late Eastonian species (*Orthograptus quadrimucronatus, Leptograptus?* sp.) occur near the top.

The key feature of the turbidite-chert sequence west of black shale band No 2 is the chert itself, which consists of centimetre-thick beds of pale-weathering black chert with bioturbated muddy partings containing conodonts. Although most of these conodonts are long-ranging, the presence of *Spinodus spinatus* restricts the range from upper Darriwilian to earliest Gisbornian. The presence of this west-dipping Lower Ordovician chert above the Upper Ordovician black shale band No 2 (which dips and youngs to the west) constrains the boundary fault between them to be contractional in nature: that is, a high angle reverse fault or a thrust.

Black shale band No 3 lies to the west of (and therefore overlies) the chert-turbidite sequence briefly described above. The best outcrop occurs in a small creek (Fig. 3a), but outcrop is generally poor, mostly consisting of small floaters and chips of strongly silicified grey siliceous shale associated with quartz veining. Graptolites have been almost totally effaced, and only one small identifiable specimen was found — an *Orthograptus pageanus* which indicates an Early Eastonian age.

Band No 3 is overlain to the west by yet another turbidite sequence. Cursory examination showed at least one east-vergent fold pair and a mesoscopic fault with west-over-east displacement. Poor outcrop prevented clarification of the relationship with black shale band No. 3.

Both White et al. (1977) and Browne (1979) showed only one black shale band in the western part of the El Paso area (the "El Paso Shale Member" of Browne 1979), and we are thus uncertain whether that band corresponds with band 2 or 3. Browne's map does suggest that his western band corresponds with band No 3, but this could be due to a misplot. Bolindian graptolites occur in a black shale band north of the Snowy River at locality v (Fig. 3a), part of Browne's (1979) "El Paso Shale Member" (Fig. 2), but correlation with shale bands south of the Snowy River is uncertain.

INTERPRETATION

While the observations reported above are based on a reconnaissance study only, they indicate that the geology of the El Paso area is considerably more complex than hitherto suspected. The new data cast serious doubt on the previous interpretations that the Ordovician rocks at El Paso form a coherent sequence which dips and youngs to the west, and instead strongly suggest that the rocks in this area can only be interpreted in terms of a sequence of Lower and Upper Ordovician rocks which has been structurally repeated by thrusting.

The key to our interpretation is the presence of black shale bands 1, 2, and 3. All these bands are similar in lithology and overlap in age. Unlike the previous interpretations, which regarded the black shale bands as separate stratigraphic units in an Upper Ordovician sequence, we regard them as repetitions of the same stratigraphic unit, the Upper Ordovician Warbisco Shale, defined originally in East Gippsland by VandenBerg (1981) (see VandenBerg et al. in prep and also Cas and VandenBerg 1988). In some black shale bands in East Gippsland, VandenBerg et al. (in prep.) have been able to map out a basal cherty interval which they call the Sunlight Creek Formation, and this correlates in age and facies with the siliceous Gisbornian basal parts of bands 1 and 2 at El Paso which are not separable at map scale. The biostratigraphic evidence for structural repetition of the Warbisco Shale in the El Paso area is very convincing. Bands 1 and 2 span almost the same biostratigraphic interval, from the Gisbornian (Gi1 or Gi2) to at least the Upper Eastonian. Further evidence that only a single black shale unit is involved comes from examination of Browne's own graptolite collections which shows that, rather than being of different age, his two western black shale bands contain a complete overlap of graptolite zones ranging from the Gisbornian (probably Gi2) to mid-Bolindian (Bo3). Take the middle black shale first. The "basal Werralong Shale Member at NUMBLA [GR]560580, Beloka Creek" (Browne 1979) contains a mixture of late Eastonian (Ea3) and Bolindian forms (including *Paraorthograptus pacificus*, index fossil for Bo3). About 3 km further northeast along the same band ("Werralong Shale Member, Snowy River, BERRIDALE 569613)" the graptolites are early Eastonian (Ea2). At NUMBLA 565585, the "Werralong Shale Member" contains Ea3 graptolites, including *Pleurograptus linearis*. For the westernmost black shale, the "El Paso Shale Member " at BERRIDALE 554615 contains Bo1 and Bo2 graptolites. At BERRIDALE 555614, the same band contains Ea3 and Ea4 graptolites.

Returning to the section along the Snowy River, the mapped data not only preclude an interpretation involving a homoclinally dipping and younging sequence, they also preclude an interpretation involving tight or isoclinal folding. This is best seen with reference to figures 3c-3f. Given the conclusion that only one stratigraphic black shale unit outcrops in the El Paso area, figure 3c presents, in stylised fashion, the elements of the structural problem set by having to join up the separate black shale bands within the constraints set by the new mapping, by youngings in the Warbisco Shale in shale bands Nos 1 and 2, and by the documented and inferred ages for the turbidite-chert sequence. Note that while only one Lower Ordovician date has been obtained from this latter sequence during this reconnaissance study, this Lower Ordovician age almost certainly applies to all the turbidite-chert sequences. This view is based on the presence of other cherts in the El Paso area east and west of band No 1 (see Fig. 2) which are similar in lithology to the dated chert which lies west of band No 2, and on the lithological similarity of turbidites associated with these cherts to those lying west of band No 2. These cherts are also comparable to cherts interbedded with turbidites which outcrop over a wide area of the greater Snowy Mountains area and from which earliest Gisbornian to Darriwilian ages have recently been obtained (e.g., in the Delegate area, Glen et al. 1989, VandenBerg et al. in press, and east of Cooma, I. Stewart written comm. 1989, pers. comm. 1990). The problem posed in Fig. 3c is answered in Fig. 3d which presents the only workable solution — one requiring the presence of contractional faults on the western side of each black shale band, putting Lower Ordovician on top of Upper Ordovician. Because the black shale bands must link up and join into the one stratigraphic unit at depth, the bounding faults must also link as well as flatten at depth. That is, they are west-dipping thrusts, splaying off a shallowly dipping floor thrust at depth, as shown in the true scale cross section of figure 3b. Solutions which use folding only (Figs 3e, 3f) do not work: they cannot explain the constant westerly youngings of the black shale bands Nos 1 and 2, and they cannot explain the documented presence of Lower Ordovician to the west of band No 2 in Fig. 3e, nor the inferred presence of Lower Ordovician west of band No 1 in Fig. 3f.

This thrust interpretation of the El Paso area is further reinforced by the presence of yet another Eastonian black shale band — the "Range View Shale Member" of Browne (1979) — which is deformed along its western margin and which outcrops east of black shale band No 1 (Fig. 2). These two eastern shale bands are separated from each other by another turbidite-chert sequence which is cut out to the south as the two bands merge (Browne 1979). If the sequence were simply west-dipping and west-younging, this "Range View Shale Member" should be older than band No 1. However, it is not, for its age overlaps that of the other bands. Graptolites from a quarry at Beloko within this easternmost band (see Fig. 2) indicate a late Eastonian (Ea3) age and include *Dicellograptus flexuosus*, *Diplacanthograptus spiniferus*, *Normalograptus tubuliferus* and *Orthograptus quadrimucronatus*.

The geometry of our thrust interpretation at El Paso is illustrated in Fig. 3b, in which east-verging, west-dipping imbricate thrusts splay off a flat or gently dipping floor thrust or detachment which lies at an unknown depth or stratigraphic level within the Lower Ordovician sequence (or even below it). These splay thrusts lie parallel to bedding for long distances in their footwalls (footwall flats) where they are localised by the mechanically weak Warbisco Shale and lie at low angles to bedding in the hanging wall (hanging wall ramps) where they are associated with fold propagation folds. Footwall ramps also occur at depth in the thrust system, where the imbricate thrusts ramp up through Lower Ordovician strata lying above the floor thrust. Other splay thrusts are probably also present in the El Paso imbricate fan, but because fine biostratigraphic control cannot be achieved in the monotonous turbidites, we can only recognise thrusts where they juxtapose Upper Ordovician black shale against Lower Ordovician turbidites and cherts. Indeed, the different thicknesses of Lower Ordovician packets between the repetitions of Warbisco Shale (Fig. 3b) suggest that either different stratigraphic levels of detachment occur in different thrust sheets,and/or that additional thrusting occurs in the Lower Ordovician section. Emergent or blind thrusting probably accounts for the presence of small black shale slivers mapped by Browne (1979) in the turbidite-chert sequence in the southern part of the El Paso area (Fig. 2).

DISCUSSION AND REGIONAL IMPLICATIONS

Stratigraphy

This paper has shown that the rocks in the El Paso area do not form a coherent west-dipping and -younging sequence through part of the Adaminaby beds but consist of an interleaving of a single Upper Ordovician black shale with a single Lower Ordovician turbidite-chert sequence. We adopt the name Warbisco Shale for the black shale unit, because its lithology, age and fauna, are identical to the Warbisco Shale in its type area. The Warbisco Shale is a constituent of the Bendoc Group (new name) which outcrops over much of the greater Snowy Mountains area, and comprises two formations — the Upper Ordovician Warbisco Shale (with a basal Darriwilian to Gisbornian Sunlight Creek Member identifiable in some areas), and a Bolindian to ?earliest Silurian mudrock sequence which includes the Akuna Formation and the Gungoandra Siltstone (Glen and VandenBerg 1987, Glen et al. 1989, Glen et al. in prep.). The name Adaminaby beds is therefore restricted to the Lower Ordovician turbidite-chert sequence, and is upgraded to group status since current work indicates it contains several units at formation status (Glen et al. in prep.). Further work in the area will enable us to define a type section. New stratigraphic names for the BEGA 1:250,000 sheet will be described by Lewis et al.(in prep.).

As thus redefined, the Adaminaby Group correlates with the Adaminaby beds in the Delegate area (Glen and VandenBerg 1985, 1987, White et al. 1989) and with the Pinnak Sandstone of East Gippsland (VandenBerg et al. in press). Work being carried out in the east Cooma and Bredbo areas by Glen et al. (in prep.) indicates that the turbidite-chert sequence there (Foxlow beds) is similarly Lower Ordovician in age and is also structurally interleaved with the Warbisco Shale. Relations between this redefined Adaminaby Group and the Boltons beds and Nungar beds most recently studied by Owen and Wyborn (1979) await further work.

Previous descriptions of the Warbisco Shale have come from the the Delegate area (BENDOC and NUMBLA 1:100,000 sheets) in northeastern Victoria and southeastern NSW (VandenBerg 1981, Glen and VandenBerg 1985, 1987, Cas and VandenBerg 1988, White et al. 1989, VandenBerg et al. in press). In the Delegate area, the maximum thickness of the Warbisco shale is around 400 m (VandenBerg 1981, Cas and VandenBerg 1988), but because the formation is rarely preserved in a coherent sequence, the true thickness is difficult to estimate. In most outcrops there is structural repetition or omission of faunal zones or excision of the top of the shale by extensional faulting (Glen and VandenBerg 1987).

Structural Geology

The recognition that the structural style at El Paso is characterised by thin-skinned tectonics increases the areal extent of the thrust belt described from the Delegate area by Glen and VandenBerg (1987). These authors suggested that the zone of thin-skinned deformation is approximated by the distribution of the Llandovery Yalmy Group and its interleaving with the Upper Ordovician Warbisco Shale, and extends from the Delegate area west to the Indi-Long Plain Fault (see Fig. 1). This present work shows that the thrust belt can also be recognised in older rocks, and extends at least some 60 km north of Delegate into the Dalgety area. A key difference between the two areas is that thrust splays in the Dalgety area are localised in their footwalls by the Warbisco Shale (with Lower Ordovician being thrust over Upper Ordovician) whereas in most of the Delegate area, the splays are localised in their hanging walls by the Warbisco Shale which is thrust over Lower Silurian rocks. The exception occurs along the Yalmy - McLaughlan Creek Fault Zone west of Delegate (Fig. 1) where the splays are also localised by Warbisco Shale in the footwall.

Glen and VandenBerg (1987) regarded the Yalmy - McLaughlan Creek Fault Zone (Fig. 1), corresponding with the I-S Line of White and Chappell (1976), as the frontal part of their thrust belt. Subsequent work east of the I-S Line in the Combienbar area of East Gippsland (VandenBerg et al. in prep.), in New South Wales in the Cooma and Bredbo areas (Glen in prep.) and west of Bombala (McQueen et al. in prep.) indicates that the thrust belt does extend further east, although there is considerable evidence for an earlier, end-Ordovician deformation in some of these areas (Glen and VandenBerg 1987, Glen in prep.). In these areas, and also in the part of the thrust belt described from the the Bungonia area east of Goulburn by Fergusson and VandenBerg (1990), the sole thrust again lies in the Lower Ordovician below the Warbisco Shale.

Our structural findings at Dalgety provide further evidence that the deformation style of the southeastern part of the Lachlan Fold Belt is characterized by upper and/or lower crustal detachments. Work by several authors (Fergusson et al. 1986, Glen and VandenBerg 1987, Gray 1988, Glen and Lewis 1990, Fergusson and VandenBerg 1990) all document a thin-skinned structural style for this part of eastern Australia. Out-of-sequence thrusting and movement on the detachments at different times account for the spread in ages of "orogenies" documented from the fold belt (Glen in prep.). These movements probably developed in response to an underthrusting event which commenced in the earliest Silurian (Scheibner 1983, Glen and VandenBerg 1985, Fergusson and VandenBerg 1990). This contrasts to the Alpine and Cordilleran orogens which developed by overthrusting involving major collisions and the upthrusting of large areas of high-grade metamorphic rocks.

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We thank Professor Ken Campbell for permission to consult Browne's thesis and for VandenBerg to examine Browne's graptolite collection from the El Paso area which is housed at the Geology Department at the Australian National University. We thank Peter Browne for permission to reproduce his map as figure 2 and we also thank Ken Campbell for discussion of our ideas on the outcrops themselves. Referee's comments aided us in clarifying our text and presentation. We thank the cartographic section, N.S.W. Department of Minerals and Energy for drafting the figures. Published with the permission of the Director-General, N.S.W. Department of Minerals and Energy, and the Director, Geological Survey of Victoria.

REFERENCES

Adamson, C.L., 1951. Reconnaissance geology of the Snowy Mountains area, Progress report No. 4, N.S.W. Department of Mines, Sydney (unpublished)

Adamson, C.L., 1955. Reconnaissance geology of the Snowy Mountains area. Progress report No. 4 - Adaminaby. Annual report for 1951 N.S.W. Department of Mines, 78-86.

Browne, P.L., 1979. Graptolite Palaeontology and Biostratigraphy, Snowy River, N.S.W. M.Sc. thesis, Australian National University, Canberra (unpublished).

Cas, R.A.F. and VandenBerg, A.H.M., 1988. Ordovician. *in* GEOLOGY OF VICTORIA. Douglas J.G., and Ferguson J.A. (Eds.). Geological Society of Australia Incorp., Victorian Division, Melbourne.

Fairbridge, R., 1953. AUSTRALIAN STRATIGRAPHY (2nd edition) University of Western Australia Press, Perth.

Fergusson, C.L. and VandenBerg A.H.M., 1990. Middle Palaeozoic thrusting in the eastern Lachlan Fold Belt, southeastern Australia. *Journal of Structural Geology*, 9, 577-589.

Fergusson, C.L., Gray, D.R. and Cas, R.A.F., 1986. Overthrust terranes in the Lachlan Fold Belt, southeastern Australia. *Geology*, *14*, 519-522.

Glen, R.A., and Lewis, P.C. 1990. The Budawang Synclinorium: a mineralized thrust system with implications for the Carboniferous tectonics of New South Wales. *Quarterly Notes Geological Survey of New South* Wales, *81*, 1-9.

Glen, R.A., and VandenBerg, A.H.M., 1985. Evaluation of the I-S Line in the Delegate area, southeastern Australia, as a possible terrane boundary. Third Circum-Pacific Terrane Conference, *Abstracts Geological Society Australia*, *14*, 91-95.

Glen, R.A., and VandenBerg, A.H.M., 1987. Thin-skinned tectonics in part of the Lachlan Fold Belt near Delegate, southeastern Australia. *Geology, 15*, 1070-1073.

Glen,R.A., White, A.J.R, and Chappell, B.W. 1989. Palaeozoic sediments *in* Numbla 1:100,000 geological sheet 8624. White, A.J.R., Chappell, B.W., Williams, I.R., and Glen, R.A. Geological Survey of N.S.W., Sydney.

Gray, D.R., 1988. Structure and tectonics *in* GEOLOGY OF VICTORIA. Douglas J.G., and Ferguson, J.A.,(Eds.). Geological Society of Australia (Victorian division) Melbourne, 1-36.

Hall, L.R., 1956. Reconnaissance geology of Snowy Mountains area. Progress report No. 5 - Berridale. Annual Report for 1952, N.S.W. Department of Mines, Sydney 131-134.

Mulholland, C. StJ., 1941. Snowy River Investigation. Geological Report. Report Geological Survey of N.S.W. (GS 1941/049) unpublished.

Owen, M. and Wyborn, D., 1979. Geology and geochemistry of the Tantangara and Brindabella 1:100,000 sheet areas. *Bulletin 204*, Bureau of Mineral Resources, Geology and Geophysics, Canberra.

Pogson, D.J. 1972. GEOLOGY OF NEW SOUTH WALES, SCALE 1:1,000,OOO. Geological Survey of N.S.W., Sydney.

VandenBerg, A.H.M., 1981. A complete Late Ordovician graptolitic sequence at Mountain Creek, near Deddick, eastern Victoria. Report Geological Survey of Victoria (1981/1) (unpublished).

VandenBerg, A.H.M. 1988. PALAEOZOIC STRATOTECTONIC MAP OF VICTORIA, scale 1;1,000,000. Department of Industry, Technology and Resources, Melbourne.

VandenBerg, A.H.M., Nott, R.J. and Glen, R.A., 1990. Bendoc 1:100,000 Map and Geological Report. Geological Survey of Victoria, Melbourne.

White, A.J.R., Williams I.G. and Chappell, B.W., 1976. The Jindabyne Thrust and its tectonic, physiographic and petrogenetic significance. *Journal geological Society of Australia, 23*, 105-112.

White, A.J.R., Chappell, B.W. and Williams, I.S., 1977. Geology of the Berridale 1:100,000 Sheet 8625. Geological Survey, N.S.W., Sydney.

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Doctoral Thesis Abstract: Inhibition of de Novo Nucleotide Biosynthesis in Mouse L1210 Leukaemia

STEPHEN D. LYONS

A new high pressure liquid chromatographic procedure has been developed for the analysis of drug-induced effects on nucleotide biosynthesis in cultured mammalian cells. More than 40 nucleotides, nucleotide precursors and related compounds (including phosphorylated drug derivatives) can be identified and quantified from their elution time, wavelength of maximal absorbance, and pattern of radiolabel incorporation of [^{14}C]bicarbonate (for pyrimidines and purines) and [^{14}C]formate (for purines) (1-3). The major sites of cytotoxicity of a number of anti-metabolites currently in clinical use, or at the investigational stage, have been determined in leukaemia cells growing in culture. These conclusions should enable more effective chemotherapy with these agents, either singly or in combination with other anti-cancer drugs. Some of this data has appeared in a review (4).

The monophosphate derivative of pyrazofurin, a nucleoside-analogue antibiotic, is a potent inhibitor of orotidine 5'-monophosphate decarboxylase of pyrimidine biosynthesis and has been postulated to inhibit 5-aminoimidazole-4-carboxamide ribotide (AICAR) transformylase of purine biosynthesis. We found that pyrazofurin inhibits only the former enzyme and, indeed, stimulates purine biosynthesis in growing leukaemia cells (5).

The drugs, brequinar and ciprofloxacin, have been implicated in the inhibition of early reactions of pyrimidine biosynthesis. Brequinar was determined to act in an analogous fashion to dichloroallyl lawsone (1), *via* potent inhibition of the ubiquinone-dependent enzyme dihydroorotate dehydrogenase. No evidence was obtained for the inhibition of any enzyme of pyrimidine biosynthesis by ciprofloxacin, although this antibiotic probably inhibits electron transport or oxidative phosphorylation in leukaemia cells (3).

The glutamine analogues, acivicin, azaserine and DON, are potent inhibitors of many purified or semi-purified amido-transferases. The major sites of inhibition of nucleotide biosynthesis were determined to be different for each antagonist in growing cells although all three antagonists inhibit *N*-formylglycineamidine ribotide (FGAM) synthetase and induce massive accumulations of the substrate for this reaction, *N*-formylglycineamide ribotide (FGAR), and its di- and triphosphate derivatives. Interference with nucleic acid synthesis by these "unnatural" metabolites may be another mechanism of cytotoxicity for glutamine antagonists (6).

The mechanism of cytotoxicity induced by methotrexate and other classical and non-glutamate containing anti-folates is still to be elucidated. Both classes of anti-folates inhibit purine biosynthesis at AICAR transformylase (reaction 9) more potently than glycineamide ribotide (GAR) transformylase (reaction 3). However, in subsequent studies we concluded that polyglutamate derivatives of dihydrofolate, accumulated due to potent inhibition of dihydrofolate reductase, induce potent inhibition of purine biosynthesis primarily at an initial reaction of the pathway prior to both transformylase reactions (7).

Fluoroorotate is structurally similar to the anti-cancer drug, flourouracil, and was used as a model compound for the development of active pro-drug derivatives of inhibitors of dihydroorotase designed and synthesized in this laboratory (*e.g.*, thiodihydroorotate; (8)). Non-polar fluoroorotate esters were the most cytotoxic with the benzyl pro-drug having an IC_{50} value of 0.26 μM compared with the free acid IC_{50} value of 4.9 μM. The benzyl ester of thiodihydroorotate has been found to have its cytotoxicity similarly enhanced relative to the free acid (9).

A phenomenon called "complementary stimulation" has been described for cells exposed to an anti-metabolite where either pyrimidine or purine biosynthesis is inhibited and the uninhibited pathway is stimulated. Potent inhibitors of pyrimidine biosynthesis (pyrazofurin, dichloroallyl lawsone and brequinar) induce a surge through the purine pathway resulting in an elevation of purine nucleotides and precursors above pre-drug levels. Purine antagonists (methotrexate and DON) have an analogous effect on pyrimidine biosynthesis. This phenomenon illustrates the interdependence of the pathways of nucleotide biosynthesis *via* their common intermediates, 5-phosphoribosyl 1-pyrophosphate (P-Rib-PP) and L-glutamine.

References

1. Kemp, A.J., Lyons, S.D., & Christopherson, R.I. (1986) *J. Biol. Chem.* **261,** 14891-14895.
2. Sant, M.E., Poiner, A., Harsanyi, M.C., Lyons, S.D., & Christopherson, R.I. (1989) *Anal. Biochem.* **182,** 121-128.
3. Lyons, S.D. & Christopherson, R.I. (manuscript submitted).
4. Christopherson, R.I. & Lyons, S.D. (1990) *Med. Res. Rev.*, in press.
5. Sant, M.E., Lyons, S.D., Kemp, A.J., McClure, L.K., Szabados, E., & Christopherson, R.I. (1989) *Cancer Res.* **49,** 2645-2650.
6. Lyons, S.D., Sant, M.E., & Christopherson, R.I. (1990) *J. Biol. Chem.* **265,** 11377-11381.
7. Lyons, S.D., Sant, M.E., & Christopherson, R.I. (manuscript submitted).
8. Christopherson, R.I. Schmalzl, K.J., Szabados, E., Goodridge, R.J., Harsanyi, M.C., Sant, M.E., Algar, E.M., Anderson, J.E., Armsrong, A., Sharma, S.C., Bubb, W.A., & Lyons, S.D. (1989) *Biochemistry* **28,** 463-470.
9. Brooke, J.H., Szabados, E., Lyons, S.D., & Christopherson, R.I. *Cancer Res.*, in press.

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Addendum to G. Neef et al: The Mt. Daubeny Formation

Right-Hand Page

ADDENDUM: Vol. 122 Parts 3/4, pp 97-106

"The Mt.Daubeny Formation"
by G.Neef et al.

to be inserted after page 101 as page 101a.

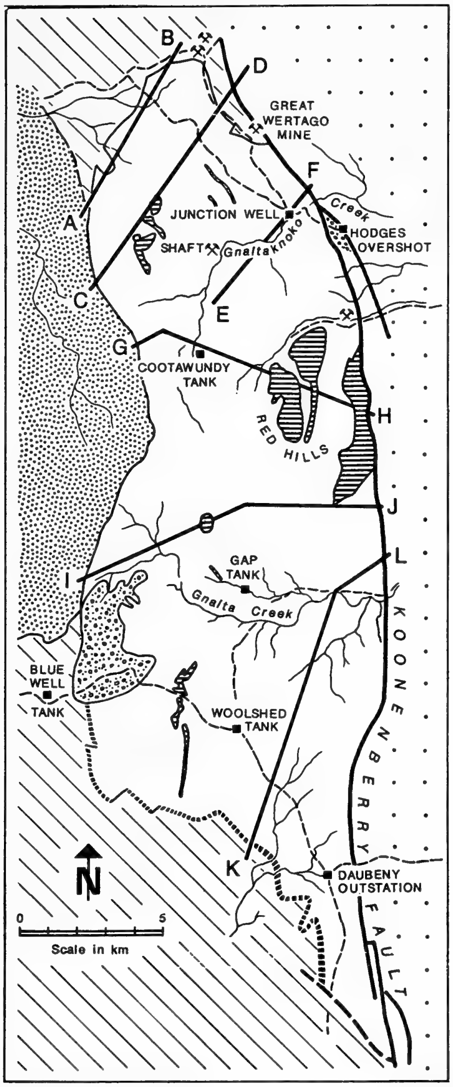

Fig. 4a. Locality map shows the location of the geological sections.

STRATIGRAPHY
DEFINITION OF STRATIGRAPHIC NAMES

MT DAUBENY FORMATION (new formation)
Synonymy: Wertago-Cootawundy Series (Kenny, 1930), Mount Daubeny Beds (Warris, 1967) Cootawundy Beds (Scheibner, 1978).

Derivation of name: Mt Daubeny (preferred spelling) (GR 57681428, Wilcannia 1:250 000).

TYPE SECTION: The type section is made in the south along geological section L-K (Fig. 4). This section trends from grid ref. (57151408) to grid ref. (57701514) on 1:250,000 Sheet Wilcannia (Frenda, 1965). This section represents the thickest relatively undeformed section known within the formation (see also the generalized geophysical map of Wilson (1967, fig. 5), which also indicates that the thickest part of the Mt Daubeny Formation lies in the section between Mt Daubeny Outstation and old Gnalta Homestead).

STRATIGRAPHIC RELATIONS: The formation is bounded in the east by the Koonenberry Fault to the east of which lies the Devonian Snake Cave Sandstone Formation. A probable outlier of much deformed Snake Cave Sandstone crops out at Gnalta Peak (~1.5 km south of Gnalta Creek and ~25 m west of the Koonenberry Fault). In the north and north-west the formation is separated from the Wonaminta Beds (for preferred spelling see Edwards, 1978) by a feldspar porphyry dike system and a sinuous north-west trending fault. The formation is unconformable on the Wonaminta Beds in the southwestern margin and there is a 15 km north-trending belt in the centre of the outcrop area where the formation is overlain unconformably by the Ravendale Formation (Warris, 1967) The Gap Fault mapped by Wilson (1967) is in error.

CONTENT: The formation, which is largely unfossiliferous and lacks widespread marker beds is largely composed of planar-bedded, immature arenite (for some typical model compositions see Table 1 and Fig. 7) which is commonly coarse and very coarse

TABLE 1.
RANGE IN COMPOSITION OF ARENITES OF THE MT DAUBENY FORMATION

	Percentage
Quartz	40-80
Lithics - (metasediments dominantly phyllite)	5-30
- (volcanics)	5-10
- (older sediments)	0.5
Feldspars - orthoclase	5-20
- microcline	0-2
- plagioclase	5.20
- perthite	0-1
Micaceous Phases - detrital	0-5
- matrix (recrystallised clays)	0-10
Others	0-1

in the west, where it is poorly sorted, and fine and very fine in the east where sorting is better. Thin sections contain abundant angular crystals which are inferred to represent reworked airfall tephras. Siltstone, commonly rippled, is more common in the east whereas conglomerate is much more common in the west and the north. In the north, west and central parts of the outcrop area the arenite is characteristically pale-red (5R6/2, colour is from Goddard *et al.*, 1970), whereas in the south east the arenite is commonly grey, brown or green and the red "oxidized" facies are less common. In the south the Koonburra Creek Quartzite is basal whereas in the north there are three horizons (~ 0.5, ~ 2.5 and ~4.5 km above basement) where andesite flows and tuffs are known. Beds of orthoquartzite, commonly 6m thick, are present in the central part of the outcrop area. Because of the presence of well developed orthoquartzite beds in the upper part of the formation in the central outcrop area the formation is best described in terms of southern, northern and central areas. The southern and northern areas representing the lower and middle parts of the formation.

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Annual Report of Council

PATRONS

The Council wishes to express its gratitude to His Excellency Sir David Martin, KCMG, AO, Governor of New South Wales, who kindly agreed to become patron of the Society following the retirement of his predecessor, Air Marshall Sir James Rowland. In accordance with tradition, the Council also invited Mr William Hayden, Governor-General of Australia, to become a joint patron in place of Sir Ninian Stephen. However Mr Hayden declined on the grounds that the Society was only state-based.

MEETINGS

Eight General Monthly Meetings and the Annual General Meeting were held during the year. The average attendance was 43 (range 15 to 102). Abstracts of the Addresses were published in the Newsletter.

The 1000th General Monthly Meeting and 122nd Annual General Meeting were held in the MacCallum and Cullen Rooms of the University of Sydney Union on April 5th, 1989. They were preceded by a buffet dinner attended by 55 members and guests. A display of historical photographs and documents was organised by Mrs J. Day. Six of the seven other General Monthly Meetings were held at the Australian Museum and one at Macquarie University. A summary of the proceedings is set out below.

The 45th Clarke Memorial Lecture was delivered by Dr Erwin Scheibner, Principal Research Scientist, N.S.W. Department of Minerals and Energy, on Wednesday, 18th October, 1989. The topic was "Tectonics of New South Wales in the Second Decade of the Plate Tectonic Paradigm". The venue was the Hallstrom Theatre of the Australian Museum.

The Society was a co-sponsor of a mini-symposium to celebrate the Rev. Julian Tenson Woods' Centenary on Thursday, 14th September, 1989, at the Australian Museum. Papers presented at the symposium will be published in the *Journal and Proceedings*.

Ten meetings of the Council were held at the Society's office, 134 Herring Road, North Ryde. The average attendance was 10.

Two special Saturday meetings of the Council were held at the Society's office on 8th July and 4th November, 1989, to discuss issues raised by the Working Party's recommendations affecting the on-going operations of the Society. A questionnaire was prepared and distributed to members of the Society.

An Annual Dinner was held on 14th March, 1990, at the Holme and Sutherland Rooms of the University of Sydney Union. Our patron, His Excellency Sir David Martin, and Lady Martin were Guests of Honour. The President, Mr. Harry Hancock, welcomed the Guests of Honour and other guests of the Society and introduced Sir David Martin. His Excellency presented the Clarke Medal to Professor John Roberts, the Edgeworth David Medal to Dr Trevor W. Hambley, and the Society's Medal to Professor John Loxton (Vice-President), and then gave an Occasional Address. Associate Professor Denis Winch (Past President) responded and thanked His Excellency. 59 persons were in attendance.

PUBLICATIONS

Volume 121, Parts 3 and 4 of the *Journal and Proceedings* were published separately during the year.

Part 3 contained the papers presented at a Symposium entitled "Problems and Prospects of preserving the portable scientific and technological Heritage" which was held on 2nd August 1986 at the National Trust of N.S.W. At the conclusion of the Symposium several resolutions were adopted. These led to amendments to certain regulations in the N.S.W. Heritage (Amendment) Act 1987, assented to on 3rd April, 1987. The publication of the proceedings of the Symposium was made possible by a grant from the New South Wales Government on the recommendation of the N.S.W. Heritage Council. Council extends its thanks to the N.S.W. Government.

Part 4 contained the Presidential Address for 1988, the Liversidge Lecture for 1988, one research paper and two abstracts of higher-degree theses.

The voluntary referees who assessed papers submitted for publication are thanked.

Ten issues of the *Newsletter* were published. Council is most grateful to the authors of short articles and reviews which are much appreciated by members.

MEMBERSHIP

The membership of the Society as at 31st March, 1990, was:

Honorary members	13
Life members	24
Ordinary members	233
Absentee members	13
Associate members	22
Total	305

With great regret, the Council received news during the year of the deaths of the following members:

Sir Philip Baxter (Honorary Member), 5.09.1989
Arthur Sinclair Ritchie, 27.09.1989
Denis Keith Tompkins, 19.10.1989
Alan Norval Carter, 9.11.1989
Michael Duhan Garretty (Life Member), 21.11.1989
Adrien Albert (Life Member), 29.12.1989
Ilse Rosenthal-Schneider (Honorary Member), 6.02.1990
Haddon Forrester King, 11.03.1990

AWARDS

The Society annually awards medals and prizes which recognise achievements of scientists. The first award given by the Society was the Clarke Medal, in 1878, to Professor Sir Richard Owen of London. The first Australian reciptient of this award was Professor Frederick McCoy of the University of Melbourne. The terms and conditions of the awards and a list of recipients since 1980 were published at pages 131 and 132 in volume 122.

The following awards were made for 1989:

Clarke Medal (in Geology):
Professor John Roberts,
School of Applied Geology,
University of N.S.W.

Edgeworth David Medal:
Dr Trevor William Hambley,
School of Chemistry,
University of Sydney.

Royal Society of New South Wales Medal:
Professor John Harold Loxton,
School of Mathematics,
Macquarie University.

The Cook Medal and the Ollé Prize were not awarded.

SUMMER SCHOOL

A successful Summer School on "Weather, Climate and Society" was held from 15th to 19th January, 1990, at Macquarie University. It was attended by twenty three Year-11 students, and sixteen speakers addressed the School on topics related to the central theme. Although the subject matter of the Summer School proved to be most interesting and the speakers and excursions were excellent, it drew fewer students than the Council considered a desirable minimum.

The Summer School was organised on behalf of the Council by Mrs. M. Krysko. The President, Mr. H.S. Hancock, and the Vice-Chancellor of Macquarie University, Professor Di Yerbury, welcomed the students and speakers. Mr Tim Moore, MP, the Minister for the Environment, opened the School. The speakers were from universities, government organisations and private industry.

Council's appreciation is extended to the speakers, to Mrs Krysko and the Council members who assisted her, and to Mrs Wyn Swaine. The Council also wishes to thank the Bureau of Meteorology and the Atmospheric Section, CSIRO Division of Coal Technology, North Ryde, for their most generous welcomes during the half -day excursion visits.

OFFICE

The Society continued during the year to lease for its office and library a half share of Convocation House, 134 Herring Road, North Ryde, on the

Plate 1. Participants in the Summer School on "Weather,Climate and Society", January, 1990, at Macquarie University. On the far right is Mrs.M. Krysko v. Tryst, Convener of the Summer School and behind her Miss Pat Callaghan, Member of Council. On the far left is Mr. H.S.Hancock, President of the Society.

southeastern edge of Macquarie University campus. The Council is grateful to the University for allowing it to continue leasing the premises.

LIBRARY

Acquisitions by gift and exchange continued as heretofore, the overseas and some Australian material being lodged in the Royal Society of New South Wales Collection in the Dixson Library, University of New England. Other Australian material was lodged in the Society's office at North Ryde. The Council thanks Mr. Karl Schmude, University Librarian, for his continuing care and concern in ensuring the smooth operation of the Royal Society Collection and associated inter-library photocopy loans.

During 1989 a catalogue of the Royal Society Collection held by the Dixson Library was published with the assistance of the "Grace Proctor Fund for Special Collections". The catalogue lists 1590 periodicals arranged in subject order in accordance with the Dewey Decimal Classification. The Council is deeply indebted to Mr. Schmude and his staff for cataloguing the vast Collection and making the necessary arrangements for its publication.

The Royal Society of New South Wales Collection is of scholarly depth and international scope. At the time of its transfer to the Dixson Library in 1983 it comprised over 30,000 volumes of periodicals, mainly in the physical sciences - in particular mathematics, geology, chemistry, astronomy and physics. Its coverage extended to every continent, embracing more than fifty countries. Development of the collection was set on a sound footing by Professor Liversidge and sustained by a succession of honorary and professional librarians. Mrs Grace Proctor came to the Society from the then Public Library of New South Wales in early 1971 and since then has made an immeasurable contribution to the well-being of the Society's library, especially during the transfers from Science House to the Science Centre and then to the Dixson Library and North Ryde. She has continued to supervise the North Ryde collection and to liaise with Mr Schmude and other New England librarians when necessary. Council is very grateful to her for her continuing voluntary assistance.

NEW ENGLAND BRANCH

The Branch held three meetings during 1989:

Wednesday, 10th May, 1989: Dr John Morris, Head of the Department of Nuclear Medicine at the University of Sydney, spoke on "The medical cyclotron and its application in positron emission tomography". About 50 were present.

Wednesday 31st May, 1989: Professor C.D. Ollier gave a talk on "Greenhouse, climatic change and the management of sea-level". About 120 were present.

Wednesday 25th July, 1989: Professor John Milburn, University of New England, gave a talk on "Recording moisture stress in plants in arid zones by the use of ultrasonic equipment". Attendance was low due to poor weather conditions.

FINANCE

The accounts for the financial year, January-December, 1989, show a surplus from operations of $5,573, an improvement of $4,692 over the previous year's result. The only substantial changes in the operating accounts were an increase of $2300 in interest received on investments, an improvement of $1400 in the result of the 1989 Summer School, and a decrease of $1800 in net outlays on the Journal and Proceedings.

The net assets of the Society at the end of 1989 were $156,400, up $20,700. This increase was largely due to the late Dr. G.H. Briggs' generous bequest, a further $13,520 of which was received during the year, bringing the total to $15,520. The assets were principally represented by interest-bearing, Trustee-Act-authorised, investments of $138,300, up $14,800.

The Society receives no regular grants from Government and must stand on its own feet financially. The Council is therefore especially appreciative of the numerous donations received during the year. Donations were made to the Library Fund, the Summer School and the Journal. The substantial, and very welcome, donation by the N.S.W. Government towards the printing of the proceedings of the seminar on portable scientific heritage (in Part 3 of Volume 121 of the *Journal*) has been acknowledged earlier in this report.

The professional assistance of Mr. A.M. Puttock, F.C.A., in the conduct of the Society's finances is again acknowledged with gratitude.

VISITORS

The Council was pleased to receive a visit from Dr John Glover, Vice-President of the Royal Society of South Australia. He spoke to the Council regarding future directions of his Society, and a round-table discussion of problems common to the Royal Societies in Australia followed.

ABSTRACT OF PROCEEDINGS

APRIL 5, 1989

(a) The 1000th General Monthly Meeting. Location: The MacCallum and Cullen Rooms, the University of Sydney Union. The President, Associate Professor D.E. Winch was in the Chair and 65 members and visitors were present.

Una Lenore Steele and Kathleen McPherson Hancock were elected to Associate Membership (Spouse).

It was announced that Emeritus Professor Adrien Albert, a Life Member, had been awarded an AO in the Australia Day Honours List.

The deaths were announced with regret of:
William Wreford Millership on 15.1.89. He was elected a member in 1940.
Dr Charles Joseph Magee on 2.2.89. He had been a member since 1947, and was President in 1952.

In conjunction with the meeting there was a large display arranged by Mrs Judith Day of historical photographs and documents with explanatory annotations.

(b) The 122nd Annual General Meeting. The Annual Report of Council for 1988-1989 and the Financial Report for 1988 were adopted, and Messrs Wylie and Puttock were re-elected as Auditors for 1989.
The following Awards for 1988 were announced:
Clarke Medal (Zoology): Barry Garth Rolfe
Edgeworth David Medal: Peter Andrew Lay
Royal Society of NSW Medal: Ragbir Bhathal

The following Office-bearers and Council were elected for 1989-1990:-
President: Mr H. S. Hancock
Vice-Presidents: Assoc Prof D.E. Winch
Professor J.H. Loxton
Emer. Prof. R.L. Stanton
Dr. F.L. Sutherland
Dr. R.S. Vagg
Honorary Secretaries:
Dr. R. Bhathal
Mrs. M. Krysko v. Tryst (Editorial)
Honorary Treasurer: Dr. A.A. Day
Honorary Librarian: Miss P.M. Callaghan
Members of Council:
Mr G.W.K. Ford, Mr J.R. Hardie, Dr R.A.L. Osborne, Mr T.J. Sinclair, Dr D.J. Swaine, and Mr J.A. Welch.

The retiring President, Associate Professor Winch, delivered his Presidential Address entitled "Earth's Magnetic Field". The vote of thanks was proposed by Dr. A.A. Day.

MAY 3, 1989

1001st General Monthly Meeting. Location: The Lilac Room, The Australian Museum. The President, Mr. H.S. Hancock, was in the Chair, and 19 members and visitors were present.

Andrew Tink, MP, was elected to Membership.

An address on "Muscle, Mathematics and People" was given by Dr. G.H. Rossmanith, Senior Lecturer in Mathematics, Macquarie University.

JUNE 7, 1989

1002nd General Monthly Meeting. Location: Hallstrom Theatre, The Australian Museum. The President, Mr H.S. Hancock, was in the Chair, and 55 members and visitors were present.

An address on "The Greenhouse Effect" was given by Professor Ann Henderson-Sellers, Professor of Physical Geography at Macquarie University.

JULY 5, 1989

1003rd General Monthly Meeting. Location: Lilac Room, The Australian Museum. The President, Mr H.S. Hancock was in the Chair, and 25 members and visitors were present.

Bruce Leonard Simmons was elected to Membership.

An address entitled "Nuclear Fusion Power (Hot or Cold): An Engineer's Viewpoint" was given by Mr G.W.K. Ford, a member of the Council.

AUGUST 2, 1989

1004th General Monthly Meeting. Location:Hallstrom Theatre, The Australian Museum. The President, Mr H.S. Hancock, was in the Chair, and 31 members and visitors were present.

The death of Dr Germaine Anne Joplin, AM, a Life Member of the Society, at the age of 86, was announced with regret. Dr Joplin was awarded the Royal Society of New South Wales Clarke Medal (Geology) in 1963 for her contributions to petrology.

An address on "Charles Darwin in Australia" was given Professor F.W. Nicholas, Department of Animal Genetics, University of Sydney.

SEPTEMBER 6, 1989

1005th General Monthly Meeting. Location: Room 100, E7B, Macquarie University. The President, Mr H.S. Hancock, was in the Chair and 102 members and visitors were present.

The following papers were read by title only:
1."The essential oils of four chemotypes of *Melaleuca citrolens* Barlow" by Joseph J. Brophy and John R. Clarkson.
2."Cook and his contemporaries: Differences in medical emphases" by Surgeon-Admiral Sir James Watt.

The death of Sir Philip Baxter, Honorary Member, on 5.9.1989 was announced with regret. Sir Philip had been a Member and later Honorary Member since 1950.

An address on "Calculus and Tomography" was given by Emeritus Professor Chong, a member of the Society.

OCTOBER 4, 1989

1006th General Monthly Meeting. Location: Hallstrom Theatre, The Australian Museum. The President, Mr H.S. Hancock, was in the Chair and 30 members and visitors were present.

Gerhard C. Lowenthal was elected to Membership.

Papers read by title only:
1. "The Earth's magnetic field", Presidential Address, 5th April 1989, by D.E. Winch.
2. "A physical identity for the blood-brain barrier" by Brian A. Hills.

It was announced that Mrs Patricia Margaret McNaughton had been elected by Council as an Associate Member (Spouse).

An address on "Obsidian analysis and peopling of the Pacific" was given by Dr J.R. Bird, Manager, Accelerator Mass-Spectrometry Project, Australian Nuclear Science and Technology Organisation.

OCTOBER 18, 1989

The 45th Clarke Memorial Lecture was delivered by Dr Erwin Scheibner, Principal Research Scientist, NSW Department of Minerals and Energy, Sydney, entitled: "Tectonics of New South Wales in the Second Decade of the Plate Tectonic Paradigm", at the Hallstrom Theatre, The Australian Museum.

NOVEMBER 1, 1989

1007th General Monthly Meeting. Location: Hallstrom Theatre, The Australian Museum. The President, Mr H.S. Hancock was in the Chair, and 15 members and friends were present.

The deaths of two members were announced with regret:
Arthur Sinclair Ritchie on 27.9.1989, at Newcastle. He had been a member since 1947.
Denis Keith Tompkins on 19.10.1989. He was elected to membership in 1954.

An address on "Transport in Developing Countries" was given by Mr Thomas Atkinson.

AUDITORS REPORT

In our opinion:

(a) the attached accounts, set out on pages 2 to 10 which have been prepared under the historical costs convention, are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society at 31st December 1989 and of the results of the Society for the year ended on that date; and

(b) the accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provisions of those Rules.

WYLIE & PUTTOCK
Chartered Accountants.

By ALAN M. PUTTOCK

BALANCE SHEET as at 31st December 1989

	RESERVES			
7310.57	Library Reserve (note 2(a))			7310.57
7276.14	LIBRARY FUND (note 2(b))			7819.35
20515.82	TRUST FUNDS (note 3)			21332.22
100643.86	ACCUMULATED FUNDS			119993.90
----------				----------
135746.39	TOTAL RESERVES AND FUNDS			156456.04
==========	======================			==========
	Represented by:			
	CURRENT ASSETS			
187.58	Petty Cash Imprest		348.25	
1855.13	Debtors for Subscriptions	1694.00		
	Less Provision For			
1855.13	Doubtful Debts	1694.00		
	Other Debtors &			
8761.76	Prepayments		12140.93	
11661.42	Cash at Bank		9835.30	
----------			----------	
20610.76				22324.48

	Less: CURRENT LIABILITIES		
21227.87	Sundry Creditors & Accruals	17044.00	
	Life Members		
35.37	Subscriptions - Current Portion	25.77	
	Membership Subscriptions		
66.57	Paid in Advance	100.21	
	Subcriptions to Journal		
1325.97	Paid in Advance	1545.59	
----------		----------	
22655.78			18715.57
----------			----------
(2045.02)	NET CURRENT ASSETS		3608.91
	Add: FIXED ASSETS		
	Furniture, Office Equipment, etc.- at cost		
886.66	less Depreciation	1076.37	
	Library - 1936 Valuation		
13600.00	(note 4)	13600.00	
	Pictures - at cost less		
10.00	Depreciation	10.00	
----------		----------	
14496.66			14686.37
----------			----------
12451.64			18295.28
	Add: INVESTMENTS		
	Commonwealth Bonds &		
3100.00	Inscribed Stock	2500.00	
100000.00	Loans on Mortgage	100000.00	
20403.60	Interest Bearing Deposits	35843.84	
----------		----------	
123503.60			138343.84
----------			----------
135955.24			156639.12
	Less: NON-CURRENT LIABILITIES		
	Life Members Subscriptions -		
208.85	Non-Current Portion		183.08
----------			----------
135746.39	NET ASSETS		156456.04
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H.S. HANCOCK President

A.A. DAY Honorary Treasurer

STATEMENT OF ACCUMULATED FUNDS
For the Year Ended 31st December 1989

881.50	OPERATING SURPLUS for the year		5572.59
801.83	Donations & Interest to Library Fund		800.12
2000.00	Proceeds Estate Late Dr G.H. Briggs		13520.54
202.05	Transfer from Library Fund		256.91
97560.31	Accumulated Funds - Beginning of Year		100643.86
101445.69	AVAILABLE FOR APPROPRIATION		120794.02
801.83	Transfer to Library Fund	800.12	
801.83			800.12
100643.86	ACCUMULATED FUNDS Current Year		119993.90

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1989

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1989. Unless otherwise stated, such accounting policies were also adopted in the preceding year

(a) Basis of Accounting

The accounts have been prepared on the basis of historical costs

(b) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

Furniture	7.50%
Office Equipment	15.00%

2. MOVEMENTS IN PROVISIONS AND RESERVES

(a) Library Reserve

7310.57	Balance at 1st January			7310.57
7310.57				7310.57
0.00	Transfer to Accumulated Funds		0.00	
7310.57	Balance at 31st December			7310.57

(b) Library Fund

6676.36	Balance at 1st January			7276.14
801.83	Add Donations and bank interest			800.12
7478.19				8076.26
202.05	Less Library purchases and expenses		256.91	
202.05				256.91
7276.14	Balance at 31st December			7819.35

3. TRUST FUNDS

Clarke Memorial Fund - Capital

5000.00	Balance at 1st January	5000.00		
5000.00	Balance at 31st December		5000.00	

Clarke Memorial Fund - Revenue

732.46	Revenue Income for Period	743.64		
98.42	Less Expenditure for Period	1409.73		
634.04		(666.09)		
75.68	Balance at 1st January	709.72		
709.72	Balance at 31st December		43.63	
5709.72				5043.63

Walter Burfitt Prize Fund - Capital

3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	

	Walter Burfitt Prize Fund - Revenue			
439.48	Revenue Income for Period	446.19		
6.00	Less Expenditure for Period	0.00		
433.48		446.19		
2600.76	Balance at 1st January	3034.24		
3034.24	Balance at 31st December		3480.43	
6034.24				6480.43
	Liversidge Bequest Fund - Capital			
3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	
	Liversidge Bequest Fund - Revenue			
439.48	Revenue Income for Period	446.19		
1039.50	Less Expenditure for Period	4.80		
(600.02)		441.39		
984.07	Balance at 1st January	384.05		
384.05	Balance at 31st December		825.44	
3384.05				3825.44
	Olle Bequest Fund - Capital			
4000.00	Balance at 1st January	4000.00		
4000.00	Balance at 31st December		4000.00	
	Olle Bequest Fund - Revenue			
585.98	Revenue Income for Period	594.91		
102.90	Less Expenditure for Period	0.00		
483.08		594.91		
904.73	Balance at 1st January	1387.81		
1387.81	Balance at 31st December		1982.72	
5387.81				5982.72
20515.82	Total Trust Funds			21332.22

4. LIBRARY

During the 1983 year the Society gifted the serials collection component of the library to the University of New England. The Society has retained that section of the library which is of historical significance. At the 31st December, 1989 a current valuation of the library had not yet been obtained.

STATEMENT OF SOURCE AND APPLICATION OF FUNDS
For the Year Ended 31st December 1989

	SOURCE OF FUNDS		
881.50	Operating surplus for the year	5572.59	
	Add:		
	Items not involving the outlay of funds in the current period:		
100.00	Depreciation of fixed assets	112.00	
1140.18	Provision for doubtful debts	509.37	
2121.68	Funds derived from operations		6193.96
801.83	Donations and interest to library fund		800.12
2197.40	Trust fund income		2230.93
2000.00	Proceeds Estate Late G.H. Briggs		13520.54
7120.91			22745.55
	APPLICATION OF FUNDS		
35.37	Reclassification of life members subscriptions in advance		25.77
0.00	Acquisition of Equipment		301.71
2404.87	Increase in investments		14840.24
1246.82	Trust fund expenses		1414.53
3433.85	Increase in working funds		6163.30
7120.91			22745.55

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31st December 1989

	INCOME	
7605.50	Membership Subscriptions - Ordinary	7235.00
35.37	Membership Subscriptions - Life Members	35.37
28.00	Application Fees	31.00
----------		----------
7668.87		7301.37
8673.32	Subscriptions and Contributions to Journal Publication Costs	13344.17
----------		----------
16342.19	Total Membership and Journal Income	20645.54
15583.33	Interest Received	17899.36
25.50	Sale of Reprints	0.00
91.50	Sale of Back Numbers	0.00
40.00	Sale of Other Publications	87.00
0.00	Photocopying Refunds	4.00
0.00	Summer School Surplus	1224.44
0.00	Annual Dinner Surplus	375.00
7.10	Other Income	4.00
----------		----------
32089.62		40239.34

	Less:EXPENSES		
1650.00	Accountancy Fees		1790.00
825.00	Audit Fees		895.00
34.70	Bank Charges & Government Duties		30.75
200.00	Branches of the Society		200.00
100.00	Depreciation		112.00
192.50	Entertainment Expenses		326.00
65.15	Insurance		80.15
	Journal Publication and Distribution Costs		
13244.14	Printing	15776.00	
2344.92	Wrapping & Postage	2673.51	
----------		----------	
15589.06			18449.51
202.05	Library Expenses		256.91
197.04	Miscellaneous Expenses		103.80
400.00	Monthly Meeting Expenses		219.80
1978.61	Newsletter Printing & Distribution		1932.07
285.48	Postage		373.30
285.81	Printing & Stationery - General		403.03
1140.18	Provision for Doubtful Debts		509.37
2000.00	Rent		2000.00
170.27	Repairs & Maintenance		0.00
5649.34	Salaries		6745.15
182.45	Summer School Deficit		0.00
60.48	Telephone		239.91
----------			----------
31208.12			34666.75
----------			----------
881.50	SURPLUS for the year		5572.59
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CLARKE MEDAL FOR 1989

The Clarke Medal for 1989 is in the field of Geology, and is awarded to **Professor John Roberts**.

Professor Roberts has contributed to the advancement of Geology in numerous ways in the past thirty years. His research on stratigraphy and palaeontology, especially in relation to rocks of Carboniferous age, has attracted world-wide attention. He has participated constructively in joint projects with geoscientists in institutions other than his own, including studies of Cambrian fossils in western New South Wales; compilation of geological maps and interpretive monographs on areas of the Hunter-Myall region of the State; research on the complex geology of the Hastings Block north from Taree; and research on the calibration in absolute years of the Devonian, Carboniferous and Permian ages of Australian rocks previously dated relatively by fossils;

Professor Roberts has advanced Geology generally in Australia by his editorship of the Australian Journal of Earth Sciences for the past four years; of the Australian Geoscience Council's Review from 1984 to 1986; and of the journal "Alcheringa", an international journal of palaeontology published in Australia, from 1978 to 1982. He has also advanced the cause of Geology on the Australian and international scenes as President of the Australasian Association of Palaeontologists, 1988-1990; as variously Chairman, Secretary and Member of numerous technical bodies, and as New South Wales Correspondent for the Harkness Fellowships of the Commonwealth Fund of New York, 1982-1985. Professor Roberts has also recently played an important role in discussions by the Australian Science and Technology Council on the role of Geosciences education and research in Australia, producing substantial documentation in rebuttal of official assertions that the Geosciences are oversupplied with graduates and over-researched in Australia.

Professor Roberts is a native of Armidale, New South Wales, and obtained his Bachelor of Science degree at the University there, proceeding to the University of Western Australia to complete a Ph. D. degree in 1963. He then joined the Commonwealth Bureau of Mineral Resources for eight years, transferring to the academic world at the University of New South Wales in 1970, where he has remained to this time. He was appointed Professor of Geology there in 1986.

Professor Roberts joined this Society in 1961. He has contributed six papers to its Journal, and received the Archibald D. Ollé Prize of the Society in 1964 for an excellent paper. It is gives great pleasure to the Council that one of the Society's own members can be thus honoured.

EDGEWORTH DAVID MEDAL

The Edgeworth David Medal for excellence of research in any area of science or applied science by a worker under 35 years of age, is awarded to **Dr Trevor W. Hambley.**

Dr Hambley has an established reputation as a chemist in both collaborative research and his personal research. He has been prolific in his role as a crystallographer and a practitioner of molecular mechanics calculations. This has resulted in many collaborations, both nationally and internationally, where these techniques have been applied to many and varied chemical problems that are of both fundamental and practical importance. We are assured that Dr Hambley has made important intellectual contributions to every collaboration in which he has become involved, as well as supplying data for it.

Two personal projects should also be highlighted. Dr Hambley has been active in the extension of molecular mechanics calculations to a number of new areas of chemistry. The more powerful computer programs that he has developed (MOMEC87) have been widely adopted. He has applied these computer programs to a number of fundamental questions on the thermodynamics and kinetics of several classes of chemical processes. Another activity involves the determination of the probable mode of action of Pt(II)-based anti-cancer drugs, and the design and development of new drugs.

AWARDS

Dr Hambley has had published 116 refereed articles and has one patent application. The quality of the research can be judged by the fact that nearly half of his publications are in international journals of the highest standing.

Dr Hambley graduated Bachelor of Science, with First Class Honours majoring in Physical and Inorganic Chemistry, at the University of Western Australia in 1978. His Ph. D. research was conducted in the Department of Physical and Inorganic Chemistry at the University of Adelaide, and he received his doctorate in May, 1983. Thereafter he held an ANU Postdoctoral Fellowship for a year, followed by an Australian Institute of Nuclear Science and Engineering Postdoctoral Fellowship. In February 1988 he was appointed a Lecturer in Chemistry at the University of Sydney.

THE ROYAL SOCIETY OF NEW SOUTH WALES MEDAL

The Society's Medal is awarded for meritorious contributions to science and to the advancement of the Society, and is awarded to **Professor John Loxton.**

John Loxton graduated BSc with First Class Honours in 1969 and MSc in 1970 from the University of Melbourne, and PhD in 1973 from the University of Cambridge. At Cambridge he studied under Professor J.W.S. Cassels, F.R.S., and there learnt an appreciation for the theory of numbers. He returned to Australia in 1973 and a lectureship in the School of Mathematics at the University of New South Wales, later becoming an Associate Professor. In 1987 he moved to a Professorship in Mathematics at Macquarie University and is currently Head of the School of Mathematics, Physics, Computing and Electronics there.

He continues research on the theory of numbers, including work on transcendental numbers and analytic number theory. Some of this rather pure mathematics has been boosted recently by application in cryptography. For example, a study of certain exponential sums related to a problem of Waring has turned into a study of the cryptographic security of random number generators. This unexpected effectiveness of mathematics is one of its chief charms.

Professor Loxton has published about 50 research papers and edited two books. He has supervised nine research students to successful doctorates. He is a member of the Council of the Australian Mathematical Society and is an Associate Editor of two of its publications.

John Loxton became a member of the Royal Society of New South Wales in 1974 and was a member of Council in 1983 and 1984, President in 1985 and has been a Vice-President from 1986 to the present. Whilst holding these offices he has conscientiously and consistently served the Society with grace and distinction and is regarded by Council as a most worthy recipient of the Society's Medal.

WILLIAM WREFORD MILLERSHIP
1909 - 1989

William Wreford Millership died on 15th January 1989, aged 80.

Raised on a farm in Byron Bay, his early education was in the local school and at Lismore High. He displayed considerable aptitude in mathematics and science in particular and was awarded a University Bursary on the completion of his studies in 1925. Even at this age, his talents in imparting knowledge were apparent, and he is remembered for his tutorials to fellow students while commuting daily between Lismore and Byron Bay.

At the University of Sydney he majored in Chemistry with mathematics as a background, graduating B.Sc. in 1930. It is of interest to note that the Bursary was for L65 per annum plus L5 per annum for books - sums which would not have much purchasing power in today's economy, and no doubt even in the 1920s did not allow much for frivolity.

Upon graduation he accepted a position as Research Chemist with Davis Gelatine Australia Pty. Ltd. This was the start of an association which lasted until his retirement in 1973. During the initial period in particular, he maintained a close liaison with the University, and in 1934 was awarded an M.Sc. for research in protein chemistry. His research interest was maintained throughout his working life in charge of the Davis laboratories, and he attracted a very strong team of technologists to the company over the yars. Indeed the development of Davis as a multinational was due in considerable measure to the research and development carried out in the Sydney laboratories and to the development of manufacturing processes unique in the world. During this period also he had considerable input into the British Gelatine and their research association in their basic research studies into the nature and structure of gelatine.

Essentially a humble and quiet-spoken man, he is remembered best in the company for his exceptional ability in analysing a problem and in explaining difficult technical matters to the uninitiated. This, coupled with a good personality and a puckish sense of humour enabled him to build a very strong team spirit in his group and to produce very worthwhile results.

Bill had very wide ranging interest and was a member of the Royal Society of New South Wales from 1940, being made a life member in 1975. Together with his interest in music and the arts, this gave him a wide circle of friends who remember him with considerable affection.

He and his wife, Con, lived for most of their married life in a house of their own design in Pymble and were able to indulge their horticultural interests in their very large garden. Con predeceased him by several years and unfortunately there was no family.

The trustees of his estate have established a fund to present an annual "Millership Science Award" at the Lismore High School for excellence in science, coupled with a desire of the student to proceed to further studies at University. The inaugural presentation of books of his choice was made in 1989 to an 18 year old student, Christopher Gibson, who has started a B.Sc. course at Griffith University in Queensland this year.

J.R.McG.

For photo see page 47

REAR ADMIRAL SIR DAVID MARTIN, K.C.M.G, A.O.

Governor of New South Wales
Patron of the Roal Society of New South Wales

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Governor of New South Wales
Patron of the Royal Society of New South Wales
1989 - 1990

It is with much sadness that we have to place on record in our Journal the death on Friday, August 10th 1990, of Sir David Martin, Patron of our Society. Owing to his severe ill-health, Sir David had been forced to resign his position as Governor on tne 8th August, just two days before his death. Sir David died of mesothelioma, a form of chest cancer thought possibly to have been induced by exposure to asbestos dust (shed by thermal insulation commonly installed in ships) during his forty-one years of service with the Royal Australian Navy.

David James Martin was born on 15th April 1933. His father, a commander in the Royal Australian Navy, died in action in HMAS Perth in 1942. One of Sir David's forebears was an officer in the Royal Marines who landed with the First Fleet.

Following a school education at Glamorgan School, Melbourne, and Scots College, Sydney, he joined the Royal Australian Naval College in 1947, graduating in 1950. He served with the RAN during the Korean War, and subsequently in numerous ships based both at home and overseas. In 1957 he married Suzanne Millear, daughter of Spencer and Sylvia Millear of Victoria. Sir David and Lady Martin have two daughters, one of whom is married to an RAN pilot, and a son, who is also a naval officer.

His appointment as Governor of New South Wales was first announced during the second half of 1988, & shortly afterwards he was knighted. This was an exceptional measure initiated only for the case of the prospective Governor, since otherwise New South Wales does not participate in the British honours system. Sir David was sworn-in as Governor on on 20th January 1989. He became deeply dedicated to his work in his new career, and established a high reputation for being tireless in his application to his duties. He made a very special effort to find out about the lives and work of the people of New South Wales. He believed very strongly in the value of the appointment of a Royal Governor to the development and welfare of the State. One of his innovative contributions was to make a video film about the life and work of the Governor to assist people to form their own opinion concerning the value to the community of having a Governor owing allegiance to the Queen. This was widely distributed through NSW (by the State Bank) to schools, libraries and community groups.

Sir David was patron of many societies and organisations, one of which was the Royal Society of New South Wales. The Society was greatly honoured by the presence of Sir David and Lady Martin on the occasion of the Society's Annual Dinner on Wednesday 14th March 1990, at which Sir David made a short address expressing his interest in the Society and wishing it well for its future development.

The Members of the Society were much distressed to learn of Sir David's death and wish to record their deep respect and appreciation both for him as a person and for the energy and enthusiasm he brought to his office; and to express their sincere condolences to Lady Martin and their children.

G.W.K.Ford — President

JOHN MANNING WARD

1919-1990

John Manning Ward who died tragically in a train crash on 6th May 1990, had been a member of the Royal Society of New South Wales since 1983. His wife Patricia, and their daughter, Jennifer, died with him.

Emeritus Professor John Ward had had a distinguished career as an academic and administrator at the University of Sydney where he had been Vice-Chancellor from 1981 to 1984, and Deputy Vice-Chancellor from 1979 to 1981. Prior to this he had been Challis Professor of History, from his appointment to the Chair in 1948 at the age of 29, and later Dean of the Faculty of Arts in 1962.

Born at Strathfield in 1919, he was educated at Fort Street Boys' High School and the University of Sydney. He graduated as B.A.(Hons.) with the History Medal in 1939, and M.A. in 1945. He wrote and published his M.A. thesis on British Policy in the South Pacific, thus establishing the expertise in Imperial and contemporary history which he had developed under the tutorship of Professor S.H. Roberts. He joined the History Department in 1944.

During this time he also ran the S.U. Extension Board, edited the "Australian Outlook" and carried a heavy load of teaching in the School of History where classes became huge with the end of the War. He has been described by his colleague Dr. Ken Cable (former Associate Professor of History at the University of Sydney) as "a prodigious worker capable of intense concentration and a dedicated and enthusiastic teacher". His appointment to the Chair of History in 1948 was a natural consequence of his demonstrated abilities. In 1951 he became Dominian Fellow at St. John's College, Cambridge, which gave him a wider outlook on the university world, and a fresh interest in Imperial history. He also worked from time to time in Oxford, Harvard and Yale.

His published works included "British Policy in the South Pacific", 1948; part author of "Trusteeship in the Pacific", 1949; contributor to "Australia" U.N. Series, California, 1947; "Earl Grey and the Australian Colonies 1846-57", 1958; and contributor to "The Pattern of Australian Culture", 1963.

In the 1960s he presided over an expanding Department and also expanded his own labours. The State Library, the N.S.W. Archives, the Royal Australian Historical Society, the Journal of Religious History, the new learned Academies in Canberra (of which he became a fellow) and the Australian Dictionary of Biography, all experienced his guiding hand.

Professor Ward was proud of the fact that he was the first student of the Sydney University History Department to occupy its Challis Chair, and more especially that he was the first graduate of Sydney University to be its Vice-Chancellor. Dr. Cable in his valedictory speech paid this tribute: "to the task of governing the University, Ward brought experience, patience, moderation and skill... Ward's qualities as the Vice-Chancellor were those of the man and the historian. They were natural to him; they formed him as a scholar and leader; they were essential to his administrative work".

He was always courteous, and treated those whom he opposed with respect, relying on the logic of his arguments to achieve his recommendations

As guest speaker at the Annual Dinner of the Royal Society of N.S.W. in the Great Hall of the University of Sydney on 2nd March, 1983. Professor Ward described the position of Vice-Chancellor as one belonging to each and every faculty. "He is required to be a scientist and a lawyer, a physician and an engineer, a dentist and a humanist". He reminded his audience of the Society's origins in 1821, as the Philosophical Society of Australasia, founded with active encouragement of the sixth Governor of N.S.W., Sir Thomas Brisbane, an amateur scientist and astronomer as well as a soldier and a sociable man;it was "a small scientific club of not more than 10 members which expired after only one year". It was revived as the "Australian Philosophical Society in 1850, the year in which the Act founding the University of Sydney was passed. One of the founding fathers of the first Society, Henry Grattan Douglass a medical doctor, had decided that N.S.W. needed a university and that the Philosophical Society, which he saw as the intellectual companion of the university, should be revived. The objectives of the revived society were "the encouragement of Arts, Sciences, Commerce and Agriculture in Australia (Arts being understood as applied arts). The Patron of the Society was the Governor-General, Sir Charles Fitzroy who was also Visitor to the University. The Vice-Provost of the University, Sir Charles Nicholson, was also Vice-President of the Society.

Professor Ward concluded his address with these words: "...the humble beginnings of the Royal Society of New South Wales were laid by men of good-will, who belonged to a generation when men took it for granted that science and literature, philosophy and geology were all intricably linked. So they are, and that is why we value so highly the individuals among us who can see the links and stimulate the imagination through them".

John Manning Ward was one who saw and valued those links, a quality which facilitated his ready rapport with people of widely varied professions and positions in society, whether academics, students or bureacrats, as he "led the University through a period of unprecedented change and conflict in Australian tertiary education".

His wife, Patricia, who was a distinguished librarian, shared his enthusiasm for the arts and documentation. Their daughter Jennifer was a dedicated and much-loved teacher. They are survived by a second daughter, Mrs. Anne Craigie.

P.M.C.

Dr. Ilse Rosenthal-Schneider

(Photograph taken in 1938, the year she arrived in Australia)

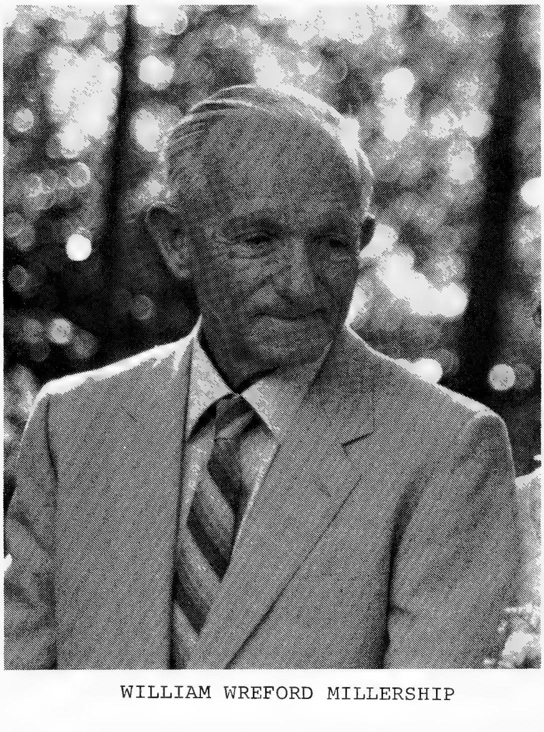
The obituary of Dr. Rosenthal-Schneider was published in Volume 122, p.135.

STANTON ERNEST COALSTAD

1907-1990

Stan Coalstad was born in Western Australia on 8th December, 1907. As a young man he joined the Royal Australian Navy as a cadet midshipman and rose to the rank of sub-lieutenant. He served in that capacity up to 1929 when he resigned to take up studies at Adelaide University, where he graduated with a degree in Chemical Engineering. After graduation he pursued a career in industry in a number of situations including the cement, leather tanning and explosives industry during World War II. In the mid-1950s he came to Sydney to accept a position on the staff of the University of New South Wales, working in the School of Metallurgy as a metallurgical chemist. On retirement he kept himself busy by pursuing courses in scientific subjects, especially at the New South Wales Institute of Technology (now the University of Technology). He was employed by this organisation as a part-time tutor in materials science at the time of his death on 20th April, 1990. He had also been an active member of the Inventors Society, as well as a regular attendant at the Monthly Meetings of the Royal Society of New South Wales, which he joined in 1961. It was his vast store of knowledge of "things scientific" and his willingness to share it with others, particularly the younger generation of students, for which Stan will be best remembered by his friends and colleagues. He is buried in the Anglican Section of Botany Cemetery, Sydney , NSW.

J.L.G.



WILLIAM WREFORD MILLERSHIP

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Manuscripts should be arranged in the following order: title; name(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgements; appendices; references; name of Institution/Organisation where work carried out/or private address as applicable. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Ünites(SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigraphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra.

Abstract. A brief but fully informative abstract must be provided.

Tables should be adjusted for size to fit the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

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Drawings should be made in black Indian ink on white drawing paper, tracing cloth or light-blue lined graph paper. All lines and hatching or stripping should be even and sufficiently thick to allow appropriate reduction without loss of detail. The scale of maps or diagrams must be given in bar form.

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Titles of journals should be cited in full — **not** abbreviated.

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THE ROYAL SOCIETY OF NEW SOUTH WALES

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Limestone Olistoliths in the Kildrummie Formation Near Cow Flat, New South Wales

T. J. FOWLER

ABSTRACT. The Cow Flat limestone quarries, south of Bathurst expose massive tabular megaliths (up to 750m long) of coarsely granular limestone designated as Kildrummie Formation (formerly Group). These blocks are enclosed within a silicic volcaniclastic unit of the Campbells Formation.

Facies characteristics of the silicic volcaniclastics suggest that they are deep-water massflow deposits. Structural relations of limestones to host volcaniclastics indicates that the former are allochthonous blocks (olistoliths). The silicic volcaniclastics and limestones are correlated with the shallow-marine Late Silurian Mullions Range Volcanics on the western side of the Hill End Trough, northwest of Cow Flat. It is suffested that at this timme the Hill End Trough had a southward sloping basin floor. This and other occurrences of limestone olistoliths in the deep-marine areas flanking the Molong Rise may have resulted from vertical movements associated with the Late Silurian Bowning Orogeny, or from collapse of unstable fault scarps bordering the rifting Hill End Trough.

INTRODUCTION

Deep-marine metasediments of the Hill End Trough, south of the Bathurst Granite, are separated from probably similar-aged shallow-marine units on the Molong Rise by the Copperhania Thrust, and from other deep-marine deposits in the northern Hill End Trough by the Bathurst Granite. Direct correlation by mapping between the southern Hill End Trough and the above areas is thus not possible, and correlation is made even more difficult by the relatively non-fossilifereous nature of the sediments in the southern Hill End Trough. The southern Hill End Trough includes shales and greywackes and silicic volcaniclastic units associated with limestones. The Cow Flat area (Fig. 1) is an area of volcaniclastics and limestones mapped as undifferentiated Campbells and Kildrummie Groups (Packham (1968b).

The stratigraphy of the Cow Flat area has been described by Stanton (1956) with some stratigraphic refinement informally proposed by Binns (1958). The area is particularly well-known for its quarries of pure white limestone which have been described by Benson (1907) and by NSW Geological Survey staff (Carne & Jones 1919, Lishmund et al 1986).

Outcrop in the area is poor but a tentative structural analysis of Cow Flat and environs has been proposed by Fowler (1989). The Cow Flat Quarries area, which is the topic of this paper, lie 1-2 km west of the locality Cow Flat (Fig. 1) and forms the steeply dipping (60-75°NW) upright southeastern limb of an inclined syncline (Fig. 1) which is probably a northern extension of the Rockley Syncline (Stanton 1956).

The aim of this paper is to report the occurrence of exotic limestone blocks within deep-marine silicic volcaniclastics. These units are correlated with similar deposits in the northern Hill End Trough and their mode of deposition is discussed. The possible tectonic or other events leading to deposition of the allochthonous limestone will also be considered.

HOST SILICIC VOLCANICLISTICS

The silicic volcaniclastic units hosting the Cow Flat Quarries limestone blocks have been included within the undifferentiated Kildrummie and Campbells Groups by Packham (1968b). Stanton (1956)

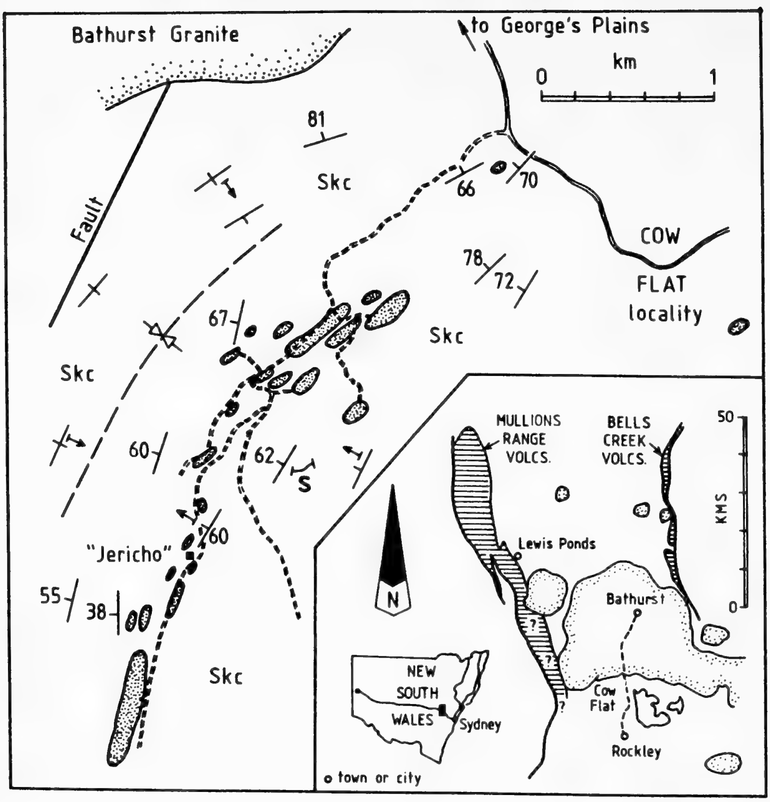

Fig. 1. Location and geological map of Cow Flat. Stippled granitoids are Carboniferous, Bathurst-type. Limestone megaliths are shaded, and entirely enclosed within Skc (undifferentiated Kildrummie and Campbells Group silicic volcaniclastics). Dip and strike symbols are bedding, small arrows indicate younging. S represents the location of the stratigraphic section shown in Fig. 2.

referred to the volcaniclastic units stratigraphically above the Cow Flat Quarries limestone as the "Cow Flat Volcanics" and those below the limestones as the "Vale Creek Volcanics" with a combined stratigraphic thickness of 1500 m. The two volcaniclastic units were combined by Fowler (1987) into the "Vale Creek Formation" which has a maximum thickness of approximately 2700 m in the nominated type section along Vale and Caloola Creeks.

The silicic volcaniclastics at the latitude of Cow Flat thin to the south and pass laterally into finer grained silic tuffaceous sediments and compositionally equivalent pelites mapped as the Campbells Group by Stanton (1954).

Lithology and Primary Structures

The volcaniclastics are mainly rhyolite-derived pebbly sediments (Figs. 2,3) and tuffs with well-preserved rhombic, embayed quartz, euhedral K- feldspar and plagioclase phenocrysts in a recrystallized (and now foliated) groundmass of quartz and feldspar with minor metamorphic biotite and muscovite. There are occasionally preserved volcanic shard and spherulite textures indicating a former glass component. Dacitic tuffs occur and contain chlorite aggregates which were probably altered glass (cf. Cas 1978). Fine-grained pelitic units of similar composition form occasional interbeds.

These units contain no structures suggestive of lavas or ignimbrites. Individual beds are often metre-thick paraconglomerates showing planar bases (Fig. 2), and invariably lacking chilled margins, vesiculation, flow bands and columnar joints. Despite an apparent range of primary particle sizes there is little evidence for graded bedding in these units (Figs. 2,3). The coarsely granular component of the metasediments appears to have been matrix supported. Pelitic interbeds show delicate laminations which are not distured by bioturbations. No shelly fossils or trace fossils have been found.

Tuffaceous units were likely to have been rapidly deposited from highly concentrated massflows (Cas 1979) rather than being primary volcanic units. The thick structureless coarse-grained sedimentary units correspond to Cas' (1979) non-graded a2 subdivision of the Bouma sequence which were rapidly deposited under viscous flow conditions. The pelitic interbeds may have been deposited during the waning stages of massflow deposition. The absence of shelly fossils and sedimentary structures indicative of shallow water tractional reworking of the sediments suggests deposition in a deep-water environment (below storm wave base ~200m).

LIMESTONE MEGALITHS

The limestones west of Cow Flat formed part of Stanton's (1956) Kildrummie Group. De Deckker (1976) redefined the unit in its type area as Kildrummie Formation of Late Silurian age. Similar Late Silurian allodapic limestones occur near Rockley (Sherwin 1973) but they thin to the north (Fowler 1987). Conodonts have not been extracted from the limestones of the Cow Flat-Rockley district (Pickett 1987). The Cow Flat limestone occurrence is quite distinct in style from the Kildrummie Formation in being composed of discrete sporadic blocks rather than relatively continuous bioclastic bands (as is typical of the Kildrummie Formation), though it may be of similar age. Similar massive limestone blocks within silicic tuffs are found nearby at the Caloola Marble Quarry and at The Mount (GR 247848, 252851 respectively, Bathurst 1:250,000 Geological Sheet (Packham 1968b).

The Cow Flat limestones have been informally called the "Jericho Limestone" by Binns (1958) who proposed the type area near the "*Jericho*" ruins (Fig. 1).

Lithology and Primary Structures

The limestones have been regionally metamorphosed and also lie within the thermal aureole of the Bathurst Granite. They are now coarse granoblastic calcite marbles which are occasionally dolomitic (Benson 1907, Carne & Jones 1919).

Quarrying has revealed planar

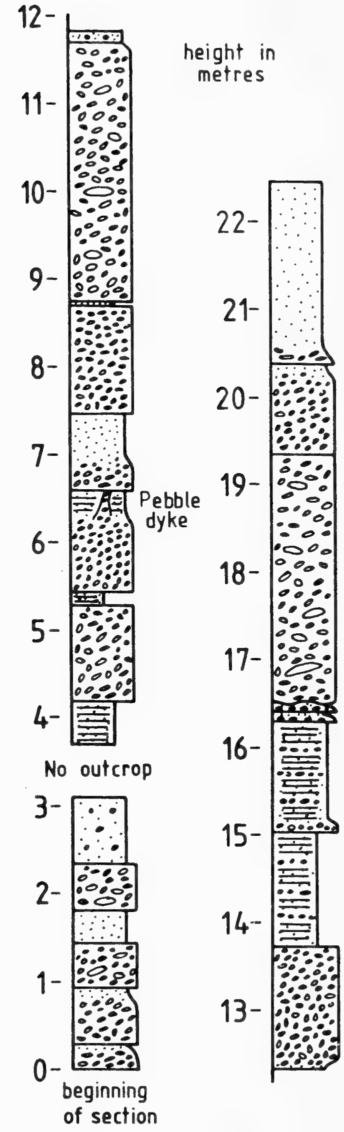

Fig. 2. Stratigraphic column for part of the acid volcaniclastic mass flow deposits. Paraconglomerate beds lack particle-size grading except towards the tops of the beds, and usually have planar bases. Horizontal rules lines represent laminations. Location of measured section is shown as S in Figure 1.

centimetre-thick greenish seams, spaced up to a metre apart (Fig. 4) composed of chlorite and calcite, with occasional embayed volcanic quartz grains. Additional metamorphic phases are phlogopite, talc, tremolite, pyrite and sphene. The seams have been referred to as veins or replacements (Benson 1907, Lishmund et al 1986) but are here considered to be former vitric tuff beds. Rare bioclastic bands occur parallel to these chloritic bedding seams. No evidence of biohermal structures has been found in these limestones.

Palaeontology

Unidentified crinoid columnals set in spar are the commonest fossils in these limestones. Benson (1907) identified *Pentamerus (Conchidium) knightii* of Late Silurian age from the Cow Flat Quarries.

Structural Relations of Limestone to Host Rocks

The limestone blocks in the Cow Flat Quarries are grouped over a strike length of 4.25 km and within a statigraphic thickness of 795 m. The blocks may reach 750 m in maximum exposed length. The overall shape is tabular with individual blocks abruptly truncated against volcaniclastics, with long axes of blocks parallel to local bedding in nearby volcaniclastic units.

Each block is enclosed in massive silicic volcaniclastics, though there are traces of stratification in the volcaniclastics units interposed stratigraphically between limestone blocks. No limestone breccias occur at the margins of the blocks. Limestone blocks do not contain interbeds of the surrounding silicic volcaniclastic units and do not have marginal lithofacies. The silicic volcaniclastics do not contain any calcareous fossils.

East of Cow Flat, along the Perthville-Rockley Road near Mt. Evernden (GR 252852, Bathurst 1:250,000 Geological Sheet, Packham 1986b), there are road cuttings exposing small pure limestone blocks enclosed in silicic volcaniclastics (Ringis 1965). Limestone blocks are also found near dumps of the old Cow Flat copper mines (GR 252851, Bathurst 1:250,000 Geological Sheet, Packham 1986b) (Fig. 5).

Figure 6 presents bedding-pole data for the Cow Flat Quarry area. Structural discordance between limestones and silicic volcaniclastics is shown by variable orientation of beds in the limestone blocks compared to the uniformly dipping beds of host silicic volcaniclastic units which lie within one limb of a syncline. No geopetal evidence was found in these limestones. The limestone beds show no significant mesoscopic folding and no soft-sediment structures. The significance of the girdle of poles to bedding in the limestones is discussed below.

DISCUSSION

Allochthonous Nature of the Limestone Megaliths

The primary structures shown by the silicic volcaniclastic units and limestone blocks in the Cow Flat Quarries and environs indicates transportation of exotic shallow-water limestone megaliths (olistoliths) into a deep-water basin. Evidence that the limestones are exotic includes (a) their non-gradational contacts with surrounding volcaniclastics, (b) the discrete tabular geometry of the blocks, (c) discordance of bedding orientations between the limestones and enclosing volcaniclastics (Fig. 6), (d) absence of any shallow-water sedimentary structures or shelly fauna in the volcaniclastics (ie anomalous association of shallow-marine limestone with deep-water massflow deposits), and (e) evidence of large limestone clasts in a road cutting and near copper mines east of Cow Flat.

Transportation and Deposition of the Limestone and Volcanics

The blocks were evidently deposited with silicic volcaniclastics as combined debris flows (massflows). The huge blocks may have rolled or slid into place, though Rodine & Johnson (1976) ascribe the transport of such large blocks down gentle slopes to floating of these clasts on a dense particle-laden poorly-sorted matrix.

Olisoliths are typically enclosed in olistostromes (Abbate et al. 1970, Heck & Speed 1987). The absence of associated breccias and olistostrome in the Cow Flat Quarries area may be due to transportation of even larger blocks which broke up near the site of deposition (Abbate et al 1970, Cook et al 1972). Features consistent with this are: (a) the close-spaced arrangement of large blocks, (b) the stratigraphic similarity between blocks along strike, and (c) the small angular differences in bedding orientation between adjacent blocks which suggests little relative rotation between adjacent blocks.

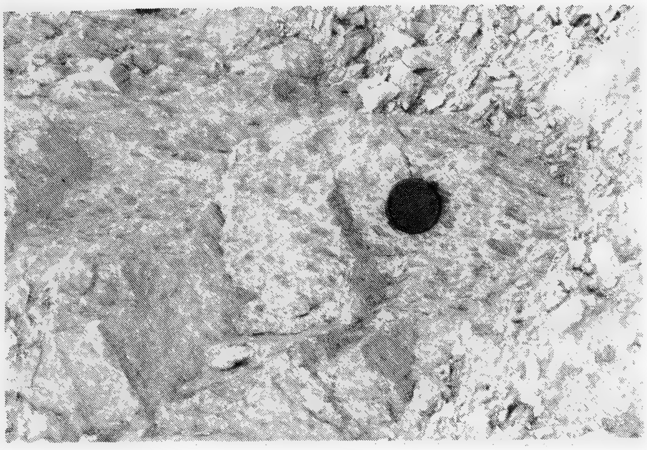

Figure 3. Typical pebbly acid volcaniclastic bed with some particle-size grading towards the top (towards the bottom-left corner). Camera lens cap diameter is 5 cm.

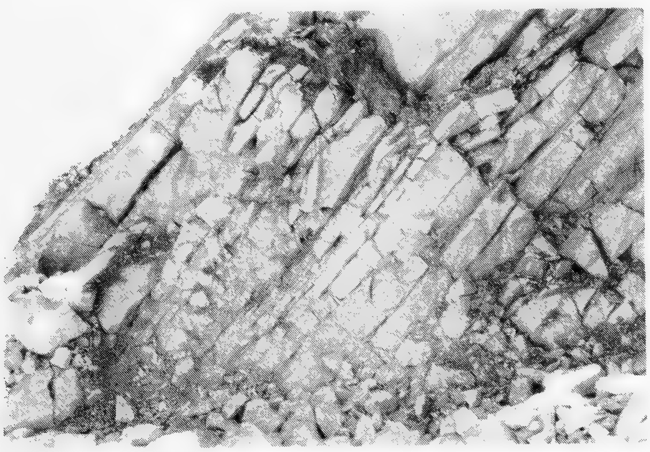

Figure 4. Regularly planar bedded limestone (looking N within the main quarry of the southernmost megalith shown on Fig. 1). Bed thickness reaches 1 m. Horizontal width of the photograph is approximately 8 m.

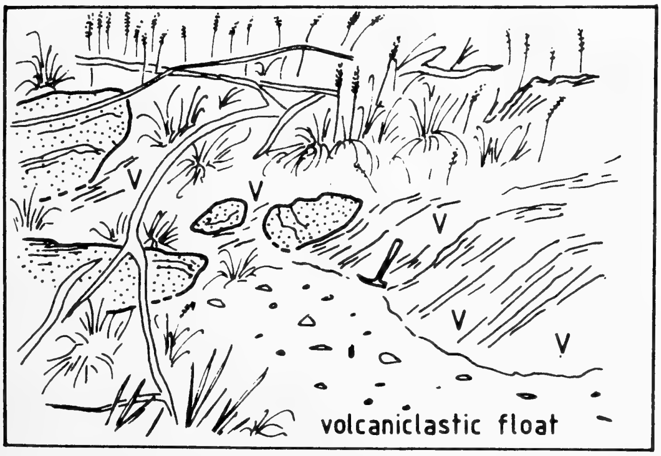

Figure 5. Non-gradational contact between limestones (stippled) and silicic volcaniclastic host (V). Sketch from near one of the Cow Flat copper mine dumps along the Bathurst-Rockley road near Mt. Evernden (GR 2523851, Bathurst 1:250,000 Geological Sheet).

The girdle of poles to limestone in Figure 6 cannot be due to the regional folding since the area lies on one limb of a syncline which lacks macroscopic parasitic folds. Moreover, the orientation of the local fold axis does not parallel the π-axis. The significance of the π-axis is not obvious but may represent imbrication of the broken limestone blocks so that some of these blocks dipped gently in the opposite direction to the seafloor slope perhaps as they rode over blocks downslope from them. The near vertical attitude of some blocks could then easily be explained as resulting from steepening of the southwestern limb of the syncline.

Regional Correlation of the Limestone and Volcaniclastic Units

The enclosure of limestone blocks within the volcaniclastics and the volcaniclastic nature of the limestone bedding seams suggest that the two lithologies may have a common source area. Thinning of the coarse-grained volcaniclastic units towards the south and a facies change to fine-grained pelitic equivalents indicates that the volcaniclastics were not derived from the south. The source for the volcaniclastics may be from the north, northwest or northeast of Cow Flat. The ultimate source of the limestone at least must have been a shallow-marine environment consistent with the margins (rather than the axis) of the Hill End Trough.

Silicic volcanics of Silurian age erupted along the margins of the newly rifted Hill End Trough (Packham 1958a, Brown et al. 1968). These volcanics are preserved today in the Middle-Late Silurian (Packham 1968a, Hilyard 1981, Pickett 1982) Mullions Range Volcanics and the Middle Silurian (Packham 1968a) Bells Creek Volcanics (Fig. 1). The inferred main source of the Mullions Range Volcanics clastic component lies south of Mullions Range (ie 50-60 km NNW of the Cow Flat area) (Hilyard 1981). Extensions of equivalent volcanic units occur southward to the latitude of the Cow Flat area along the Copperhania Thrust (Stevens 1975) (Fig. 1).

The Mullions Range Volcanics consists of up to 2000 m of porphyritic dacite and rhyolite lava and volcaniclastics. The volcaniclastics were deposited as gravity-driven debris flows and contain occasional allochthonous crinoidal limestone lenses (Jones 1978, Hilyard 1981, Skirrow 1983, Lishmund et al 1986). Jones (1978) also noted limestone blocks in this volcanic formation. Limestones within equivalents of the Mullions Range Volcanics occur between Mullions Range and Cow Flat at Lewis Ponds (Lishmund et al. 1986). These latter limestones are described as having formed on small topographic highs east of the Molong Rise.

The Bells Creek Volcanics consists of porphyritic rhyolite tuffs and lavas with maximum thickness 460 m along the eastern flank of the Hill End Trough. Farther east in the Sunny Corner Synclinorium allochthonous limestone blocks up to 100 m across are incorporated in Middle Silurian to Early Devonian massflow mudstones and breccias. Silicic volcaniclastics are a minor component of these latter units (Bischoff & Fergusson 1982).

On the basis of similar lithologies, proximity, style of deposition, interposed similar deposits between Cow Flat and Mullions Range, and permitted by the poorly constrained ages of stratigraphic units; the silicic volcaniclastics and exotic limestones in the Cow Flat Quarries area are correlated with the Silurian Mullions Range Volcanics. Further it is suggested that the Mullions Range Volcanics may be the source of volcaniclastic debris flows at Cow Flat. This would require that the seafloor between Mullions Range and Cow Flat had a gentle southward slope component at this time.

Other allochthonous Limestones south of the Bathurst Granite

The Cow Flat and Apsley Cu-Zn mines (Binns 1958, Felton et al. 1974, Weber 1974) are associated with actinolite-chlorite rocks within the same silicic volcaniclastics as at the Cow Flat Quarries (Scheibner 1974, Stevens 1974). The similarity of these actinolite-chlorite rocks to the green bedding seams described above suggests that these peculiar rocks are blocks of mixed silicic volcanic ash and carbonate, ie tuffaceous marl of similar age and origin to the exotic limestone blocks in quarries to their west. Calc-silicate hornfels lenses occurring in silicic volcaniclastics east of Ben Chifley Dam (GR 263850, Bathurst 1:250,000 Geological Sheet, Packham 1968b) (Fowler 1987), may also be stratigraphic equivalents.

Gravity collapse deposits in the Hill End Trough and their Significance

The western margin of the north Hill End Trough presents several examples of mass movement of shallow-water detritus into deep-water environments during the Silurian and Early Devonian. Limestone blocks as large as 1 km have been described from the Early Devonian Nubrigyn Formation (Conaghan et al. 1976). These blocks were dislodged by gravity, seismic events or tsunamis and transported at least 10 km down submarine canyons incised into the eastern edge of the Molong Rise, into the deep-water basin facies of the Hill End Trough (Byrnes 1976).

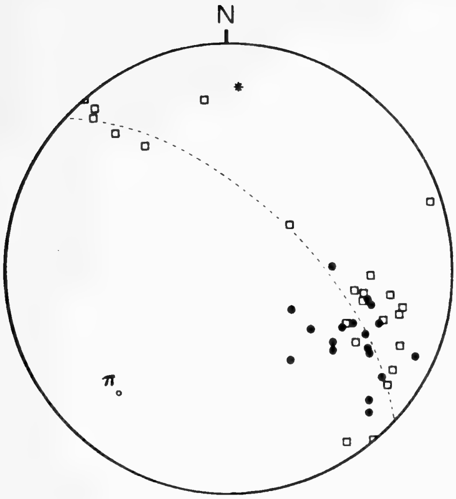

Figure 6. Distribution of poles to beds in the silicic volcaniclastics (dots) and the limestone megaliths (squares) in the Cow Flat quarries area. Volcaniclastic beds have clustered orientation (average 55°/297°) compared to limestone beds. The star represents the local fold axis orientation. See text for the significance of the π-girdle.

Early Devonian megaslump structures and gravity overfolds have also been recorded with similar sense of mass movement (Packham 1968a, Russell 1976). These may be due to vertical movements associated with the weak Tabberabberan Orogeny (Webby 1972, Powell & Edgecombe 1976).

The dislodgement and transportation of exotic shallow-water limestone blocks and massflow silicic volcaniclastics into deeper parts of the basin in the southern Hill End Trough may be due to disruptive processes described above or to instability accompanying uplift during the Siluro-Devonian Bowning "Orogeny" (Cas 1983). Alternatively, continued rifting near the margins of the Hill End Trough, itself responsible for silicic volcanism, may have generated unstable fault scarps which collapsed carrying volcanic detritus and limestone olistoliths into deep-water parts of the basin (cf. Eastoe et al. 1987, who propose a similar collapse mechanism for olistostrome formation).

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REFERENCES

Abbate, E., Bortolotti, V. and Passerini P. 1970. Olistostromes and olistoliths. *Sedimentary Geology, 4,* 521-57.

Benson, W.N., 1907. The Geology of Newbridge, near Bathurst. *Proceedings of the Linnaean Society, 32,* 523-53.

Binns, R.A., 1958. The geology of the Cow Flat district, near Bathurst, N.S.W. *B.Sc. (Honours) Thesis, University of Sydney.* (Unpublished).

Bischoff, G.C.O. and Fergusson, C.L., 1982. Conodont distributions, and ages of Silurian and Devonian limestones in the Palmers Oakey district, N.S.W. *Journal of the Geological Society of Australia, 29,* 469-76.

Brown, D.A., Campbell, K.S.W. and Crook, K.A.W. 1968. The Geological Evolution of Australia and New Zealand. Permagon Press, Sydney. 409 pp.

Byrnes, J.G., 1976. Silurian environments of the northern Molong Rise. *Bulletin of the Australian Society of Exploration Geophysicists, 7,* 18-22.

Carne, J.E. and Jones, L.J., 1919. The Limestone Deposits of New South Wales. *Geological Survey of New South Wales, Mineral Resources 25.*

Cas, R.A.F., 1978. Silicic lavas in Palaeozoic flysch-like deposits in New South Wales, Australia: behaviour of deep subaqueous silicic flows. *Geological Society of America Bulletin, 89,* 1708-14.

Cas, R.A.F., 1979. Mass-flow arenites from a Palaeozoic interarc basin, New South Wales, Australia: mode and environment of emplacement. *Journal of Sedimentary Petrology, 49,* 29-44.

Cas, R.A.F., 1983. A review of the palaeogeographic and tectonic development of the Palaeozoic Lachlan Fold Belt of southeastern Australia. *Geological Society of Australia Special Publication No. 10.*

Conaghan, P.J., Mountjoy, E.W., Edgecombe, D.R., Talent, J.A. and Owen, D.E., 1976. Nubrigyn algal reefs (Devonian), eastern Australia: allochthonous blocks and megabreccias. *Geological Society of America Bulletin, 87,* 515-30.

Cook, H.E., McDaniel, P.N., Mountjoy, E.W. and Pray, L.C., 1972. Allochthonous carbonate debris flows at Devonian bank ("reef") margins, Alberta, Canada. *Bulletin of Canadian Petroleum Geology, 20,* 439-97.

de Deckker, P., 1976. Late Silurian (Late Ludlovian) conodonts from the Kildrummie Formation, south of Rockley, New South Wales. *Journal and Proceedings of the Royal Society of New South Wales, 106,* 59-69.

Eastoe, C.J., Gustin, M.M. and Nelson, S.E., 1987. Problems of recognition of olistostromes: an example from the lower Pit Formation, Eastern Klamath Mountains, California. *Geology 15,* 541-44.

Felton, E.A., Gilligan, L.B., Matson, C.R. and Stevens, B.P.J., 1974. Base-metal mineralization associated with Silurian acid volcanics in the eastern part of the Lachlan Fold Belt of New South Wales. *Records of the Geological Survey of New South Wales, 16,* 139-57.

Fowler, T.J., 1987. A stratigraphic, structural and tectonic analysis of the Rockley district, New South Wales. *Ph.D. Thesis, University of New South Wales* (Unpublished).

Fowler, T.J., 1989. Superposed folding in the Rockley district, Lachlan Fold Belt, New South Wales. *Australian Journal of Earth Sciences, 36,* 451-68.

Heck, F.R. and Speed, R.C., 1987. Triassic olistostrome and shelf-basin transition in the western Great Basin: palaeogeographic implications. *Geological Society of America Bulletin, 99,* 539-551.

Hilyard, D., 1981. Environmental, palaeogeographic and tectonic setting of the Mullions Range Volcanics, New South Wales. *Journal of the Geological Society of Australia, 28,* 251-60.

Jones, P., 1978. Progress Report June to December 1978. Orange EL 1075, N.S.W. Amoco Minerals Australia Company Report 117. *Unpublished Report of the Geological Survey of New South Wales, GS 1978/81.*

Lishmund, S.R., Dawood, A.D. and Langley, W.V., 1986. The Limestone Deposits of New South Wales. *Geological Survey of New South Wales Mineral Resources 25, 2nd edn.,* Department of Mineral Resources.

Packham, G.H., 1968a. The lower and middle Palaeozoic stratigraphy and sedimentary tectonics of the Sofala - Hill End - Euchareena region, New South Wales. *Proceedings of the Linnaean Society of New South Wales, 93,* 111-63.

Packham, G.H., 1968b. Bathurst 1:250,000 Geological Series Sheet SI 55-8. Geological Survey of New South Wales, Sydney.

Pickett, J., 1982. The Silurian System of New South Wales. *Geological Survey of New South Wales Bulletin, 29.*

Pickett, J., 1987. Marine fossils from the Rockley area. *Unpublished Palaeontological Report 87/9. Geological Survey Report No GS 1987/208.*

Powell, C. McA. and Edgecombe, D.R., 1976. Mid-Devonian movements in the northeastern Lachlan Fold Belt. *Journal of the Geological Society of Australia, 25,* 165-84.

Ringis, J., 1965. The Mineral Industry of New South Wales, No. 23 "Dolomite". Gelogical Survey of New South Wales, Department of Mines.

Rodine, J.D. and Johnson, A.M., 1976. The ability of debris, heavily freighted with coarse clastic materials, to flow on gentle slopes. *Sedimentology, 23,* 213-34.

Russell, H.Y., 1976. The geometry of the Gowan Green Overfold and its relationship to the regional deformational histroy. *Bulletin of the Australian Society of Exploration Geophysicists, 7,* 22-3.

Scheibner, E., 1974. Definition and review of structural elements, *in* THE MINERAL DEPOSITS OF NEW SOUTH WALES, pp. 109-13. N.L. Markham and H. Basden (Eds.). Geological Survey of New South Wales, Department of Mines.

Sherwin, L., 1973. Silurian fossils from the Rockley district. *Unpublished Palaeontological Report No. 73/23.* Geological Survey of New South Wales.

Skirrow, R.G., 1983. The geological setting and genesis of base-metal mineralization in the Calula area, New South Wales. *Postgraduate Diploma of Science Thesis, University of Newcastle* (Unpublished).

Stanton, R.L., 1954. Lower Palaeozoic mineralization and features of its environment, near Bathurst N.S.W. *Ph.D. Thesis, University of Sydney* (Unpublished).

Stanton, R.L., 1956. The Palaeozoic rocks of the Wiseman's Creek - Burraga area, N.S.W. *Journal and Proceedings of the Royal Society of New South Wales, 89,* 131-56.

Stevens, B.P.J., 1974. Hill End Synclinorial zone, in THE MINERAL DEPOSITS OF NEW SOUTH WALES, pp. 227-93. N.L. Markham and H. Basden (Eds.). Geological Survey of New South Wales, Department of Mines.

Stevens, B.P.J., 1975. Metallogenic Study, Bathurst 1:250,000 Sheet. Geological Survey of New South Wales, Sydney.

Webby, B.D., 1972. Devonian geological history of the Lachlan Geosyncline. *Journal of the Geological Society of Australia, 19,* 99-123.

Weber, C.R., 1974. Surface geological mapping at the Apsley Copper Mine, near Perthville. *Records of the Geological Survey of New South Wales, 16,* 111-38.

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Palaeokarst Deposits at Jenolan Caves, New South Wales

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ABSTRACT. Limestone breccias and internal sediments with unconformable stratigraphic relations to bedrock are exposed in cave walls at Jenolan Caves. These deposits show no sign of deformation and geopetal structures in the deposits indicate that they were deposited after the last major deformation to affect the limestone. They are highly lithified and clearly pre-date the development of the present cave system. The breccias and internal sediments are interpreted here as palaeokarst deposits filling caves, or possibly an extensive cave system, that developed in the limestone during Permo-Carboniferous times.

INTRODUCTION

Jenolan Caves (Fig. 1) is the best known karst in New South Wales. It is one of a number of karst landscapes with significant caves formed on limestones of the Lachlan Fold Belt (Osborne and Branagan, 1988).

The caves and other karst features at Jenolan Caves are developed in the Late Silurian Jenolan Caves Limestone. Jenolan Caves is located in mountainous country, forming the dissected eastern margin of the highland plateau east of Oberon.

Osborne (1984a) presented preliminary evidence, based on the exposure of palaeokarst deposits in caves, that a number of the limestones in the Lachlan Fold Belt (Borenore Limestone, Bungonia Limestone, De Drack Formation, Garra Formation, Jenolan Caves Limestone, Rosebrook Limestone, Wombeyan Limestone) had been subjected to multiple periods of karstification over geologically significant periods of time.

Subsequently palaeokarst deposits have been described from Billys Creek (Osborne & Branagan, 1985) and Timor Caves (Osborne, 1986a). Osborne and Branagan (1988) presented a geological history of karstification in New South Wales indicating that karst processes operated on a number of separate occasions during Palaeozoic times.

Research in progress suggests that there are many palaeokarst deposits in the Jenolan Caves Limestone. These deposits fill an ancient, possibly extensive, cave system. This paper describes the palaeokarst deposits studied so far and discusses their likely age.

Specimen numbers refer to material held in the Petrology Collection of the Department of Geology and Geophysics, University of Sydney.

GEOLOGICAL SETTING

The Late Silurian Jenolan Caves Limestone (Chalker 1971), crops out continuously over a strike length of some 5 km in the Jenolan Caves area and then continues north as a series of discontinuous outcrops for a further 4 km. The Limestone is 265 m thick near Caves House (Stanley, 1923) and has a steep, variable dip, ranging from almost vertical to steeply westwards near the Grand Archway, to eastwards just north of the Devils Coach House. In the south, along Camp Creek, and in the North, along the Jenolan River the limestone dips westwards. Allan (1986) attributed these changes in dip to folding along sub-horizontal axes. Chalker (1971) reported evidence found by J. Byrnes that the Limestone faces east and is in places overturned. This was confirmed by Allan (1986) who found that the Limestone faces east and has conformable boundaries.

Exposures in the caves and in an unlined tunnel, the Binoomea Cut (Fig. 2, "A"), indicate that the Limestone is composed of three facies; a basal thinly bedded facies, a middle (thickest) massive lime mudstone facies, and an upper (eastern) bedded stromatoporoidal calcirudite facies. Cave development has been most pronounced in the upper calcirudite facies.

To the west the Limestone overlies an andesite and laminated siliceous mudstones, to the east the Limestone is overlain by silicic volcaniclastics (Fig. 2) forming a sequence that probably spans the Siluro-Devonian boundary.

The Siluro-Devonian sequence is unconformably overlain to the east by shallow marine-terrestrial sediments of the Late Devonian Lambie Group (Fig. 3). Early Carboniferous granitic plutons intrude the sequence to the north, east, and south of Jenolan Caves.

Permo-Triassic sediments of the Sydney Basin unconformably overlie Carboniferous and older rocks 15 km east of Jenolan Caves. Outliers of the Sydney Basin, with basal elevations of approximately 1 150 m A.S.L., occur within 3 km of Jenolan Caves.

The basal unconformity of the Sydney Basin sequence represents a significant period of subaerial exposure and erosion during Carboniferous-Early Permian times. Osborne (1984a) suggested that the Jenolan Caves Limestone may have been exposed to surface conditions during this erosional episode. Since Jenolan Caves lies very close to the western limit of Sydney Basin sedimentation, any Permo-Triassic cover over the area must have been quite thin.

Regional uplift (and/or subsidence of the region to the east), probably during the Late

Cretaceous, raised the area to its present elevation and initiated the latest cycle of erosion and karstification. Tertiary basalt flows occur on the plateau 7 km south-west of Jenolan Caves.

GEOMORPHOLOGY AND CAVES

Jenolan Caves lies in an area of high relief where steep-sided, narrow, deeply-incised valleys have cut into the plateau forming the highland in the Oberon district. Relief in the area is in the order of 480 m. The plateau edge west of Jenolan Caves is marked by the 1 200 m contour. The geomorphology of Jenolan Caves has been summarised by Kiernan (1988).

The Jenolan Tourist Caves have formed at the confluence of the Jenolan River, Surveyors Creek, and Camp Creek (Fig. 2). Here a wall of limestone 90 m high and 150 m wide, the top of which is known as Lucas Rocks, blocks the valleys and has been breached by the Grand Archway and the Devils Coach House at the present creek level (770 m). A relict breach, the Carlotta Arch, is located above the Devils Coach House.

Cave development at Jenolan (Figs. 4 & 5) is related to systems of underground drainage that parallel the Jenolan River (the Jenolan Underground River) to the north of the Grand Archway and Camp Creek (the Styx) to the south of the Grand Archway.

The caves north of the Grand Archway (including the tourist caves; Imperial Cave, Chifley Cave and Jubilee Cave, Fig. 4) are strike-controlled, generally horizontal, stream passages with higher levels joining lower ones by vertical shafts. They contain few large chambers.

The caves south of the Grand Archway (including the tourist caves; Lucas Cave, River Cave, Cerebus Cave, Orient Cave, Temple of Baal and Ribbon Cave, Fig. 5) have large chambers, both solution and breakdown, and lack the horizontal development shown by the northern caves. Passages in these caves are often vadose-incised phreatic conduits with steep gradients, sometimes forming loops.

BRECCIAS

Breccias composed of large (in places 1m+) angular blocks of limestone are exposed at a number of localities in Jenolan Caves .

Breccia is exposed in the roof of the Exhibition Chamber in Lucas Cave (Fig. 5, "A"). Here, very large angular blocks of limestone form a block-supported breccia with a red matrix (Fig. 6). The boundary of this deposit is not exposed. Although it is difficult to judge the scale of the clasts, due to the height of the cave roof, the larger blocks are over 1 m across. The blocks show no preferred orientation.

A similar breccia is exposed in the roof of Katies Bower in Chifley Cave (Fig. 4, "C") . In this case, bedding traces (Fig. 7) are visible both in clasts within the breccia and in the bedrock that surrounds it. The bedding traces in the clasts demonstrate that they have each undergone considerable, but different, amounts of rotation relative to the bedrock. It can also be seen in this exposure that the breccia is restricted to well defined zones forming an irregularly-shaped, involuted boundary with undisturbed bedrock. An apparently related deposit with convoluted laminations is exposed in the western wall of Katies Bower (Fig. 8).

The lack of disruption to surrounding bedrock indicates that these breccias are not tectonic in origin. The presence of a sharp, often involuted, boundary between the breccias and bedrock, and the degree of lithification that must have taken place prior to the blocks assuming their present positions suggests that the breccias are not syngenetic in origin.

The nature of the clasts, and the shape of the breccia / bedrock boundaries are consistent with the breccias being produced by karst breakdown. The breccias may either be the roots of collapse dolines or may represent collapse chambers within a cave system.

INTERNAL SEDIMENTS

Internal sediments are sediments deposited in cavities within limestone, other than those deposited in modern caves.

Three main types of internal sediment, crystalline, laminated, and dolomitic have been recognised in the caves at Jenolan. Exposures have not yet been found which show the boundaries between the internal sediments themselves, or between them and the breccias described above. It seems likely, however, that the breccias and internal sediments are lateral facies, representing different sub-environments within an integrated cave system. This type of relationship in modern caves was described by Osborne (1984b, 1986b).

Crystalline internal sediments

Crystalline internal sediments in Imperial Cave (Fig. 4) were first described by McClean (1983) and were interpreted by Osborne (1984a) as palaeokarst deposits. They have the form of vugs, with coarse calcite crystals forming concentric layers growing in from the cavity walls (Fig. 9). Some vugs have layers of fine crystalline sediment interbedded between the large crystals. Where these are present they are found at the bottom of the vugs, indicating that the vugs are in depositional orientation, and have not been tilted by post-depositional tectonism.

These crystal-filled vugs are exposed in the walls of phreatic cave passages and so (as recognised by Osborne, 1984a) must have been excavated and filled prior to the development of the present caves.

The main exposures in Imperial Cave

indicate that the cavities filled by the internal sediment were over 1 m in diameter and formed an interconnecting system which extended for at least 100 m horizontally and at least 10 m vertically. In the Upper Branch of Imperial Cave crystalline internal sediment cuts through an older zone of breccia.

Crystalline internal sediment, called "early crystal" by the cave guides, is found in small patches south to River Cave (Fig. 5), and has been recognised as far north as Spider Cave, 100 m north of Jubilee Cave, (Fig. 4), (T.L. Allan, pers. comm.). In the entrance area of Lucas Cave (Fig. 5) crystalline internal sediment is overlain unconformably by a well-cemented sandstone. Both the sandstone and the crystalline sediment are truncated by the present cave passage.

The crystalline internal sediments were deposited in a system of cavities containing carbonate saturated water. The lack of clastic sediments in these vugs suggests that they were part of an isolated phreatic system.

Davis (1930) described crystal caverns of a larger scale in Missouri (U.S.A). White (1976) noted that it is difficult to achieve supersaturation in phreatic water and that most crystal-lined caves are related to either raised temperatures or unusual mineralogy. The crystalline deposits at Jenolan Caves have not been sampled because they are exposed in tourist caves, however, they appear to be composed mainly of calcite.

Laminated internal sediments

Anastomosing bodies of laminated carbonate are found in the Grand Arch, Devils Coach House, Arch Cave, Imperial Cave, Lucas Cave and River Cave (Fig. 5). The deposits are most abundant close to the Grand Arch with the most northerly exposure being found near the Sinkhole in Imperial Cave (Fig. 4, "B") and the most southerly exposures occurring in River Cave.

The laminations in these deposits are generally orientated at a high angle to the bedding of the Jenolan Caves Limestone and are thus not part of the Silurian succession. The deposits are truncated by the present caves and thus predate them.

The laminated carbonate is highly lithified. Sample U.S.G.D. 65735 from "B" in Fig. 5 is composed of graded beds of lime-mudstone alternating with wackestone layers.

The greatest concentration of laminated internal sediment is found in the southern side of the Grand Archway in small cave passages near the entrance to Lucas Cave (Fig. 5, "C"). Here the relationship between the laminated limestone and the bedrock is clearly unconformable (Fig. 10), and in some exposures, slumping is visible. Much of the breakdown in the south eastern part of the Grand Archway is a result of parting along zones of laminated limestone which are significantly weaker than the bedrock.

The irregular outcrop pattern of the laminated carbonate, its unconformability with the Jenolan Caves Limestone, and its truncation by the caves, indicates that it is a palaeokarst deposit. The anastomosing form, fine grainsize, graded-bedding, and presence of slumping, suggest deposition as a phreatic cave sediment.

The laminated limestone does not appear to have undergone any tectonic deformation. The orientation of slump structures in the laminated limestone and the sub-horizontal bedding of larger exposures, such as those in the northern wall of the Grand Archway (Fig. 5, "B") suggest that there has been little tilting since deposition. Thus, like the crystalline internal sediments described above, the laminated carbonate deposits remain in a position close to their original orientation.

Dolomitic internal sediments

Dolomitic internal sediments unconformable with the Jenolan Caves Limestone are found in River Cave, Cerebus Cave, and Imperial Cave (Figs. 4 & 5). The deposits in River Cave resemble the laminated deposits described above. Dolomitic bodies with unclear relationships to the Jenolan Caves Limestone are found in Jubilee Cave, Ribbon Cave, River Cave and Cerebus Cave. The dolomitic deposits form the substrate on which most of the aragonite speleothems in Jenolan Caves have been deposited.

The largest dolomitic internal sediment deposit occurs in River Cave in the area between Mossy Rock and Olympia (Fig. 5, "D" & "E"). Here sub-horizontally bedded dolomite (now largely de-dolomitized) is exposed in the cave walls (Fig. 11), representing the edges of a deposit at least 15 m long x 5 m wide and 5 m thick. The upper and lateral boundaries between the deposit and the enclosing Jenolan Caves Limestone are exposed in part. These boundaries are sutured and unconformable (Fig. 12). In thin section , U.S.G.D 65736, the deposit is seen to consist of fine-grained saccharoidal rhombs of iron-stained dolomite. Liesegang bands, mimicking cross beds, are developed.

Another sub-horizontally bedded deposit in River Cave occurs in the passage between the Junction and Mossy Rock (Fig. 5, "F"). This deposit was interpreted by McClean (1983) as thin beds within the Silurian succession, although the bedding in the Jenolan Caves Limestone is almost vertical. In thin section, U.S.G.D. 65737, the deposit is seen to be composed of crystalline carbonate with euhedral dolomite rhombs, most of which are now iron-oxide pseudomorphs, although some still retain a carbonate centre.

A complex dolomitic deposit occurs in the Oberon Grotto area of Cerebus Cave (Fig. 5, "H"). In this deposit bodies of dolomite that are horizontally laminated occur in close proximity to vertically orientated ones. Some of the vertically bedded bodies parallel the strike of the limestone, while others (e.g. at Fig. 5 "G") are oblique to it. In places the horizontally laminated dolomite contains angular clasts up to 40 mm long and crystalline vugs.

Two deposits of internal sediments, the most southerly of which is dolomitic, are exposed in the river passage of Imperial Cave, downstream from the bridge ("D" in Fig. 4). The southerly deposit has a dyke-like outcrop pattern, striking perpendicular to the strike of the Jenolan Caves Limestone, and dipping to the south. It is composed of coarse crystalline calcite, interspersed with iron-stained dolomite rhombs and aligned organic-rich mud chips, U.S.G.D. 65740. Some authigenic quartz has developed.

Like the crystalline and the laminated deposits, the dolomitic deposits do not appear to have undergone any deformation, and are significantly more lithified than any of the relict cave sediments found in the present caves.

Similar laminated dolomites have been described by Mussman *et. al.* (1987) among the palaeokarst deposits associated with the Ordovician Knox unconformity in the Appalachians, U.S.A. where marine carbonates overlie an extensively karstified surface. Similarly, the dolomites at Jenolan may have formed when sea water from a marine transgression entered karst cavities.

DISCUSSION

The maximum age of the breccias and internal sediments is constrained by the tectonic history of the Jenolan Caves area, while their minimum age is constrained by its geomorphic history.

The breccias and internal sediments are neither folded nor cleaved, and where geopetal structures are developed they are orientated to the present horizontal. The limestone in which the sediments are enclosed, is, however, steeply bedded and overturned. The sediments must therefore have been deposited after the limestone had achieved its present attitude.

The sediments cannot then be older than the latest regional deformation to affect the area. This was the so-called Kanimblan Orogeny which deformed Late Devonian Strata to the east of Jenolan Caves, but not the nearby Lower Carboniferous granites.

I have previously indicated (Osborne, 1984a), the Late Devonian strata would have covered the Jenolan Caves Limestone during the Kanimblan Orogeny, however, it is possible that the Middle Devonian surface may have been irregular leaving the Limestone exposed to karstification during Mid to Late Devonian times. If this were the case and if Kanimblan folding was restricted to particular areas, then some of the relatively undeformed palaeokarst deposits at Jenolan could have a Mid to Late Devonian age.

It seems probable, however, that the Jenolan Caves Limestone was covered during the Kanimblan event. Since it would have taken some time to remove the Late Devonian cover the deposits are unlikely to be older than Late Carboniferous-Early Permian. At this time significant erosion is known to have produced the irregular erosional surface at the base of the Sydney Basin (Herbert, 1972). This erosion would have exposed the Jenolan Caves Limestone, thus resulting in karstification.

During Permo-Triassic times the unconformity surface was covered with a mantle of sediments. The outliers of the Sydney Basin on the plateaux adjacent to Jenolan Caves are remnants of this sedimentary mantle.
Significant karstification is unlikely to have occurred again until this mantle was removed, probably during the latest cycle of erosion which began in the Late Cretaceous or Early Tertiary.

The minimum age of the sediments is constrained by the age of the present caves which truncate and expose the palaeokarst deposits.

A guide to the likely age of the present landscape features, including the caves, can be inferred by applying incision rates determined for streams in the Highlands of eastern Australia. Bishop (1985) determined that the incision rate in the upper Lachlan valley during the last 20 Ma was 8 m/Ma. Young (1977) calculated that headward erosion of Kangaroo Valley during the Eocene and Oligocene occurred at a rate of 2-3 m/Ma. If such rates can be applied, even roughly, at Jenolan Caves then Carlotta Arch (60 m above the present stream bed), and the most relict present cave, is a Tertiary feature, possibly Miocene in age. An internal sediment deposit is exposed in the southern wall of the Carlotta Arch.

If the most relict of the present caves formed in the Mid to Late Tertiary, the palaeokarst deposits must be older than Mid Tertiary.

These time-constraints require the palaeokarst deposits to have filled caves which developed during the Permo-Carboniferous period of exposure. The dolomitic deposits would have been produced by sea-water entering karst cavities as the sea transgressed over the unconformity surface early in the history of the Sydney Basin.

CONCLUSIONS

The Jenolan Caves Limestone was subjected to a significant phase of karstification prior to the deposition of the Sydney Basin. Caves that developed during this time are now filled by palaeokarst deposits of probable Permo-Carboniferous age. Breccias, laminated, crystalline, and dolomitic palaeokarst deposits are likely to have been deposited as lateral equivalents, representing different sub-environments within an extensive, integrated cave system.

ACKNOWLEDGEMENTS

The research for this paper formed part of the author's PhD studies in the Department of Geology and Geophysics, University of Sydney under the supervision of D. F. Branagan. E. Holland, of Jenolan Caves, provided accommodation, made available his extensive local knowledge, and assisted with work in the field. P.J. Osborne assisted with preparation of the text.

REFERENCES

Allan, T. L., 1986. Geology of Jenolan Caves Reserve. *BSc (Hons.) Thesis, University of Sydney,* (unpublished).

Bishop, P., 1985. Southeast Australian late Mesozoic and Cenozoic denudation rates: A test for late Tertiary increases in continental denudation. *Geology ,13* , 497-482.

Chalker, L. E., 1971. Limestone in the Jenolan Caves area. *Records of the Geological Survey of New SouthW ales.*, *13* (2), 53-60.

Davis, W. M., 1930. The origin of limestone caves. *Geological Society of America Bulletin ,41* , 475-628.

Herbert, C., 1972. Palaeodrainage patterns in the southern Sydney Basin. *Records of the Geological Survey of New South Wales , 14* (1), 5-18.

Kiernan, K., 1988. The geomorphology of the Jenolan Caves area. *Helictite, 26* (2), 6-21.

McClean, S. M., 1983. Geology and cave formation, Jenolan Caves, N. S. W. *B. App. Sc. Thesis, N. S. W. Institute of Technology,* (unpublished).

Mussman, W. J., Montanez, I. P. and Read, F., 1987. Ordovician Knox paleokarst unconformity, Appalachians. *in* PALEOKARST. .James N. P. and Choquette, P. W, (Eds.). Springer-Verlag, New York, 211-228.

Osborne, R. A. L., 1984a. Multiple karstification in the Lachlan Fold Belt in New South Wales: Reconnaissance evidence. *Journal and Proceedings of the Royal Society of New SouthWales* , *117* , 15-34.

Osborne, R. A. L., 1984b. Lateral facies changes, unconformities and stratigraphic reversals: their significance for cave sediment stratigraphy. *Cave Science,* *Transactions of the British Cave Research Association, 11* (3), 175-184.

Osborne, R. A. L., 1986a. Cave and landscape development at Timor Caves, New South Wales. *Journal and Proceedings of the Royal Society of New South Wales , 118* (1), 55-76.

Osborne, R. A. L., 1986b. Sedimentation in caves- a review. *Publication Geological Society of Australia, New SouthWales Division., 2* , 189-187.

Osborne, R. A. L., and Branagan D. F., 1985. ? Permian palaeokarst at Billys Creek, New South Wales. *Journal and Proceedings of the Royal Society of New SouthWales , 118* (3/4), 105-111.

Osborne, R. A. L., and Branagan D. F., 1988 Karst Landscapes of New South Wales, Australia. *Earth-Science Reviews . 25* (1988), 467-480.

Stanley, G. A. V., 1923. Note on the thickness of the Jenolan Caves Limestone. *Sydney University Science Journal , 7* (1), 34-35.

Trickett, O., 1925. *The Jenolan Caves, New South Wales.* (map) Jenolan Caves Reserve Trust, Jenolan Caves.

White, W. B., 1976., Cave minerals and speleothems. *in* THE SCIENCE OF SPELEOLOGY, Ford, T. D. and Cullingford, C. H. D. (Eds.). Academic Press, London, 267-327.

Young, R. W. , 1977. Landscape development in the Shoalhaven catchment. *Z.eitschrift fuer Geomorphologie N.E. 21* , 262-283.

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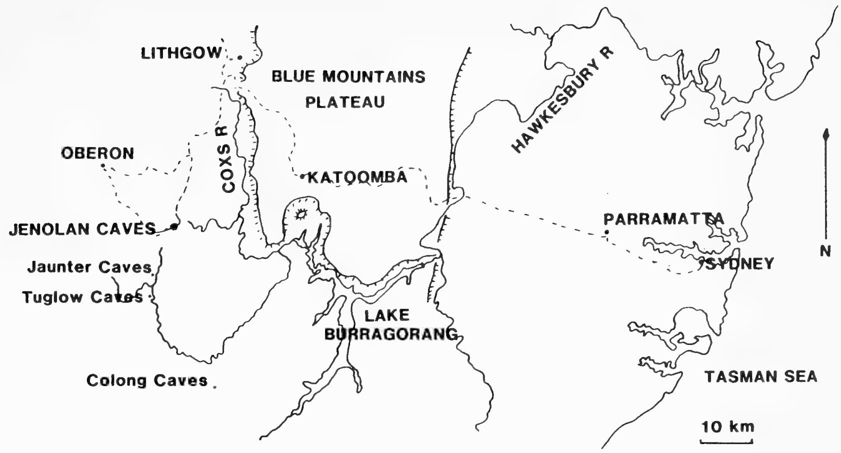


Figure 1. Location

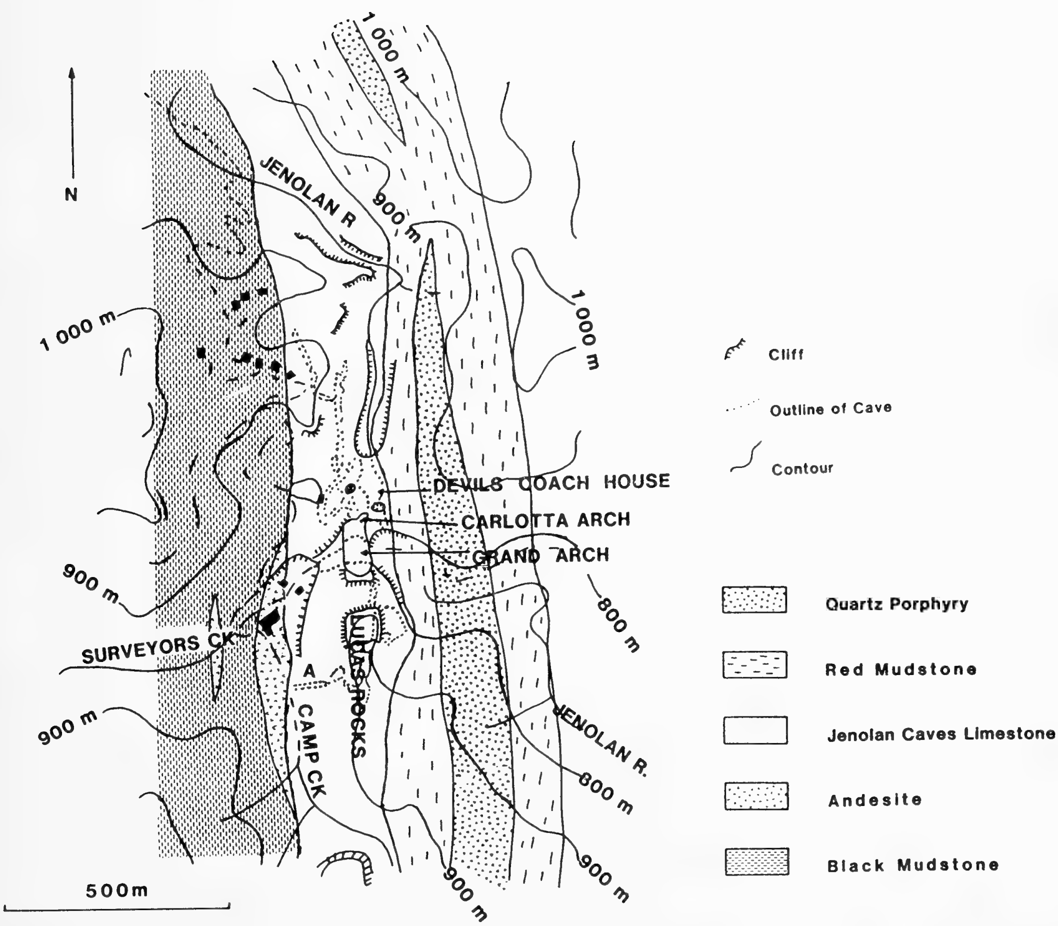
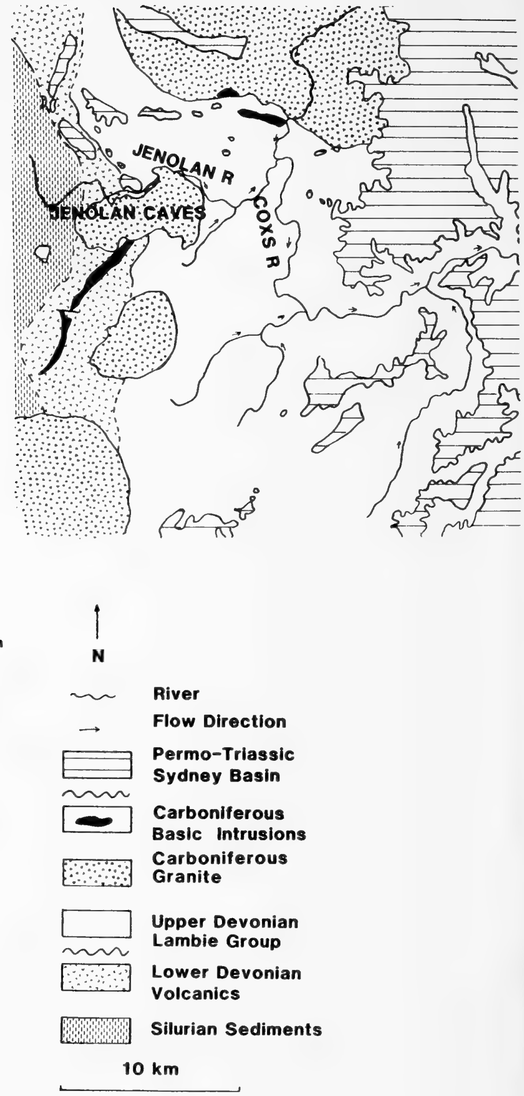


Figure 2. Geology and Topography at Jenolan Caves. Geology simplified after Allan (1986).

Figure 3. Geological Setting.



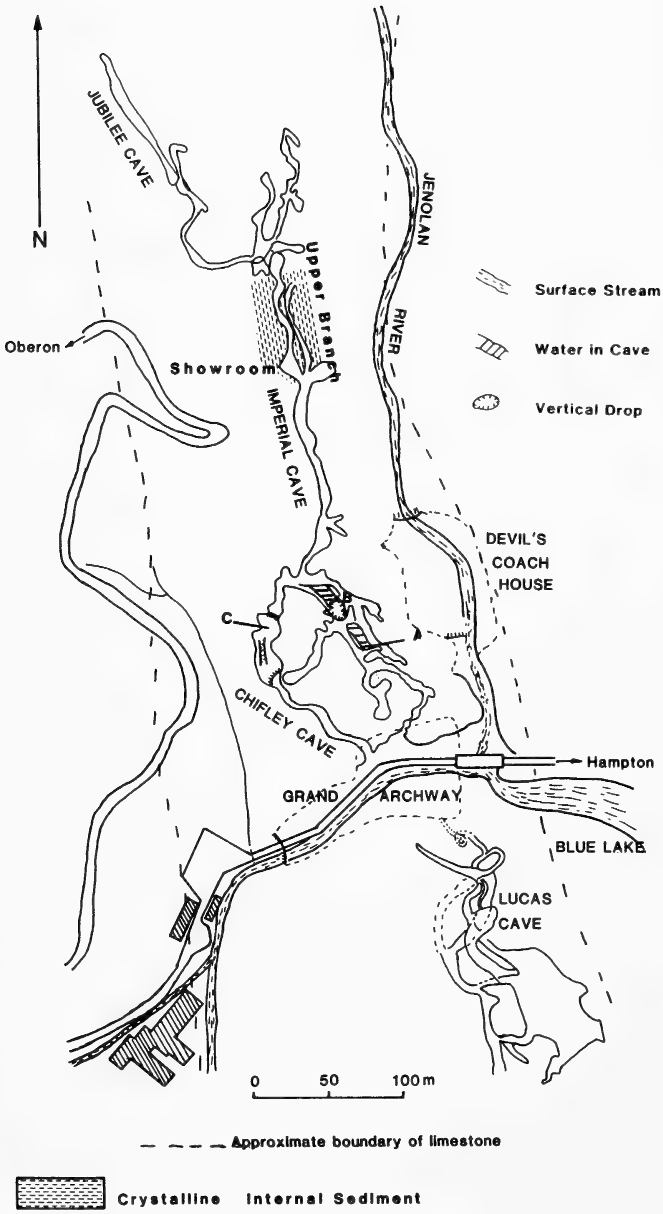


Figure 4. Northern Tourist Caves, modified after Trickett (1925).

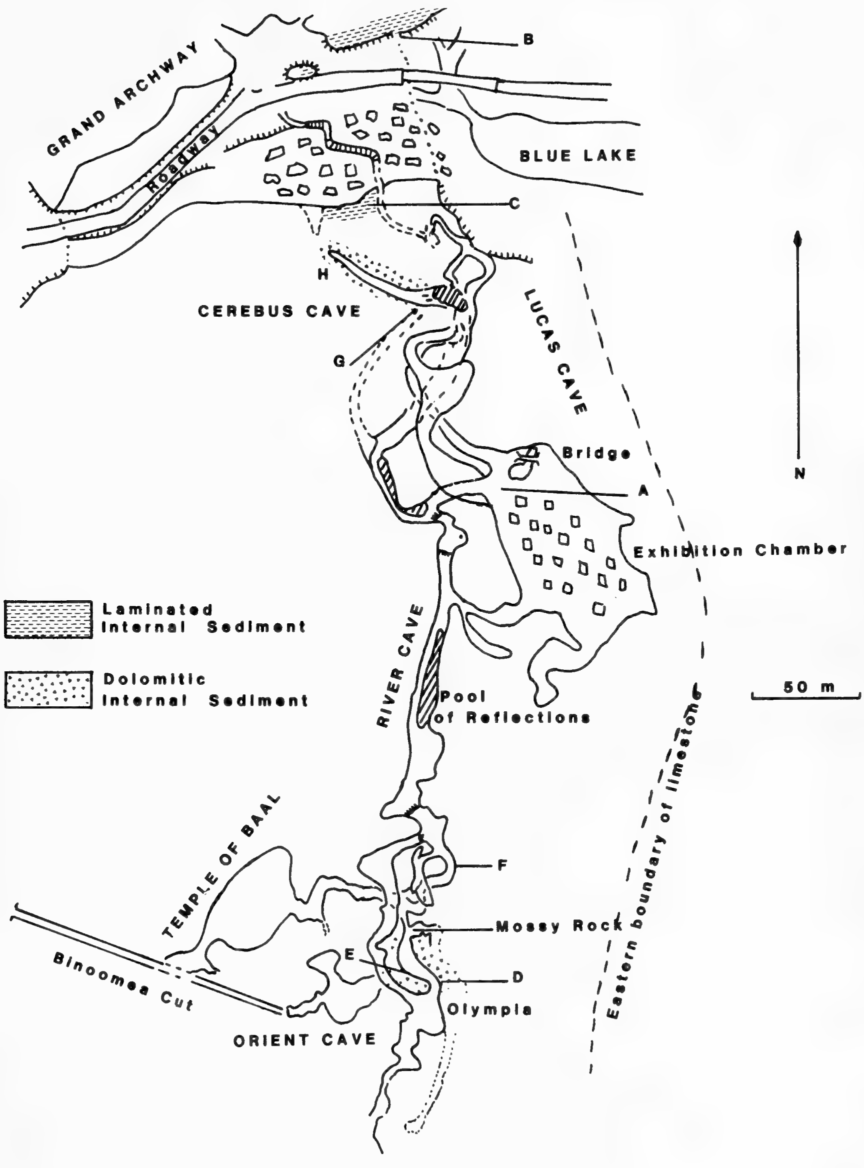


Figure 5. Southern Tourist Caves, modified after Trickett (1925).

Figure 6. Limestone block breccia in roof of Exhibition Chamber, Lucas Cave, "A" in Fig. 5, Field of view approx 3 m.

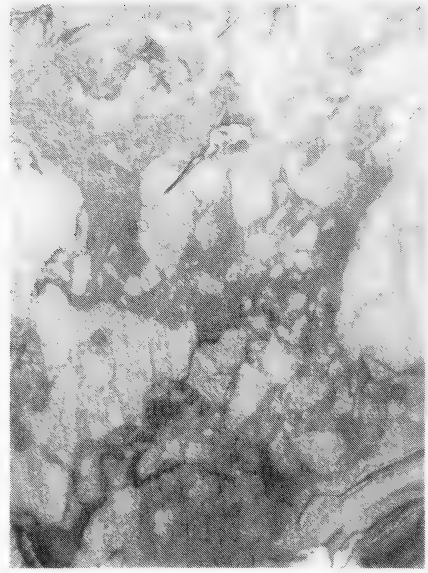


Figure 7. Limestone block breccia, with brown matrix, in roof of Katies Bower, Chifley Cave (Fig. 4). Note boundary between bedrock and breccia, and orientation of bedding in breccia blocks compared with that in bedrock.

Figure 8. Laminated internal sediment exposed in wall of Katies Bower, Chifley Cave (Fig. 4). Field of view approx 1 m x 2 m.

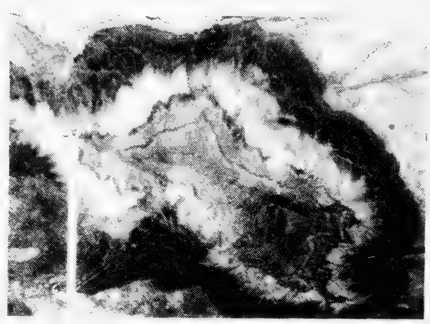


Figure 9. Crystalline Sediment near the Showroom in Imperial Cave. Tape 300 mm. After Osborne (1984a).

Figure 10. Exposure of laminated carbonate near entrance to Lucas Cave ("C" in Fig. 5). Note unconformable boundary between steeply-dipping Jenolan Caves Limestone, to the left of lens cap, and horizontally bedded laminated carbonate to the right of lens cap. Lens cap 55 mm.

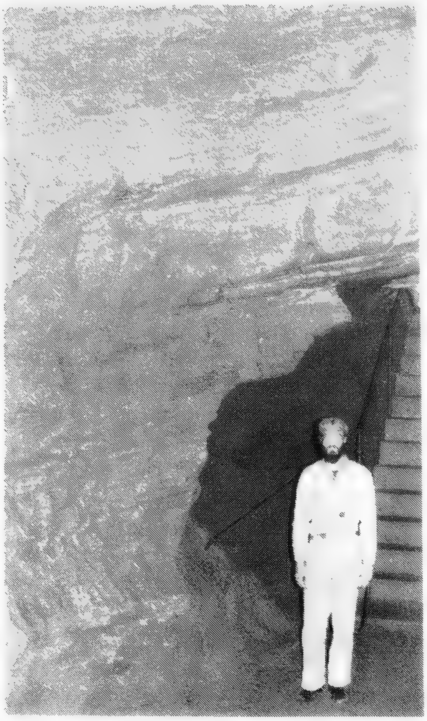


Figure 11. Sub-horizontally-bedded dolomitic sediment exposed in River Cave. Looking south at base of steps to Olympia ("D" in Fig. 5).

Figure 12. Unconformable boundary between steeply-dipping Jenolan Caves Limestone (top of frame) and horizontally-bedded dolomitic sediment (Bottom of Frame) Finger points to boundary. Side passage near the Furze Bush ("F" in Fig. 5).

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Palaeogeography of the Braemar Deep-Lead Sapphire Deposit, New South Wales

ROBERT R. COENRAADS

ABSTRACT. Exploration areas for deep lead sapphire deposits, such as those found at Braemar in the New England gemfields, northeastern New South Wales, may be defined via mapping of palaeochannels in which the deposits are situated. Palaeotopographic reconstruction was carried out using the elevation of the contact between the Tertiary volcanic rocks and the Palaeozoic basement, as well as drill hole data where available. The potential sapphire-bearing palaeochannels have been delineated within the zone in which the 19-23 million year old volcanics forming the western portion of the Central Volcanic Province (the West Central Province) overlap onto 32-38 million year old sapphire bearing volcanics forming the eastern portion of the province (the East Central Province). In this zone, the 19-23 million year old basaltic lavas flooded a number of major palaeodrainage systems already containing 32-38 million year old basalt flows and alluvial deposits reworked from them.

Potential sapphire deposits have been delineated in the Braemar palaeochannel and its tributaries up-palaeostream from the Braemar sapphire mine, in which sapphires are recovered along with other heavy minerals, with the highest concentration occurring at the base of the channel. "Braemar-type" deep lead deposits considered in this paper had approximately 10 million years in which to form, and required the presence of a younger basalt capping (19-23 million year old) for their preservation.

Potential sapphire-bearing alluvials are also delineated along the topographically inverted palaeo-Swan Brook. The extent of these "deep lead" deposits to the east of Braemar, in palaeochannels that drained the sapphire-bearing East Central Province, is related to the easternmost incursions of the lavas of the West Central Province.

INTRODUCTION AND AIMS OF THE INVESTIGATION

Since the beginning of this century Australia has been an important supplier of sapphire to the world market (Spencer, 1983). Australian sapphires are typically found in Quaternary and Tertiary alluvial deposits associated with Cenozoic-Mesozoic lava field provinces. The two deposits which contain known economic concentrations are the Central Province in northern New South Wales (the New England field) and the Hoy Province in central Queensland (the Anakie field). In recent years, the New England field contributed in excess of 50 percent of Australia's sapphire production which, although not well documented, was probably in excess of 5 million carats annually (T.J. Nunan Pty Ltd, pers. comm., 1989).

Sapphires are considered to be derived from the 32 - 38 million year old (Ma.) volcaniclastic and basaltic rocks of the Central Province (MacNevin, 1972; Brown & Pecover, 1986; Brown, 1987; Pecover & Coenraads, 1989; Coenraads et al, 1990), and to have been concentrated through fluvial processes into economic placer deposits occupying the flat floors of basalt filled valleys. Such sapphire deposits can be explored for and mined using standard techniques (Nunan, 1989; Coenraads, 1990).

The Braemar sapphire deposit is located along the Gwydir Highway 18.5 kilometres east of Inverell, New South Wales. The sapphire-bearing material, exposed in Mr. Col Rynnes quarry on the side of a hill, has a tuffaceous/brecciated appearance and is overlain by a flow-basalt. Braemar was recognized by the New South Wales Government Department of Minerals and Energy geologists as being particularly important because of its non-conventional setting (being on a hillside), and thereby presenting new opportunities for sapphire exploration in the New England region, and also in many of the other eastern Australian volcanic provinces. A seminar entitled "Tertiary Volcanics and Sapphires in the New England District" was held by the New South Wales Department of Minerals and Energy on the 1st May 1987 to promote research and exploration.

Since an initial model for Braemar was proposed by Lishmund and Oakes, (1983), in which the deposit was considered to be tuffs and breccias formed around a diatreme, a significant amount of further work has been carried out in the area. The sapphire-bearing sediments at Braemar were first considered to be palaeochannel deposits by Temby (1986) owing to their appearance and the discovery of cassiterite, derived from the Permian basement, in heavy mineral concentrates. Drilling by Brown and Pecover (1986) confirmed that the sediments lie in deep basement channels.

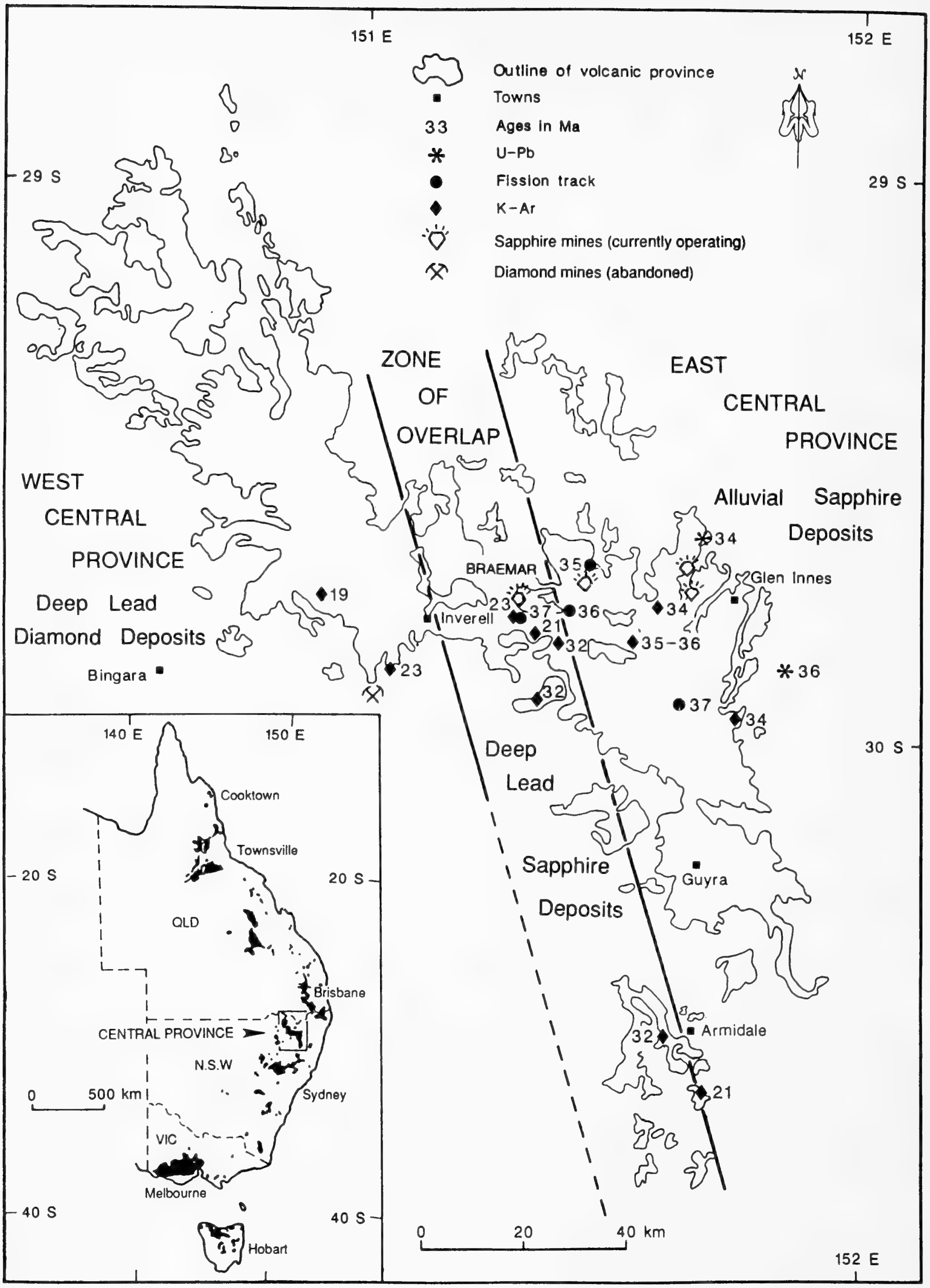

Figure 1. Location of the Braemar sapphire deposit in the zone-of-overlap between the East and West Central Provinces. Locations of age data for the Central Province are shown (sources of data listed in Coenraads et al, 1990).

The physical processes involved in the concentration of sapphire and other heavy minerals as placer deposits in the Braemar palaeochannel appear to be similar to those which formed the major sapphire deposits at Kings Plains and Reddestone creeks (Coenraads, 1990). Braemar is unique, however, in that it is situated in an area in which the younger (19-23 Ma.) volcanics of the West Central Province overlap onto the older (32-38 Ma.) volcanics of the East Central Province (Fig. 1). The sapphire-bearing, intrabasaltic sediments contain minerals which are derived from the older volcanic rocks, as demonstrated by Hollis & Sutherland, (1985) from a fission track age of 37 Ma. for a zircon from Braemar. The sediments are overlain by a basalt flow dated at 23 Ma. (C.D. Ollier, pers. comm.) and must therefore have an age of between 23 and 37 Ma.. McMinn (1989) reached a similar conclusion, dating the sediments as Eocene/Oligocene on the basis of palynology.

At least two generations of sapphire-bearing alluvial deposits exist at Braemar (Temby, 1986; Pecover & Coenraads, 1989). The oldest economic deposits lie in a palaeochannel exposed in a quarry, and are worked intermittently by Mr. Col Rynne. The deposits are Eocene/Oligocene in age, and are clay-rich, white and grey, fluvio-lacustrine and tuffaceous sediments with the highest grades of sapphires occurring at the base of the channel amongst weathered basalt boulders which range in size up to half a metre. These earlier sapphire-bearing alluvials have been preserved by a capping of basalt. The youngest deposits at Braemar are Holocene alluvial gravels which are situated in Schumachers Gully and its tributaries (Figs. 2 and 3). These have undergone at least two cycles of reworking and deposition and, as a result, are the richest deposits with the highest proportion of gem-quality sapphire (C. Rynne, pers. comm.).

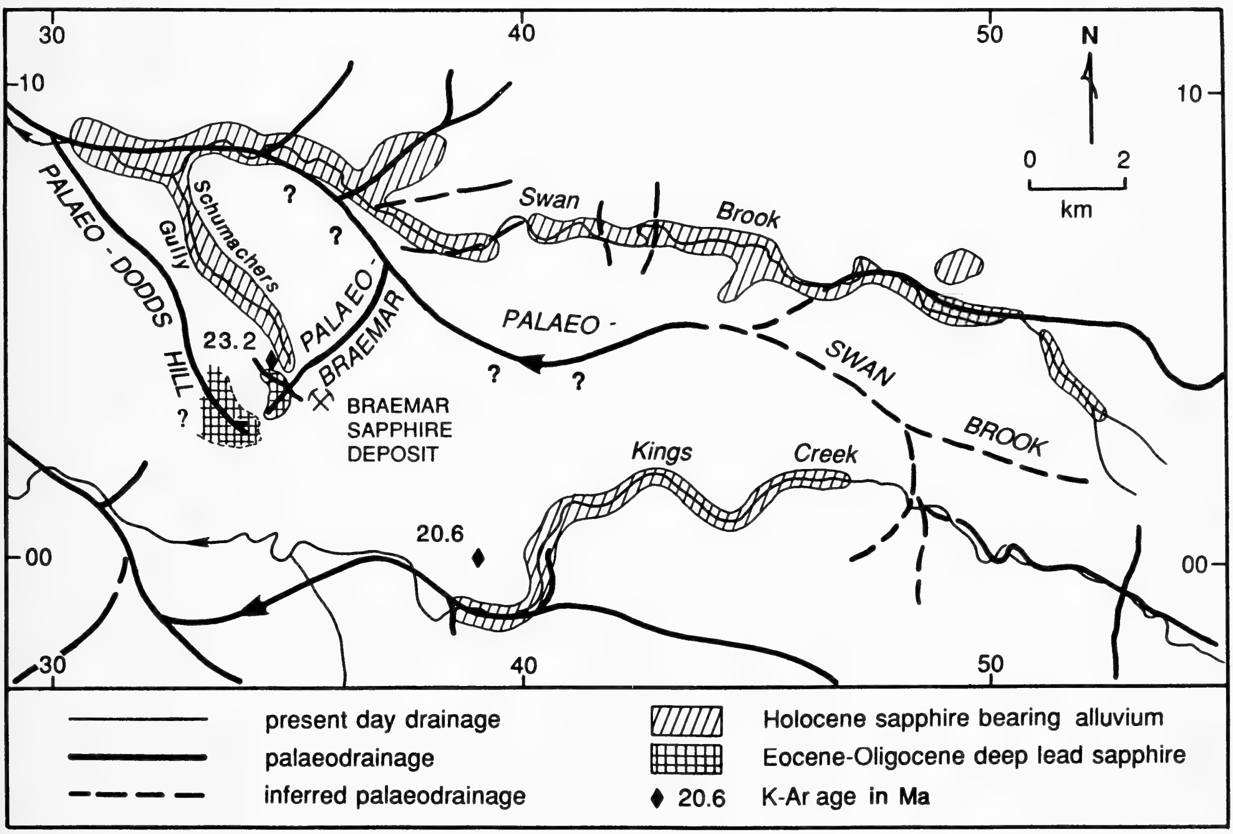

Figure 2. Distribution of Eocene/Oligocene deep lead sapphire deposits and Holocene sapphire-bearing alluvium. The Braemar deposit is associated with the Braemar palaeochannel and the nearby Holocene deposits in Schumachers Gully are reworked from them. The potential for further deep lead deposits associated with the palaeo Swan Brook (now a table-top ridge) is highlighted by question marks. Such deposits may be responsible for shedding sapphire into the soils flanking the ridge and the lateral streams, Swan Brook and Kings Creek. Location of K-Ar ages are also shown.

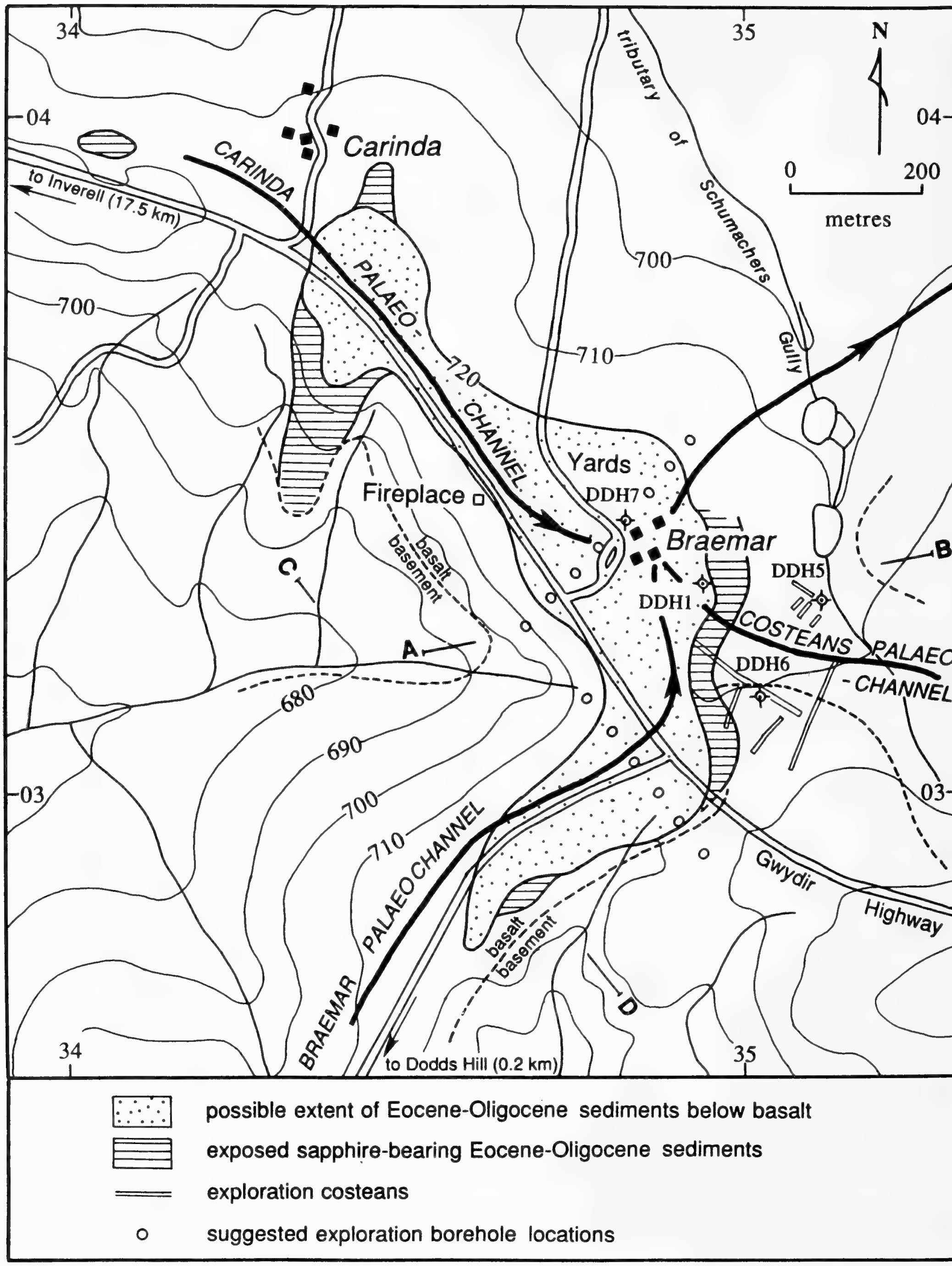

Figure 3. Eocene/Oligocene sapphire-bearing sediments at Braemar. Their proposed extent beneath a capping of 23.2 Ma. basalt is indicated as the stippled area bounded approximately by the 720 m elevation contour. The positions of the Braemar, Carinda and Costeans palaeochannels are shown, and two lines of exploration bore holes, one incorporating DDH 7, are proposed to test the extent of the deposits in these palaeochannels. The location of DDH 1, 5, 6 and 7; the exploration costeans; Braemar and Carinda homesteads; and the locations of sections AB and CD are also shown.

Zircon, ilmenite and chrome-spinel are associated with the sapphire at Braemar (Temby, 1986; Slansky, 1987; Coenraads, 1990). Cassiterite is also found in small quantities where Permian basement rocks have been reworked (Temby, 1986; Slansky, 1987) and two diamonds have been reported (J. Rynne, pers. comm.).

Braemar is the only mine known to the author where sapphires are recovered from below basalt, although, further west in the Copeton and Bingara areas, diamond-bearing deep leads have been worked sporadically since 1872.

The aims of this paper are as follows:

1. To use a palaeotopographic reconstruction technique, based on the elevation of the basalt-basement contact and available drill hole data, to determine the course of the palaeochannel in which the Braemar sapphire deposit is situated.
2. To define the extent of the Eocene/Oligocene sapphire-bearing sediments lying below 23 Ma. basalt in the Braemar palaeochannel and its tributaries.
3. To define other palaeochannels in the area of influence of the 19-23 Ma. basaltic lavas likely to have undergone a similar series of events and hence also likely to contain deep lead sapphire.

1. THE SAPPHIRE-BEARING PALAEODRAINAGE SYSTEMS NEAR BRAEMAR

The palaeotopography of the Braemar area was mapped using the elevation of the basalt-basement contact based on detailed geologic mapping by Temby (1986), Brown & Pecover (1986), Brown (1987), Stroud (1989) and Pecover & Coenraads (1990). The geological boundaries between Central Province volcanics and older basement rocks were overlain on the topography. Elevations for each mapped boundary were plotted and then contoured (Fig. 4). The interpretation used is conservative. In areas of basalt cover the basement surface is interpreted to dip gently and smoothly underneath. The least amount of basalt cover required was interpreted in areas of poor control. The interpretation was refined with the assistance of borehole data obtained from the New South Wales Government Department of Water Resources, and Brown & Pecover (1986). The bore data generally supported the basement-topographic analysis and, in many cases, indicated that the basalt-filled valleys are steeper and deeper than are given by the conservative analysis. The positions of the palaeochannels can thus be better constrained, particularly in the Braemar area, than the position inferred by Temby (1986) based on the regional distribution and grainsize of outcropping sub-basaltic sediments

The sapphire-bearing Eocene/Oligocene fluvio-lacustrine sediments are situated in a basalt-filled, northeasterly trending tributary of the palaeo-Swan Brook, referred to as the "Braemar palaeochannel" (Figs. 2 and 4). A tongue of basalt extending towards Dodds Hill, south of Braemar (Figs. 3 and 4), is apparently an upstream continuation of the Braemar palaeochannel. Two smaller tributaries join the Braemar palaeochannel in the vicinity of Braemar Homestead (Fig. 3); the larger of the two trends southeasterly from Carinda Homestead (the Carinda Branch) and the smaller, trending westerly (the Costeans Branch), has been exposed in the exploration costeans mapped by Pecover and Coenraads (1989). Diamond drill holes DDH 1 and DDH 7 at Braemar (Brown & Pecover, 1986) indicate that this channel is filled with at least 60 m of flow-basalt. Fig. 5 shows cross sections, AB and CD, of the Braemar palaeochannel. Section AB incorporates the data from drill hole DDH 1 (Brown & Pecover, 1986). The locations of the sections are shown on Fig. 3. The present day topography (Fig. 3) and the sections, indicate that lateral stream activity, post dating the 19-23 Ma. basalt flows, has begun to invert the topography.

Diamond drill holes DDH 2 at McCarthys Knob and DDH 3 at Dodds Hill (Brown & Pecover, 1986) support the presence of another palaeochannel that heads in a northwesterly direction from Dodds Hill (Figures 2 & 4) and eventually joins the palaeo-Swan Brook. DDH 2 & 3 did not reach basement rocks, but penetrated some 45 metres of white and grey, tuffaceous and fluvio-lacustrine channel fill sediments similar to those exposed in the Braemar quarry. The accumulation of such a major sedimentary sequence is thought to be due to a damming of the westerly flowing palaeochannels by faulting associated with the Severn Thrust (Temby, 1986). Alternatively, the damming may have occurred as a result of uplift and volcanism of the West Central Province which also appears to have been responsible for the deflection of the major westerly flowing rivers such as the Gwydir and Macintyre (Coenraads, 1990). Local evidence for the damming of streams by lava flows is reported by Smith (1989).

The present-day Schumachers Gully and its tributaries flow at right angles to the former flow direction of the Braemar palaeochannel (Fig. 3). They flow to the northwest across rocks and sediment filling the Braemar palaeochannel and then onto late Palaeozoic metasedimentary basement. The Holocene alluvials, which have been mined for sapphires in the tributaries of Schumachers Gully, are apparently reworked mainly from the Eocene/Oligocene sediments associated with the Braemar palaeochannel (Pecover and Coenraads, 1989).

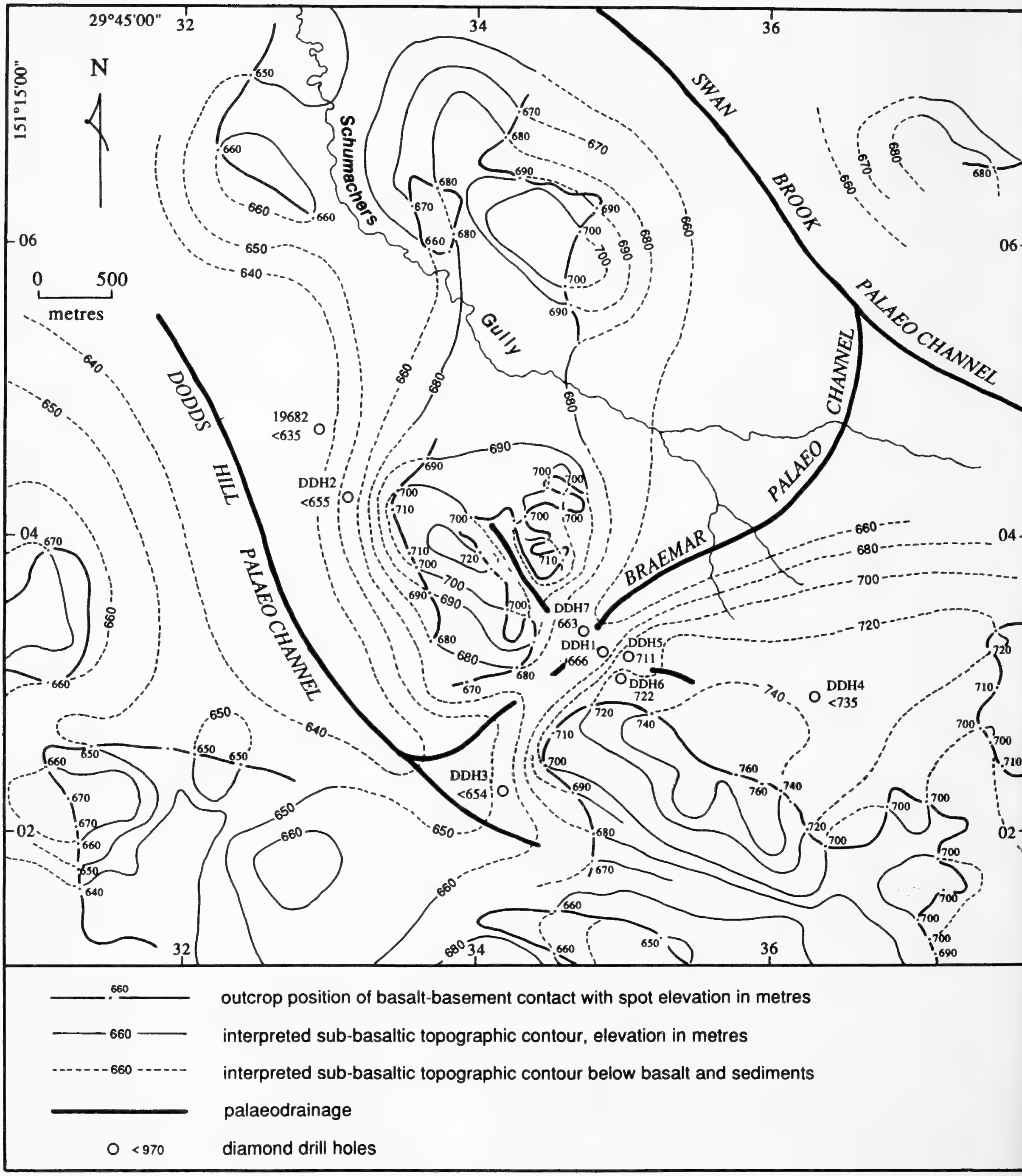

Figure 4. Positions of the Braemar and Swan Brook palaeochannels as determined by basement palaeotopographic analysis on the Elsmore 1:25,000 sheet. The two tributary palaeochannels join the palaeo-Braemar in the vicinity of diamond drill holes DDH1 and DDH7, shown enlarged in Fig. 3. The contours indicate the interpreted topographic surface prior to the 32-38 Ma. basaltic eruptions.

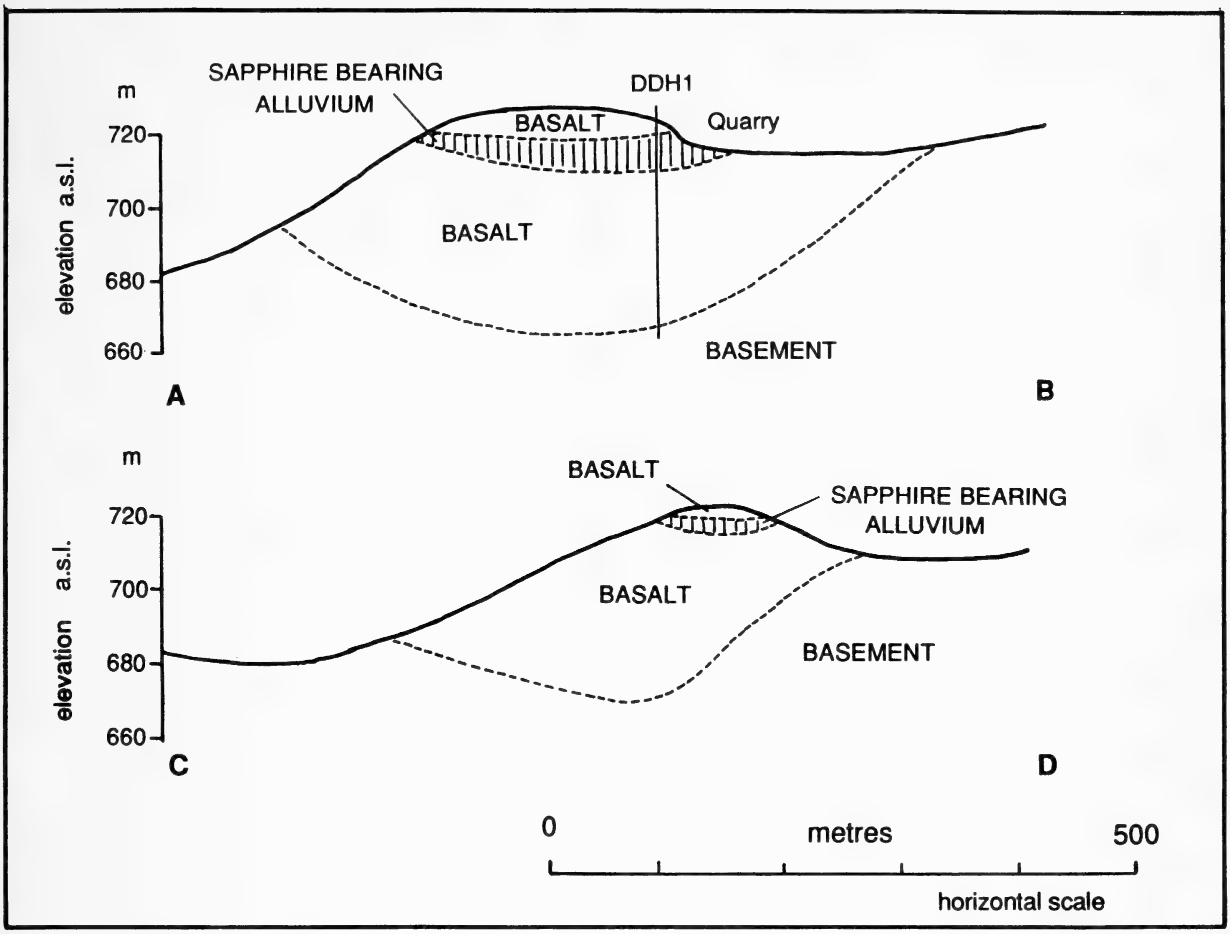

Figure 5. Cross sections AB and CD of the Braemar palaeochannel looking north. The assumed extent of the Eocene/Oligocene sapphire-bearing sediments beneath the 23.2 Ma. basalt cap is shown. The Braemar Quarry and DDH 1 are shown on section AB. The location of the sections are shown on Fig. 3.

2. EXTENT OF THE EOCENE/OLIGOCENE SAPPHIRE-BEARING SEDIMENTS BELOW BASALT NEAR BRAEMAR

The Eocene/Oligocene sapphire-bearing sediments at Braemar are associated with the Braemar palaeochannel and were preserved by a protective capping of 23 Ma. basalt. Locally the base of the young basalt appears to be at about 720 m above sea level. White and grey, tuffaceous and fluvio-lacustrine sapphire-bearing sediments are exposed below the basalt at this level in the quarry at Braemar (Pecover & Coenraads, 1989). Similar material outcrops close to this level, south of the Gwydir Highway and near Carinda (Fig. 3) and has been mapped by Brown & Pecover, (1986). Based on this level, the 23 Ma. basalt cap is interpreted to extend up-palaeostream in both the Braemar palaeo-channel and the Carinda tributary. It is predicted that sapphire-bearing sediments exist beneath a thin basalt cover within the stippled area in Fig. 3. White and grey volcaniclastic sediments have also been mapped by Brown & Pecover (1986) at about 690 to 710 m along the sides of the palaeochannel heading northwest from Dodds Hill, in the vicinity of Dodds Hill and also south of the Gwydir Highway in the vicinity of McCarthys Nob.

Diamond drill holes DDH 2 and DDH 3 indicate the sediment in the Dodds Hill Palaeochannel (Fig. 4) to be more than 5 times thicker than that in the Braemar palaeochannel. Hence the axial deposits, with presumably the highest sapphire concentrations, are predicted to be deep and therefore difficult to test and extract. The exploration licence for this area (E.L.2987) was held by Hooker Resources Pty. Ltd. (Pithers, 1988) and at the time of preparation of this manuscript their findings were confidential.

In the downstream direction along the Braemar palaeochannel, in the vicinity of Schumachers Gully and its tributaries, the basalt cap is absent. It is unknown however, whether the young basalt is again present as the terrain rises at, and beyond, the intersection of the Braemar palaeochannel with the palaeo-Swan Brook.

3. IMPLICATIONS OF THE BRAEMAR DEPOSIT IN THE SEARCH FOR SIMILAR DEPOSITS IN THE ZONE-OF-OVERLAP BETWEEN THE EAST AND WEST CENTRAL PROVINCES

The sapphire-bearing Eocene/Oligocene sediments at Braemar are associated with the basalt-filled Braemar palaeochannel which is a tributary of the palaeo-Swan Brook. Similar sediments also exist immediately to the south of Braemar in the Dodds Hill palaeochannel which also joins the Swan Brook palaeochannel. The deposits are protected by a capping of younger basalt, and demonstrate that similar deposits may exist elsewhere in the zone-of-overlap between the East Central Province and the West Central Province. Owing to the limited number of ages available for the Central Volcanic Province, the extent of the zone-of-overlap can only be approximately defined by the lines shown on Fig. 1. The existence of similar "Braemar-type" deep leads further to the east is dependent on the presence of younger basalts further east of Braemar in the Swan Brook and other palaeochannels.

The ages of the volcanic rocks in the vicinity of Braemar are shown in Figs. 1 and 2. An age of 20.6 Ma. (Smith, 1988) at grid reference GR:389001 on the Elsmore 1:25,000 topographic sheet (Fig. 2) demonstrates that young basalt, and hence the potential for deep lead "Braemar-type" deposits, extends eastward at least as far as this location. Such deposits, if present, would exist on or close to the axis of the relief-inverted palaeochannels, such as the flat-topped basalt ridge running along the axis of the topographically inverted palaeo-Swan Brook (indicated by question marks on Fig. 2). Therefore, the Windy Ridge near Bellview (GR:440050 Elsmore 1:25,000), Bald Hills near Golden Grove (GR:470050 Elsmore 1:25,000) and possibly Table Top Mountain (GR:503022 Elsmore 1:25,000) are worthy of more detailed investigation.

If "Braemar-type" sapphire-bearing deep leads exist in these areas, then the presence of sapphire in the present-day lateral streams, Swan Brook and Kings (Newstead) Creek (Fig. 2), may well be explained in part by the exhumation of such deep lead deposits. This process is shown schematically in Fig. 6. This hypothesis may also explain the occurrence of sapphires in soils (Mr. Doug Erry, of Golden Grove property, pers. comm.) below a certain level on hillsides on the southern side of Swan Brook which form the northern flank of the topographically inverted palaeo-Swan.

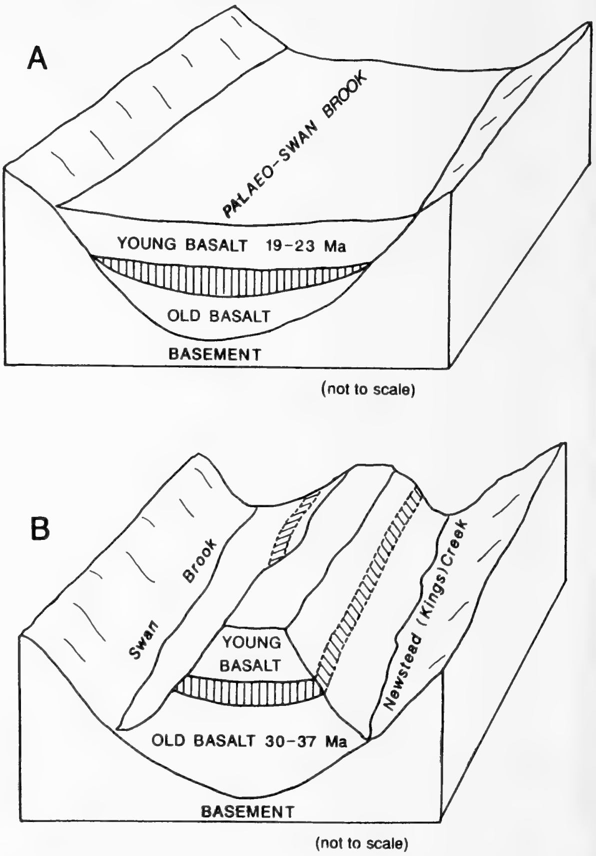

Figure 6. Block diagrams A and B:- Part A shows the inversion of the palaeo-Swan Brook by lateral streams, Swan Brook and Kings Creek and part B shows potential deep lead sapphire deposits, sandwiched between the older and younger basalt flows, exposed in a similar fashion to those in the Braemar palaeochannel.

CONCLUSIONS AND EXPLORATION/MINING PROBLEMS

Potential sapphire-bearing deposits within the zone-of-overlap between the 32-38 Ma. East- and the 19-23 Ma. West Central Volcanic Provinces have been delineated in the Braemar palaeochannel and its tributaries, up-palaeostream from the Braemar sapphire mine. Potential sapphire-bearing alluvials are also delineated along the topographically inverted palaeo-Swan Brook.

Deep lead deposits within the zone-of-overlap would be poorly exposed and may be situated at a level well above the present day alluvials, as is the case at Braemar. The only clue to their presence may be trails of sapphires and associated heavy minerals in soils and recent alluvials downslope from the deposits.

The "Braemar-type" deep lead deposits require a capping of younger basalt for their preservation. Hence, in any exploration program for deep leads, the first step is to determine of the presence or absence of young basalts. This could be assessed by K-Ar dating basalts along the relief inverted palaeochannels, such as along the palaeo-Swan Brook at the sites mentioned earlier. If K-Ar dating were to yield young ages (19-23 Ma), then deep leads may exist below these basalts. An attempt to distinguish between the older and younger basalts, based on their chemistry, is not considered as useful an exploration tool as K-Ar dating. Coenraads (in prep), using all available analyses for the Central Province, found the compositional ranges of major and minor elements for basalts of the West Central Province to largely overlap those of the East Central Province. The only exception being the tholeiites found by Duggan (1972) in the vicinity of Inverell.

Once the extent of potential cover rocks has been established, the presence and position of any palaeochannel axes may be identified using a palaeotopographic reconstruction, such as that carried out at Braemar. In the vicinity of Braemar it was possible to determine the course of the palaeochannel axes to an accuracy of ± 200m, or to within ± 50m in areas of high drill hole control. The position of such palaeoaxes could subsequently be appraised by geophysical techniques relying on detectable property differences between the basement rocks of the palaeovalleys and the material filling them. Gravity surveying has been tried in this regard, yielding an accuracy of the order of ± 50m in other basalt filled palaeovalleys of the Central Province (Coenraads, 1989). It must be noted however, that the course of potential sapphire-bearing intrabasaltic channels may not conform exactly to the oldest palaeochannel axis, especially in wide valleys.

Ultimately, the presence of sapphire-bearing deep lead sediments and their economic potential must be verified by costeaning or drilling which may prove to be the economic restraint on exploration for this type of deposit. The more expensive exploration and mining program must be supported by the commodity price. At Braemar, two lines of holes are proposed (Fig. 3), comprising a maximum of 12 holes spaced at 50 m to a depth of between 5 and 20 m, to test Eocene/Oligocene sediments below a capping of hard basalt, and to determine the position of potentially sapphire rich placer deposits. Exploration holes would have to be drilled in excess of 45 m in the Dodds Hill palaeochannel.

An efficient mechanized mining operation can profitably recover grades as low as 5 grams per cubic metre (Mr. T.J. Nunan pers. comm.), from Holocene placer deposits, if the quality of stone is high. However these deposits are mined at depths of 4 to 9 metres from below soft alluvium using backhoe excavators and from areas whose grades have been proved by large diameter-bucket drilling (Coenraads, 1990). In the case of deep lead sapphire deposits, both hard basalt and excessive depth would preclude the use of cheaper large-diameter bucket drills and necessitate diamond drilling yielding a much smaller sample that cannot be used to estimate grade or quality.

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REFERENCES

Brown, R.E., 1987. Detailed geological mapping in the Elsmore and Kings Plains areas, New South Wales Geological Survey - Report GS1987/058, pp. 22-24. (Unpubl.).

Brown, R.E. and Pecover, S.R., 1986. The geology of the Braemar sapphire deposits. New South Wales Geological Survey - Report GS1986/270. (Unpubl.).

Coenraads R.R., 1989. Evaluation of the natural lagoons of the Central Province, N.S.W. - are they sapphire producing maars? *Bulletin of the Australian Society of Exploration Geophysicists*, *20*, 347-363.

Coenraads, R.R., 1990. Key areas for alluvial diamond and sapphire exploration in the New England Gem Fields, New South Wales, Australia. *Economic Geology*, *85*, 1186-1207.

Coenraads R.R., (in prep). Evaluation of Potential Sapphire Source Rocks within the Catchments of Kings Plains Creek and Swan Brook, near Inverell, New South Wales, *Records of the Australian Museum.*

Coenraads, R.R., Sutherland F.L. and Kinny P.D., 1990. The origin of sapphires: U-Pb dating of zircon inclusions sheds new light. *Mineralogical Magazine, 54*, 113-122.

Duggan, N.T., 1972. Tertiary volcanics of the Inverell area, *Honours Thesis, University of New England, Armidale.* (Unpubl.).

Elsmore 1:25,000 scale topographic sheet. Central Mapping Authority of New South Wales, Lands Department, Sydney, 2000.

Hollis, J.D. and Sutherland, F.L., 1985. Occurences and origins of gem zicons in Eastern Australia, *Records of the Australian Museum, 36*, 299-311.

Lishmund, S.R. and Oakes, G.M., 1983. Diamonds, sapphires, and Cretaceous/Tertiary diatremes in New South Wales. *New South Wales Geological Survey - Quarterly Notes, 53*, 23-27.

McMinn, A., 1989. Tertiary palynology in the Inverell area. *New South Wales Geological Survey - Quarterly Notes, 76*, 1-10.

MacNevin, A.A., 1972. Sapphires in the New England district, *New South Wales. New South Wales Geological Survey - Records, 14* (1), 19-35.

New South Wales Government Department of Minerals and Energy., 1987. Tertiary Volcanics and Sapphires in the New England District, seminar held in Sydney, 1st May 1987. 29-57 Christie St, St. Leonards, New South Wales, 2065.

New South Wales Government Department of Water Resources, 10 Valentine Ave, Parramatta, New South Wales, 2150.

Nunan, T.J., 1989. The mining of sapphires. *The Australian Gemmologist, 17* (1), 7-12.

Pecover, S.R. and Coenraads, R.R., 1989. Tertiary volcanism, alluvial processes, and the origin of sapphire deposits at "Braemar" near Elsmore, northeastern New South Wales. *New South Wales Geological Survey - Quarterly Notes, 77*, 1-23.

Pithers, G., 1988. Final Report for E.L.2987, Inverell-Tingha Area, Hooker Resources Pty. Ltd. Report New South Wales Geological Survey - Report GS1988/248. (Unpubl.).

Slansky, E., 1987. X-ray examination of concentrates from sapphire-bearing rocks. New South Wales Geological Survey - Report GS1987/12, pp. 1-8. (Unpubl.).

Smith, N.M., 1988. Reconstruction of the Tertiary drainage systems in the Inverell Region, *Honours Thesis, University of Sydney.* (Unpubl.).

Spencer, L.K., 1983. Sapphires in Australia. Amax Office, Inverell, N.S.W. 2360. Report, August 1983, 83p. (Unpubl.).

Stroud, W.J., 1989. Elsmore 1:25,000 Geologic Sheet. Department of Minerals and Energy, Armidale Branch, State Government Office Building, cnr. Faulkner and Dumeresq streets, Armidale, N.S.W., 2350.

Temby, P.A., 1986. Exploration Licence 2285, Elsmore. Final report covering the period 24/10/85 - 24/10/86. Blue Circle Southern Cement Limited. New South Wales Geological Survey - Report GS1985/246. (Unpubl.).

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Doctoral Thesis Abstract: Stereochemical Studies on Metal Chelates of Novel Asymmetric Ligands

RONALD R. FENTON

This work reports the synthesis and characterisation by high resolution ^{1}NMR, chiroptical and X-ray crystallographic techniques of a series of new chiral multidentate ligands and their representative *cis*-octahedral and square-planar metal complexes. The design of the ligands was such that they all contain sterically demanding terminal pyridyl groups and each coordinating segment of the multidentate is capable of forming a five-membered chelate ring. The purpose of synthesising these ligands was two-fold. Firstly to examine the effects that bulky substituents at different sites of the ligands have on the topology adopted and the consequent stereoselectivity achieved on coordination to metal ions. Secondly these metal complexes then were used to investigate the intermolecular discriminations arising from their use as chiral templates in the synthesis and resolution of α-amino acids.

The ligands picchxnMe$_2$ (*N,N'*-dimethyl-*N,N'*-di(2-picolyl)diaminocyclohexane), picpnMe$_2$ (*N,N'*-dimethyl-3-methyl-1,6-di(2'-pyridyl)2,5-diazahexane) and picpyrrMe (*N,N'*-di(2-picolyl)-*N'*-methyl-2-aminomethylpyrrolidine) coordinate stereospecifically to cobalt(III) forming *cis*-octahedral complexes. The *R* or *R,R* forms of the ligands always adopt Δ-α topology while their enantiomers produce Λ-α forms, with these geometries being retained during a variety of substitution reactions.

When the ternary complex Λ-α-[Co(*R,R*-picstien)Cl$_2$]$^+$ (picstien = 3,4-diphenyl-1,6-di(2'-pyridyl)-2,5-diazahexane) is reacted with 2-amino-2-methylpropandioicacidato anion (AMMA^{2-}) the chloride ions are displaced by the bidentate AMMA^{2-} which stereospecifically adopts the β$_1$ and stereoselectively the *pro-S* configurations. Decarboxylation of this complex in warm acidic solution produces a mixture comprising 93 ± 3% Λ-β$_1$-[Co(*R,R*-picstien)(*R*-ala)]$^{2+}$ and 7 ± 3% Λ-β$_1$-[Co(*R,R*-picstien)(*S*-ala)]$^{2+}$, as shown by ^{1}H NMR experiments. The chiral environment imposed on the prochiral AMMA^{2-} fragment by the coordinated *R,R*-picstien ligand thus allows a stereoselective asymmetric synthesis of *R*-alanine in high enantiomeric excess.

The crystal structure of the decarboxylation intermediate species Λ-β$_1$-[Co(*R,R*-picstien)-(AMMA)]ClO$_4$.2H$_2$O complex was determined. *Crystal data:* $C_{30}H_{35}N_5O_{10}ClCo$ is orthorhombic, space group $P2_12_12_1$, with a = 9.598(2), b = 11.964(2), c = 26.477(3) Å and Z = 4. The structure was refined by block-matrix least-squares methods to R = 0.039 for 2622 non-zero diffractometer data. For the symmetrical *cis*-α picchxnMe$_2$ cobalt(III) complexes no evidence of any chiral induction was found in their use for the synthesis of α-alanine. However, these complexes were found to be successful in the resolution of the more sterically demanding α-amino acid proline.

Coordination of a series of chiral and mesomeric bis-picolylamine ligands to square-planar palladium(II) was used to demonstrate the steric effects present in these complexes. Alkyl substituents were placed on the central diaminoethane link, at the secondary nitrogen atoms and at the 6-positions of the terminal pyridyl rings of the tetradentates. The chiral forms of these ligands with two vicinal substituents on their central links show stereospecific coordination behaviour irrespective of the presence of the methyl substituent on the 6-position of the terminal pyridyl rings. However, with protons at the 6-position and methyl groups on the backbone nitrogen atoms, or with only one asymmetric substituent on the central diamine link, they are stereoselective. The *meso* forms of the ligands produce two conformational isomers on coordination, but with methyl

substituents at the 6-position only one isomer form is formed. Two optically active bis-picolylinamide ligands, bpstienH_2 (*N,N'*-bis(2'-pyridinecarboxamide)-1,2-diphenylethane) and bpstyenH_2 (*N,N'*-bis(2'-pyridinecarboxamide)phenylethane), and their bivalent copper, nickel and palladium deprotonated complexes were synthesised. The square-planar nickel(II) and palladium(II) complexes adopt rare molecular structures, having their phenyl substituents occupying axial position(s) on the central chelate rings.

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M.Sc. Thesis Abstract: Late Pleistocene Geocryology of the Bogong High Plains

E. J. MINTY jun.

The Bogong High Plains comprises fragmented, elevated surfaces (at 1600m to 1986m elevation), of low to moderate relief and contains relic cryogenic features. Conclusive evidence of glacial features has not been observed on the Bogong High Plains.

This thesis has examined the distribution of the cryogenic features and their lateral equivalents in the adjoining valleys of the Mitta Mitta and Kiewa Rivers, with a view to defining processes active in the late Pleistocene. The stratigraphy of thirty-six sites in these valleys reveals relic alluvial fans on the valley sides and in the piedmont zone up to 1 200m ASL. These relic alluvial fans correlate with relic cryogenic features at higher altitudes.

Three areas at Mt Nelse, Basalt Hill and Pretty Valley were targeted for detailed description and analysis of surficial geology. The cryogenic features defined from this study have been compared to those described in other studies of Alpine areas in south-eastern Australia.

The suite of relic cryogenic features mapped and described in detail includes: cryoplanation surfaces, nivation hollows, blockfields, block glacis, block slopes, block streams and talus. The differentiation of these block deposits is based on distribution patterns controlled by slope angle, aspect, prevailing wind direction, altitude range and availability of moisture, as well as the availability of appropriately jointed bedrock, such as basalt and granodiorite. There would appear to be an associated suite of transport mechanisms ranging from low angle ($<2°$) transport of cobbles and blocks by frost creep and possibly gelifluction to high angle ($\geq 30°$) rolling and sliding downslope.

Surface features, including thermokarst, on some of the block accumulations suggest considerable interstitial ice during the period of accumulation.

The relic status of block accumulations is evident from encroaching vegetation, insitu weathering and adjoining stratigraphy. Frost wedging and associated frost creep appear dormant now and the shallow depth of seasonal frost prohibits gelifluction within the present climate. The development of blockstreams and blockslopes which bear thermokarst pitting would appear to have required deep seasonal freezing and accretion of interstitial ice as lenses or blisters near the water table beneath the block layer.

The model for accumulation of these block deposits presented in this thesis requires deep seasonal freezing without the need for permafrost conditions. Mean annual temperatures of about 0°C would have been necessary to preserve interstitial ice down to about 1 300m ASL, during the period of accumulation.

Relic nivation hollows at 1 500m to 1 600m ASL suggest a minimum 5°C decrease in average temperatures during the last cold climate phase. The lateral equivalents of these block deposits in the adjoining valleys (relic alluvial fans) suggest semi-arid conditions with at least 50% less precipitation than present.

Transistion of the above relic cryogenic features towards rock glaciers is suggested in the Kosciusko area, which is generally 300m higher than the Bogong High Plains. Increased snow accumulation and increased depth of freezing in the Kosciusko area may account for this transistion.

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Biographical Memoirs

Frederick Noel Hanlon

Frederick Noel Hanlon was born at Dulwich Hill in Sydney on 2 January 1914. He died on 2 June 1990 at Mosman, aged 76, after a long illness. As well as being a fine and well respected geologist, Fred was a likeable and considerate colleague and a loving family man. Mourned and sadly missed he lives on in the hearts and minds of the family and friends he leaves behind.

Fred was educated at Canterbury Boys High School and at The University of Sydney where he graduated with a Bachelor of Science in 1934, having majors in Geology and Mathematics. This was followed by a Diploma in Education which Fred obained from the same university in 1935. He became a geologist and undertook a nineteen year stint with the Geological Survey, New South Wales Department of Mines.

Here he began working upon what were to become recognised as his major scientific achievements: geological surveys of the South Coast district and of the North-Western Coalfield in New South Wales. The results of this work are published in this and other scientific Journals and in the Annual Reports of the Department of Mines.

In November 1953 Fred resigned to take up an appointment as Senior Lecturer in Geology at NSW University of Technology (now the University of New South Wales), where he was geologist in charge in the Department of Technical Education. The following year he entered private practice as a Consulting Geologist. Fred's integrity, professional knowledge and wide experience were highly regarded by the mining community. It was tragic that in the early 1980s, his career was ended prematurely by Parkinsons Syndrome.

Major contributions to both stratigraphic and economic coal geology of the Gunnedah Coalfield were made by Fred in the late 1940s. In 1975 he participated in a revision of the coalfield's stratigraphy and introduced a modern terminology for the main coal members. This work laid the foundations for company drilling since 1975 and for major exploratory drilling programmes by the Department of Mineral Resources and the Electricity Commission in the 1980s.

In 1947 Fred described the geology of the Ashford Coalfield as a basis for exploratory drilling by the Bureau of Mineral Resources and the Joint Coal Board, resulting in the development of a small open-cut mine for local power station use.

In the early 1950s Fred was the major force in the erection of a new stratigraphy for the Narrabeen Group and the Illawarra Coal Measures in the Stanwell Park - Coledale area, recording in great detail the lithològic attributes of the rock units of these sequences. This worth was incorporated into studies jointly carried out at various times in the distinguished company of Germaine Joplin, Lyn Noakes and Harold Raggatt, in the correlation of the Narrabeen Group between the South Coast and the Narrabeen - Gosford districts.

Other major contributions included revision of the stratigraphic nomenclature of the Mesozoic and Permian units of the Cumberland Basin and the Illawarra District generally, all incorporated in 1952 into the text accompanying the Wollongong 4-mile geological sheet. This was published by the Bureau of Mineral Resources, a landmark publication, being the first of the now complete statewide series subsequently published by the New South Wales Geological Survey.

While undoubtedly more generally recognised for his stratigraphic and economic work in the Gunnedah Coalfield and Southern Coalfield, Fred's geological activities included such diverse topics as the appraisal of the bauxite deposits of New South Wales and applications of etch figures of quartz. More importantly, his Presidental Address to the Royal Society of New South Wales in 1958, concentrated on the problems and solutions of landslide control in the Illawarra District, in which work he stressed the absolute necessity of establishing adequate drainage systems in active or potentially active landslide areas. Particular emphasis was placed on the need to constantly *maintain* such systems. Sadly, it appears that this has not always been done effectively, as evidenced by recent mass movement in that district.

In 1969 Fred became a Director and the General Manager of Magnum Explorations N.L. In this capacity he took charge of exploration activities for Magnum in areas such as Gunnedah - Boggabri, Hillgrove, Ardlethan and Ashford in NSW, and Kanowna, in Western Australia. Assisted by the extensive knowledge he gained of the Gunnedah-Boggabri coalfields, beginning in the 1940s, and by the precise manner in which he conducted an extensive drilling programme, substantial reserves of high-grade coal, known as the "Vickery" deposits, were established.

Fred was a Fellow of the Australasian Institute of Mining and Metallurgy, which he joined in 1939. In 1940 he became a member of The Royal Society of New South Wales. Then in 1957 he was elected President of the Society. As President Fred was accorded the honour of representing the scientific community at official State functions, such as the opening of Parliament and receptions at Government House. A memorable highlight in February 1958 was when he and his wife Bonnie met the Queen Mother at the State Government's reception at the Town Hall, Sydney. He was made a life member of the Society in September 1975.

In his private life Fred loved music and particularly the classical pianists and the great operatic tenors, one of his favourites being the Swedish tenor Jussi Bjorling. He enjoyed playing the piano and the slide-guitar and had an extensive record collection. He was an impressive golfer in his earlier days and a keen A-grade tennis player. However his major involvement was in family life to which he devoted considerable time and energy. He met Veronica Anne (Bonnie) nee Gazeley at the Department of Mines; they married in 1943 and raised three children - John, Margaret (Marnie) and Philip - of whom Fred was a proud father. He was also proud of his three grandaughters, Marnie, Tina and Phillipa. Towards the end of his life he enjoyed regular contact and outings with his children and grandchildren - whom he lovingly said made life really worthwhile.

The first symptoms of Fred's illness appeared in the 1970s and eventually diagnosed as Parkinsons Syndrome. He was admitted to Bradleys Head Private Hospital in February 1986 and remained there until his death on 2 June 1990.

Cliff McElroy, George Beattie, Margaret Hanlon
June 1991

Publications

Hanlon, F N, 1943 "The Etch Figures of Basal Sections of Quartz. Their Use in the Orientation of Waterworn Crystals.", *Journal and Proceedings of the Royal Society of NSW*, v.77, pp.40-51.

_________ 1944 "The Bauxites of NSW. Their Distribution, Composition and Probable Origin.", *Journal and Proceedings of the Royal Society of NSW*, v.78, pp.94-112.

_________ 1947 "Geology of the Ashford Coalfield", *Journal and Proceedings of the Royal Society of NSW*, v.81, pp.24-32.

_________ 1947 "A Magnetic Survey in the Vicinity of the Volcanic Neck at Dundas, NSW", *Journal and Proceedings of the Royal Society of NSW*, v.81, pp.69-76.

_________ "Geology of the North-Western Coalfield, *Journal and Proceedings of the Royal Society of NSW*

1948a Part I "Geology of the Willow Tree District", v.81, pp.280-286.
1948b Part II "Geology of the Willow Tree-Temi District", v.81, pp.287-291.
1948c Part III "Geology of the Murrurundi-Temi District", v.81, pp.292-297.
1949a Part IV "Geology of the Gunnedah-Curlewis District", v.82,pp.241-250.
1949b Part V "Geology of the Breeza District", v.82, pp.251-254.
1949c Part VI "Geology of the South-Western Part of County Nandewar", v.82, pp.255-260.
1950a Part VII "Geology of the Boggabri District", v.82, pp.297-301.
1950b Part VIII "Geology of the Narrabri District", v.82, pp.302-308.

_________ 1950, "Wolfram Deposits - Wild Cattle Creek.", *NSW Dept of Mines - Geological Reports* for 1939-1945.

_________ 1950, "Quartz Crystal - Kingsgate. The Arsenic Shaft and Water Cut.", *NSW Dept of Mines - Geological Reports* for 1939-1945.

_________ 1950, "Attunga Copper Mine.", *NSW Dept of Mines - Geological Reports* for 1939-1945.

Hanlon, F N, Joplin, G A & Noakes, L C, June, 1952 "Review of Stratigraphical Nomenclature. 1. Mesozoic of the Cumberland Basin.", *Aust. J. Sci.*, v.14, No.6, pp.179-182.

_________ 1953b "Review of Stratigraphical Nomenclature. 2. Permian Units in the Illawarra District.", *Aust. J. Sci.*, v.15, pp.160-164.

_________ 1953c "Review of Stratigraphical Nomenclature. 3. Post-Palaeozoic Units in the Illawarra District of NSW", *Aust. J. Sci.*, v.16, No.1, pp.14-16.

Hanlon, F N, Osborne, G D & Raggatt H G, 1953a "Narrabeen Group: Its Subdivisions and Correlations Between the South Coast and Narrabeen-Wyong Districts, *Journal and Proceedings of the Royal Society of NSW*, v.87, pp.106-120.

Hanlon, F N, 1953 "The Geology of the NSW Coalfields", *Fifth Empire Min. Met. Congress*, **6**,1.

_________ 1954, "Development of Coal Seams between the Southern and South-Western Coalfields.", *A. Rep. Dep. Mines N.S.W.* for 1950, pp.71-73.

_________ 1954, "Limestone Deposits at Bingleburra, Gresford District.", *A. Rep. Dep. Mines N.S.W.* for 1950, pp.87-89.

_________ 1954, "Limestone Deposits of the District East of Gloucester.", *A. Rep. Dep. Mines N.S.W.* for 1950, pp.89-91.

_________ 1955, "Correlation of Coal Seams worked at Tongarra, Avondale and Huntley Collieries.", *A. Rep. Dep. Mines N.S.W.* for 1949, pp.66-67.

_________ 1956a "Geology of the Southern Coalfield. Illawarra District." *A. Rep. Dep. Mines N.S.W.* (1952), pp.95-104.

_________ 1956b "Southern Coalfield. The Geology of the Stanwell Park-Coledale Area." Tech. *Rep. Dep. Mines N.S.W.*, 1, pp.20-35.

_________ 1958, "Presidential Address: Geology and Transport - With Special Reference to Landslides on the Near South Coast of NSW", *Journal and Proceedings of the Royal Society of NSW*, v.92, pp.1-15.

Hanlon, F N, 15 December 1967, "Construction and the Geologist", *Rydge's Construction, Civil Engineering & Mining Review*, pp.6f.

Britten, R A & Hanlon, F N, 1975 "North-Western Coalfield" Economic Geology of Australia and Papua New Guinea, 2. Coal, *The Australasian Institute of Mining & Metallurgy*

Unpublished Reports, including:

Hanlon, FN, 1949, "The Geology, Structural Evolution & Palaeogeography of the North-Western Coalfield, NSW." Unpub. Rep.

_________ 1951, "Geological Reconnaissance of the Moss Vale-Berima-Bundanoon District.", Unpub. Rep. geol. Surv. NSW.

_________ 1958, Geological Report on Grafton-Clifden Area. Clarence River Basin Oil Expln Co NL.

_________ 1963, Report on drilling at Clifden. Clarence River Basin Oil Expln Co NL.

_________ 1967, Clarence Oil Binerah Downs No 1 Well, Completion Report.

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Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigaphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT 2601, Australia.

Abstract. A brief but fully informative abstract must be provided.

Tables should be adjusted for size to fit the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

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Henry Chamberlain Russell:- 19th Century Astronomer, Meteorologist and Organizer of Australian Science

R. BHATHAL

ABSTRACT. The life and work of Henry Chamberlain Russell spanned a key phase in the development of science in Australia. It was a time of transition - from a colonial to an independent period of science. H. C. Russell was an influential figure in this development. He was responsible for some of the major physical science programs that were undertaken in 19th century Australia, some of which were internationally of high importance. This paper examines Russell's scientific work in 19th century colonial Australia.

INTRODUCTION

Henry Chamberlain Russell was the first president of the Australasian Association for the Advancement of Science, three times a president of the Royal Society of New South Wales and the first local graduate from the University of Sydney to be elected a Fellow of the Royal Society of London (in 1886) and to be appointed to head a major scientific institution in the second half of 19th century Australia. (Walsh 1974, 1976, Wood 1958).

His life and work spanned an important and critical phase in the development of science in Australia. This was a period when Australian science was in transition from a dependent colonial scientific community to a community which was beginning to assert its own individuality and sense of purpose (Home 1988, MacLeod 1982, Moyal 1976,1986). In Russell is seen a healthy tension between dependency and autonomy. Both struggle for expression in his scientific work.

It was a time when the leadership of the scientific community was passing from the amateur naturalist to.the new professionals in the physical sciences. It was also the time of the great intercolonial scientific movements which led to the formation of the first national scientific society - the Australasian Association for the Advancement of Science (AAAS).

Russell was a member of Australia's 19th century scientific elite. A number of them (Robert Ellery, Henry Chamberlain Russell, Frederick McCoy and Ferdinand von Mueller) were elected members of the Royal Society of London in recognition of their work in science in the colonies.

Although Russell played an important role in 19th century science in Australia he has been neglected by historians of science. He was a great organiser and was extremely successful in winning government funding for major projects to advance the cause of science by 'clothing' the goals in terms of utility or prestige for the colony.

BIOGRAPHICAL SKETCH

Henry Chamberlain Russell was born in West Maitland on 17th March 1836. He suffered a severe illness in 1903 and died of a heart failure on 22nd February 1907 at Sydney Observatory. He was survived by his wife Emily Jane, nee Foss (d. 1923), a son and four daughters.

He was educated at West Maitland Church of England Grammar School and the University of Sydney. He was awarded the Deas-Thompson Scholarship for physics and chemistry and graduated BA in 1858, the year that Sydney Observatory was completed. Immediately on leaving the Universty he was appointed an assistant to William Scott (1825-1917), the first government astronomer and director of Sydney Observatory. At the young age of 36 he became the government astronomer. He held this post for 35 years. Being the director of a major scientific institution, Russell was placed in an excellent position to use the relationships between science and politics for the advancement of science in the colony. He was also placed in a position to influence the direction of certain scientific developments. This is well illustrated in a perceptive letter written by the amateur astronomer R. T. A. Innes (1892) to John Tebbutt (1834-1916) regarding the formation of an Australian Astronomical Society and its presidency. He wrote: "...if we decline to make Mr Russell president will it hurt us with the Government".

His father was the Honourable Bourn Russell - a member of the Legislative Council from 1858 to 1880 and a colourful character. Gail Macqueen (1988), a memebr of the Russell family wrote of him in a note to the author : "Bourn Russell was a master mariner, storekeeper and politician at various stages of his life. He was the captain of the Lady Rowena which brought convicts to New South Wales in 1826 and which was later used for whaling in the Pacific ... he settled in Maitland as a storekeeper ... He stood for election to the Legislative Assembly in 1856. Although he was declared the winner of the poll he was disqualified for rigging the votes. In 1858 he was appointed to the Legislative Council".

Bourn Russell was described as a "doer" - a man who got things done. This same attitude to life was transmitted to his son. From his father Russell acquired a knowledge of how the bureaucracy was run.He also acquired from his father a rather stern, forceful and, at times, a blunt manner to his subordinates. This blunt manner is attested in some of the correspondence he had with his voluntary meteorological workers. For example, in a letter (Russell 1867) to Gibson, a meteorological observer at South Head, he wrote: "Why have no observations been sent this morning? In future state reasons when observations are not sent". His relations with some of the junior staff at the Observatory left much to be desired. In 1877 an attack was made on his life when an explosive device was delivered to him and in 1899 he was assaulted by one of his workmen at the Observatory.

Despite these shortcomings in his character, Russell was an extremely energetic person and got on well with his fellow scientists and peers. Scott had a high opinion of him as an astronomer. Commenting on a paper (Nebula around Eta Argus) read by Russell (1871a) at the monthly meeting of the Royal Society of New South Wales in May 1871, W. Scott (1871) noted that he was assured that Russell "would bring the Observatory with which he was connected into great repute". His confidence in Russell's abilities were more than justified in the years ahead.

Russell was an outstanding organiser and advocate of science. Under his leadership Sydney Observatory grew in international stature. It was involved in some of the major local and international scientific programs in the 19th century. Apart from his astronomical, meteorological and geophysical work Russell played an important role in the development of scientific societies and technical education.

COLONIAL TO INDEPENDENT SCIENCE

Attempts have been made by historians of science (Home 1988, Inkster 1985, MacLeod 1982) to discuss the history of Australian science within the conceptual framework of imperialism and isolationism. It will be useful in this paper to place Russell's work within the broad framework of this conceptual scheme in order to understand his role in the development of science in Australia.

In a perceptive paper on the development of science in frontier or colonial societies Basalla (1967) notes that science passed through three phases, viz: an exploration and collecting phase (Phase 1), an imperial or colonial phase (Phase 2) and finally through an independent phase (Phase 3). MacLeod (1982) refined this model to five phases with no more significant insights into the development of science in colonial Australia.

In the first phase science was undertaken by visiting scientists and explorers who after sampling the new environment returned to Europe and published their results there. The second phase begins when local residents begin to take an active role in scientific programs. This is still dependent science, in the sense that local practitioners look to Europe to supply their scientific needs and materials, such as,books, laboratory equipment, training and scientific honours. In the third phase there is a conscious attempt to create local scientific honours, scientific institutions, societies, journals and the manufacture of scientific equipment with local design talent, labour and materials. The scientists major ties are to come from "within the boundaries of the country in which he works". (Basalla 1967).

On this model Russell's scientific work would span the colonial phase (Basalla's Phase 2) and the beginnings of the independent phase (Basalla's Phase 3).

On the one hand Russell drew inspiration and guidance from the European centres for his major astronomical programs and on the other hand he also carried out an independent program in the areas of meteorology, astronomy and geophysics. So we have here a case of the two strands in the develoment of science in Australia running in parallel. There was a creative tension between dependency and autonomy in Russell's scientific programs. He was deeply involved in carrying out and solving pressing local problems which required a science base. His papers in the areas of astronomy and meteorology were of such a high standard as to be accepted in international journals of the day. By aligning himself to the scientific programs of the European centres of science, Russell was able to make valuable contributions to the general body of scientific knowledge. He was able to utilise his organisational skills in getting major scientific programs off the ground in the colony.

PROJECTS AND PROGRAMS

In assessing Russell's life and scientific work it will be necessary to review his contributions to some of the major projects and programs in 19th century Australia.

Russell's involvement in major projects and programs include:

(1) the intercolonial science movement
(2) Sydney Observatory building
(3) meteorological and geophysical studies
(4) astronomical expeditions
(5) the astrographic project and other astronomical programs

(6) design and invention of scientific equipment, and
(7) advocate for science and technical education.

Éach of these projects and the role Russell played in advancing the cause of astronomy and science in 19th century Australia are explored in this paper.

INTERCOLONIAL SCIENCE MOVEMENT

Several years before the political federation of the Australian colonies took place in 1901, scientists were active in bringing about intercolonial co-operation in their scientific ventures and programs. In 1888 this culminated in the formation of the federally constituted scientific society - the Australasian Association for the Advancement of Science. (Hoare 1975, MacLeod 1988). By this initiative the scientists were one step ahead of the politicians in forging a federation of people with like interests, thus setting an example for politicians to follow. Sir James Hector (1834-1907), a New Zealander who was president of the Association in 1891 quite rightly noted that "Politicians should take this well to heart". (Hector 1891). Along with Professor Liversidge of the University of Sydney, Russell was a strong advocate of the intercolonial science movement and a firm supporter of a federally constituted scientific society. At a monthly meeting of the Council of the Royal Society of New South Wales held on 30th June 1886, Russell along with other Council members supported and approved the resolution "that steps be taken to form an Australasian Association for the Advancement of Science ... and that the Council take part in the furtherance of Professor Liversidge's proposal". (Royal Society of NSW 1886).

Russell's standing within the scientific community (he was one of eight Fellows of the Royal Society of London who were resident in Australia in 1886) and the political and bureaucratic elites in New South Wales placed him in an ideal situation to be elected as the first president of the Association. In his presidential address Russell (1888) spelt out the nature and funtion of the society thus: "The Australasian Association is for the Advancement of Science ... it is not the hobby of a few individuals, or of one colony; it takes in all who wish to advance science in the colonies". So was launched the first federally constituted scientific society in Australia. Russell was to play an important role in its growth and in its affairs. He served on the Council of the Society for several years and presented papers at its meetings.

However, Russell's first forays into the organisation of science on an intercolonial basis date back to the 1870s. One year after he was appointed the director of the Sydney Observatory he collaborated with Robert Ellery (1827-1908), the government astronomer of Victoria, in the organisation of the Australian Eclipse Expedition which went to Cape Sidmouth in Queensland to observe the eclipse of the Sun. According to Hoare (1975) this "enterprise was the first real attempt at formal intercolonial scientific co-operation on any scale". Russell was the leader of the five man team from New South Wales. Since no vessel was offered by the Victorian party Russell managed to induce the Queensland government to lend their steamer "Governor Blackall" to carry the observers to the Cape. He also obtained the necessary funds from the New South Wales government towards the expense of the expedition. (Russell 1871b). The vessel was fitted out in Sydney.

Russell's consuming interest in meteorology led him to advocate the need for a systematic and properly documented study to understand the Australian climate. Together with Charles Todd (1826-1910), the government astronomer of South Australia, and Robert Ellery he established a system of Australian weather telegraphy. By 1877 Russell (1877a) claimed that the daily weather data link-up between the colonies was one of the most efficient and advanced of the times.

Russell was actively involved in the international and intercolonial exhibitions which were held in the late 19th century. (Russell 1875a, Sydney International Exhibition 1881). He also served as judge for exhibits on horology and scientific instruments at these exhibitions and his involvement gave him a suitable platform to further the cause of intercolonial co-operation in meteorology. In 1879 Russell took advantage of the Sydney International Exhibition held in the Royal Botanic Gardens in Sydney, to convene an Australian Meteorological Conference "with a view to bringing about more complete co-operation in the study of Australian meteorology". (Todd 1893). With Ellery's and Todd's assistance he drew up guidelines for standardising the meteorological work carried out in the colonies. The work of this group laid the foundations for the eventual formation of the Commonwealth Bureau of Meteorology in 1907 under H. A. Hunt (1866-1946) who had been a meteorological assistant under Russell.

SYDNEY OBSERVATORY BUILDING

Architecture in 19th century Australia drew its inspiration from European designs and styles which were adapted to suit local conditions and the availability of materials. The use of a bluish-grey slate in Victoria and sandstone in New South Wales gave the buildings in these colonies a character of their own. The simplicity of the earlier architectural styles gave way in the 1850s to more lavish Classical and Gothic Revival designs (Latta 1984). This was due to the growing prosperity of the eastern colonies as a result of the discovery of gold.

While the Gothic Revival style was used mainly for church buildings, the Classical Revival design came to dominate public buildings and scientific institutions. A latter style was adopted for public buildings to foster "an impression of dignity, antiquity and permanence". (Forgan 1986). Victorian architecture in the colonies was not only based on the Gothic and Classical Revival styles but was also influenced by a mixture of styles as diverse as the Italian and French Renaissance. It was against this background of architectural styles that Sydney Observatory was designed and constructed in the late 1850s. Built of Sydney sandstone its design belongs to the Italianate style of architecture.

On being appointed the government astronomer in 1870, Russell set about re-organising and re-furnishing the Observatory. (Russell 1875b). Within seven years of his appointment he added seven new rooms, an additional dome and replaced the old instruments with new ones. Apart from a minor addition of a cement rendered building in the courtyard in 1906 (this was demolished in the building restoration program in 1983) the original fabric of the Observatory building has remained very much as in the 1870s.

METEOROLOGICAL AND GEOPHYSICAL STUDIES

Apart from his major astronomical programs, Russell was also actively involved in meteorological and geophysical studies. (Day 1966). He established himself as one of the early authorities in the study of Australian meteorology. (Gentilli 1967, Walsh 1974). He was a prolific writer and published several papers and reports on meteorology and climatology in both local and international journals. He was a pioneer of the global approach to meteorology (Russell 1893a) and the "first to think comprehensively about the southern hemisphere and show that those in the northern [hemisphere] may learn something fundamental from its study". (Priestly 1971, Wood 1983). Russell made the radical suggestion that the movement of anticyclones was a hemispheric phenomena. This raised the eyebrows of the northern meteorologists who believed that anticyclones were typically quasi-stationary circulation systems. C. B. Priestly (1971) states: "Time has proved the substantial difference in behaviour between the two hemispheres. Russell's name should live as a pioneer of the global approach" to meteorology.

In 1877 Russell published his major book on the "Climate of New South Wales" which had 189 pages, five pages of diagrams, a large folding map and sixty-five pages of tables. (Russell 1879b). His other book on "Physical Geography and Climate of New South Wales" was published in 1884. (Russell 1884). A second edition was printed in 1892.

When W. Scott was appointed the first director of Sydney Observatory in 1856 he established twelve meteorological stations in places as far apart as Brisbane (then still part of New South Wales) and Albury. (Scott 1859). Each station was equipped with a standard barometer, wet and dry bulb thermometers, maximum and minimum thermometers and a rain gauge. However, some of these stations were closed or allowed to fall into disuse, by the second government astronomer G. R. Smalley due to ill health and his concentration on baseline work for trignometrical purposes. (Russell 1870).

On being appointed the government astronomer, Russell re-established and extended the number of stations. In a letter to the American Consul, Russell (1889a) wrote: "I was appointed Astronomer in 1870 ... I found 5 meteorological stations at work and at the end of 7 years the number had risen to 68 and since than more rapidly so that now we number nearly 1000".

Russell not only trained the voluntary observers but also designed and constructed much of the equipment that was used at these stations. Sydney Observatory was also equipped with a continous self recording barograph and thermograph, pulviometer and anemograph.

The collection of statistical data on weather by Russell allowed him to publish a daily weather map in the Sydney Morning Herald commencing in 1877. (Russell 1877a). This was a major innovtion in Australia since it was the first time that a weather map had been printed in a newspaper in the colonies. Fortunately he was able to persuade the proprietors of the newspapers to print the map without charge to the government in view of its relevance to the shipping and agricultural communities in the colony.

Russell astutely persuaded the government to support the project. His arguments were based on the utilitarian value of the meteorological information to the colony and his comparison of the low cost involved to similar work in England and America. Writing to the Under Secretary for Justice and Public Administration Russell (1875c) argued: "Indeed no stronger argument to prove its utility and money value, could I think be addressed, than the Americans (who) consider it one of the duties of Government and pay the ... costs ... without a grumble. Our small cost compared with England and America is explained by our different circumstances and management".

After several years of studying the weather data Russell was able to arrive at a synthesis and interpretation of the anticyclones in the Australian region. The Hon. Ralph Abercromby was so impressed by the work carried out by Russell and Hunt that he edited a collection of their papers on Australian weather (Abercromby 1896).

Russell's successful meteorological program attracted criticism. In pursuing it he tended to de-emphasise the astronomical work at the Observatory which drew adverse comments from John Tebbutt, the gentleman astronomer from Windsor Observatory. Tebbutt (1891) noted that for ten years, 1880 to 1890, the cost of the establishment including instruments was 41 103 pounds of which a sum of 24 594 pounds (about 60%) was paid for the maintenance of the meteorological instruments alone. Tebbutt wrote a letter to the Sydney Morning Herald complaining about the emphasis which Sydney Observatory placed on meteorology at the expense of astronomy. The Herald refused to publish the letter. In order not to be "quietly snuffed out", as Tebbutt put it, he published a critical pamphlet on the work of the Observatory for wide distribution in the colony (Tebbutt 1891). Russell was not impressed but it certainly stirred Russell to correct the imblance and spend more time on astronomy after the 1890s.

Was Tebbutt's criticism justified? Certainly not. Tebbutt was not aware of the constraints under which Russell worked. Russell's statement of duties required him not only to work on astronomy but also on meteorology and other scientific programs including tidal and magnetic measurements. He was responsible to Parliament which had a powerful agricultural and commercial lobby. Members of the Legislative Assembly made it a point to raise questions in Parliament if the records were late or had not been produced on time (Russell 1889b). The importance of these records to the people in the colony was succinctly expressed by Todd (1893): "To successfully occupy and establish industries in new countries, a knowledge of climate and meteorological conditions under which we are to labour is essential to success".

Russell (1882a) showed a keen interest in the artificial modification of the weather as he felt this was an important question for an essentially agricultural country. He reviewed the French, British and American literature on the production of artificial rain and commented that "In America, during the Civil War, it was a matter of common observation that rain followed the great battles and the belief in this became so general that farmers began the practice of making large heaps of brushwood on each farm and when they wanted rain,lighting them all together" (Russell 1882a). Since there were no great battles to refer to in Australia, Russell studied the relationship between rain and great fires. He concluded that "there is not one instance in which rain has followed within forty-eight hours as an evident consequence of the fire" (Russell 1882a). His studies on the disappearance of vast bodies of river water in the interior was a significant contribution to hydrological studies as it led to the finding of the first artesian flow of water in New South Wales (Pittman 1914). From the hydrological data he collected for Lake George and the Murray and Darling Rivers Russell postulated that the reason for the very small proportion of the rainfall on the Darling River catchment that flows downstream at Bourke was due to the fact that much of the water was absorbed and passes underground at depth (Russell 1879, 1889c). A. A. Day (1966) remarks that although Russell's "conclusions were incorrect in detail, in part due to his lack of understanding of the geological and petrophysical factors involved in the storage and movement of underground water, his observations led to the discovery and exploitation of the vast reserves of water held in the Great Artesian Basin"

Russell continued the work on geomagnetism and tides commenced by G. R. Smalley, the second government astronomer. However, the introduction of the tramways in Sydney in 1899 made it impossible to carry out magnetic measurements at the Observatory. The work was later transferred to the branch Observatory at Red Hill, near Pennant Hills.

Russell also established tide gauges at Newcastle and other ports which enabled him to compile mean sea levels. His interest in sea-levels was aroused by the work of Rev. W. B. Clarke, and others, who were working on the problem of the relative rising and falling of the coastlines in relation to the mean sea-level. After a thorough analysis of the data collected by the Sydney tide-gauges over a period of twelve years Russell concluded that "there has been no appreciable change, and therefore we cannot say that the east coast at Sydney is either rising or falling" (Russell 1885a). Russell was also one of the world's pioneers in the field of limnology.

His recording of changes in the level of Lake George led to his recognition of seiches in the lake. By analysing the water quality of Lake George, Russell found that the water contained 187.5 grains of mineral matter to the gallon. This, he concluded, made it unfit as a source for town water supply as some had suggested. In his studies of Lake George he also speculated on the history and size of the Lake in former geological times. In another extensive program Russell collected data on ocean surface currents around Australia. He carried out a few studies on the tides of the solid Earth in 1885 because of disturbances in the orientation of his telescopes (Russell 1885b). He also obtained a Ewing seismograph in 1888 to detect short period movements in the Earth.

ASTRONOMICAL EXPEDITIONS

Russell lived in an age when exploration and scientific expeditions were still a common feature of scientific life in the colonies. The expeditions were initiated either locally or by the the British or European centres of science. In the period from 1870 to 1885 Russell was involved in organising four major astronomical expeditions for observing important astronomical phenomena at places remote from Sydney Observatory. These were : the total eclipse of the Sun of December 1871, the transits of Venus of December 1874 and December 1882 and the transit of Mercury of November 1881.

The proposal to mount the expedition to observe the solar eclipse came from Professor William Wilson (1826-1874), the professor of mathematics at the University of Melbourne. It was a joint venture between Sydney and Melbourne Observatories. The Eclipse Committee of the British Association for the Advancement of Science sent special instruments for use by the expedition. The observation station was located on Eclipse Island off the north coast of Queensland. However, bad weather and a severe thunderstorm prevented the astronomers from making any useful observations. In his letter to the Secretary of the Royal Astronomical Society in London, Russell (1871b) reported : " a severe thunderstorm during which lightning passed down the iron stays of the ship five times and exploded between the stay and the hull fortunately without damage. Heavy rain followed". But the expedition was not a complete failure. In the same letter Russell informed that an extended series of observations were made "of the temperature of the water in the great south current which is considered to affect the climate of New South Wales considerably".

The biologists on the expedition fared a little better. John Brazier (1842-1930), a conchologist, collected terrestrial and marine shells and named some of the species: Helix (Conulus) Elleryi, Helix (Conulus) Russelli, Pupa (Vertigo) Scotti, Pupa (Vertigo) Macdonnelli and Cyclophorus (Diptropis) Whitei, after the astronomers on the expedition - R. Ellery, H. C. Russell, W. Scott, W. J. Macdonald and E. J. White. It was the first time biological specimens were labelled with the names of astronomers (Brazier 1874).

Russell also played an active role in observing the transits of Venus in 1874 and 1882 and the transit of Mercury in 1881. Of all these, the transit of Venus expedition of 1874, proved the most successful.

G. R. Smalley, the second government astronomer of New South Wales until 1870, had made no preparations for observing the forthcoming 1874 transit of Venus and indeed expressed his intention of "taking no part in the work". (Russell 1892a). On succeeding Smalley, as the government astronomer in 1870, Russell (1892a) wrote: "I at once took steps to prepare for the great astronomical event, fully realising the great importance of taking advantage of our favourable geographical position on the eastern coast of Australia for observing the egress".

In order to carry out the project Russell needed to marshall a range of forces. He had to obtain support and funds from the colonial government, approach the Royal Society of New South Wales for further support for the project, obtain the necessary equipment from Europe and equip the observing parties in time to observe the transit of Venus, organise the photographic work, set up meteorological stations to collect weather data for the selection of four suitable sites for observing stations, arrange for temporary structures to be set up to house the instruments and the members of the observing parties, and arrange for four parties of four people for the observations who had to be trained in the use of the instruments and methods of observing the transit of Venus. Only 3 of the 16 members of the project team belonged to the staff of the Observatory. The others were volunteers.

In pursuing the Observatory's meteorological work Russell had argued that the meteorological programs were of a utilitarian value to the economy of the colony. For the transit of Venus project Russell now argued that "It was obviously for the honour of the Colony, as well as for the advancement of science that the transit of Venus should be as complete as possible". (Russell 1872a, 1892a). To give his arguments greater weight, Russell requested the Council of the Royal Society of New South Wales to send a deputation to the government to impress on it the importance of the scientific work. By both manoeuvres, Russell won 1 000 pounds from the government to enable him to carry out the project.

The planning and execution of the project must have taxed Russell's abilities of organisation. He quickly found out that the instrument makers in Europe had their shops full of work for the European scientists and could not take orders at such a late period. However, he managed to purchase a photo-heliograph with Jansen apparatus and an objective glass with accessories from the European manufacturers to construct a large equatorial telescope in the colony. The rest of the equipment he had built by local mechanics who "for the most part were unused to delicate work" (Russell 1892a). This meant additional work in designing, supervising and generally checking up on the work. Russell trained the volunteer observers by making them practice on a model of an "artificial transit" (Russell 1892a).

Four sites were selected at Eden, Goulburn, Woodford and Sydney respectively. On 9th December 1874 the astronomers awoke to a fine day for their long awaited observations. The project was a success. Russell collated the data from New South Wales and went to England in February 1875 to present his results to the Royal Astronomical Society. Russell's observations were given double weight by Captain Tupman who collected and analysed the British observations with the Astronomer Royal in England. Russell's data lowered the value of the solar parallax. This was a significant contribution to world astronomy. While in England Russell ordered equipment for the trigonometrical survey and a six-inch transit instrument from Troughton and Sims of London. He also made it a point to meet leading astronomers and instrument makers in Europe and America before returning to Sydney in October 1875.

Russell's arrangements for the observation of the transit of Mercury in 1881 were also characteristically thorough involving observers at Bathurst, Katoomba and Sydney. But this project was rendered unsuccessful by cloudy weather at all three places. (Russell 1881c).

In October 1881 Paris hosted an International Conference of astronomers from eleven European nations and three American states to organise the observation of the transit of Venus in 1882. (Russell 1882a). The delegates to the conference agreed to carry out observations which were based upon the proposals of the British Commission. Russell organised, equipped and trained five teams for the project. Once again he was able to persuade the government to supply him with the necessary funds to purchase the equipment. Fifteen observers took part in the work. The observers were stationed at Port Macquarie, Clarence River, Mt Dromedary, Katoomba, Lord Howe Island and Sydney Observatory. Yet once again weather conditions prevented the parties from obtaining meaningful results.

ASTROGRAPHIC PROJECT AND OTHER ASTRONOMICAL PROGRAMS

Russell's innovative and organisational skills are once again evident in his undertaking of a collaborative international project. His reasons for embarking on this venture centred on prestige for the colony and the advancement of science.

Two technological developments transformed the study of astronomy during the second half of the nineteenth century. These were the invention of the spectroscope and the photographic plate. (Lankford 1984). The spectroscope yielded information on the physical and chemical composition of the stars. Together with the photographic plate these devices provided the foundations of the new astronomy, i.e. astrophysics. Russell whole-heartedly embraced both these developments in instrumental astronomy. He even purchased a large spectroscope by Hilger of London, which gave dispersion through eighteen prisms and a very large "Rumkorff" coil for spectroscopic work. However, he concentrated his efforts on the photographic plate for carrying out work on positional astronomy and neglected the new developing field of astrophysics which was to have a major impact on twentieth century astronomy.

As early as 1886 Russell had begun experimenting with the possibility of applying photography to astronomy. He successfully took photographs of double stars and the Moon and, realising the usefulness of photography to astronomy, became thus one of the early pioneers of astronomical photography in Australia (Russell 1893b).

An ambitious program to chart and photograph the sky was mooted by the astronomers in the European centres of science in the late nineteenth century. (Turner 1912). Russell was one of fifty-six scientists from nineteen countries who attended the International Astrographic Conference held in Paris in 1887. Being the only Australian representative, Russell pledged Sydney and Melbourne Observatories to photograph the declination zones from -52 degrees to the South Celestial Pole. (Sydney from -52 degrees to -64 degrees south declination and Melbourne declination -65 degrees to the South Celestial Pole).

The delegates to the Astrographic Conference decided on the size of the telescope that was to be used by the observatories undertaking the project. Instead of ordering a complete astrograph from the manufacturer (Grubb of Dublin) as many of the other major observatories such as Greenwich had done, Russell decided to design and build one in the colony. This was a major initiative on his part. He purchased only the objective glass and some accessories for the telescope from Grubb. He designed the Star Camera and supervised its construction by the local engineering firms Mort's Dock and Engineering Company, and the Atlas Engineering Company. (Russell 1892b). The clockwork microscopes and the smaller parts were made by W. I. Masters, the instrument maker at the Observatory.

Russell housed the completed camera in a specially constructed building in the grounds of the Observatory which had an innovative design. The walls and roof of the building could be rotated around the astrograph. The telescope was ready for use by 1891. However, it was soon found that city lights interfered with the photographic work and the astrograph was accordingly moved to a country location at Red Hill near Pennant Hills.

While waiting for the lens to arrive from Grubb, Russell produced some excellent photographs of the Milky Way and the "Nubeculae Major and Minor" (i. e. the Large and Small Magellanic Clouds) with one of Dallmeyer's largest portrait lenses. These according to Russell (1890), were the first photographs of their kind of the southern sky, and these broke substantial new ground. They created a sensation when shown at the Royal Astronomical Society rooms in London and indeed became the only Australian investigation to be mentioned in Pannekoek's authoritative "History of Astronomy". Russell was also one of the very first astronomers who pointed out the spiral structure of the large cloud. (Russell 1891). His photographs are the earliest photographic record of the Australian sky and form an important document in Australia's scientific heritage.

By undertaking the astrographic project Sydney Observatory placed itself amongst the leading observatories in the world. Harley Wood (1911-1984), the seventh government astronomer of Sydney Observatory, would complete the Sydney and Melbourne portions of the work in 1964. "The astrograhic work", wrote Wood (1983), "has been an important part of the program of Sydney Observatory which has determined more star places than any other observatory". Yet without realising it, Russell locked the Observatory to a program that was to consume its astronomers for the next 74 years in a tremendous amount of routine work. The international project turned out to be more costly and time consuming than the organisers had foreseen. As a consequence of undertaking the astrographic project the staff at Sydney Observatory was not able to commit resources and time to the new and growing field of astrophysics. Research in astrophysics was thus retarded at the Observatory with serious consequences for the institution's survival in the 1980s. While other observatories, for example, in the United States and elsewhere moved into the field of astrophysics Sydney Observatory was left behind to carry out a program in positional astronomy. (Orchiston 1988).

Russell's only foray into the new field of astrophysics was his paper on a spectroscopic analysis of the Comet of 1881 which was discovered by John Tebbutt. (Russell 1881a). According to Agnes Clerk (1893) : "Cometary photography came to its earliest fruition with it ; and cometary spectroscopy made a notable advance by means of it". Russell was amongst one of a few 19th century astronomers who made a spectroscopic analysis of the spectra of the comet. It was the first comet in which hydrocarbon bands were traced throughout the length of the tail.

Soon after being appointed government astronomer Russell began an independent research program on double stars. The study of double stars had been pioneered by William Herschel and by the late nineteenth century, John Herschel, Herschel's son, had discovered and catalogued thousands of double stars. Russell began by re-measuring the double stars which Herschel had discovered earlier at the Cape of Good Hope. Russell wrote to the Astronomer Royal to suggest that he measure the stars "within 30 degrees of the South Pole" as this would allow for a division of labour in the study of double stars between the northern and southern astronomers. (Russell 1872b). Between 1871 and 1894 Russell discovered over 500 new double stars. (Russell 1880, 1881b, 1882b,1883, 1894).

Russell's other astronomical programs included the study of comets, star clusters, nebulae, meteorites, the changes in the surface of Jupiter, and star observations for the determination of the longitude of Sydney Observatory. This work also included the keeping of time for the colony which was of vital importance for shipping.

DESIGN AND INVENTION OF SCIENTIFIC EQUIPMENT

Russell had a great flair for the design and invention of scientific equipment. He both designed and constructed and supervised the construction of about 23 instruments for use in meteorology, geophysics and astronomy, although the majority of his inventions were in meteorology. These included a self-recording anemometer and pluviometer, a self-recording tide gauge, an electrical barograph, various self-recording pluviometers and a meteorograph. His self-recording anemometer was the first to be set up in the Australian colonies. One of his portable anemometers is housed in the collections of the Science Museum in London. He also invented a hand anemometer for use in ships where a large fixed anemometer would have been cumbersome. The gunners used this too for estimating the allowance to be made for the force of the wind. In one of his anemometers the motion of the force of the vane and cups was conveyed 75 feet vertically to the recording parts. This anemometer also permitted rain to drop 65 feet down the centre of a large tube and be recorded on the same sheet as the wind. Among his other mechanical innovations were a governor for driving clocks and the use of two pendulums to produce rotary motion.

His inventive skills also led him to design and make improvements on astronomical equipment. He designed the equatorial stand for the 11.5 inch refractor, an equatorial mounting for a 15 inch reflector, an astrograph (Russell 1892b) and a photographic transit circle (Russell 1895). His novel design for an equatorial mounting (Russell 1878) with a yoke at the upper end of the polar axis has a striking resemblance to the present day 200 inch telescope at Mount Palomar.

In the 1880s he was given the task of superintending the purchase and erection of the clock tower and chimes for the General Post Office clock in Martin Place in Sydney. He was also responsible for designing the chime mechanism for it.

By designing and constructing most of the meteorological instruments himself, Russell was able to distribute the equipment in a most cost effective manner to his volunteer corps of meteorological workers spread over various parts of New South Wales. His confidence in designing and having the large telescopes built in the colony helped to foster the growth of technical skills in the embryonic scientific instrument industry. By embarking on this course of action he was also saving foreign exchange for the government.

ADVOCATE FOR SCIENCE AND TECHNICAL EDUCATION

Despite some pragmatic emphasis in his view of science, Russell was aware of the benefits of a science culture. He advocated the study of science and was against those whose "only measure for scientific value is a coin of the realm". (Russell 1888). In his 1888 Presidential Address to the members of the Australasian Association for the Advancement of Science he said:"Science stands or falls as a whole; if we limit it to certain purposes, it ceases to be science and becomes mere empiricism. This Association stands as a protest against the short-sighted and utilitarian policy of those who would cultivate only what they characteristically call the bread and butter sciences" (Russell 1888). Russell was actively involved in the promotion of science through the Royal Society of New South Wales and the Australasian Association for the Advancement of Science. He served for several years on the Councils of both these societies.

By 1882 Russell (1882a) could boast in his presidential address that the Royal Society of New South Wales had a membership of nearly 500. By the 1880s Sydney and Melbourne had become the centres of science in Australia. They provided the intellectual leadership in the sciences and there developed a close relationship between these centres and provincial centres by the development and spread of Mechanics' Schools of Arts and technical colleges in Sydney and country centres, such as Bathurst, Newcastle and Goulburn.

Russell was also a strong advocate of the publication in local journals of scientific work done in the colonies. He urged members of the Royal Society of New South Wales to publish their scientific work in the colony so that "we can secure ... for the Colony the credit of all its intellectual activity". (Russell 1882a). The Society's journal which had a subsidy from the New South Wales government, was distributed and exchanged widely with other scientific societies in the world with the "object of spreading knowledge" (Russell, 1882a). Russell, perhaps idealistically, likened the Society to the Smithsonian Institution in America which had been established for the "Increase and diffusion of knowledge among men". (Russell 1877a). For Russell the Society fullfilled a similar role.

Russell was involved in the popularisation of astronomy to the public and to students, particularly from the University of Sydney. Although the popular lectures were a source of distraction from his professional work, he was "more than pleased by the pleasure which visitors express". (Russell 1900). His lectures were illustrated with photographs of the night sky taken by Russell and members of his staff. The public were also given the opportunity to view the heavens through the telescope at the Observatory.

In 1892 Russell proposed the establishment of a "Leake School of Practical Astronomy" at the University of Tasmania in Hobart. (Russell 1892c). The funds were to come from the estate of Mr Leake who had left 1 000 pounds for the foundation of a School of Astronomy. Russell argued that the school should concentrate on astronomical photography because of the clear sky and favourable latitude of Hobart.

Russell was very active in the promotion of technical education in the colony. In 1883 the government decided to establish a state system of technical education in New South Wales. The management of the Technical College was transferred from the Committee of the School of Arts to a Board of representatives chosen from the officers of educational institutions and professional and trade societies. Russell was appointed to the Board of nineteen members and for two years performed the duties of acting president during the absence of the president. He was a strong advocate of technical education for improving the industrial knowledge of workmen by teaching the science and principles underlying their handicrafts. His desire to promote and encourage the development of technical skills in the colony led him to place orders with the local industry to build telescopes and other equipment for the Observatory.

Russell's keen interest in scientific and technical education led to his appointment in 1891 as the Vice-Chancellor of the University of Sydney. In 1912 a Henry Chamberlain Prize for astronomy was founded at the University of Sydney by a gift from Mrs H. C. Russell in memory of her husband. The annual prize is awarded for "an essay, a thesis or research report on an Astronomical subject written by a student enrolled for a degree within the University".

CONCLUSION

This paper illustrates Russell's role as an organiser of science and one of the major figures in 19th century science in Australia. His 35 year career as the director of Sydney Observatory, an important scientific institution in colonial Australia highlights some of the issues and strands in the development of science in a frontier society. He was both participant and leader in the intercolonial science movements which led to the formation of the Australasian Association for the Advancement of Science that marked the beginning of an independent scientific community. Russell as such represented a healthy tension between dependency and autonomy from the European centres of science. Both influences struggled creatively to furnish a rich tapestry for the making of science in Australia.

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REFERENCES

Abercromby, R. (ed), Russell, H. C. and Hunt, H. A., 1896. THREE ESSAYS ON AUSTRALIAN WEATHER. White. Sydney. 16pp.

Bassalla, G., 1967. The spread of western science. *Science*, **156**, 611 - 622.

Brazier, J., 1874. Descriptions of eleven species of terrestrial and marine shells from north-east Australia. *Transactions of the Royal Society of New South Wales*., 29 - 33.

Clerke, A. M., 1893. A POPULAR HISTORY OF ASTRONOMY DURING THE NINETEENTH CENTURY. Adam & Charles Black, Edinburgh. 468pp.

Day, A. A., 1966. The development of geophysics in Australia. *Journal and Proceedings of the Royal Society of New SouthWales*. **100**, 33 - 60.

Forgan, S., 1986. Context, image and function : A preliminary enquiry into the architecture of scientific societies. *British Journal for History of Science*. **19**, 89 - 98.

Gentilli, J., 1967. History of meteorological and climatogical studies in Australia. *University Studies in History*. **5** , 54 - 88.

Hector, J., 1891. Inaugural Address. *Report Australasian Association for the Advancement of Science*. **3**, 1 - 21.

Hoare, M. E., 1975. The intercolonial science movement in Australasia 1870-1890. *Records of the Australian Academy of Science*. **3** , 7 - 28.

Home, R. W. (ed)., 1988. AUSTRALIAN SCIENCE IN THE MAKING. Cambridge University Press. Melbourne. 413pp.

Inkster, I., 1985. Scientific enterprise and the colonial model : Observations on Australian experience in historical context. *Social Studies of Science*. **15**, 677 - 687.

Innes, R. T. A., 1892. Letter to John Tebbutt dated 17 January 1892. In Letters to John

Tebbutt. January - June, 1892. Mitchell Library, Sydney.

Lankford, J., 1984. The impact of photography on astronomy, in GENERAL HISTORY OF ASTRONOMY. VOL. 4. ASTROPHYSICS AND TWENTIETH CENTURY ASTRONOMY TO 1950, pp 16 - 39. O. Gingerich (Ed.). Cambridge University Press, Cambridge.

Latta, D., 1984. EARLY AUSTRALIAN ARCHITECTURE. Bay Books, Sydney. 43pp.

Macqueen, G., 1988. Personal communication.

MacLeod, R., 1982. On visiting the 'moving metropolis' : Reflections on the architecture of imperial science. *Historical Records of Australian Science*. **5**, 1 - 16.

MacLeod,R., 1988. THE COMMONWEALTH OF SCIENCE. Oxford University Press. Melbourne. 417pp.

Moyal, A. M., 1976. SCIENTISTS IN NINETEENTH CENTURY AUSTRALIA : A DOCUMENTARY HISTROY. Cassell Australia, Sydney. 280pp.

Moyal, A. M., 1986. A BRIGHT AND SAVAGE LAND : SCIENTISTS IN COLONIAL AUSTRALIA. Collins, Sydney. 192pp.

Orchiston, W., 1988. From research to recreation : The rise and fall of Sydney Observatory. *Vistas in Astronomy*. **32**, 49 - 55.

Pannekoek, A. , 1989. A HISTORY OF ASTRONOMY. Dover Publications, New York. 521 pp.

Pittman, E. F., 1914. THE GREAT AUSTRALIAN BASIN AND THE SOURCE OF ITS WATER. NSW Department of Mines, Sydney. 57pp.

Priestly, C. B., 1971. The global atmosphere : a memorial to H. C. Russell. *Search*, **2**, 273 - 278.

Royal Society of NSW., 1886. Minutes of the Monthly Meeting of the Council of the Royal Society of New South Wales dated 30 June 1886.

Russell, H. C., 1867. Letter to M. Gibson dated 29 July 1867. In Sydney Observatory Letterbook 1867 - August 1870. Archives Authority of NSW, Sydney.

Russell, H. C., 1870. Letter to John Tebbutt dated 12 November 1870. In Sydney Observatory Letterbook 1869 - 1874. Archives Authority of NSW, Sydney.

Russell, H. C., , 1871a. On the nebula around Eta Argus. *Transactions of the Royal Society of New South Wales*. 15-24.

Russell, H. C., 1871b. Letter to Secretary Royal Astronomical Society dated 29 December 1871. In Sydney Observatory Letterbook 1869 - 1874. Archives Authority of NSW, Sydney.

Russell, H. C., 1872a. Letter to the Principal Under Secretary dated 20 August 1872. In Sydney Observatory Letterbook 1869 - 1874. Archives Authority of NSW, Sydney.

Russell, H. C., 1872b. Letter to Astronomer Royal dated 25 March 1872. In Sydney Observatory Letterbook 1869 - 1874. Archives Authority of NSW, Sydney.

Russell, H. C., 1875a. Letter to Principal Under Secretary dated 22 November 1875. In Sydney Observatory Letterbook 1857 - 1889. Archives Authority of NSW, Sydney.

Russell, H. C., 1875b. Letter to Under Secretary for Justice and Public Administration dated 29 October 1875. In Sydney Observatory Letterbook 1857 - 1889. Archives Authority of NSW, Sydney.

Russell, H. C., 1875c. Letter to Under Secretary for Justice and Public Administration dated 25 November 1875. In Sydney Observatory Letterbook 1857 - 1889. Archives Authority of NSW, Sydney.

Russell, H. C., 1877a. Anniversary Address. *Journal and Proceedings of the Royal Society of New South Wales.* **11**, 1 - 20.

Russell, H. C., 1877b. CLIMATE OF NEW SOUTH WALES. Acting Government Printer, Sydney. 189pp.

Russell, H. C., 1878. On a new form of equatorial mounting. *Journal and Proceedings of the Royal Society of New South Wales.* **12**, 249 - 251.

Russell, H. C., 1879. The River Darling - the water which should pass through it. *Journal and Proceedings of the Royal Society of New South Wales.* **13**, 169 - 170.

Russell,H. C., 1880. Some new double stars and southern binaries. *Journal and Proceedings of the Royal Society of New South Wales.* **14**, 25 - 31.

Russell, H. C., 1881a. The spectrum and appearance of the recent comet. *Journal and Proceedings of the Royal Society of New South Wales.* **15**, 81 - 86.

Russell, H. C., 1881b. New double stars and measures of some of those found by Sir John Herschel. *Journal and Proceedings of the Royal Society of New South Wales.* **15**, 93 - 158.

Russell, H. C., 1881c. Transit of Mercury, November 8th, 1881. *Monthly Notices of the Royal Astronomical Society.* **15**, 159 - 173.

Russell, H. C., 1882a. Anniversary Address. *Journal and Proceedings of the Royal Society of New South Wales.* **16**, 1 - 30.

Russell, H. C., 1882b. RESULTS OF DOUBLE STAR MEASURES MADE AT SYDNEY OBSERVATORY. Government Printer, Sydney. 68pp.

Russell, H. C., 1883. List of double stars. *Journal and Proceedings of the Royal Society of New South Wales.* **17**, 123 - 128.

Russell, H. C., 1884. PHYSICAL GEOGRAPHY AND CLIMATE OF NEW SOUTH WALES. Government Printer. Sydney. 33pp.

Russell, H. C., 1885a. Anniversary Address. *Journal and Proceedings of the Royal Society of New South Wales.* **18**, 1 - 27.

Russell, H. C., 1885b. Local variations and vibrations of the Earth's surface. *Journal and Proceedings of the Royal Society of New South Wales.* **18**, 51 - 81.

Russell, H. C., 1888. Presidential Address. *Report of the Australasian Association for the Advancement of Science*, **1**, 1 - 21.

Russell, H. C., 1889a. Letter to Griffin, Esq. In Sydney Observatory Letterbook. 1857 - 1889. Archives Authority of NSW, Sydney.

Russell, H. C., 1889b. Letter to Under Secretary for Public Instruction dated 15 July 1889. Sydney Observatory Letterbook. 1887 - 1902. Archives Authority of NSW, Sydney.

Russell, H. C., 1889c. The source of underground water in the western districts. *Journal and Proceedings of the Royal Society of New South Wales.* **23**, 57 - 63.

Russell, H.C., 1890. PHOTOGRAPHS OF THE

MILKY WAY AND NEBECULAE AT SYDNEY OBSERVATORY IN 1890. Government Printer, Sydney. 15pp.

Russell, H. C., 1891. Preparations now being made in Sydney Observatory for the Photographic Chart of the Heavens. *Journal and Proceedings of the Royal Society of New South Wales*. **25**, 61 - 70.

Russell, H. C., 1892a. OBSERVATIONS OF THE TRANSIT OF VENUS, 9 DECEMBER 1874; MADE AT STATIONS IN NEW SOUTH WALES. Government Printer, Sydney. 43pp.

Russell, H. C., 1892b. DESCRIPTION OF THE STAR CAMERA AT THE SYDNEY OBSERVATORY. Government Printer. Sydney. 11pp.

Russell, H. C., 1892c. On the proposed Leake School of Practical Astronomy. *Papers and Proceedings of the Royal Society of Tasmania*, 26 - 32.

Russell, H. C., 1893a. Moving anticyclones in the Southern Hemisphere. *Quarterly Journal of the Royal Meteorological Society*. **19**, 23 - 30.

Russell, H. C., 1893b. The progress of astronomical photography. *Report of the Australasian Association for the Advancement of Science*. **5**, 70 - 96.

Russell, H.C., 1894. Recent measures of double stars made at Sydney. *Astron. Nachr.*, **135**, 418 - 423.

Russell, H. C., 1895. Design for a photographic transit circle. *Report of the Australasian Association for the Advancement of Science*. **6**, 211 - 215.

Russell, H. C., 1900. Letter to Under Secretary for Public Instruction dated February 7, 1900. In Sydney Observatory Letterbook 1899 - 1902. Archives Authority of NSW, Sydney.

Scott, W., 1859. SYDNEY OBSERVATORY REPORT. Government Printer, Sydney. 10pp.

Scott, W., 1871. In Minute Book Royal Society of New South Wales. July 1867 - May 1876. Archives of the Royal Society of New South Wales, Sydney.

SYDNEY INTERNATIONAL EXHIBITION 1879 : OFFICIAL RECORD. 1881. Government Printer. Sydney. 514pp.

Tebbutt, J., 1891. THE SYDNEY OBSERVATORY AND THE "SYDNEY MORNING HERALD" : A PLEA FOR ASTRONOMY IN NEW SOUTH WALES. Geo. Murray & Co., Ltd. Printers, Sydney. 4pp.

Todd, C., 1893. Meteorological work in Australia : a review. *Report Australasian Association for the Advancement of Science*. **5**, 254 - 258.

Turner, H. H., 1912. THE GREAT STAR MAP. BEING A GENERAL ACCOUNT OF THE INTERNATIONAL PROJECT KNOWN AS THE ASTROGRAPHIC CHART. Murray, London. 79pp.

Walsh, G. P., 1974. H. C. Russell : An Australian Man of Science in the Nineteenth Century. Lecture given to the Canberra and District Historical Society.

Walsh, G. P., 1976. Henry Chamberlain Russell, in AUSTRALIAN DICTIONARY OF BIOGRAPHY, **6**, 1851 - 1890, pp 74 - 75. Bede Nairn (Ed). Melbourne University Press, Melbourne..

Wood, H. 1958. Sydney Observatory : 1858 to 1958. Sydney Observatory Papers, **31**, 1 - 32.

Wood, H., 1983. Sydney Observatory 1858 to 1983. *Proceedings of the Astronomical Society of Australia*. **5**, 273 - 281.

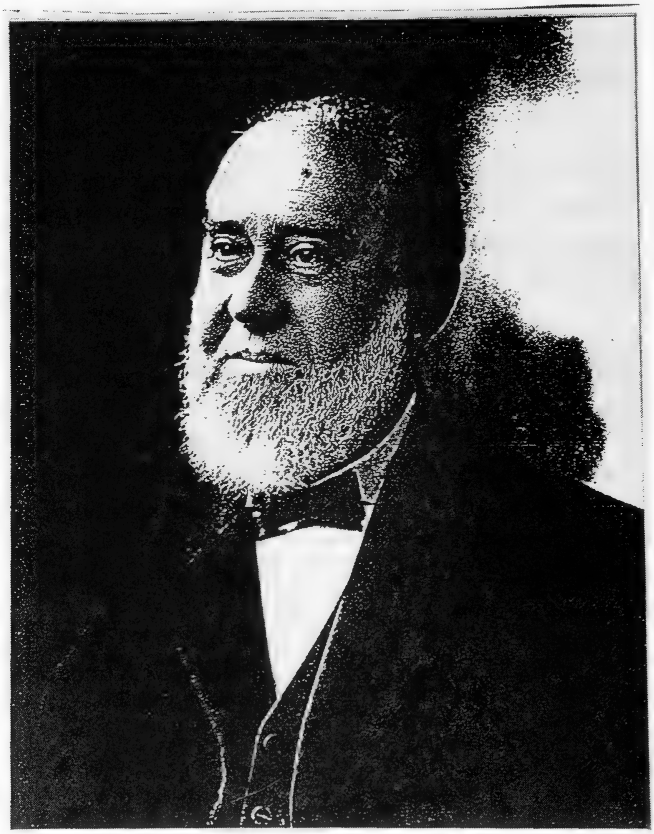

Figure 1. H.C.Russell - the third government astronomer of New South Wales.

Figure 2. Sydney Observatory in the 1870s.

Figure 3. The 11.5inches equatorial telescope at Sydney Observatory.

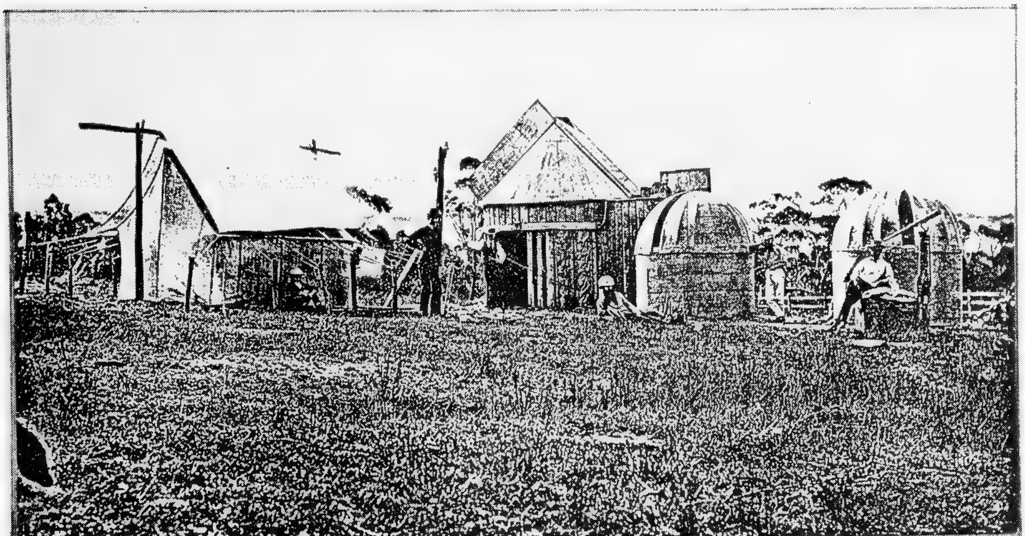

Figure 5. Waiting for the transit of Venus at Woodford.

Figure 4. Members of the 1874 transit of Venus expedition.

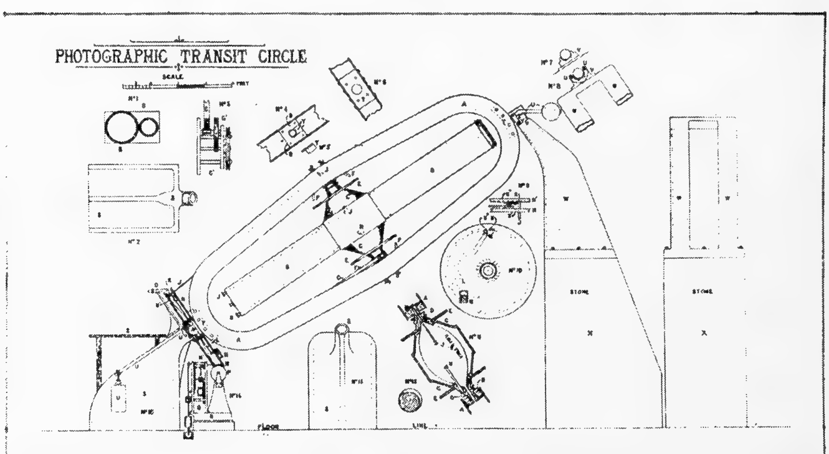

Figure 6. Drawing of the photographic transit circle designed by H.C.Russell.

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Figures 1,2, and 3:- From the Author's private collection of scientific photographs.

Figure 4:- From H.C. Russell:Observations of the transit of Venus, 9 December 1874; made at stations in New South Wales. Government Printer, Sydney. 1892.

Figure 5:- From H.C.Russell: Observations of the transit of Venus, 9 December 1874; made at stations in New South Wales. Government Printer, Sydney. 1892.

Figure 6: From H.C.Russell: Design for a photographic transit circle. Report of the *Australasian Association for the Advancement of Science, 6,* 211-215, 1895.

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Ilmenite-Mantled Rutile Crystals from the Uralla District, New South Wales

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and F. LIN SUTHERLAND

ABSTRACT. Ilmenite-mantled rutile crystals of enigmatic origin are found in Late Tertiary conglomeratic arkoses and Quaternary alluvium in the vicinity of Uralla, New South Wales. They comprise homogeneous, single, rutile crystal cores with ilmenite replacing the crystals and penetrating along (100) planes. The ilmenite ranges from higher TiO_2 adjacent to the rutile core to higher FeO at the outer edge. MgO decreases away from the core. This is consistent with reaction in a magma containing iron but poor in magnesium. The crystals are not associated with any obvious parent rock type. Comparisons of the chemistry of the ilmenites with a wide range of known ilmenite associations indicate that the source rock is unlikely to be mafic or ultramafic and that they are an unlikely to be an indicator for diamond source rocks. The minerals may have formed as late-stage or cavity crystallizations from fractionated felsic magmas before eruption.

INTRODUCTION AND AIM OF INVESTIGATION

Dense dull-black mantled crystals ranging from 0.5 to 4 cm in length are found in Rocky Creek, Kentucky Creek and the upper Rocky River drainages, west of Uralla (Fig. 1). Other heavy minerals found with them include zircon, spinel, tourmaline, corundum (rare) and diamond (rare) together with ironstone pisoliths.

The mantled crystals were briefly described by David (1886) as "Titaniferous Iron" and as comprising part of the heavy mineral assemblage found in Recent alluvium along with zircon, spinel and quartz. He also reported that "nodules of titaniferous iron are abundant at Wallaby Gully, where a pebble of that mineral has been found 2 inches in diameter" (GR 509108 9136-I-N Balala 1:25000).

These crystals are of interest because of their restricted occurrence and their physical resemblance to crystals found in kimberlite pipes (Mitchell, 1979).

GENERAL GEOLOGY

The study area (about 30 km^2, Fig. 1) is situated within the Palaeozoic New England Fold Belt (Leitch, 1974), in a region where the oldest country rocks are members of the Sandon and Dummy Creek associations. Palaeontological evidence suggests that the Sandon beds are of late Devonian to early Carboniferous age (Crook, 1958; Korsch, 1977) and plant fossils in the Dummy Creek associations at Tilbuster, north of Armidale N.S.W suggest a late Permian age (McKelvey and Gutsche, 1969; Korsch, 1977).

The Sandon Beds consist of greywackes, mudstones, minor cherts, jaspers, intermediate to basic volcanics, and rare limestones and conglomerates. All clastic components are turbidites of deep marine origin (Korsch, 1977). Incipient greenschist facies regional metamorphism is characteristic of these rocks, with some local thermal metamorphism around the Uralla Plutonic Suite to grades generally not higher than hornblende hornfels facies.

The Dummy Creek Association consists of shallow water marine to terrestrial deposits mainly of conglomerates, with minor sandstones and mudstones intimately associated with calc-alkaline acid volcanic rocks (tuffs, agglomerates and flows). The latter are thought to be co-magmatic with members of the Uralla Plutonic Suite of the New England batholith. Locally the rocks of the Dummy Creek association occur about 1-4 km southwest of the study area and are known as the "Why Worry" rocks. These rocks have not undergone regional metamorphism, but locally have been contact metamorphosed by surrounding granitoids to mostly hornblende hornfels grade.

Granitoid intrusions, making up part of the Uralla plutonic suite, are dominated by the Uralla granodiorite which forms the prevailing basement for the study area. The Uralla granodiorite is asymmetrically zoned with granodioritic margins, adamellitic cores and sporadic leucocratic schlieren (Flood, 1971). This pluton, along with other members of the Uralla plutonic suite, displays geochemical characteristics consistent with intermediate I-S-type granitoids (Shaw and Flood, 1981).

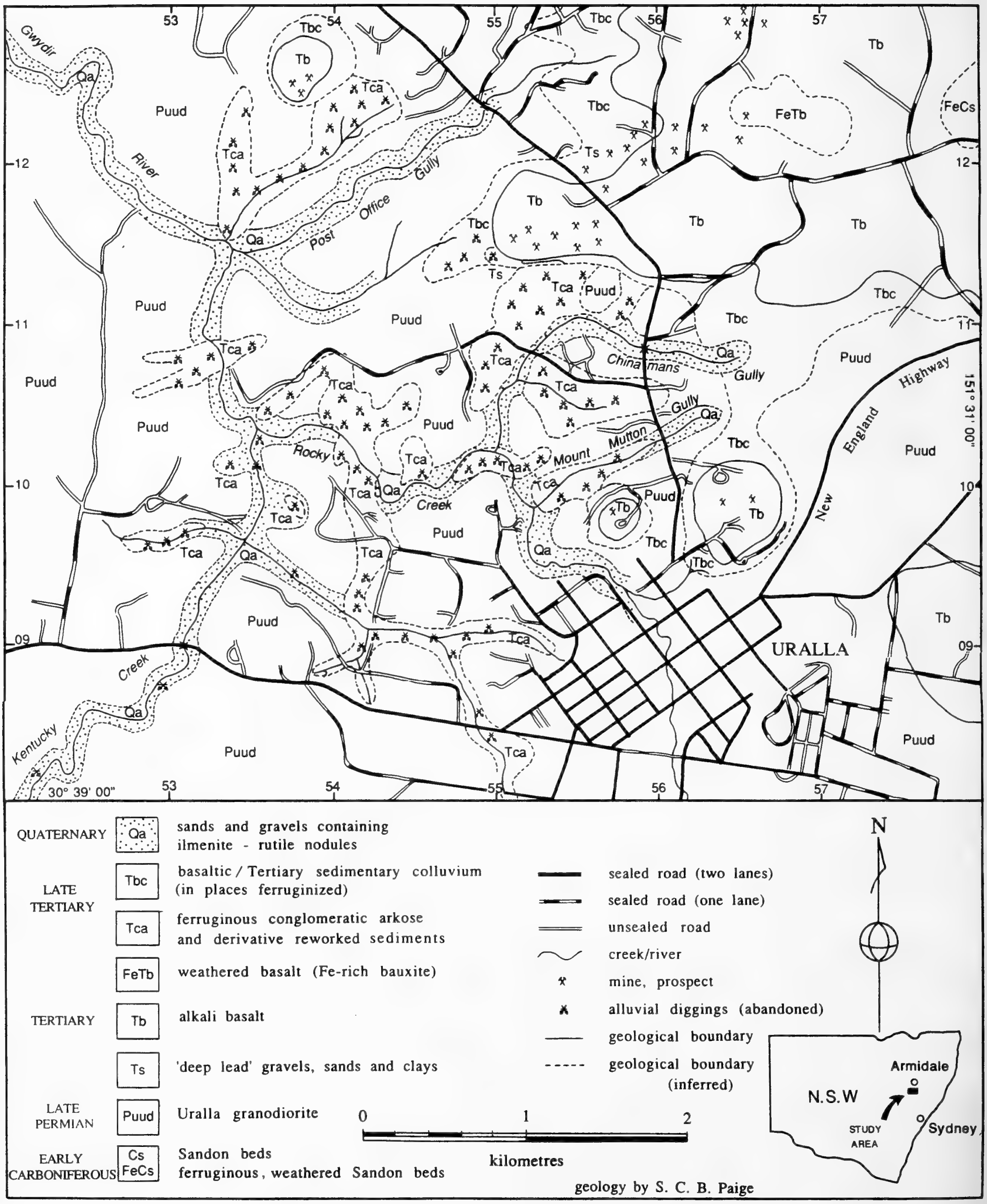

Figure 1. Geology of the Uralla district, New South Wales. The ilmenite mantled rutile crystals occur in late Tertiary ferruginous arkose (Tca) and Quaternary sands and gravels (Qa).

The basement is intruded by; quartz veins (<0.5 to 45 cm width), some containing pyrite, arsenopyrite, stibnite and occasional base metal (Pb, Cu, Zn) sulphides or boxwork replacement thereafter; pegmatite dykes and leucocratic segregations (1-5 cm thick), often containing grey/brown quartz, alkali feldspar and schorl (black) tourmaline; aplite dykes (up to 40 cm width) and occasional granophyre; basaltic dykes, sometimes occurring in swarms; lamprophyre dykes, mostly biotite lamprophyres and minettes (10 cm to 1.2 m thick). The plutons and intrusives are of probable late Permian age (Ransley,1970).

The Tertiary basalts in the northwestern and northeastern parts of the study area (Fig. 1) cap hills and form stepped areas of high topographic relief (1000 to 1100 m a.s.l.). They are mostly alkali-olivine basalts, with some more alkaline variants such as olivine nephelinites and range in age from about 21-32 Ma (Wellman and McDougall, 1974; McDougall and Wilkinson, 1967). In the northeast, the basalt is strongly weathered (FeTb on Fig.1), consisting of a hard, bright orange-red, iron-rich bauxitic material and, in part, covers semi-lithified and silicified Tertiary "deep lead" sediments. These sediments (Ts on Fig.1) were rich sources of alluvial gold and are composed mostly of quartzose sands and gravels ("hailstone wash") with lesser clayey/muddy strata containing, in places, abundant Tertiary (older than 40 Ma) floral remains. The "hailstone" gravels comprise well rounded to subangular quartz pebbles (0.5 to 3 cm in diameter) cemented together by ferruginous micaceous clay.

Weathering during the Tertiary and possibly early Quaternary periods resulted in the formation of ferruginous soil profiles developed upon all major lithologies in the area. Extensive fossil soil profiles, mostly characterized by poorly to well developed lateritic profiles, are commonly developed upon arkosic sediments. The arkose (Tca on Fig. 1) is commonly well stratified, with many conglomeratic bands and lenses, generally less than 20 cm thick, and with bedding concordant with the approximate slope angles of modern hillsides. The texturally and mineralogically immature arkosic sediment is composed mostly of weathered detritus from the Uralla granodiorite and sometimes resembles the *in situ* weathered granodiorite. Conglomeratic strata contain clasts, mostly angular, of local dyke and vein lithologies, many well-rounded silcrete pebbles and small boulders, some chert, red jasper and rare silicified wood. Basaltic clasts are common in those arkoses near to basalt capped hills or occurring downslope from a basalt cap. Laterite/ironstone crusts (duricrusts) are thickest (up to 1.5 m) and best developed in the immediate vicinity of basaltic outcrops which are sources of iron.

Alluvium in all modern drainages consists of the weathering and erosion products of all lithologies in the study area (Qa, on Fig. 1).

Heavy Mineral Associations

Within the study area, the specified heavy minerals occur, listed in decreasing order of abundance, in the following settings:

1. Tertiary "Deep Lead" Sediments (Ts, Fig. 1).
   Pleonaste; schorl tourmaline; clear/pale-pink/straw zircons (well rounded to sub rounded); rutile rods and blades; sapphire.

2. Tertiary Arkoses (Tca, Fig. 1).
   Ilmenite-rutile crystals (concentrated within the conglomerate bands by virtue of their density and occurring mostly as broken fragments, sometimes in profuse abundance); dark red to orange zircons; pleonaste from basalts; limonite pisoliths; Tertiary sedimentary heavy minerals (reworked); occasional sapphire (up to 7 mm) and very rare green zircons.

3. Quaternary Alluvium (Qa, Fig 1).
   Limonite pisoliths; ilmenite-rutile crystals (profusely abundant in gravel where concentration of heavy components is high); red zircons (equal in abundance with ilmenite-rutile crystals), pleonaste, all above listed heavy minerals (from Tertiary sediments and arkoses), and rare diamonds (mostly too small to be recognized in concentrates and therefore possibly more common than realized).

The ilmenite-rutile crystals are not known to occur in basaltic soils, Tertiary "deep lead" sediments nor in granodiorite, lamprophyre, pegmatites, aplites etc. Their source is therefore problematic.

DESCRIPTION OF THE ILMENITE-RUTILE CRYSTALS.

The Ilmenite-rutile crystals (Fig. 2) are stumpy to cylindrical in shape and are always rounded. A core of rutile is exposed below the mantle of ilmenite if the specimen has been broken or is cut and in thin slices the rutile is a deep translucent red.

Four crystals were selected for detailed study. Polished blocks were prepared for electron microprobe analysis and thin sections were cut parallel, and perpendicular, to the long axis of the cylinder, (photomicrographs shown in Fig. 3). Uniform extinction parallel to the long axis of the cylinder (Fig. 3d),

Figure 2. Ilmenite mantled rutile crystals from the Rocky River Goldfield near Uralla. These specimens range in size from 0.5 to 4 cm. Australian Museum mineralogy collection registration number D48733; collector S.C.B. Paige. (Photograph by S. Ranson).

indicates that the rutile cores are single tetragonal crystals with the c-axis parallel to the direction of elongation of the cylinder. In reflected light the ilmenite mantle comprises a number of subgrains. Fig. 3c shows the interface between the rutile core and ilmenite mantle. at which blades of ilmenite interlock with those of rutile thereby creating a large surface area of contact. The ilmenite appears to be replacing the rutile crystals and its planes of penetration appear to be controlled by the crystal structure of the rutile. The planes are exactly 90° apart and are penetrating at right angles to the prism faces, that is, in the {100} direction. Also apparent in Fig. 3c are the good {110} cleavage planes which are free of ilmenite replacement, so possibly opened during the thin sectioning procedure. In Fig. 3d the dark ilmenite blades are parallel to the c-axis of the rutile crystal, confirming replacement along the {100} planes.

Electron Microprobe Results

Analyses were performed on the polished sections (cut normal to the c-axis) along transect lines at intervals approximately 1 mm apart. Initially the full spectrum of each representative mineral was examined using Macquarie University's Link 1000 Energy Dispersive Analytical System and analyses of the elements detected were carried out using the Siemens wavelength dispersive system.

Four analyses near each desired location were averaged for plotting, and the bars in Fig. 4 indicate the calculated standard deviations.

The rutile cores contain 0.34 to 0.44% $FeO_{(total)}$, but there is no discernable variation in FeO across individual cores.

The variation in ilmenite compositions are 50.5-55.7% TiO_2, 40.3-45.0% FeO, 1.9-3.0% MnO and 0.3-1.4% MgO. In individual samples TiO_2 increases and FeO decreases, by about 1% from the outside to the inside of the rim. Mn shows no variation. In some ilmenite rims MgO increases towards the core, with the highest values recorded within the ilmenite replacement blades within the rutile core (1.4%, not shown on Fig. 4).

A detailed transect of 11 data points, 0.3mm apart, was made across one section of the ilmenite rim in grain 3 (Fig. 4). The overall fall in TiO_2 and a rise in FeO from the rutile-ilmenite contact to the outer edge is neither smooth nor gradational, but the changes between successive points generally lie within the error bars.

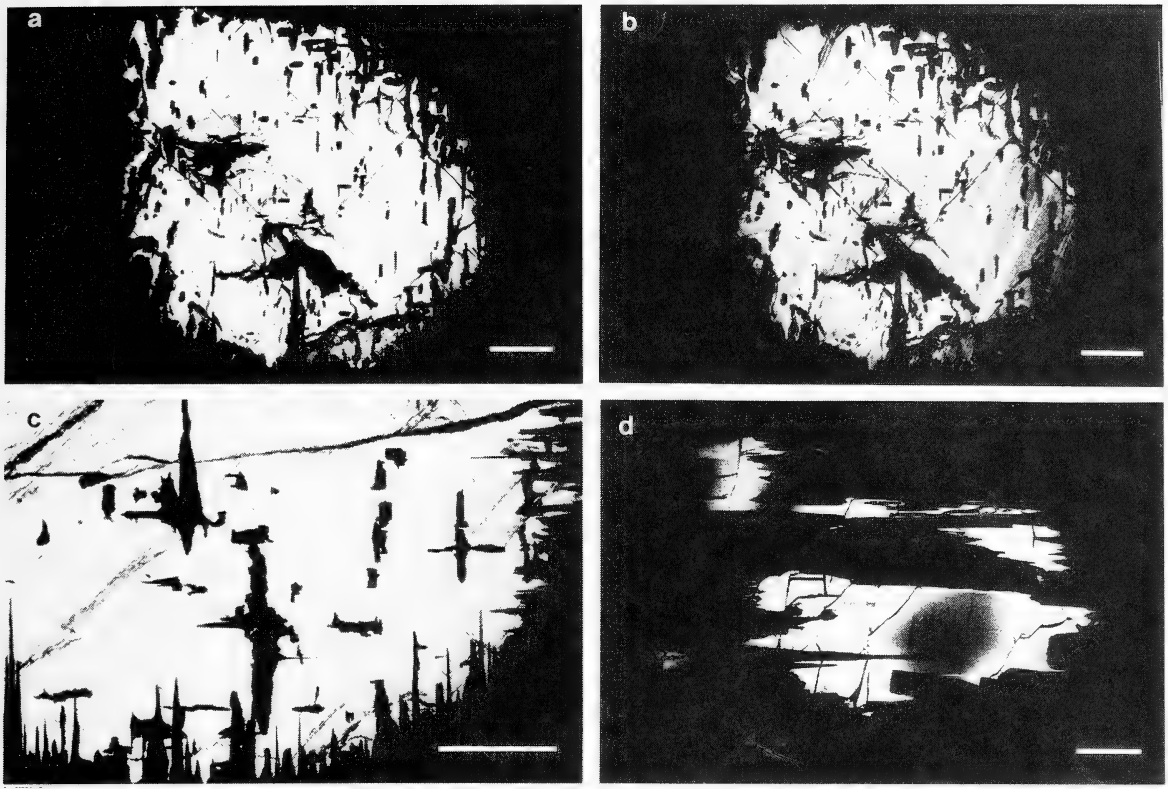

Figure 3 Transmitted light photomicrographs of sections cut through ilmenite mantled rutile crystals: a) Normal to the c-axis. Interlocking blades indicate replacement of rutile by ilmenite along the {100} direction of rutile crystal. Orthogonal {110} cleavages post date the ilmenite replacement; b) Same section as photo a, with crossed-polars, zoning or twinning is visible in the rutile; c) Normal to the c-axis, clearly visible is the ilmenite replacement along two orthogonal planes and the cleavage postdating the replacement; d) Parallel to the c-axis. Uniform extinction indicates that the rutile is a single crystal; replacement by ilmenite occurs parallel to {100}. The scale bar on all photos is 1 mm.

COMPARISONS WITH ILMENITE - RUTILE CRYSTALS AND ILMENITE FOUND ELSEWHERE

The main elemental oxide contents of the Uralla ilmenite relative to published ilmenite compositions from many different rock associations is presented in Table 1 and summarized in Fig. 5. This highlights their somewhat unusual composition and helps to suggest potential sources.

Discrete crystals of rutile commonly mantled by magnesian ilmenite are found in heavy mineral concentrates from some kimberlites, such as at Somerset Island, Canada (Mitchell, 1979). The rutile is homogeneous but the ilmenite may be compositionally zoned with increased Mg, Cr and Mn towards the edges. Dawson (1980) proposed that fragmented eclogite xenoliths are the probable source of the rutiles prior to their mantling with kimberlitic ilmenite. Samples from the Wesselton Pipe, South Africa (Mitchell, 1973) show that the ilmenite is a replacement of the rutile. Kimberlitic ilmenites are well known for high MgO, (see Table 1E), with enrichment towards the edges because of magmatic reaction with the more magnesian kimberlitic melt.

The Uralla rutiles, unlike cores of rutile in kimberlite, show reaction relationships with a magma rich in Fe but poor in Mg. Rutiles with replacement rims of ilmenite occur in granulitic xenoliths from Australian basalts but these ilmenite rims are also more magnesium-rich. The Uralla ilmenites again differ from ilmenite in the adjacent Central Volcanic Province and from uncored kimberlitic ilmenites, being significantly higher in MnO, lower in MgO and having no Cr_2O_3.

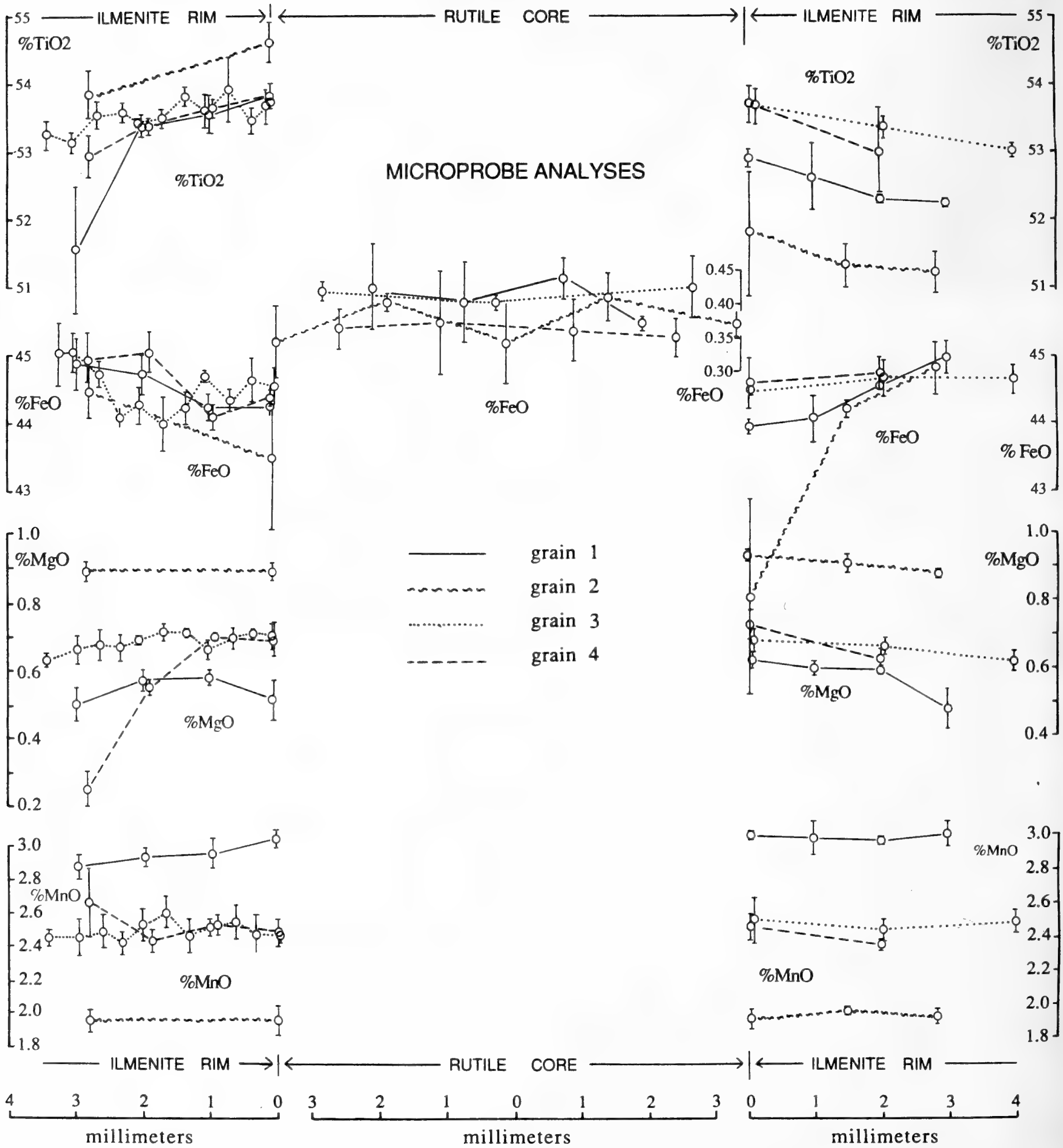

Figure 4. Summary of electron microprobe results along transects across four ilmenite mantled rutile crystals cut perpendicular to the c-axis. For each transect, the edge data points in the rutile core are immediately adjacent to the inside data points taken in the ilmenite mantle. Each point represents the average of four analyses and the error bar indicates the standard deviation.

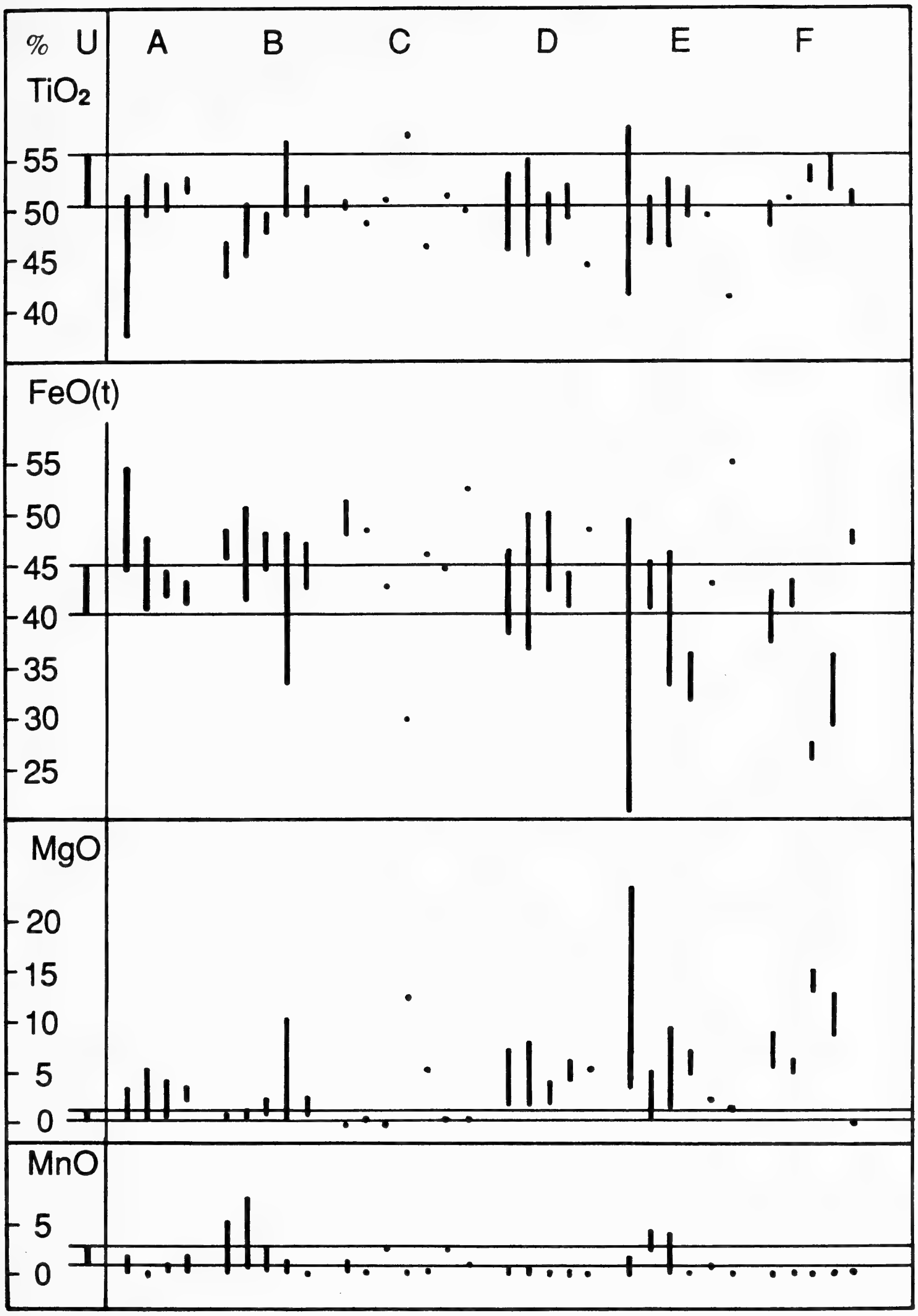

Figure 5. Summary of the main elemental oxide ranges in the Uralla ilmenite compared to those in literature sources (from Table 1). The order of associations follow those as listed under the main categories in the Table (A-F). The Uralla ilmenite is designated U and the limits for each elemental oxide are carried through to show bands of intersection with the other ranges.

TABLE 1: COMPARATIVE ILMENITE ANALYSES

A. URALLA SITE & EXTRUSIVES (groundmass/late stage crystallizations)

Suite & Analysis	mantles on rutile, Uralla[1]	silicic/salic volcanics[2,3]	alkali basalts S. Highlands N.S.W[4]	coarse phases of leucitites, Aust[5,6]	cavity fillings, basalts, Aust[7,8]
TiO2	50.47-55.71	37.60-51.60	49.40-53.60	50.04-52.40	51.94-53.04
FeO total	40.26-45.02	44.20-54.70	40.50-47.80	42.00-44.77	41.18-43.26
MnO	1.09-3.02	0.46-2.17		0.64-1.02	0.61-2.04
MgO	0.25-1.35	0.10-3.79	0.12-5.52	0.83-4.10	2.26-3.72
Al2O3	0.00	0.00-0.36		0.05-1.00	0.00-0.19
Cr2O3	0.00	0.00-0.21	0.00-015	0.00-0.06	0.00-0.04
CaO	0.00	0.00-0.06	0.00-0.88	0.00-0.19	0.00-0.10
SiO2			0.00-0.83	0.03-0.32	0.00-0.64
V2O3		0.00-1.80			

B. UPPER CRUSTAL INTRUSIONS

Suite & Analyses	granites & pegmatites[9]	syenites-foyaites[10]	gabbros-troctolites[11,12]	high Mg-tholeiite complex, S.Africa[13]	ultramafic-mafic complex[14]
TiO2	43.25-46.38	45.43-50.85	47.92-49.71	49.52-56.98	49.90-52.20
FeO total	45.54-48.52	41.38-50.87	44.73-48.52	33.19-48.11	42.79-47.19
MnO	0.30-5.63	0.70-7.80	0.85-2.88	0.40-1.35	0.05-0.10
MgO	0.03-1.10	0.05-1.60	1.00-2.50	0.28-10.22	0.09-2.90
Al2O3	0.55-1.70	0.00-1.06	0.03-088		0.10-0.30
Cr2O3	0.00-0.20	0.00-0.01	0.00-0.12	0.04-1.08	0.00
CaO	0.02-1.15	0.01-0.06	0.00		0.05-0.13
SiO2	0.10-1.49	0.19-0.28	0.00-0.08		0.20-0.70
V2O3	0.00-0.10	0.00-0.12	0.00-0.07		0.01-0.05

C. METAMORPHIC SUITES

Suite & Analyses	nodules(+rutile) greenstones W.A.[15]	granulite India[16]	biotite rock (+rutile)[17]	rim on rutile granulite, Tas.[18]	rim on rutile gnt granulite Qld[19]	gnt quartz granulite W.A.[20]	medium grade greenstone W.A.[21]
TiO2	50.13-50.20	48.90	51.03	57.64	46.30	51.57	52.00
FeO tot.	48.04-51.60	48.45	43.14	29.89	46.14	44.96	44.00
MnO	0.54-1.49	0.35	2.90	0.31	0.53	2.91	3.00
MgO	0.00-trace	0.56	0.08	12.34	5.34	0.34	<0.12
Al2O3		0.54		0.59	0.91		
Cr2O3				0.52	0.13		
CaO		0.65		0.19	0.28	0.06	
SiO2	0.00-0.95	0.11	0.19			0.07	
V2O3							

D. MEGACRYST SUITES; BASALTIC ROCKS

Suite & Analyses	alluvial grains Braemar, NSW[22]	alluvial grains Yarrow Riv.NSW[23]	alkali basalts S.E.Queensland[24]	alkali basalts Nebo Queensland[25]	lamprophyre Mt.Woolooma NSW[26]
TiO2	45.96-53.64	45.17-55.40	46.77-51.50	49.54-52.56	44.47
FeO total	38.41-46.36	36.98-50.06	42.69-50.39	41.11-44.32	48.61
MnO	0.21-0.86	0.16-0.70	0.14-0.45	0.24-0.49	0.15
MgO	1.90-7.41	1.99-8.25	2.04-4.24	4.21-6.17	5.32
Al2O3	0.14-1.67	0.04-1.99	0.21-0.84	0.21-0.51	1.53
Cr2O3	0.00-0.03	0.00-0.08		0.00-0.13	
CaO	0.00-0.10	0.00-0.06	0.00-0.02	0.00-0.15	0.23
SiO2	0.00-0.09	0.00-0.12	0.00-0.02		0.68

E. MEGACRYST SUITES; KIMBERLITES, CARBONATITES, ALNOITES, LAMPROITES

Suite & Analyses	kimberlites global[27,28]	carbonatites global[29]	kimberlitic rocks W.Australia[30]	alnoites malaita[31]	lamproite Zambia[32]	kimberlitic nodule[33]
TiO2	41.40-58.45	46.90-51.85	46.35-53.59	49.20-52.10	49.74	41.48
FeOtotal	20.64-49.64	41.80-45.59	33.20-46.29	31.90-35.80	43.34	55.05
MnO	0.00-1.99	2.60-4.59	0.17-4.34	0.17-0.24	1.02	0.07
MgO	3.90-23.10	0.10-5.10	1.28-9.54	5.23-7.13	2.37	1.60
Al2O3	0.03-0.84	0.00-0.07	0.19-0.83	0.17-0.83	0.02	0.32
Cr2O3	0.02-3.37	0.00-0.28	0.23-0.79	0.02-0.03	0.15	0.14
CaO	0.00-0.30	0.00-0.13			0.17	
SiO2	0.00-0.05		0.00-0.35			
NiO	0.04-0.30				0.05	

F. MANTLE INCLUSIONS

Suite & Analyses	gnt pyroxenites Brigooda, Qld[34]	apatite-rich rock East.Aust[35]	pyroxenites Lesotho[36]	in diamond Africa-USSR[37]	in diamond Brazil[37]
TiO2	48.67-50.89	51.00-51.20	53.10-54.60	52.10-55.60	50.50-51.90
FeO total	37.60-42.56	41.00-42.70	26.10-27.80	29.50-36.50	47.40-48.20
MnO	0.00-0.27	0.57-0.76	0.22-0.48	0.27-0.30	0.64-0.68
MgO	6.17-9.15	5.59-6.20	13.49-15.04	9.10-13.00	0.11-0.14
Al2O3	1.33-1.78	0.20-0.31	0.70-1.16	0.22-0.78	0.21-0.36
Cr2O3	0.00-0.03		2.17-2.83	0.01-2.50	0.01-0.04
CaO	0.00-0.06	0.07-0.20	trace	0.00-0.04	0.01-0.07
SiO2	0.30-0.36	0.03-0.10	0.14-0.17	0.01-0.04	0.12-0.16
NiO			0.12-0.19	0.00-0.30	

Comments Table 1.
1 This paper. 2 Carmichael (1967, p.140-2, Tab.2-4, analy.1-29). 3 Haggerty (1976, p.Hg258, analy.9-18). 4 Wass (1973, p.430, table III, analy.1-17; p.434, Tab.IV). 5 Cundari (1973, p.478, Tab.VI, analy. BQ-PEGM, BEH-C, BEH-D). 6 Birch (1979, p.379, Tab.6, analy.CLOG-44, CLOG-45, CLOF-53). 7 Birch et al. (1982). 8 F.L.Sutherland & D.F.Hendry, unpublished data. 9 Haggerty (1976, p.Hg258 & 260, analy.1, 3-4, 6-8, 45). 10 Haggerty (1976, p.Hg259, analy.21-27). 11 Deer et al (1975, p.29, table 5, analy.3-4). 12 Haggerty (1976, p.Hg260, analy.41-44, 46-47). 13 Cawthorne et al. (1988, p.149, Tab.1A, 21/1-15, 16/1-10, NGL/9,11, 54, 56, 62, 110). 14 Haggerty (1976, p.Hg260, analy.48-54). 15 Simpson (1951, p.651, Tab.33, analy.1-6). 16 Deer et al. (1975, p.29, Tab.5, analy.5). 17 Rumble (1976, p.R4, table R2, analy.1). 18 This paper. 19 Sutherland (1980, v.2, Tab.6e, analy.1D). 20 Jaques et al. (1989, p.133, Tab.7.6, analy.7), 21 Cassidy et al. (1988, p.1055, Tab.3, analy.1) 22 Coenraads (1990, p.1205, Fig.19, 55 analy.). 23 Coenraads (1990, p.1205, Fig.19, 45 analy.). 24 Hollis et al. (1983, p.191, analy. Bal.149, Nan.II, Mt.Mit). 25 Sutherland (1980, v.2, Tab.5g, analy.1-7). 26 Jaques & Perkin (1984, p.35, analy.5). 27 Haggerty (1976, analy.1-15). 28 Dawson (1980, Tab.11, p.78, 302 analy.). 29 Haggerty (1976, p.Hg258, analy.13,15-18). 30 Atkinson et al. (1984, p.208, Tabs.1&2, 6 analy.). 31 Neal & Davidson (1989, p.1980, Tab.5, 12 analy.). 32 Scott Smith et al. (1989, p.196-7, Tab.11.3, analy.P6/2). 33 Clarke & MacKay (1990, p.231, Tab.1). 34 F.L.Sutherland, A.D.Robertson & J.D.Hollis unpublished data. 35 Wass et al. (1980, p.338-9, Tab.1, analy.K41, K3, K13A1). 36 Harte et al. (1987, pp.187-188, Tabs.3&4, 4 analy.). 37 Moore (1987, p.248, Tab.1, 3 analy.). Oxides are in weight percent. For comparison purposes all iron is presented as FeO and oxides are listed in decreasing order of abundance for the Uralla samples.

In general there is too much MnO and/or too little MgO in the Uralla ilmenites to match typical ilmenites in alkali basalts, high Mg-tholeiite and mafic-ultramafic suites, including highly undersaturated melts from deep sources such as kimberlites, carbonatites, picritic monchiquites, alnoites and lamproites, or those in mantle xenoliths and xenocrysts. A rare exception is ilmenite inclusions in diamonds from Brazil, though low Mg ilmenites are not found in most other diamond suites. The contrast in size is a marked point of difference between the Brazilian and Uralla ilmenites which makes a related source unlikely. Ilmenite attributed to immiscibility processes in kimberlite melts at crustal levels (Clarke and MacKay, 1990) also differs from the Uralla compositions.

Uralla ilmenites are more akin to those found in salic igneous rocks. Comparison of their compositions with those of silicic volcanics show only a partial overlap as the latter are mostly lower in TiO_2 and higher in FeO. Ilmenites from the intrusive equivalents, granites and pegmatites are distinctly lower in TiO_2, and those from less silicic intrusions (syenite-monzonite-diorite-foyaite) barely overlap the Uralla range.

Metamorphic rocks rarely have ilmenite with compositions within the Uralla range. Of the samples known, one is a crustal xenolith of ilmenite-garnet-amphibole-plagioclase-quartz granulite from Western Australia and the other, also a crustal xenolith, comes from low grade metamorphism of mafic-ultramafic rocks. However the latter is not typical of the great majority of ilmenites found in various grades of metamorphism of these rocks (Cassidy et al, 1988).

Low MgO in the Uralla ilmenite might suggest a relatively low pressure origin, as most high pressure ilmenites show high MgO contents. However, the amount of Mg entering the mineral is regarded more as a function of melt composition rather than a reflection of a depth or pressure effect (Haggerty, 1976).

CONCLUSIONS

The source of the ilmenite mantled rutile crystals has not yet been identified. Their rounded appearance is interpreted to be due to magmatic corrosion with only minor modification due to transport. The crystals are found, concentrated by virtue of their size and weight, within conglomerate bands in arkoses of possible late Tertiary to Quarternary age (Fig. 1). They also occur in high concentration in modern streams draining the arkoses, but are fragmented within a short distance downstream. All this implies a proximal source.

Areas of high concentration of particular heavy minerals, such as zircon, do not always correspond directly to areas of high ilmenite-rutile crystal concentration.

No metamorphic rocks (Sandon Beds and Dummy Creek Group) exist in the areas of highest concentration of the crystals so are unlikely to be the original source. Panned concentrates of numerous samples of sub-basaltic Tertiary gravels, chiefly from mullock heaps around shafts and from rare outcrops, contained no ilmenite-rutile crystals. Panned soil samples from around basalt outcrops produced no crystals and none were seen in hand-specimens of a wide variety of basalts from numerous locations around Uralla.

The chemical comparisons, discussed above, also indicate that the source rock is unlikely to be mafic or ultramafic in composition. Owing to the restricted distribution of the crystals, it is probable that the host rock also had a restricted outcrop area, thus excluding the Uralla granodiorite, and it must be local because of the immaturity of the arkoses and the inability of the crystals to withstand fluvial transportation. Possibly the host rock was easily weathered and hence difficult to recognize, or has been covered by younger deposits.

Comparison of the main elemental oxide contents of the Uralla ilmenite relative to ilmenite compositions in the literature helps to suggest potential sources. The Uralla TiO_2, $FeO_{(total)}$, MgO and MnO contents only intersect four of the thirty two ranges listed from the literature (salic volcanics, syenites-foyaites, coarse phase leucitites and a quartz granulite xenolith).

One possible source is a magmatic precipitate from a magnesium poor, iron and titanium enriched melt. If there is a link with the abundant near-source zircon crystals in the district, then these minerals could represent late-stage or cavity crystallizations from fractionated felsic magmas in subvolcanic chambers or conduits before eruption. This would be compatible with ilmenite compositions overlapping those of salic volcanics. Zircons from the Rocky River give mid to late-Tertiary ages of formation and eruption (red to orange crystals, 27 to 3 Ma; F.L. Sutherland and P.D. Kinny, unpubl. data). This relates these zircons to the Tertiary volcanic activity in the area. Such an association for these minerals could account for their apparent absence from the sub-basaltic Tertiary sediments.

Another possible source may be a course grained metamorphic or vein rock related to the obscured Uralla Granodiorite contact in the area. The least likely association is as an indicator for diamond source rocks.

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REFERENCES

Atkinson, W.J., Hughes, F.E. and Smith, C.B., 1984. A review of the Kimberlitic rocks of Western Australia, *in* KIMBERLITES L. KIMBERLITES AND RELATED ROCKS. Developments in Petrology, 11A, pp. 195-224. J. Kornprobst (Ed.). Elsevier, Amsterdam.

Birch, W.D., 1979. Mineralogy and Geochemistry of the leucitite at Cosgrove, Victoria. *Journal of the Geological Society Of Australia, 25,* 369-385.

Birch, W.D., Smith, N. and Hately, J., 1982. Andesine, augite and ilmenite in vesicles in an alkali olivine basalt from Portland, Victoria. *Australian Mineralogist, 37,* 195-198.

Carmichael, I.S.E., 1967. The iron titanium oxides of salic volcanic rocks and their associated ferromagnesian silicates. *Contributions to Mineralogy and Petrology, 14,* 36-64.

Cassidy, K.F., Groves, D.I. and Binns, R.A., 1988. Manganoan ilmenite formed during regional metamorphism of Archaean mafic and ultramafic rocks. *Canadian Mineralogist, 26,* 999-1012.

Cawthorne, R.G., Maske, S., de Wet, M., Groves, D.I. and Cassidy, K.F., 1988. Contrasting magma types in the Mount Ayliff (Insizwa complex), Transkei: evidence from ilmenite compositions. *Canadian Mineralogist, 26,* 145-160.

Clarke, D.B. and MacKay, R.M., 1990. An ilmenite-garnet-clinopyroxene nodule from Matsoku: Evidence for oxide-rich liquid immiscibility in kimberlites? *Canadian Mineralogist, 28,* 229-239.

Coenraads, R.R., 1990. Key areas for alluvial diamond and sapphire exploration in the New England Gem Fields, New South Wales, Australia. *Economic Geology, 85,* 1186-1207.

Crook, K.A.W., 1958. Note on the occurrence of a Carboniferous plant near Armidale, N.S.W. *Australian Journal of Science, 20,* 216.

Cundari, A., 1973. Petrology of the leucite bearing lavas in New South Wales. *Journal of the Geological Society of Australia, 20,* 465-492.

David, T.W.E., 1886. Report on the geology of the Rocky River goldfields. New South Wales Department of Mines Annual Report for 1885, pp. 153-158.

Dawson, J.B., 1980. KIMBERLITES AND THEIR XENOLITHS (Minerals and Rocks; 15). Springer-Verlag, Berlin. J.B. Dawson (Ed.).

Deer, W.A., Howie, R.A. and Zussman, J., 1975. ROCK-FORMING MINERALS 5. NON-SILICATES, Longmans Green and Co., London. W.A. Deer, R.A. Howie and J. Zussman (Eds.).

Flood, R.H., 1971. A study of part of the New England Batholith, New South Wales. *Ph.D. thesis, University of New England, Armidale, N.S.W.* (Unpubl.).

Haggerty, S.E., 1976. Opaque mineral oxides in terrestrial igneous rocks, *in* OXIDE MINERALS. REVIEWS IN MINERALOGY 3, pp. Hg-101 to Hg-300. P.H. Ribbe and D. Rumble III (Eds.). Mineralogical Society of America, Washington. D.C..

Harte, B., Winterburn, P.A. and Gurney, J.J., 1987. Metasomatic and enrichment phenomena in garnet peridotite facies mantle xenoliths from the Matsoku kimberlite pipe, Lesotho, *in* MANTLE METASOMATISM, pp.145-220. M.A. Menzies and C.J. Hawkesworth (Eds.). Academic Press Inc., London.

Hollis, J.D.., Sutherland, F.L. and Pogson, R.E., 1983. High pressure minerals and the origin of the Tertiary Breccia pipe, Ballogie Gem Mine, near Proston, Queensland. *Records of the Australian Museum, 35,* 181-194.

Jaques, A.L., Kerr, I.D., Lucas, H., Sun, S.S. and Chappel, B.W., 1989. Mineralogy and petrology of picritic monchiquites from Wandagee, Carnarvon Basin, western Australia, *in* KIMBERLITES AND RELATED ROCKS 1, pp. 120-139. I.J. Ross (Ed.). Geological Society of Australia, Special Publication, 14.

Jaques, A.L. and Perkin, D.J., 1984. A mica, pyroxene, ilmenite megacryst-bearing lamprophyre from Mt Woolooma, north eastern New South Wales. *Bureau of Mineral Resources Journal of Australian Geology and Geophysics, 9,* 33-40.

Korsch, R.J., 1977. A framework for the Palaeozoic geology of the southern part of the New England Geosyncline. *Journal of the Geological Society of Australia, 24,* 339-355.

Leitch, E.C., 1974. The geological development of the southern part of the New England Fold Belt. *Journal of the Geological Society of Australia, 21,* 133-156.

McDougall, I. and Wilkinson, J.F.G., 1967. Potassium-argon dates on some Cainozoic volcanic rocks from northeastern New South Wales. *Journal of the Geological Society of Australia, 14*(2), 225-233.

McKelvey, B.C. and Gutsche, H.W., 1969. The geology of some Permian sequences on the New England tablelands, New South Wales. *Geological Society of Australia, Special Publications, 2,* 13-20.

Mitchell, R.H., 1973. Magnesian ilmenite and its role in kimberlite petrogenesis. *Journal of Geology, 81,* 301-311.

Mitchell, R.H., 1979. Mineralogy of the Tunraq kimberlite, Somerset Island, N.W.T. Canada. *Proceedings of the Second International Kimberlite Conference.* Volume1: The Mantle Sample: Inclusions, *in* KIMBERLITES AND OTHER VOLCANICS. F.R. Boyd Jr and H.O.A. Meyer (Eds.). American Geophysical Union, Washington D.C.

Moore, A.E., 1987. A model for the origin of ilmenite in kimberlite and diamond: implications for the genesis of the discrete nodule (megacryst) suite. *Contributions to Mineralogy and Petrology, 95,* 245-253.

Neal, C.R. and Davidson, P., 1989. An unmetasomatized source for the Malaitan alnoite (Solomon Islands): Petrogenesis involving zone refining, megacryst fractionation and assimilation of oceanic lithosphere. *Geochemica et Cosmochimica Acta, 53,* 1975-1990.

Ransley, J.E., 1970. The petrology of the New England Batholith in the Yarrowyck-Balala-Uralla area, northeastern New South Wales. *M.Sc. thesis. University of New England, Armidale, N.S.W.* (Unpubl.).

Rumble, D., 1976. Oxide minerals in metamorphic rocks, *in* OXIDE MINERALS. REVIEWS IN MINERALOGY 3, pp. R1-R24. P.H. Ribbe and D.Rumble III (Eds.). Mineralogical Society of America, Washington D.C..

Scott Smith, B.H., Skinner, E.M.W. and Loney, P.E., 1989. The Kapamba lamproites of the Luangwa Valley, Eastern Zambia. *in* KIMBERLITES AND RELATED ROCKS I, pp. 189-205. J. Ross (Ed.). Geological Society of Australia Special Publication, 14.

Shaw, S.E., and Flood, R.H., 1981. The New England Batholith, eastern Australia. Geochemical variations in time and space. *Journal of Geophysical Research, 86,* 10530-10544.

Simpson, E.S., 1951. Minerals of Western Australia 2. Government Printer, Perth, Western Australia.

Sutherland, F.L., 1980. The Geology and Petrology of some Tertiary Volcanic Rocks in the Bowen-St.Lawerence Hinterland. *PhD. Thesis, James Cook University of North Queensland, Townsville.* (Unpubl.).

Wass, S.Y., 1973. Oxides of low pressure origin from alkali basaltic rocks, Southern Highlands, N.S.W., and their bearing on the petrogenesis of alkali basalt magmas. *Journal of the Geological Society of Australia., 20,* 427-448.

Wass, S.Y., Henderson, P. and Elliot, C.J., 1980. Chemical Heterogeneity and metasomatism in the upper mantle: Evidence from Rare Earth and other Elements in Apatite-Rich Xenoliths in Basaltic Rocks from Eastern Australia. *Philosophical Transactions of the Royal Society of London,* A., *297,* 333-346.

Wellman, P. and McDougall, I., 1974. Potassium-Argon ages on the Cainozoic volcanic rocks of New South Wales. *Journal of the Geological Society of Australia., 21,* 247-272.

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Permian Climate of the Sydney Basin - Cold or Hot ?

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ABSTRACT. The concept of a frigid to glacial climate prevailing in the Sydney Basin throughout most of the Permian has received general acceptance. Yet, on the basis of mineral composition of the strata, this conclusion is difficult to substantiate. Indeed, from the evidence available it would appear more likely that humid, warm to hot conditions, favourable for the development of kaolinite and in part bauxitic clayrocks, persisted at least intermittently from the earliest Permian through almost to the Middle Jurassic.

INTRODUCTION

Much has been written concerning the climate of southeastern Australia during the Late Palaeozoic and a review of this literature leaves little doubt that the concept of frigid to glacial conditions prevailing in the Sydney Basin from the Late Carboniferous (Stephanian) to almost the close of the Permian has received general acceptance. Evidence to this effect comes from observations on such diverse aspects as the lithologic and textural characteristics of the strata (e.g. David & Sussmilch, 1931; Dulhunty & Packham, 1962), palaeontology (e.g. Dickins, 1978), oxygen-isotope ratios (e.g. Rao & Green, 1982; Bird & Chivas, 1988) and palaeomagnetism (e.g. Irving, 1964; Embleton, 1973). Indeed, consensus of opinion of these and other authors accords well with the views expressed by Crowell & Frakes (1971, p. 140) that "Carboniferous glaciation in New South Wales was alpine in nature and limited to mountains not far from the palaeo-Pacific and near a lowland along the Tamworth Trough. Continental glaciation on the other hand, occurred later (Late Sakmarian to the beginning of the Kazanian) after mountains had largely worn down to an undulating highland and there may have been a non-glacial interval lasting through part of the Stephanian and Sakmarian. The true glaciation in this part of Australia is therefore wholly Permian."

If these proposals are substantially correct the mineral composition of the Permian strata in the Sydney Basin and adjoining areas should conform for the most part to that characterising sediments of the present day polar regions. But, whereas to date this aspect has not been investigated to the full extent, the evidence that is available, mainly from coal measure and other non-marine sequences, appears much more consistent with a humid, warm to hot climate similar to that experienced in parts of the present day tropics and not appreciably different from that generally contended for development of the Carboniferous coal measures in both Europe and North America (Schwarzbach, 1963; Kutzvart & Konta, 1968; Crowell, 1978).

DETRITAL COMPOSITION IN RELATION TO CLIMATE

Climate is of paramount importance in the development of detrital sediments for not only does it exert a dominating influence on the manner and rate of weathering of the parent rocks but furthermore, it is a significant factor determining the composition of the new phases generated from the weathered products (Loughnan, 1969). Thus, in glacial and other regions of intense cold chemical reactions are greatly retarded whereas the processes of rock disintegration including frost action, ice movement and mass wasting, are much enhanced. As a result detritus originating in these environments generally comprises abundant rock fragments while the fine-grained material consisting of rock flour experiences little or no mineral alteration during weathering, erosion and deposition. This is well illustrated with the X-ray trace of a varve shale from the Seaham area of New South Wales (Fig. 1) in that clay minerals are absent and despite the ultrafine grainsize the rock is composed predominantly of feldspar in a remarkably fresh state of preservation. Nevertheless, under less severe conditions there may be some development of clay minerals mainly illites, chlorites and mixed layers of such (Grim, 1968; Millot, 1968).

In contrast, the humid tropics are characterised by vigorous chemical activity while physical disintegration except in areas of recent upthrusting and mountain building, is minimal. In these environments decomposition of the source rocks proceeds rapidly through leaching of the potentially mobile constituents, namely Na_20, K_20, $Fe0$, $Ca0$ and $Mg0$, by infiltrating rainwater resulting in residual crusts enriched in alumina mainly in the form of kaolinite. For the formation of bauxitic crusts however, the conditions are somewhat more stringent. Thus, Garrels and Christ (1965) have shown from a study of the stability of phases in the system Al_20_3-$Si0_2$-H_20 at 25°C and 1 atmosphere, that a pH value above 4.2 and a silica content of less than 1.5 ppm in the associated ground waters are essential for the development of free alumina minerals. Consequently, the only environment likely to give rise to a bauxite crust is a well drained site subjected to a seasonal climate in which a period of intense rainfall is succeeded by one sufficiently hot and arid to bring about oxidation of plant debris and thereby prevent the system becoming excessively acid.

Erosion of these crusts results in detritus composed of abundant kaolinite, with or without bauxite minerals, and it is not surprising therefore that the ocean floor sediments of the present day tropics are characterised by a preponderance of such minerals (Biscaye, 1965; Rateev et al., 1969). This also appears to have been the mode of origin for the peculiar clayrocks known as flint clays or bauxitic clays (Keller et al., 1953; Loughnan, 1978) that constitute parts of coal measure and other non-marine sequences in Europe, North America and elsewhere including the Sydney Basin (Fig. 2) of southeastern Australia.

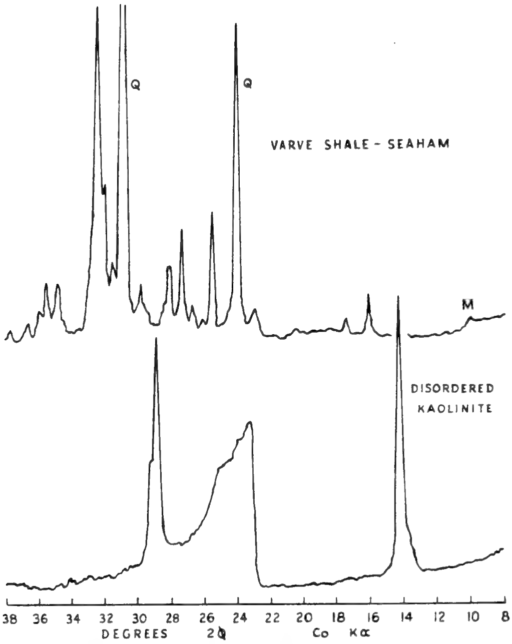

Fig. 1. X-ray diffraction traces *top* varve shale, Seaham N.S.W., Q = quartz, M = mica, unlabelled reflections due to feldspar *bottom* disordered kaolinite, Bonnybridge, Scotland.

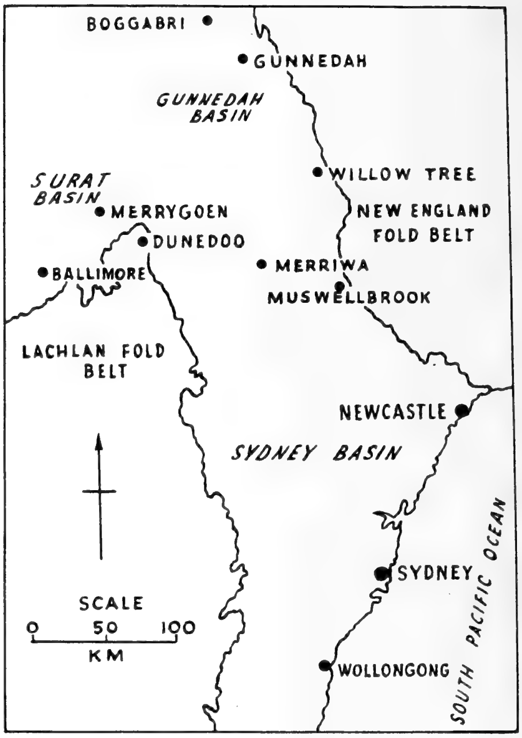

Fig. 2. Sydney Basin and adjoining areas.

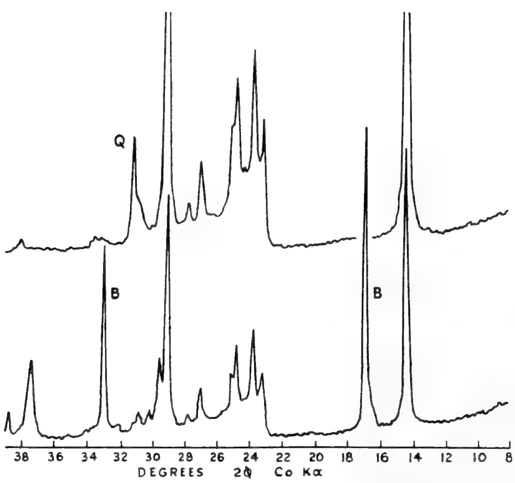

Fig. 3. X-ray diffraction traces of flint clays *top* from the Dunedoo Formation *bottom* from Narrabeen Group Q = quartz, B = boehmite, unlabelled reflections due to kaolinite.

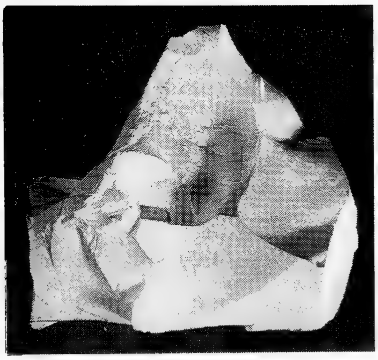

Fig. 4. Fine grained flint clay from the Dunedoo Formation showing conchoidal fracture. Sample 12 cm across.

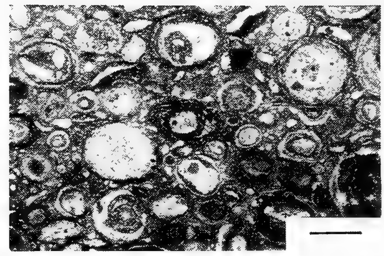

Fig. 5. Photomicrograph of oolitic flint clay from the Narrabeen Group. (Bar = 0.5 mm).

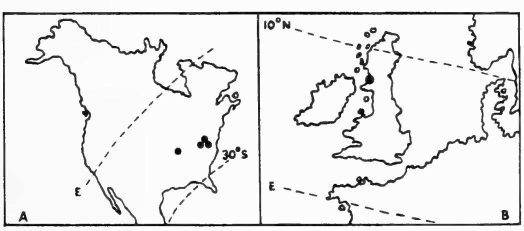

Fig. 6. Palaeolatitude of A. North America and B. Western Europe during the Carboniferous. (After Kutzvart & Konta, 1968). Also shown are areas of flint clay deposits.

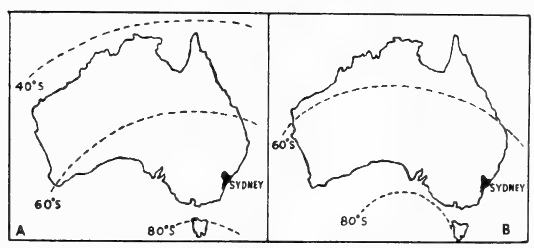

Fig. 7. Palaeolatitude of Australia, A. during the Mesozoic, B. during the Permian. After Embleton (1973).

FLINT CLAYS OF THE SYDNEY BASIN

Flint clays are massive, dense and indurated clay rocks that range from white to grey or deep red-brown depending upon the extent of contamination by organic matter and ferric oxide respectively. They comprise kaolinite frequently to the exclusion of other detectable crystalline phases although siderite, haematite and boehmite may be present additionally and quartz and anatase are common accessories (Loughnan, 1978). The kaolinite is well crystallised (Fig. 3) in contrast to the disordered form of the mineral (Fig. 1) commonly encountered in non-marine sediments. Many of these clayrocks are fine grained and break with a conchoidal fracture (Fig. 4) and in consequence bear a superficial resemblance to flint. The majority however, are either arenaceous or rudaceous consisting of oolites, pisolites, pellets or clasts or kaolinite set in a matrix of similar composition. The clasts range from angular to well rounded with some containing residual volcanic textures while others are characterised by aggregate birefringence and apparently represent reworked floodplain deposits (Loughnan & Corkery, 1975). Vermicular crystals of kaolinite may also be present but rarely do they predominate.

Clayrocks with most if not all of these features have been recorded from five separate stratigraphic intervals within the Permian-Mesozoic succession of the Sydney Basin and adjoining areas (Table 1). Three of these are referable to the Permian viz the Temi Formation, the Greta Coal Measures and their lateral equivalents and the Illawarra Coal Measures including the Dunedoo Formation, whereas the remaining two form part of the Early Triassic Narrabeen Group and the Early Jurassic Ukebung Formation.

McPhie (1984) has described an isolated occurrence of flint clay in the Temi Formation exposed approximately 3.5 km southeast of Willow Tree (Fig. 2) where in association with mudstones it apparently forms a 20 m interval located 90 m above the base of the unit. Flint clays of the Greta Coal Measures and their equivalents on the other hand, are the most extensive in the world in that they have a thickness well in excess of 100 m in places and have been traced by intermittent outcrop from near Muswellbrook in the central Hunter Valley to beyond Boggabri in the Gunnedah Basin, a distance of nearly 200 km (Loughnan, 1975a, 1975b). Boehmite is a common constituent in parts of the area and the deposits are generally underlain by a thick and partly eroded palaeosol or weathered crust developed on the Werrie Basalts. But, undoubtedly the most interesting feature of these clayrocks is the resemblance in texture, composition and mode of occurrence they bear to the Ayrshire Bauxitic Clay, which forms a relatively persistent unit in the Carboniferous (Namurian) coal measures of the southern Strathclyde, Scotland (Wilson, 1922; Monro et al., 1984). Indeed, the similarities are such that it is difficult to believe the two deposits formed under anything but identical environmental conditions.

TABLE 1
DISTRIBUTION OF FLINT CLAYS IN THE SYDNEY BASIN

		Toarcian	*Ukebung Fm*
		Pliensbachian	
JURASSIC	L	Sinemurian	
		Hettangian	
		Rhaetian	
	U	Norian	
		Carnian	
TRIASSIC	M	Landinian	
		Anisian	
	L	Scythian	*Narrabeen Gp.*
			Dunedoo Fm.
	U	Tatarian	*Illawarra C.M.*
		Kazanian	
PERMIAN	M	Kungurian	
		Artinskian	*Greta C.M.*
	L	Sakmarian	*Temi Fm.*

Although kaolinite is prevalent in the sandstones, shales and other strata comprising the Illawarra Coal Measures (Loughnan, 1966), deposits with the distinctive characteristics of flint clays are sparse and confined to the southern margin of the basin. Nevertheless, lenticular beds of dense, fine grained flint clay (Fig. 4) up to a metre thick and having most of the features of those in the Carboniferous (Pennsylvanian) of Missouri (Keller et al., 1953), occur at a number of horizons within the Dunedoo Formation, which is the equivalent of the Illawarra Coal Measures in the adjoining Surat Basin (Loughnan & Evans, 1978). Some of these flint clays have a deep red-brown colour due to the presence of a relatively high concentration (>10%) of haematite.

In the southern Sydney Basin flint clays of the Triassic Narrabeen Group rarely exceed 2 m in thickness but nevertheless extend over an area of more than 1000 km^2 (Loughnan, 1970). They differ from those of the Permian in not forming part of coal-bearing sequences but rather are intimately associated with red beds and other strata notably deficient in organic matter. The red beds, commonly termed "chocolate shales", have much the same colour and composition as the haematite-rich flint clays of the Dunedoo Formation. In the Blue Mountains to the west of Sydney however, flint clays and red beds of comparable age to those in the southern Sydney Basin form lenticular units within massive quartzose sandstones (Loughnan et al., 1974). The Narrabeen flint clays vary in texture from predominantly pelletal to profusely oolitic (Fig. 5) with the latter appearing similar in thin section to those of Pennsylvanian age in Kentucky (Patterson & Hosterman, 1962). They also resemble in texture the bauxite from near the type area in southern France and like the latter, they contain boehmite in addition to kaolinite (Fig. 3).

In contrast, the flint clays of the Early Jurassic Ukebung Formation have many aspects in common with those of the Greta Coal Measures in as much as they are unusually thick, predominantly pelletal and frequently incorporate stringers of coal (Loughnan & Evans, 1978). In addition they are remarkably persistent extending from the west of Ballimore to the vicinity of Merriwa a distance of more than 100 km (Fig. 2). Unlike the Greta Coal Measures however the deposits are not underlain by a thick palaeosol and as a result the source of their detritus has not been established with certainty.

CONCLUSIONS

From this brief review of the distribution of flint clays in the Sydney Basin and adjoining areas it is apparent that conditions conducive to their development persisted at least intermittently from the beginning of the Permian through to the end of the Lower Jurassic, a time span of nearly 100 m years. Moreover, since clayrocks comparable in virtually every respect to these flint clays have been found in the Carboniferous of the U.S.S.R. (Chukhrov, 1970), Poland (Gorzynski, 1968), Scotland (Monro et al., 1984), Missouri (Keller et al., 1953) and the Appalachian states of U.S.A. (Williams et al., 1968; Patterson & Hosterman, 1962), presumably the same environmental conditions also prevailed in these areas. But, evidence has been advanced to show that whereas most of Europe and North America during the Carboniferous enjoyed a tropical climate (Fig. 6), the Sydney Basin throughout the Permian and for much of the Mesozoic lay within the Antarctic Circle and for part of the time was subjected to continental glaciation (Crowell & Frakes, 1971). The two interpreted environments are obviously at variance and hence to those concerned with the Permian climate in the Sydney Basin this is an enigma that requires resolution.

REFERENCES

Bird, M.I. and Chivas, A.R., 1988. Stable-isotope evidence for low-temperature kaolinitic weathering and post-depositional hydrogen-isotope exchange in Permian kaolinites. *Chemical Geology (Isotope Geoscience Section)* 72, 249-265.

Biscaye, P.E., 1965. Mineralogy and sedimentation of recent deep sea clays in the Atlantic and adjacent seas and oceans. *Geological Society of America, Bulletin 76*, 803-832.

Chukrov, E.V., 1970. Analogues of flint clays in Soviet literature. *Clays and Clay Minerals* 18, 1-12.

Crowell, J.C., 1978. Gondwana glaciation, cyclothems, continental positioning and climate changes. *American Journal of Science* 278, 1345-1372.

Crowell, J.C. and Frakes, L.A., 1971. Late Palaeozoic glaciation in Australia. *Journal of Geological Society of Australia* 17, 115-155.

David, T.W.E. and Sussmilch, C.A., 1931. Upper Palaeozoic glaciation in Australia. *Geological Society of America Bulletin* 42, 481-522.

Dickins, J.M., 1978. Climates of the Permian in Australia. *Palaeogeography, Palaeoclimate & Palaeoecology* 23, 33-46.

Dulhunty, J.A. and Packham, G.H., 1962. Notes on Permian sediments in the Mudgee district, N.S.W. *Journal of the Royal Society of New South Wales* 95, 161-166.

Embleton, B.J.J., 1973. The palaeolatitude of Australia through Phanerozoic time. *Journal of Geological Society of Australia* 19, 475-482.

Garrels, R.M. and Christ, C.L., 1965. SOLUTION, MINERALS AND EQUILIBRIA. Harper & Rowe, N.Y., 450 pp.

Grim, R.E., 1968. CLAY MINERALOGY 2nd edition. McGraw Hill, N.Y. 596 pp.

Gorzynski, Z., 1968. Carboniferous bauxites and argillites *23rd International Geological Congress, Prague* 14, 115-124.

Irving, E., 1964. PALAEOMAGNETISM AND ITS APPLICATION TO GEOLOGICAL AND GEOPHYSICAL PROBLEMS. Wiley, N.Y., 399 pp.

Keller, W.D., Westcott, J.F. and Bledsoe, A.D., 1953. The origin of the Missouri fire clays. *2nd National Conference on clays and clay minerals. National Academy of Science*, Washington, 7-44.

Kutzvart, M. and Konta, J., 1968. Kaolinite and laterite weathering crusts in Europe. *Geologica, Acta Universitatis Carolinae* 1, 1-19.

Loughnan, F .C., 1966. A comparative study of the Newcastle and Illawarra Coal Measures of the Sydney Basin, New South Wales. *Journal of Sedimentary Petrology* 36, 1-8.

Lougnnan, F.C., 1970. Flint clay in the coal-barren Triassic of the Sydney Basin, Australia. *Journal of Sedimentary Petrology* 40, 822-828.

Loughnan, F.C. 1975a. Laterites and flint clays in the Early Permian of the Sydney Basin, Australia, and their palaeoclimatic implications. *Journal of Sedimentary Petrology* 45, 591-598.

Loughnan, F.C., 1975b. Correlatives of the Greta Coal Measures in the Hunter Valley and Gunnedah Basin, N.S.W. *Journal of Geological Society of Australia* 22, 243-256.

Loughnan, F.C., 1978. Flint clays, tonsteins and the kaolinite clayrock facies. *Clay Minerals* 13, 387-400.

Loughnan, F.C. & Corkery, R.W., 1975. Oriented kaolinite aggregates in flint clays and kaolin tonsteins of the Sydney Basin, N.S.W. *Clay Minerals* 10, 471-473.

Loughnan, F.C. and Evans, P.R.,. 1978. The Permian and Mesozoic of the Merriwa-Binnaway-Ballimore area, N.S.W. *Journal of the Royal Society of New South Wales* 111, 107-119.

Loughnan, F.C., Goldbery, R. and Holland,W.N., 1974. Kaolinite clayrocks in the Triassic Banks Wall Sandstone of the Western Blue Mountains, N.S.W. *Journal of Geological Society of Australia*, 21, 393-402.

McPhie, J., 1984. Permo-Carboniferous silicic volcanism and palaeogeography of the western edge of the New England Orogen, northeastern New South Wales. *Australian Journal of Earth Science*, 31, 133-145.

Millot, G. 1964. GEOLOGIE DES ARGILLES. Masson et Cie., Paris, 409 pp.

Monro, S.K., Loughnan, F.C. and Walker, M.C., 1983. The Ayrshire bauxitic clay: an allochthonous deposit? *in* RESIDUAL DEPOSITS: SURFACE RELATED WEATHERING PROCESSES AND MATERIALS. R.C.L. Wilson (Ed.). Geological Society of London, 47-58.

Patterson, S.H. and Hosterman, J.W., 1962. Geology and refractory clay deposits of the Haldeman and Wrigley Quadrangles, Kentucky. *United States Geological Survey Bulletin 1122-F.*

Rao, C.P. and Green,D.C., 1982. Oxygen and carbon isotopes of Early Permian cold water carbonates, Tasmania, Australia. *Journal of Sedimentary Petrology* 52, 1111-1125.

Rateev, M.A., Gorbunoya, Z.N., Lisitzyn, A.P. and Nasov, G.L., 1969. The distribution of clay minerals in the oceans. *Sedimentology*, 13, 21-43.

Schwarzbach, M., 1963. CLIMATES OF THE PAST: AN INTRODUCTION TO PALAEOCLIMATOLOGY. D. van Nostrand, N.Y., 328 pp.

Williams, E.G. Bergenbach, R.E., Falla, W.S. and Udagawa, S., 1968. Origin of some Pennsylvanian underclays in western Pennsylvania,. *Journal of Sedimentary Petrology* 38, 1179-1193.

Wilson, G.V., 1922. THE AYRSHIRE BAUXITIC CLAY. Memoirs of the Geological Survey, Scotland 28 pp.

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The Impact of Humans upon the Biota of Australasia

address by TIM FLANNERY

The following is a summary of an address delivered by Dr.T.F.Flannery before the Royal Society of New South Wales on Wednesday 3rd July 1991* at the Australian Museum.

The Society was especially pleased to hear from one of its Medallists: Dr Flannery, who is the Head of the Mammal Section, Division of Vertebrate Science, The Australian Museum, was awarded the Society's Edgeworth David Medal in March 1991 for his outstanding contributions in the field of mammal studies.

Australia's last c.40,000 years has been a period of great changes, probably coinciding with the arrivals of humans in the region. Quite early in this period, perhaps during only the first few 1000 years, all the large mammals of over 1000 kilograms (4 species) became extinct, and also all mammals over 100 kg (15 sp.) also became extinct. In the 10 to 100 kg range, some survived (humans fall in this range). Below 10 kg, none of the mammals became extinct in the earlier part of the period, but were affected in the most recent times. Reptiles were also affected, for example a giant snake, 6m. long & weighing 100 kg, and giant goannas and land-based crocodiles. Many of these reptilian species were carnivores and major predators on the mammals. The largest mammalian carnivore on the Australian continent at any time was the human being. This has been a unique situation compared with other continents.

The cause of extinctions is subject to much debate: Dr Flannery's personal view is that there have not been climatic changes on the Australian continent during this period such as could have caused extinctions, and that the major cause on this continent was hunting by humans. Many of the animals were large and slow moving, so readily hunted. They had no large warm-blooded predators, and were not prepared for the human onslaught. There were no large warm-blooded carnivores because the Australian environment was relatively resource-poor and hence impoverished as regards food-sources. The impact of humans was very profound since they took for themselves a very large share of the available energy budget.

Following the initial big decline in large mammal species during the first few thousand years after the arrival of humans, there was little change in the residual population of small mammals until the arrival of Europeans 200 years ago. A new phase of extinctions then commenced, which has resulted in the extinction of 23 species of medium-size mammals and one bird. This is a very strange extinction event: excepting the Thylacine, all of them were the common animals in the range 100 grams to 5 kilograms, almost all mammals, & all living in the drier parts of Australia. Half of these were rodents, one of the most successful orders of mammals alive on Earth today. Researches in NW Australia, where there has never been a significant impact of European imported rabbits, foxes, sheep and cattle, indicate that the prime cause was probably the removal of Aboriginal people from the landscape. This changed the fire regime from one in which small patches were burnt regularly to the more recent situation in which large areas are burnt at one time, consequent on prolonged periods of fuel build-up followed by large natural fires.

The medium-sized animals left in the large burned areas could not migrate to unburnt areas to find food and became victims of wide-ranging predators such as quolls and wedge-tailed eagles and, later, foxes. The larger mammals could escape to other areas, and the residual very small animals could survive in the small un-burnt patches which usually remain after a fire. Dr Flannery believes that this small-patch fire regime mimicked the effect of the 60 species of large herbivores which existed before the arrival of the Aborigines. The fossil record appears to confirm this concept. Examples of these recently extinct medium-sized mammals include the Eastern Hare Wallaby, the Desert Rat-kangaroo, & the Broad-faced Potoroo. Today, in much of the arid and semi-arid country there is not a single middle-sized mammal to be found: nothing between a rat and a Red Kangaroo: only their bones remain. Fossils indicate a rich fauna in these areas before the arrival of humans.

Dr Flannery then reviewed the very different situation in New Guinea. Here there were very few large mammals. Only 3 species weighed more than 100 kilograms, and only 7 were between 10 and 100 kilos. Of these some six species became extinct many tens of thousands of years ago, probably soon after the arrival of humans. The two regions have basically the same fauna, but differ greatly in regard to terrain and in biomass available to support animals. New Guinea is a very hostile environment for large mammals, including humans, due to the mountainous and rain-forested terrain. In the last ten thousand years or so agriculture developed, coinciding with the local extinction of several more mammals, including species of fruit bat; and two thousand years ago the dog was introduced and commenced a very large predation on the mammals, especially the wallaby (Thylogale). Today the several species of Tree-kangaroo are under intense threat from human hunting activity. This is on account both of the big increases in human population due to improved food supplies and medical care, resulting in the tripling of the population in some areas in the last fifty years, and because people can now hunt anywhere despite the difficulties of terrain and forestation.

Dr Flannery then reviewed extinctions in other parts of the Pacific. The arrival of humans in New Zealand only around 1000 years ago had a catastrophic effect on the fauna. All 12 species of Moa, about 30 other species of birds including swans, ravens, geese and even small birds became extinct. Also large frogs, large insects, geckoes, tuataras and others. It seems probable that changes in forest structure and in fire regimes over the period of human habitation must also have contributed to the extinction processes.

Timor lost its 12 species of the world's biggest rats some 5000 years ago. The Philippines and the Solomons also lost their giant rats, mostly due to forest destruction. Some such rats are known to have had femur bones as much as a centimetre thick, and may have been a metre long. Some forest-dwelling rats construct large nests, similar to those of birds of prey,in large trees, which makes them very vulnerable to the destruction of forests by humans. Christmas Island was untouched until about 1880, but unfortunately for the fauna phosphate was discovered; the native rats were probably destroyed by diseases imported with European rats.

Returning to Australia and the present times, recently the Orange Roughy was discovered as a fishing resource. These 12 inch long fish, which take 100 years to grow to adult size, are being dredged in enormous numbers from a kilometre depth on the continental shelf off south-east Australia, using sophisticated modern equipment, and then sold for a mere $9 to $12 per kilogram as "Ocean Perch". They are being harvested at a rate far too high for the population to replace itself and the species may well be doomed to 'commercial extinction'.

Almost every Australian fishery has been subjected to the same process. Australian coastal waters are very nutrient-poor: we have not got any great fisheries as in the North Atlantic or South American coasts. In the Great Barrier Reef fish are being taken at 12,000 tonnes per year and is the cause of great problems.

Australia is a very large land-mass: 7.6 million square kilometres, with only 17 million people. But Australia is by far the most resource-poor of the continents. The seas surrounding Australia are basically biological deserts. There is tremendous species diversity, but very little productivity. The average levels of nutrients (nitrates and phosphates) in Australian soils is about half those of soils overseas. We also have a very erratic climate, basically dominated by the ENSO cycle,as no other continent. Hence this is a land of rain and flood and then long periodic droughts, on about a 10 or 15 year cycle. The soils in Australia are very thin and infertile compared with those of other continents. We have some 77 million hectares of arable land in Australia, but all of it is marginal on a world scale: of that, we have used about 30%, of which some 60% is suffering serious degradation. Evidently the amount Australians are taking out of national productivity is disproportionately large.

Although there are only 17 million people living on this continent, we have one of the highest standards of living in the world, and we depend on exports to support this level. We also have the most rapid rate of population growth in the Western World. These three factors combine to form a recipe for disaster: the poorest continent on Earth, the most rapid rate of population growth and one of the highest standards of living in the World. These three factors are pushing us to use resources quite beyond a level we which we should never even approach. We are using natural resources far faster than they can replace themselves.

We are not the first people on Earth to exploit to excess a limited resource base: there are many examples all over the World from all epochs of history of peoples which have done this and eventually run into serious problems. One small-scale example is Easter Island, which was probably discovered by Polynesian explorers about 1400 years ago, as evidenced by sediments in a crater lake on the Island. It was covered by forest, including endemic palms and perhaps endemic birds: an island paradise. The people thrived for some 700 years. The Island was discovered by Dutch explorers in 1722. The huge statues facing inland demonstrate that there must have been timber available for rollers to move the huge stones; wood was used for sea-going canoes. Some 100 years later visiting Europeans found a breakdown of social order, particularly the taboo system for reserving resources for particular needs; there was no more wood and there was serious starvation. The population rapidly declined to about 160 survivors from tens of thousands.

In poetry Shelley's 'Osymandias' provides an example of places all around the Mediterranean which once supported great cities but which now lie in the middle of deserts; similar events have occured in the south-west of the United States and in the Middle East. All these places share horrifying similarities with the Australian landscape, and the pattern of the extinctions we have seen in those areas are very similar to those seen in Australia. The big fauna disappears in the Pleistocene sometime, people get in and develop agriculture and suppress the remaining carnivores, they apply irrigation to fragile soils, and eventually exceed the ability of the environment to sustain them. The terrifying thing is that those areas have never recovered: there is still desert in those areas which were over-exploited as much as 2000 years ago.

There is not a lot of optimism for the situation in Australia and in the south-west Pacific in general, simply because of the growth in human numbers. Maintenance of our current (world) fertilty of 3.8 children per family would result, by 2100, in 50 million people on Earth. It seems unlikely that resources will be sufficient to support 10 times the present population. If we reduce our fertility to an average of 3 children per family, even in that case we should have 20 million people on Earth in 110 years time: 4 people for every one now, which also seems hardly feasible. At replacement fertility the Earth's population might grow to 6 billion and then remain steady. This might enable us to deal with our resource and other problems. But we still seem to want to keep going as before.

Further Reading

Burbridge, A., Fuller,P., Johnson, K. and Southgate, R. 1987. Vanishing desert dwellers. Landscape 2, 7-12

Burbrige, A.A., Johnson, K.A., Fuller, P.J. and Southgate, R.I. 1988. Aboriginal knowledge of the mammals of the central deserts of Australia. Australian Wildlife Research 15, 9-39.

Burbridge, A.A. and McKenzie, N.L. 1989. Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. Biological Conservation 50, 143-198

Flannery, T.F. 1989. Plague in the Pacific: a new perspective on the last 40,000 years. Australian Natural History 23, 20-29.

Flannery, T.F. 1989. Who killed Kirlipi? Australian Natural History 23, 234-242.

Flannery, T.F. 1990. Pleistocene faunal loss: implications of the aftershock for Australia's past and future. Archaeology in Oceania 25, 45-67.

OZYMANDIAS of EGYPT

Percy Bysshe Shelley
(1792 - 1822)

I met a traveller from an antique land

Who said: "Two vast and trunkless
legs of stone
Stand in the desert. Near them
on the sand,
Half sunk, a shattered visage lies,
whose frown
And wrinkled lip and sneer of cold command

Tell that its sculptor
well those passions read
Which yet survive, stamped
on these lifeless things,
The hand that mocked them
and the heart that fed;
And on the pedestal these words appear:

'My name is Ozymandias, king of kings;

Look on my works, ye mighty,
and despair!'
Nothing beside remains. Round the decay

Of that colossal wreck,
boundless and bare,
The lone and level sands
stretch far away."

* (Prepared by Mr G.W.K.Ford, Vice-President, from a tape-recording of the address: Dr.Flannery kindly reviewed and corrected the text, and provided the list of 'Further Reading')

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Fire from Heaven
Proton Power:- Past, Present and Perspective

G.W.K. Ford

Proton Power energises and materialises the Universe. The Address attempted to illustrate this general concept with a leavening of Ancient Greek Cosmogony and a Theogony of Olympic Gods, a few monochrome versions of various works of art, and brief extracts from the writings of Aeschylus, Milton, Virgil & other poets. Although many entities in science derive their names from classical sources, the relating of selected events in mythology to modern interpretations of cosmic and sub-atomic processes is obviously contrived and only intended to entertain and to aid the memory! It was hoped, however, that this treatment would also serve as a token of the broad scope of the Society's interests by mixing together Science (at an elementary level), with Art, Literature and Philosophy, (albeit at a superficial level), having the particular aim of interesting our non-scientist Members & Associates, as well as those specialist in various sciences outside, in this case, the worlds of nuclear physics, cosmogony and nuclear engineering.

The main thesis of the lecture was the essential role of the proton in the original creation, the formation and heating of stars, the synthesis of all the chemical elements, the supply of radiant energy to the Earth's surface, and the heating of the Earth's crust, thus facilitating continental drift, mountain building & weather, and hence soil formation and the support of plant and animal life. Mankind is able to employ proton-based nuclear fission & fusion reactions to provide small-scale local heat sources and explosions.

ORIGINS

The human race has passed through many phases of contemplation of the works of nature both in the Heavens and on Earth, and has developed theories as to their causes and being. This evolution of thought is still in progress, with ever-larger numbers of people engaged in its pursuit, with increasingly powerful, complex and costly tools for investigation. But although we can now see infinitely further than the ancients and are able to examine the infinitesimally small, we seem perhaps to be as far removed as ever from any sort of understanding of what it is really all about.

Mankind has always had need for creation myths, and these have been developed from the earliest phases of human history. For the purposes of this Address attention is confined to the earliest Greek concept as recorded by Hesiod, neglecting for our purposes the rival Orphic myth. In the beginning was Chaos, vast and dark, from which was born Erebus & Night: uniting, these gave birth in turn to Ether, the 'Organising Principle', & Hemera, the Day. Gaea, the 'Deep-breasted Earth', was also born from Chaos: & finally was created Eros, the fructifying influence. (The Orphic myth, by conrast, commenced with Cronus (Time) instead of Chaos).

There was one further asexual stage in this creation myth: Gaea gave birth to Uranus, 'the Sky crowned with Stars', and to Pontus, 'the Sea and Waves'. Uranus & Pontus in turn united with Gaea and gave rise to the heirarchy of gods displayed in the associated Theogony, derived from Hesiod & other writers.

The accelerating rate of discoveries in the two & a half millenia since these myths were current have revealed a Universe of immense magnitude, composed of particles unbelievably small. The particles push and pull upon each other in complex ways over vast or miniscule distances through mechanisms which are as yet unobserved. We have no idea as to the 'true nature' of these particles and their various coupling 'wavons' (gravitons, photons, gluons etc), their electric charges & other mysterious properties. We can, however, observe their various interactions & measure their masses, energies, charges etc with great accuracy, and make excellent predictions regarding their expected behaviour.

We hear theories of the origin of the Universe based on marvellous observations of the constitutions, distances and speeds of the stars and their galaxies. Celestial bodies of astonishing variety have been identified, ranging from red and blue giants down to neutron stars and through to planets, moons, comets and asteroids. Quasars have been observed & black holes conjectured. Theories for the formation of these amazing entities range from the Big Bang concept of recent popularity to steady state theories of an everlasting Universe, with many and varied concepts in between.

For the purposes of this Address, none of these theories really helps us any more than does Hesiod's. All we really need to know for this review is one approximate fact: that somehow or other, sometime or other, to create that part of the Universe accessible to our observation, around 10exp80 protons (see Note,final page) were manufactured,together with an equal number of oppositely-charged electrons. These protons are by no means simple things,such as Newton conceived to be the nature of atoms, which we now know are 10,000 times larger than protons. In his 'Optiks' (1730, Book Three, Part I) Newton wrote: "All these things being consider'd, it seems probable to me, that God in the Beginning form'd Matter in solid, massy, hard, impenetrable, moveable Particles, of such Sizes & Figures, & with such other Properties, & in such Proportion to Space, as most conduced to the End for which he form'd them;even so very hard, as never to wear out or break in pieces; no ordinary power being able to divide what God himself made one in the first Creation".

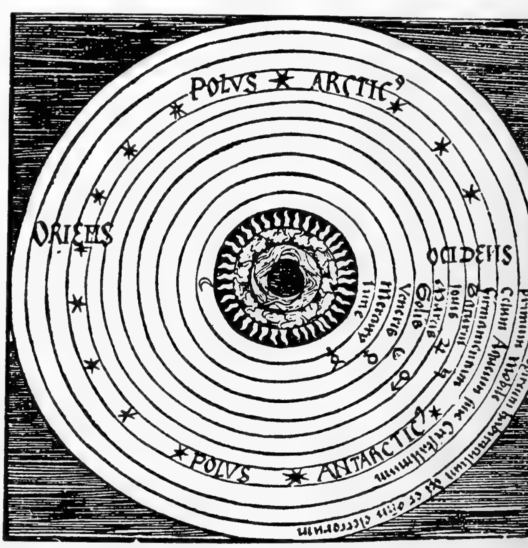
Fifty years ago this would have been equally satisfactory as the definition of a proton: we now know that even the proton seems to have an internal structure (of three particles called 'quarks'); that within the atomic nucleus protons can be converted into neutrons; that outside the nucleus the neutron converts back, by a process of radioactive decay, on average in about a quarter hour, into a proton; & we now have good reason to suspect that the proton itself may have a finite life, albeit vastly long, perhaps 10exp20 times the supposed age of the 'Big Bang' Universe (1 to 2 times 10exp10 years).

ENGINEERING PHYSICS

Mankind has been able to make effective practical progress in the development of his civilisation, in the fields of engineering and technology, without need of deep understanding at a fundamental level. However, increasingly with the passage of time, where appropriate the engineer has borrowed extensively from the findings and tools-of-trade of the scientists & philosophers. In turn, the engineers have returned to the scientists new tools-of-trade which have had a great influence on the advances of science, and, in turn, on philosophy.

Until very recently, the technologist has been able to make all the progress he required by assuming a Newtonian world, with relatively simple modifications to deal with the additional effects of electromagnetism and a few consequences of quantum theory and relativity. He could get a long way with a billiard-ball model of the atom and its nucleus, and would not go too far wrong in regarding the atom as a Bohr 'solar system' (c.1913), simply ignoring the inherent logical difficulties. These ideas are a now a long way astern of modern developments in physics & other sciences, but for the purposes of this Address, which leads to the history of a particular engineering speciality, they are really quite adequate, & are readily understandable in their entirety, insofar as practical developments are concerned, by anyone reasonably informed concerning our present technological age.

The mechanistic models used to illustrate the fundamentals of many aspects of the physical & engineering worlds often take the form of circular diagrams purporting to represent some object or system having, essentially, a spherical or cylindrical form. Such 'mechanical model' cross-sections of nuclei, atoms, planets, stars & engineering systems are very familiar; an early example of such diagrams is provided by the middle-ages portrayal of the Aristotelian, Earth-centred Universe. The set of diagrams on the final page of this paper illustrates some of the entities & concepts discussed here. They all indicate systems having numerous interacting concentric zones, ranging from Aristotle's Unmoved Mover, through thermal diffusion & mass transport to nuclear interactions.



Aristotelian Scheme of the Universe
Geocentric, Four Elements, Crystal Spheres

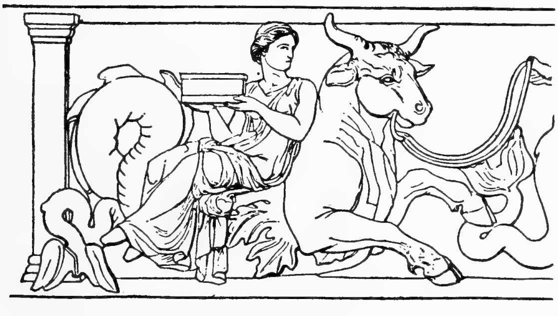
Somewhat more detailed technical figures were presented in the Address to the Society, but apart from the page of sketches, they have been excluded from this written version in favour of pictures conjured by descriptive words, text illustrations being limited to the much less familiar but more pleasing drawings of the pantheon of Greek & Roman gods.

Poseidon (Neptune)

Furthermore, the various 3-dimensional interactions between spherical bodies can be visualised as 2-dimensional encounters on the billiard table, or maybe as pushing or pulling mechanical springs coupling pairs or groups of bodies together.

PROTEUS & PROTEAN WAYS

The union of Gaea with Uranus gave birth to many offspring, outstanding amongst which were the twelve Titans. A further union between Gaea and Pontus, the god of the sea, led eventually to the birth of their grandchild, Amphitrite, whose union with Poseidon, a grandson of Uranus, gave birth to Proteus and Triton.



Amphitrite

Proteus was a slippery and elusive character: he could change shape at will, and could fortell the future. Half man and half fish, he lived deep in the ocean, where he herded Poseidon's seals. But each midday he would bring the herd of seals to land to graze, and if a mortal could then trap him and hold him fast, he was forced to resume his normal shape and could be induced to prophesy.

However, powerful though Proteus' repute, in Paradise Lost, Book III, Milton underrated Proteus & supposed him unable to create the philosopher's stone:

'In vain, though by thir powerful Art
they bind
Volatil Hermes, & call up unbound
In various shapes old Proteus
from the sea,
Draind through a Limbec to his
native forme.'

As scientific ideas began to take shape over the centuries, Proteus became associated with ideas of primitive matter. In 1825 William Prout associated the atom of hydrogen with the 'prima materia' of the ancients: and in 1886 William Crookes suggested that all the elements had evolved from one antecedent form of matter, which he named 'protyle' (from the Greek, prote hyle = first matter).

Tritons: Proteus was one of the Tritons

The electrically charged nucleus of the hydrogen atom was eventually identified as the true building block for all nuclei, & hence also of the resultant atoms, electrically neutralised by their associated cohorts of electrons. This basic unit of matter was first observed in nuclear processes in 1914, and subsequently named 'proton' in 1919 by Sir Ernest Rutherford: beams of protons had in fact been the subject of experiment by Golstein, Thomson & others since 1886, but not then as yet recognised as a component of the nucleus. The chemical element named 'hydrogen' by Lavoisier in 1783 is alternatively & aptly named 'protium' (='first element').

Just as the single positively-charged proton forms an electrically neutral hydrogen atom by associating with just one negatively-charged electron, or negatron, which dances around the nucleus to give the atom its external spatial form, so each chemical element heavier than hydrogen is uniquely characterised by an increase of one proton per element up to the total of 92 protons in the heaviest naturally-occurring element, uranium, with a corresponding increase of electrons in the atom's outer structure.

The number of protons in the nucleus defines the 'Atomic Number', a number unique to each chemical element. It is the basis of all classifications of elements, such as the Periodic Table.

ZEUS and ELECTRYON

Zeus was the most powerful of the gods and ruled the Heavens. He had the power to hurl thunderbolts, the very embodiment of electric charge. He had a grandson,

Zeus holding Thunderbolt & Sceptre

Electryon ('The Brilliant'): it is attractive to relate these gods to our electron, the basic carrier of electric charge which we designate as 'negative', & named in the 19th century after the Greek word for amber, 'elektron'.

Today the electron and the quark are seen as being the 'truly fundamental' particles of matter, 'point objects', perhaps 100,000 times smaller than the proton, &, so far as at present can be determined, having no internal structure. The electron has a mass but a two-thousandth of that of the proton, and, to ensure overall electrical neutrality of all major entities from atoms to stars, must be equal in numbers to the universe's inventory of protons.

Thus, every normal, neutral atom comprises a nucleus containing protons, & a dynamic outer structure of electrons which delineate the apparent 'external dimension', or the outer few 'onion skins', of the whole atom (some 10,000 times the size of the nucleus), & which contains an equal number of electrons. At the temperatures of the interiors of stars the nuclei are no longer closely coupled to the electrons, but form a loose mixture, or 'plasma' electrically neutral overall. Estimates suggest that some 98% of the matter in the Universe is in the plasma state.

CELESTIAL FIRE

Hephaestus (or Vulcan) was responsible for the production of heavenly & subterranean fire, whilst Hestia (Vesta) had responsibilty for the fire in the domestic hearth. Hephaestus also made the thunderbolts for Zeus. He was born deformed & ugly & so was thrown out of heaven by his father. John Milton tells us in Paradise Lost, Book I:

' . . . and how he fell
From Heav'n, they fabl'd, thrown by angry Jove
Sheer o're the Chrystal Battlements: from Morn
To Noon he fell, from Noon to dewy Eve,
A Summers day; & with the setting Sun
Dropt from the Zenith like a falling Star,
On Lemnos th' Aegean Ile:thus they relate,
Erring; for he with this rebellious rout
Fell long before;nor aught availed him now
To have built in Heav'n high Towrs; nor did he scape
By all his Engins, but was headlong sent
With his industrious crew to build in hell

Hephaestus (Vulcan) at his Forge

Presumably, whilst in Heaven, Hephaestus built the celestial proton furnaces we call stars. How did he go about this?

It seems probable that the primordial protons combined with the electrons to form neutral atoms of hydrogen gas, maybe filling all space at an extremely low gas pressure. The gravitational pull operating beween each and every atom eventually condensed & compressed vast volumes of hydrogen to form proto-stars. The multi-millionfold compression produced a corresponding rise in temperature: when this reached some 10 million degrees the fusion of hydrogen nuclei (protons) was initiated due to the close approach of the nuclei to each other, despite the very powerful repulsive force between such positively-charged entities, on account of the very high particle velocities corresponding to the high temperatures. This is the process of 'thermonuclear fusion'. The end product of the process, which in fact comprises three successive nuclear reactions, needing on average billions of years for its completion, is the fusion of four protons to form a nucleus of helium. Much, but not all, of the energy which keeps the stars shining comes from this process.

ENERGY from the GODS

The primordial source of the energy which is released or absorbed during nuclear transformations is a total mystery: we are little further forward than Hephaestus. It has been conjectured that the inherent energy of mass possessed by all particles had its origin in the transformation of radiation existing in the very earliest stages of the so-called 'Big Bang': but how this supposed radiation, with its inherent energy, came into existence is beyond conjecture. Certainly in all changes of state of nuclear particles in which energy is absorbed or released, an exactly corresponding amount of mass materialises or vanishes: everyone is familiar with Einstein's E=Mcexp2.

It seems now well-established that the production of energy in the stars is due to the fusion of protons to form first helium, and then, by an indirect series of stages of successive nuclear reactions, of increasingly heavy elements up to the nucleus of iron,which contains 26 protons. All these reactions release energy through a small reduction of mass at each stage. This energy, in the form of both electromagnetic radiations (eg gamma rays) and particles (of many types) diffuses out towards the surface of the star, undergoing many complex transformations on the way, but serving to prevent the inward collapse of the material of the star under the force of gravity. Because some of the key nuclear reactions have a very low rate of occurrence the stars can last for billions of years.

The final transformations as these energetic entities approach the surface of the star include those of an atomic energy form rather than nuclear, resulting in the production of visible light, which constitutes a major proportion of the energy emitted by the star into space. But this light is accompanied by other radiations and by particle emissions, including a powerful stream of protons, which, in the case of our own Sun, give rise to the 'solar wind': on reaching the Earth, these protons become trapped by the Earth's magnetic field (due to their electrical charge) & give rise to the displays of aurora near the poles.

Although the hydrogen, helium & other nuclei in the very hot interior of the star are not bound to electrons, in the cooler outer atmosphere the nuclei bind to their electrons to form the neutral atoms of the corresponding chemical elements, hydrogen, helium etc, the presence of which can be detected by their optical absorption spectra. It is these complete, or partially-complete ('ionised'), atoms which emit or absorb visible radiations.

Helios, the Sun-God

Within the Sun protons, the primordial cosmic fuel, are being converted into helium at a prodigious rate. The total mass of the Sun is estimated at 2x10exp27 tonnes, & its central temperature 15 million degrees, at a pressure of a billion atmospheres. The central nuclear reaction zone is of the relative proportion of the fiery zone in the picture of the Aristotelian Universe: the remaining outer region is essentially all very hot hydrogen (= proton) plasma awaiting fusion as the 'boundary' of the core reaction zone creeps outwards. Some 6.16x10exp8 te H/s are being fused to form 6.12x10exp8 te He per second: thus the Sun loses mass at 4 million tonnes per sec.

The ARES CATASTROPHE

In the ancient world the metal iron was associated with the Greek god of war, Ares, named Mars by the Romans. Hephaestus built stellar furnaces much larger than the Sun (eg up to 100 times its mass) in which the fusion of light elements could progress far beyond the production of helium, the main energy-producing nuclear reaction in the Sun. However, even in the

Ares, or Mars

largest possible star, it is impossible to synthesise elements heavier than iron by nuclear fusion reactions. This is because further additions of nucleons (protons or neutrons) to the iron nucleus demands the application of energy rather than its being available for release; for as the nuclei become larger they are less tightly bound together, tending more & more towards instability.

Therefore, in these large stars elements could be synthesised, by nuclear fusion reactions, beyond helium through carbon, oxygen, neon, magnesium & silicon (& most elements between), only until the nucleus of Ares, iron, is reached. Concentric fusion-reaction zones are visualised, with a model-diagram very similar to the Aristotelian Universe picture: the outer zone dominated by hydrogen, the next inwards by helium, and so on until the core zone is iron-dominated. In fact, all through the star there will be a small production of elements heavier than iron through the absorption of free neutrons produced by some minority nuclear reactions, but this is thought not to be an important contribution to the net production.

Thus, because iron cannot serve as the fuel for energy-releasing fusion reactions, once most of the available nuclear fuel provided by the other, lighter, elements has been consumed, there is insufficient energy production to maintain the radiation output of the core, so the star becomes unstable and collapses violently under the force of gravity.

The star may have been 5 million kilometres in diameter, but its central region is compressed by huge gravity forces to a mere 10 kilometres or so, such that the complex nuclei built up are disintegrated into protons & electrons; the electrons combine with the protons to form neutrons, and a new celestial object is born: a 'neutron star', composed of 'degenerate' nuclear material, having a density a hundred trillion (10exp14) times water.

The remaining material of the star is conjectured to experience a reflected shock-wave at the moment of consolidation of the neutron star 'core', of such extreme intensity that a very large population of free neutrons is generated, which by successive absorption convert some of the lighter elements, which the star created by nuclear-fusion synthesis processes, into all the remaining chemical elements from cobalt (27 protons) to uranium (92 protons) & beyond. This is a 'supernova' explosion, and scatters all the stellar-generated elements through neighbouring space. In this way the heavy elements are thought to have become available for mixing with the primordial hydrogen of space for eventual incorporation into other stars, one of which is our Sun.

The COSMIC MESSENGERS

How does the proton interact with other protons and with other types of particles and with radiations? These are very profound questions, so far but little understood. The key activity seems to be the ability of sub-atomic particles to emit and absorb entities through the operation of which they are able to push or pull other particles. It is no longer believed that there is some magical 'action at a distance': all interactions, whether between sub-nuclear particles or between celestial bodies, result from the exchange of entities. The 'lines of force' of what we regard as familiar force-fields, are in fact but maps of the average effects of these entities. When no second particle is present to experience the 'field' the potential for interaction is nevertheless present in the form of fleetingly existing (or 'virtual') entities, continuously emitted and re-absorbed by the particle. This represents the energy stored in the force-field.

Hermes, or Mercury, was the messenger of the gods, and indeed his wings, helmet and caduceus were fabricated for him by none other than Hephaestus. However, the job of communication by messenger particles travelling at the speed of light between every pair of particles in the Universe seems totally beyond any imagination.

Hermes, or Mercury

Nevertheless, to make comparison with more discernible & somewhat similar processes, consider the zillions of light photons which arrive each second at the retina of your eye. A broadcast of all possible colours ('white light') was emitted 8 minutes ago by zillions of atoms at the surface of the Sun, & but a few nano-seconds ago a minute fraction of these were absorbed by a blade of grass, which selected all the photons other than green for its own purposes, and then re-emitted, in all directions, the green photons to space, a tiny fraction of which (some xillions of photons) were intercepted by your retina. Perhaps the creation of forces between particles at any range is neither more nor less remarkable.

There are four types of force: gravity, weak nuclear, electromagnetic and strong nuclear. The entities which transmit the force between particles are respectively gravitons, W & Z particles, photons and gluons. Gravitons and gluons have not yet been directly observed, but their presence is inferred from indirect observation.

PROTEUS RESTRAINED

For the purposes of this Address it is not necessary to do more than acknowledge these recently-discovered processes and ideas. For most of the practical matters dealt with in the paper it is convenient to revert to the simpler mechanical models of the atom & its nucleus which were being evolved in the 1930's and before, and to be content with magical 'action at a distance'.

Here we have the concept of a nucleus comprising protons and neutrons in rather close-packed association, which might be thought of as a bag of red and green balls ('protons' and 'neutrons') of diameter around 10exp(-12)cm. Around this nucleus, & distant some 10,000 diameters from it, circulate the electrons in 'orbits' analogous to planets around the Sun: but the Sun to Earth is only some 107 diameters, so planet Pluto is a more apt comparison, at 7,375 million km from the Sun, whose diameter is around 1.4 million kilometres, ie 5,300 Sun-diameters away.

The nucleus may be regarded as being held together by the strong nuclear pulling force('springs'in our mechanical model), a very short-range force, which acts equally on the protons & the neutrons (but which has no effect on electrons). This pulling force relaxes as the nucleons approach each other closely, within the confines of the nucleus, so they cannot 'coalesce'.

The electric force may either push (like charges) or pull (unlike charges) but has no effect on neutrons.

Inside the nucleus, the powerful but short-range nuclear pulling force only operates effectively between neighbouring nucleons. But the electric force does not fall away so rapidly with distance, so all the charged nucleons within the nucleus collectively repel each other. Therefore nuclei containing only protons (except, of course, the lone-proton hydrogen nucleus) could not hold together. Proteus, our changeling, can deal with this problem, as protons are added in one-by-one to build up the nucleus, by changing half or more of the incoming protons into neutrons. For example, the helium nucleus contains 2 protons & 2 neutrons, but the uranium nucleus, which is around 238 times the mass of a hydrogen nucleus, contains 92 protons & 92 + 51 neutrons.

The neutrons are not acted upon by the electric force, but are pulled equally with the protons by the nuclear force. The neutrons in effect disperse the protons thus to reduce their mutual electrical repulsion, whilst leaving the nuclear pulling force between neighbouring nucleons essentially unchanged.

Neutrons may be regarded as disguised protons: the neutron has a mass very close to that of the proton, but is electrically neutral. As already noted, inside the nucleus the neutron appears to be effectively everlasting, but once freed from the nucleus it can only survive as a free neutron for (on average) some 18.5 minutes, at which point it changes, by radioactive decay, back into a proton.

To achieve this state the neutron emits an electron (ie negatron, or 'beta-particle') and an anti-neutrino (anti-matter particle of zero charge and zero or near-zero mass), and loses around a thousandth of its mass due to giving up the energy which had to be provided to create and emit the negatron. Note that it is not considered that there are electrons in existence inside the nucleus or associated with the nucleons: the electron is created at the moment of its emission, just as photons appear to be created at the moment of their emission through an energy change within a light-emitting atom. The conversion of a proton into a neutron inside the nucleus is essentially the reverse of this process: the nucleus emits a positron (positive electron, an anti-matter particle) and a neutrino.

PROTEUS VINDICATED

Lord Byron compared Proteus with Voltaire, on account of his versatility and talent:

'He was all fire and fickleness: a child
Most mutable in wishes, but in mind
A wit as various - gay, grave, sage or wild -
Historian, bard, philosopher, combined;
He multiplied himself among mankind
The Proteus of their talents; but his own
Breathed almost in ridicule,- which, as the wind
Blew where it listed, laying all things prone,
Now to o'erthrow a fool, and now to shake a throne.'

However, the stability of the Universe depends crucially upon the stability of the proton, for all its changability if moving in and out of nuclei. In theory, a proton may decay to a positron & a neutral pion (very short-lived intermediate-mass particle), which would very rapidly then decay into gamma rays, thus destroying the very foundation of 'matter' itself. This decay process has not yet been observed, although intense efforts are being made to do so. Estimates suggest a half-life for the proton of around 10exp31 years, which might seem to make the detection of such a process all but impossible, having regard to the age of the Universe of order estimated at 1 or 2 times 10exp10 years only.

BIRTH of the TITANS

There is little doubt today that the Sun gave birth to the Earth & other planets, asteroids & comets. But it is entertaining to think that Zeus, the supreme god, & his wife Hera, the goddess of the Sky, may have had a hand in it: after all, Zeus threw Hephaestus, their son, out of Heaven to carry on his work in Hell, which, as we shall see, was most important for the development of the Earth. Also, Zeus had the power to throw thunderbolts, & we should note that this may have been crucial in tranferring the angular momentum of the Sun, which contains 99.8% of the mass of the solar system, to the planets, which possess 99% of the angular momentum. The ubiquitous protons & their consort electrons, in the plasma mode, made possible the transmission of the necessary billions of amperes in the 'thunderbolts'.

The Marriage of Zeus & Hera

So Helios, a medium-size, hydrogen-burning star, was formed from primordial hydrogen mixed with around a percent or so star-dust from supernovae, thus containing small quantities of all the chemical elements. It seems that the gas/dust cloud, from which the Sun was formed, was set slowly spinning when the condensation process was initiated by some cosmic disturbance, sometimes attributed to the influence of a supernova shock wave.

As the gas-cloud was compressed by gravitation, conservation of angular momentu caused the speed of rotation to increase, so that the perhaps originally spherical cloud swelled out at its equator to a shape like an old-fashioned humming-top. The central region eventually ignited under the compression-induced high temperature (many millions of degrees) to become the proto-Sun: but the outer periphery of the spinning disc remained cool. Therefore, chemical atoms of all types were present, and as these atoms became more closely-packed in the condensing cloud, and were heated to low temperatures by the radiations from the proto-Sun, many types of chemical compounds would be formed.

Eventually, heating, radiation pressure & solar wind is thought to have blown the lighter, more volatile constituents (eg hydrogen, methane etc) of the equatorial ring's chemical/gas/dust mixture to the outer periphery of what was to become the solar system, whilst the more refractory compounds (eg oxides of silicon & other elements, including uranium & thorium) were left in the inner regions. Within each of these two groups of materials an accretion process commenced, thought to be, at first, electrostatic, & then, as the aggregates grew, gravitation-induced, eventually building up the four small rocky planets in the inner region, & the four giant gassy planets in the outer region;& outermost of all,Mars-size Pluto.

Our Earth was formed in a fortunate zone at a fortunate size: distant from the Sun such that water would remain predominantly in the liquid phase, large enough that gravity would prevent the escape of water molecules to space, but not so large that possible materials of construction (eg wood & bones) would be unable to form vertical supports.

URANIUM CONCENTRATED, WATER PRESERVED

Our particular interest in relation to Fire from Heaven concerns the uranium & the water. Fortunately the water was not all blown away to the outer regions, probably because much of it was bonded to the refractory compounds as water of crystalisation. With the normal water was some heavy water, or deuterium oxide.

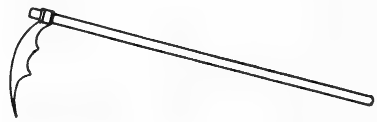
Uranium appears to be the rarest element in the Universe, at about one U atom per trillion H atoms, doubtless because it was the last of the elements having long-term stability to be formed in the supernova explosions, since it was the nucleus requiring the greatest number of nucleons to be added. Therefore, it must have been equally rare in the Sun. However, it has gone through a very remarkable series of concentration processes, the first of which was its winnowing by the solar wind. Estimates from meteorites of the likely uranium content of the planet before any differentiation commenced indicate around 10 parts per billion: already a factor of 10,000 above the abundance in the Universe.

Hephaestus thus had a good starting point from which he and 'his industrious crew could build in Hell'. In the first place, chemical physics came to his aid because it so happens that the uranium ion is large, comparable with ionised sodium, which causes such ions to enter any melted mantle material and hence to migrate upwards towards the crust. A powerful factor aiding this process is the heating due to the radioactivity of the uranium, which is a direct cause of local melting within the mantle. The net result of such migration may have been that around half of the Earth's uranium has migrated to the crustal region, resulting in an effective further concentration of some 200 times.

Eventually, at the surface of the Earth, very remarkable geological processes, depending upon a sequence of erosion and chemical environment conditions, have re-deposited uranium-bearing rock material in ore bodies that may reach tens of percent of uranium content, or more typically of average mines, around one part in 10,000. This is an astonishing gain factor over the abundance in the Universe of one part per trillion.

URANUS & the DISINTEGRATION of URANIUM

Uranus and Gaea had the misfortune to produce some very unattractive offspring: moreover, Uranus was deeply worried that one of them would displace him as master of Heaven & Earth. So Uranus decided to imprison them for life. His son Cronus (or



Scythe used by Cronus to Castrate Uranus
(after Vasari, c.1550)

Saturn), one of the Titans, & his wife Gaea, plotted to defeat this sentence, & one night, whilst Uranus slept, Cronus castrated him (according to the painting by Georgio Vasari c.1550, now in the Palazzo Vecchio, Florence, by the use of a ferocious-looking scythe), and threw the severed genitals into the ocean, where they eventually gave birth to Aphrodite; & the blood gave rise to the Three Furies.

Uranium, a silvery metal about as heavy as gold, discovered in 1789 by Klaproth, was first isolated in 1841 by Peligot, & was named after the planet Uranus. Like its namesake, the nucleus of uranium also sheds vital parts & completely changes its nature as a result, by two main processes: radioactice decay, and nuclear fission.

In the case of very heavy nuclei, including that of uranium,if a group of protons, (associated with neutrons), is caused by some fluctuation to stray outside the confines of the nucleus, then, because the nuclear pulling force very rapidly falls off with distance (at a much higher power law index than inverse square), the electric repulsive force is able to exceed the nuclear pulling force & to push the errant particle, be it a product of radioactive decay or a fission process, away from the vicinity of the remainder of the nucleus with very great force, which is directly converted into the very high 'mechanical' kinetic energies associated with nuclear processes.

Alpha particle radioactivity & nuclear fission, the processes by which the Scythe of Cronus thus pries out very energetic particles from the uranium nucleus, have a good deal in common. Both processes can take place spontaneously: for this to occur, a chance aggregation of nucleons within the nucleus in an inherently stable formation must chance to acquire enough energy to escape the pull of the short-range nuclear force which holds all nuclear particles within the nucleus. Such particularly stable sub-assemblages of nucleons occur in the case of the alpha-particle, or helium nucleus, comprising 2 protons + 2 neutrons; or a fission fragment containing either 50 protons or 50 neutrons. If such a chance circumstance can propel the particle to such a range that the electrostatic repulsion between the positively-charged parent nucleus & the positively-charged particle becomes dominant, then the particle will escape completely & be driven to high speed (a few percent of the speed of light), and hence high energy, by the repulsive force.

URANUS DEVASTATED

In the case of nuclear fission a pleasing 'mechanical' model not only gives a satisfying mental picture, but also accounts very well in a quantitative way for the fission process. In this model, the initially spherical nucleus (to be thought of as a 'bag' of protons & neutrons behaving as though it were a rubber balloon full of liquid: the so-called 'liquid drop' nuclear model) is set into oscillation,distending to 'rugby football' shape, and then, as the oscillation intensifies, to 'peanut' shape, essentially two spherical parts joined together by a neck.

If the oscillation becomes sufficiently intense, the neck breaks because the electrostatic repulsion between the two 'nuts' becomes stronger than the nuclear attractive force, and then the two nuts are violently propelled apart, achieving an initial speed about a thirtieth of the speed of light. The two 'nuts', or 'fission fragments', interact violently with the neighbouring atoms, causing them to vibrate more intensely (in a solid), ie they are heated, & the fission fragments are quickly brought to rest (in a distance if a few millionths of a metre). So most of the energy of the fission process is immediately converted into heat in the material surrounding the fission site.

The two fission fragments take with them some, but not all, of the original inventory of orbital electrons of the uranium atom. The new atoms are thus very highly ionised (= charged due to losing one or more orbital electrons), so they interact strongly with the atoms of the material (eg uranium) through which they penetrate. They quickly & progressively gather the remainder of the cohort of electrons appropriate to the number of protons in each fragment (usually unequal) and so become neutral atoms. Immediately after the fission (10exp(-14) second) the new nuclei also disgorge their surpluses of neutrons (the 'prompt neutrons': two or three per fission), and emit some gamma-ray photons (because they have been left with an excess of internal energy). Finally, certain types amongst the population of fission fragment nuclei are still left neutron-rich, and emit these residual surpluses after a short but variable delay (depending on the particular type of nucleus) ranging from tenths of a second to several minutes. These are the 'delayed neutrons', which are quite vital to the possibility of creating a steady-state nuclear chain reaction.

The fission products span a range of atomic weights from around 72 to 161, and include over 80 primary fission product elements. Virually all of these are still left with a surplus of internal energy, & return to the stable state over periods ranging from tens of seconds to tens, even thousands, of years by a variety of radioactive decay processes which in general transmute the original fission products through a succession of different elemental forms until they reach their final, stable, state.

URANUS EMASCULATED

From the point of view of Zeus & Hephaestus, & indeed from all points of view, the radioactive decay of uranium, commencing with the emission of an alpha-particle, is a far more important reaction than nuclear fission. It is the heat produced by radioactive decay which maintains the Earth's mantle and the sub-crust (asthenosphere) in a plastic state such that slow-moving convection currents can be induced by gravity forces which propel the continental plates in various directions over the Earth's surface; causes the melting of sub-crustal material to form the magmas which emerge to fill the widening gaps at the mid-ocean ridges; & energises the volcanoes which over the billenia have produced the gases which have given the Earth its atmosphere.

ATLAS the MOUNTAIN BUILDER

Hephaestus having produced the heat and brimstone to enable the plates to move, it must have been Atlas, his indirect uncle, who actually moved the plates and brought them into collision, thus to build the mountain ranges. At some stage he was turned into stone (& indeed his body became a mountain) by the sight of the

Gorgon's head, held up to him by Perseus, a half-brother of Hephaestus. This was unfortunate, for mountain-building is a dynamic process which needs constant attention, & which has gone on since continents were first formed billenia ago. Perhaps Atlas was un-frozen, or Hephaestus took over the job.

Atlas Carries the World on his Shoulders

THE FURNACE of HEPHAESTUS

Uranium has two principal naturally-occurring isotopes: U235 and U238, both having 92 protons in the nucleus, but U235 having three less neutrons than the 146 in the U238 nucleus. It is therefore spoken of as 'the light isotope of uranium', and this small difference in mass makes possible the partial separation of the two isotopes by various physical processes, including especially gaseous diffusion, centrifugation, & electromagnetic methods.

Both the isotopes are radioactive, but they have very different, although very long, half-lives (the time for half an amount of the material to decay, ie self-transmute, into another isotope or a different element). For U238 this time is 4.5 billion years: thus, in the time the Earth has so far existed (about 4.6 billion years), about half of the original inventory of U238 has changed into a stable isotope of lead (Pb206). In the case of U235, the half-life is much shorter: 0.71 billion years. Thus some six half-life periods have elapsed since the Earth was born, so that only about a hundredth of the original inventory of this isotope remains. It is finally converted into another stable isotope of lead: Pb207.

Each isotope actually decays to the stable form through a succession of around a dozen different radioactive emissions, at some of which an alpha particle, ie helium nucleus, is emitted, at others a beta-particle, ie an electron, & in many of the steps gamma rays are also emitted. These steps are all much quicker than the initial alpha decay, which determines the effective half-life, but may cause delays of tens of years or minute fractions of a second on the way to the final stable form. In the case of U238 one of these intermediate delays occupies hundreds of thousands of years.

However, although each step only yields a relatively modest amount of energy (as compared with the fission process), in aggregate each overall change of either isotope of uranium to stable lead releases in all around 60 MeV (million electron-volts, a convenient nuclear energy unit), which compares quite favourably with the more spectacular uranium fission process, which yields about three times as much.

The total heat output from uranium decay is somewhat augmented by energy from the decay of thorium and potassium 40, which between them produce about half as much again. This heat all leaks out at the surface of the Earth (since the Earth is not heating-up, but is more-or-less in thermal equilibrium); it is estimated that the total heat output from the Earth due to radioactive decays is between 30 and 40 terawatts (a trillion watts, or 10exp12). This may be compared with the present total heat generated artificially by the activities of mankind of some 10 terawatts or the re-radiation of 5000 times this amount of solar heat reflected back from the Earth to space.

This radioactive heat generator within the Earth's crust operated by Hephaestus is indeed a proton furnace of importance no less than the solar proton furnace operated by Helios. The solar input, of course, keeps the Earth's surface warm; evens this heating out by driving atmospheric circulation & evaporating & circulating water vapour, also causing rain; energises & facilitates virtually all life through photosynthesis in plants; & provides optical illumination for animals.

However, without Hephaestus's internal furnace we should have no mountains for the rains & winds to erode, & hence there would be no soils, & we should have but a moon-scape by way of the Earth's surface topography.

The PROMETHEAN EXPERIMENT

Perhaps Prometheus, a first-generation descendant from the Titans, had already planned to provide Mankind with fire resulting from chemical reactions. Pandora, the first Woman (surely a goddess), was sent to Prometheus & his brother, Epimetheus, by Zeus as a gift (Pan-dora = 'all-gifted'), 'to punish Prometheus for his part in stealing fire from Heaven': perhaps the 'punishment' was that Pandora married Epimetheus; or perhaps Pandora was sent to tempt Prometheus into a far more mischievous experiment.

A unique property of the U235 nucleus presented an irresistable temptation to Prometheus, so that two billion years before Man was created, Prometheus was already experimenting with nuclear energy from uranium.

Perhaps the far more terrible punishment later inflicted on Prometheus by order of Zeus was really for his work on developing the nuclear fisson properties of uranium. Aeschylus tells us, in his epic poem 'Prometheus Bound',in the words of Kratos, acting for Zeus, directing Hephaestus as his agent:

'Here at the furthest verge of earth
we stand,
The Scythian pale, a lone & ghastly land.
Hephaestos!Now bethink thee of the charge
Our Father on thee laid:against the marge
Of this sky-piercing precipice to bind,
In gyves of adamant & bondage blind,
This wrecker of the law.
'Twas he who stole
Fire, thine own glory, fire,
that is the soul
Of every art, & flung to man away.
For which sin to all heaven
he needs must pay
Atonement, till he learn
our Master's plan
To accept, & cease this love for
mortal man.'

Prometheus Stealing the Fire in a Reed

Prometheus must have made a remarkable discovery, re-discovered by Mankind (Hahn, Strassmann, Meitner & Frisch in 1938): that the light isotope of uranium, alone amongst all the naturally-occurring isotopes of the heavy elements, could be fissioned by external stimulus using a 'slow-moving' (2 km/sec) neutron! Being electrically neutral, the neutron is not repelled by the electrically-charged uranium nucleus, &, together with being 'slow', it has a very high chance of absorption. Prometheus must also have realised that if the fission process releases two or three neutrons, & that if most (but not all) absorptions of a single neutron in U235 cause a further fission, he had the makings of a nuclear chain reaction.

The astonishing geological processes referred to earlier (no doubt implemented by Hephaestus) succeeded in making an alluvial deposit of uranium in the delta of a river which emptied into the then sea in Gabon, in the Congo region of Africa. This deposit contained as much as 10% by weight of uranium. Furthermore, because two billion years ago the U235 had only passed through some 4 half-life periods, (since the birth of the Earth) the concentration of the light isotope had been reduced by a factor of 16 only, compared with more than 64 (ie 6 half-lives) today. This made the concentration ('enrichment') of the U235 some 3% of the total uranium, compared with about 0.72% for today's natural uranium. This was quite enough to enable a thermal neutron nuclear fission reactor to operate in the form of a relatively small volume of a more or less uniform mixture of an oxide of uranium, some sand, and very pure water.

It has been shown beyond doubt that just such a reactor came into spontaneous (or did Prometheus arrange it?) operation between 1.7 & 1.9 billion years ago in Africa in the Gabon: (much later, Africa was also to be the continent of creation of Homo sapiens, in which Prometheus also had an important role). It consisted of a pseudo-spherical volume of uranium-oxide/sand/water mixture effectively about a metre in diameter.

The reaction process would have started off with the production of a few stray fast neutrons from spontaneous fission (mostly from U238). These would be slowed down due to collisions with the nuclei of hydrogen atoms in the water molecules (ie protons): a few neutrons would be lost by absorption (to form deuterons, the nuclei of 'heavy hydrogen'); some neutrons would be absorbed by U238 (eventually to form plutonium); & some would be lost to 'parasitic absorbers' such as the silicon in the sand, and other impurities.

But for each, say, 100 original fissions, on average a few more than a 100 neutrons would each undergo the necessary 18 or so (on average) collisions to slow them down to 'thermal neutron' speeds: ie the colliding neutrons come into thermal equilibrium with the water molecules, having been slowed to an average speed of around 2 kilometres per second, compared with 10,000 times this when born from fission.

The surviving neutrons now have a high probability of absorption in a U235 nucleus to cause further fissions: some will be 'wastefully' absorbed in U235 (ie will fail to cause fission), but if: losses due to leakage to outside the reaction zone; the parasitic absorptions; & non-fission capture in U235, are together sufficiently low, then a nuclear chain reaction can proceed, &, given a small excess of surviving neutrons, can 'diverge', or build up to high rates of fission, and hence of power production.

The Oklo 'fossil' reactor is thought to have operated at some 10 to 100 kilowatts. In all probabilty it was a pulsed mode of operation, because, in the absence of deliberate control, the reaction would build up until the reaction zone temperature reached 100 deg C; some of the water would then turn to steam, forming steam 'voids' in the water so that the reactor could no longer operate due to loss of 'moderator', the neutron-slowing-down agent. It may have operated for around 100,000 years, & probably consumed about 6 tonnes of U235.

Perhaps this experiment was the original 'Pandora's Box', but it seems to have been relatively benign, the fission products & 'transuranium' elements (essentially the various isotopes of plutonium) having been mainly adsorbed on to rock particles and not to have migrated very far. The 'noble' (inert) gas fission products (all short-lived) would, of course, have escaped to atmosphere.

The Oklo reactor (there may well have been others) was undoubtedly a very successful reactor experiment, and may well have been what really angered Zeus, rather than the presentation by Prometheus to Mankind of of ordinary chemical fire. Because, once given the 'nuclear hint' by Prometheus, Mankind found out about the possibility of a nuclear fission chain reaction, but only after quite successfully using chemical fire for perhaps a million years or so, two billion years after Oklo.

The EPIMETHEAN EXPERIMENT

And Mankind's initial intent with nuclear fire was far from benign: the aim was to produce an entirely new explosive for purposes of war, vastly more powerful than anything which could be done with chemical reactions.

Was Epimetheus (meaning 'after-thinker', cf. Prometheus, meaning 'fore-thinker'), really the inventor of the nuclear bomb? The bomb is a much less subtle thing than a steady-state reactor, and this may have been the object, which we now call a 'vase', which aroused the interest of Pandora, the wife of Epimetheus. We all know what happened when she found it.

The key idea was to produce an extremely fast divergent chain reaction. This could be achieved with the fast neutrons immediately from fission, any slowing-down due to the presence of any light elements, eg hydrogen,being minimised by careful exclusion from the materials of construction. The device would need near-pure U235 as metal, which required that the light isotope (U235) be separated from the heavy U238: the U238 could indeed be fissioned by fast neutrons, but most of the fast neutrons entering U238 are slowed down or absorbed without causing fission: thus a chain reaction is impossible in U238.

Pandora Opens Her Vase
(Drawing by Giocomo Rosso:
Ecole des Beaux-Arts, Paris)

However, with the light isotope, U235, fission is the dominant reaction. The neutrons are moving at very high speed immediately after birth in fission. They will nearly all make their first collisions with U235 nuclei. Some will cause immediate fission, but perhaps ten times as many will be scattered: but these will hardly be slowed-down at all because they are so light compared with the massive uranium nucleus. These scattered, still-fast neutrons will then have second & further chances of causing fission.

The survivors will leak from the system, although a few may be able to be scattered back in by means of the shell of heavy metal 'tamper'. The relationship of the number leaking to the number causing fission is reduced by making the sphere of U235 metal increasingly large, so reducing the surface-to-volume ratio. When the number of fission-inducing captures is large enough to promote a divergent chain reaction, the system is 'supercritical', & we have the conditions for an explosion.

Because the neutrons are not slowed-down by any moderating material, the time between birth in fission & fission-inducing absorption is very short, despite successive scattering. The generation time for fission neutrons in such a fast neutron system is therefore tenths of a microsecond rather than the millisecond order characteristic of thermal neutron systems. These are therefore ideal circumstances for creating an explosive reaction.

Philosophically, it is interesting to reflect that the nuclear fission bomb could have been made (indeed the first was made) without any need ever to develop nuclear reactors. Nor would there have been any dependence on delayed neutrons, so vital for a steady-state nuclear reactor. Furtherthermore, even had uranium 235 not existed, weapons could still have been manufactured by creating fissile material not available directly from nature, such as plutonium 239 or uranium 233, by bombarding U238 or Th 232 with neutrons in an electrical machine.

The mechanics of making such a bomb is very simple in principle, but very complex in practice. The essence of the device is a hollow spherical shell formed from some six kilograms of U235 metal about the size of a large grape-fruit (the first test-device was some 14 cm in diameter). This is surrounded by a heavy metal 'tamper', eg U238, to serve as a neutron reflector & to help to provide some inertial confinement; the tamper is surrounded in turn by a thick shell of chemical explosive. A powerful 'priming' source of neutrons is associated with the system,& the explosive detonated, crushing the hollow sphere to a smaller, 'solid' sphere. Before the chemical implosion the hollow sphere was very leaky in regard to retaining a population of neutrons, but the 'solid' sphere is sufficiently neutron-retentive to facilitate a divergent chain reaction. The picture of Aristotle's Universe can be mentally modified to give a good general idea of such a system.

The PROMETHEAN BEQUEST

But despite the unfortunate intervention of Epimetheus & Pandora, Prometheus still hoped to provide a gift of immeasurable benefit to Mankind. Aeschylus tells us of Prometheus' words in 'Prometheus Bound':

' Hear now the sorry tale
Of mortal man. A thing of no avail
He was, until a living mind I wrought
Within him, and a new mastery of thought.
I cast no blame on man; I do but crave
To show what love was in
the gifts I gave.
. . .

Thus man to knowledge came
of things to be,
Deep hid before. Yes, I put eyes to see
Into the face of fire, and gave to him
A fount of knowledge that before was dim.
All that from me thou seekest
thou shalt hear
And not in riddles,
but as friend speaks clear
To friend, and fully openeth his desire.
I am Prometheus, he who gave man fire.

(& Io, exiled mistress of Zeus, replies):

'Thou star of blessing to mankind! . . '

However, so many years had elapsed between the original Oklo experiment and the arrival of Mankind on Earth, that the U235 concentration had fallen to 0.72% of the U235/238 isotopic mixture as compared with the 3% at the time of Oklo. At such a low concentration it was not possible to create the conditions for a nuclear fission chain reaction in any possible uniform mixture of slowing-down materials (light atoms such as H, Be, C). There were now only two options for producing such a reactor: either the concentration of the U235 must be increased by some isotope enrichment technique, or a non-uniform mixture of the naturally-occuring uranium must be employed. This second option became the first choice for building a steady-state reactor, which depended on a key invention.

The FERMIAN AEGIS

Enrico Fermi & Leo Szilard devised the idea of forming a mixture of a moderator (of very pure carbon, eg. graphite) & uranium in the form of lumps, ideally spherical, preferably in its highest density form, uranium metal. The problem was that the most wasteful absorptions of neutrons would be in U238 nuclei when the neutrons had been partially slowed-down, but had not yet achieved the low ('thermal') speeds at which they would attain their maximum effectiveness for causing fission in U235. But if the uranium was in lumps, neutrons leaving the graphite, where they had just completed some of the stages of slowing-down (it takes about 120 collisions in graphite to 'thermalise') & entering uranium at this medium range of neutron ('resonance') speeds at which U238 is a very strong absorber, then these 'resonance' neutrons would all be absorbed in a thin outer layer of the uranium. The main bulk of the uranium, enclosed inside this layer, would never be exposed to resonance-speed neutrons: thus, the uranium was 'self-shielded'.

By careful choice of lump size & spacing, first estimated by calculation, and then optimised by an extensive series of rather large-scale experiments, it was eventually determined that a pile of graphite, near spherical in shape, about 20 feet diameter (weighing some 385 tonnes), with lumps of uranium in the form of cylinders 2.25 inches diameter & height, spaced from each other 8.25 inches, should constitute a critical reactor. It was found to need a bit over 42 tonnes of uraniferous material to achieve criticality: 5.6 tonnes of uranium metal were available to form the central core, & this had to be surrounded by 36.6 tonnes of uranium in the much less satisfactory, low-density oxide form due to shortage of supply, at the time, of the much higher density uranium metal. Criticality of this first man-made nuclear fission reactor was realised on December 2nd 1942 at the University of Chicago.

The immediate application of this blessing from Prometheus was to manufacture plutonium for use in nuclear weapons.Both routes to bomb development were followed: separation of U235 by physical methods; & the creation of plutonium by transmuting some of the U238 in situ in the uranium metal in reactors developed from the Chicago pile, but provided with cooling, shielding, & arrangements for un-loading irradiated uranium and re-loading with new aluminium-clad uranium-metal rods.

PLUTO & CERBERUS

The absorption of a neutron by U238 leads to the immediate formation of a nucleus of an isotope of uranium, U239, which is very unstable (radioactive), emitting an electron to transmute itself into a daughter-nucleus, the nucleus of an element which does not exist in nature: element 93, neptunium (Np). This has a half-life of only 23.5 minutes & in turn, also by emitting an electron, transmutes itself into a grand-daughter, element 94, plutonium 239. This is an alpha-emitter with a half-life of 24,000 years, so is esentially a stable (though radioactive) metal from an engineering point of view.

This new element 'grows-in' in situ in the uranium rods in the pile. If left a long time in the pile, a substantial amount of the Pu239 absorbs neutrons & is transmuted into Pu240: this itself absorbs neutrons & transmutes into Pu241. So long-irradiated U238 contains Pu239, a good deal of Pu240 and some Pu241. The Pu 239 & 241 behaves something like U235, and so may be used for bombs or piles: but Pu 240 behaves like U238, & so is detrimental to bombs. This is the reason why power reactors, which irradiate the uranium fuel to the maximum practicable extent to extract the greatest possible amount of energy, are not well suited to production of bomb-grade plutonium, which calls for reltively short irradiation times to minimise the dilution of fissile Pu239 by non-fissile Pu240.

Pluto, known to the Greeks as Hades, was the god of the underworld & of the dead. The three heads of his dog, Cerberus, might be thought of as representing the three isotopes of plutonium. He abducted Proserpine (Persephone), the daughter of Ceres (Demeter) and dragged her with him below the Earth to the underworld. In the course of her search for her daughter Ceres wrongly blamed, & cursed, the soil, for causing her loss, with the result that crops failed & there was famine in the land. All was finally settled by compromise & the land became fertile once more.

Pluto and Cerberus

In our own times land has been cursed by radiocaesium from Chernobyl & plutonium at Maralinga. Caesium was named after its blue spectral line (by Bunsen): the Latin word means the bluish-grey of the eyes, but is often mis-quoted as 'sky blue'. We might conjecture Ceres had grey-blue eyes.

The plutonium can be separated from the uranium & fission products in the irradiated material to a high degree of purity by chemical techniques. This is, in principle, simpler than the physical methods needed to separate uranium isotopes, but in practice is a matter of major complexity because of the highly radioactive nature of the irradiated uranium & its associated fission products & transuranium elements (ie. elements having more than 92 protons in the nucleus: small quantities of elements beyond neptunium (93) & plutonium (94) are always produced in pile irradiations, including americium (95), curium (96) etc).

In the early days of nuclear energy the alumnium-clad natural-uranium metal rods were kept as cool as necessary to prevent materials damage, by forced convection water or air cooling in a simple open circuit, & the large amount of low-temperature heat produced was simply discarded to the environment.

Later plutonium production reactors (eg Calder Hall, Hanford) were more sophisticated, with the coolant operated at higher pressure & temperature so that some of the heat could be converted into mechanical energy via a heat-engine (steam turbine) thus to make electricity as a by-product. Later still, even more advanced reactors, still based on natural uranium metal fuel (clad in magnesium alloy) and graphite moderator, were developed in Britain for electric power production, with plutonium as a by-product: the 'Magnox' reactors.

HORSES for POSEIDON'S CHARIOTS

In parallel with the development of natural uranium reactors, which were necessarily very large (30 to 50 feet in diameter), development of much more compact reactors was put in hand for the propulsion of ships, especially submarines. Nuclear power offered very much superior performance: high speed, no surfacing to charge batteries, & enormous operating range. These would be ships of war really worthy of Poseidon, & equipped with a nuclear-tipped trident which would do much more than shatter rocks.

To develop these reactors, highly enriched uranium, essentially the same as weapons-grade uranium, was used in the form of thin plates of suitable metallic alloy, clad in stainless steel or zirconium & dispersed through a volume of water to act as a moderator. This could result in reactors only a few feet in diameter; the reacting core was enclosed in a pressure vessel able to withstand a tonne per square inch internal pressure so that the heat could be removed at quite high temperature (about 300 deg.C) & used to generate steam in a separate boiler. From this the steam was supplied to the propulsion turbines.

PROMETHEUS REVIVED

From this line of development followed the 'Pressurised Water Reactor' which forms the most numerous type used the world over for the production of electric power. These reactors have returned very closely to the conditions which Prometheus established in his Oklo experiment: the uranium is restored to the 3% enrichment of 2 billion years ago by physical isotope separation processes (gaseous diffusion through porous membranes),& used in the form of uranium dioxide. The uranium dioxide is formed into short pellets about the diameter of an AA flashlamp battery (finger-size) & half the length,& inserted & sealed into zirconium alloy tubes about ten feet long (eg 10 million pellets in 50,000 tubes) which are dispersed, close-spaced, throughout a 10-foot diameter cylindrical volume of the water which fills the enclosing 15-ft, 9-inch-thick, pressure-vessel.

The cladding-tubes serve three purposes: to provide a structure to disperse the uranium uniformly through the volume of water; to prevent chemical attack of the oxide fuel by the very hot water; & to contain the radio-activity. The water moderator, which also serves as the heat-removal medium, is pressurised so that it shall remain liquid at 300 deg.C (ie.prevented from boiling), & is circulated through the nuclear reacting core & thence outside the reactor vessel to a boiler, or 'steam generator', in which the hot water in the closed 'primary circuit' raises steam in a secondary circuit; & the steam is fed to the steam turbine (some recent concepts place the boilers inside the reactor vessel). The whole system is enclosed in a large 'containment building' to prevent leakage of radioactivity to the environment in event of an accident.

Many & various schemes for power reactors have been devised over the last forty years, a few of which have been quite successful; but essentially all thermal neutron power reactors being developed today use Prometheus' basic formula: 'low enrichment' (3% U235) fuel & water moderator. Designers are aiming for reactors which meet another of Prometheus' achievements: 'walk-away' integrity. They will be doing well to produce a reactor which can remain intact for 100,000 years.

TAMING EPIMETHEUS' BOMB

But are the ideas of Epimetheus merely confined to war? The answer is most certainly 'No'. If the extraction of power from uranium is to provide a really major energy resource, much larger than the vast amount known to be available from coal, it will be necessary to adapt Epimetheus' bomb to make a steady-state fast neutron reactor. Fortunately the delayed neutrons from fission are just as useful for establishing a steady-state in a fast neutron reactor as in a thermal reactor.

If such a fast neutron reactor is enclosed within a thick 'blanket' (ie. concentric sphere or cylinder) of U238, the uranium will absorb the surplus neutrons leaking out of the highly-enriched U235 or Pu239 core & become progressively transmuted into plutonium. Because with fast neutrons fewer neutrons are wastefully absorbed in impurities in structure, fuel & coolant, as compared with a thermal reactor, & because fast neutrons cause the release of a slighly greater number of neutrons from fission than do thermal neutrons, the fast neutron reactor has a very good 'neutron economy'. Consequently, for every fissile atom fissioned in the core, fractionally more than one new fissile atom is formed in the blanket. Over tens of years, the inventory of fissile material in the system will double & this surplus can be used to build additional fast reactors.

Due to the accumulation of parasitic losses, thermal reactors can only extract a few percent of the available energy from the original uranium, even if their 'bred' plutonium is recycled several times. Hovever, the fast neutron reactor can, by repeatedly recycling the uranium & plutonium materials, extract over 60% of the fission energy potentially available in the original uranium. Thermal reactors are needed to create the initial core inventories of plutonium, because fast reactors perform best with plutonium cores, but the fast reactors would eventually become the dominant reactor type in a long-term fission-power energy system.

To generate the energy which Mankind seems to need might in principle be realised by catching the rays from the proton furnace of Helios. But so far the preferred course has been to dig down towards the underworld of Pluto & extract coal, oil or uranium. To provide coal to run a 1000 MWe (megawatt electric) power station for a year requires the mining & transport of 3 million tonnes of coal, equivalent to a block of coal 140 metres on the side. If mined by open cut, some 10 to 40 tonnes of 'overburden' per tonne of coal must be removed & (hopefully) replaced. The coal (mostly carbon) burns to carbon dioxide, which goes to atmosphere; at least a quarter million te of ash must be dumped; & sulphur in flue gases must be extracted.

By contrast, to produce the same amount of energy (1000 MWe for a year) from a thermal neutron fission reactor requires only 0.1 of a million tonnes of a typical uranium ore (0.2%) to be mined (cf 3 million te of coal), and virtually all the mined material is left at the mine site; only the 200 tonnes of natural uranium extracted from the ore at the mine site need be shipped out. This would seem to be orders of magnitude superior to coal in terms of environmental damage; & also in mine casualties, which are roughly proportional to the quantity of material mined: in Britain & USA one miner dies for each ten-million tonnes of coal extracted.

So far as mining is concerned, the fast reactor would place a demand on the environment fifty times smaller still.

The ADAMANTINE GATES of TISIPHONE

If the irradiated fuel is reprocessed & the uranium & plutonium recycled, as it should be, or whether, alternatively, the fuel is used in a wasteful 'once-through' fuel cycle, & the spent fuel discarded without re-processing, the radioactive products of the irradiation of uranium must be stored securely for very long periods of time to avoid leakage of radioactivity to the environment.The volumes of material to be so disposed are very small in comparison with the wastes from burning coal, & nearly all of it can be transformed into solid form suitable for deep rock-burial.

Such repositories might take the form of bore-holes drilled kilometres deep into the realm of Pluto, & the material would be guarded for ever behind the adamantine doors guarded by Tisiphone, one of the Erinys, or Furies, at the gates of Hades,

One of the Erinys, or Furies

behind which her sister Furies torment the souls of imprisoned offenders. This seems quite appropriate, for it will be recalled that the Furies were the direct product of the blood of Uranus resulting from his castration by Cronus.

STARFIRE and the TRITONS

The true Fire from Heaven would be a proton fusion plasma such as keeps Helios burning; but even with Prometheus' best skills this reaction could not be established and sustained in devices which could possibly be built at the Earth's surface. There are two reasons for this: first, the chances of fusion between two protons to produce a deuteron (the first step in the 'proton chain' series of fusion reactions in the stars) are so miniscule that the characteristic reaction time for the process is billions of years; secondly, to sustain even the very low volumetric rate of reaction in the Sun requires the huge pressures and consequent high densities characteristic of the cores of stars & produced by the gravity forces available only in celestial bodies approaching 100 times the diameter of the Earth. The compression due to these same gravity forces is also responsible for the initial heating of the core to the 10 million degrees needed to initiate the fusion reaction.

However, Proteus' brothers Deuteron & Triton fortunately provide one possible way out of the difficulty. It so happens that the nuclei of the two rare isotopes of hydrogen, deuterium & tritium (note: d = deuteron = proton fused to a neutron; t = triton = proton fused to 2 neutrons), fuse together very much more easily than do pairs of protons, with characteristic reaction times of fractions of a second instead of billions of years at the temperatures typical of the cores of stars (tens of millions of degrees). When this fusion occurs,a helium nucleus is formed & a very fast neutron is released.

It is also feasible to achieve an adequate reaction rate for practical purposes at very much lower densities than those in stars. Moreover, the energy released per fusion reaction is very high: 17.6 MeV per d-t fusion reaction, which compares well with the 'proton-chain' reaction in the stars, & is twice the energy per nucleon reacting in uranium fission.

Again, good fortune, or Proteus, comes to the rescue: there is sufficient deuterium in the natural waters of the Earth (1 part in 6,500) to meet World energy needs for millions of years. And although tritium (which is radioactive: 12.3-year half-life) is not directly available from nature, it can be manufactured by transmuting lithium (the lightest non-gaseous element, a metal rather similar to sodium & potassium), of which there are abundant supplies in various forms (land & sea). The lithium, in a suitable chemical form, would be placed in a metre-thick 'blanket' surrounding the fusion reaction zone so as to absorb the escaping neutrons. The energy released by the fusion reactions, carried by the neutrons as kinetic energy, changes to heat in the blanket as a result of successive slowing-down collisions with the atoms of the blanket material & exothermic nuclear reactions. This heat can then be converted into useful power.

Fortunately, matters can be so arranged that the (very) fast neutrons emitted by the d-t fusion reaction may be caused, as they enter the lithium blanket,to interact with certain materials having special nuclear properties (eg Be, Pb) to produce more neutrons of lower energy. This last is a vital consideration because the d-t fusion reaction only produces one neutron: & one neutron must be captured in lithium to produce a replacement atom of tritium. For a practical self-sustaining plant an effective 'neutron multiplier' system is thus essential to make available several neutrons per tritium atom consumed.

The d-t nuclear fusion reaction can easily be performed in laboratory particle accelerators, but for energy efficiency a confined plasma of d & t is needed to create conditions for thermonuclear fusion.

CONFINING a TRITON: CYRENE and ARISTAEUS

Perhaps we can gain some inspiration on the matter of confining tritons from the story of Cyrene, who was a nymph & a huntress. Once, whilst fighting a lion on Mount Pelion, she was seen by Apollo, who greatly admired her. Apollo carried her away to Libya: her son, Aristaeus, was the outcome. He became a farmer & shepherd, & pioneered beekeeping. When all his bees died in a plague & drought ravaged his farm, he sought advice from his mother in a water-nymph's cave by a river. Virgil tells of Cyrene's words in 'Georgics':

''There dwells in the Mediterranean
a seer,' she began to say -
'Sea-blue Proteus, one who drives
through the mighty deep
His chariot drawn by harnessed fish
& two-legged horses.
. . . Him we nymphs & ancient Nereus hold
In honour, for he knows all
That is, that has been, & all that is
about to be -
Knows all by the god Neptune's grace,
whose herds of monsters
And hideous seals he pastures
in meadows submarine.
This seer, my son, you must
bind in fetters before he'll tell you
The whole truth of your bees' sickness
& put things right.
Except to violence he yields
not one word of advice; entreaties
Have no effect; you must seize him,
offer him force & fetters,
On which in the end his wiles
will dash themselves to waste.
. . . But when you have him fast
in a handhold & fettered, then
With the guise & visage of various
wild beasts he'll keep you guessing;
Suddenly he'll turn into
a bristling boar, a black tiger,
A laminated dragon
or lioness tawny-necked,
Or go up in a shrill burst of flame
& thus from his fetters
Escape, or give you the slip
gliding off in a trickle of water.
But the more he transforms himself,
The tighter, my son, you must strain
the shackles that bind his body,
Until at last it changes back
to the first likeness.''

Perhaps this verse reflects the enormous difficulties which characterise the major problem of plasma confinement: intabilities of a wide variety of types, from the snaking & wriggling of the plasma as a whole,through subtle internal convolution, to major collapses of the plasma known as 'disruptions' which place great stresses on the engineering structure & cause local melting of the walls of the primary containment vessel. Instabilities of one sort or another bedevil every type of confinement system, electrical or otherwise.

We have much yet to learn about Fire from Heaven & Proton Power:perhaps the Pantheon of Greek gods can yet inspire our thoughts & help place our ideas in perspective.

ZEUS' THUNDERBOLTS and the RING of FIRE

Instead of gravity, as used for plasma confinement in stars, on Earth electrical forces can be used both to confine and to heat a plasma of deuterons, tritons & electrons. A mixture of deuterium and tritium gas (simply forms of hydrogen gas)is first made electrically conductive, in much the same manner as for the current in a fluorescent lamp: to do this, the original non-conducting gas mixture has had some of the planetary electrons 'knocked off' the gas atoms (eg. by radio-frequency excitation) to form an electrically-conducting plasma viz. a mixture of positive-charged ions (deuterons & tritons) with negative-charged electrons.

The initial pressure of the gas in the containing vessel (several 100 cu.m.) is very low:say a millionth of an atmosphere, & even in a large device there would only be a fraction of a gram of mixture in the vessel. However, when eventually heated to a 100 million degrees, the 'gas' pressure exerted by the ions is very large: perhaps a 100 atmospheres or more.

This pressure must be resisted by the confinement, which in the electromagnetic devices takes the form of a magnetic field. The ions, being electrically charged, become bound to the magnetic field-lines, along which they move in a corkscrew motion. The field lines can be arranged to resist the expansive force of the 'gas'(ie plasma), and keep the plasma away from the metal walls of the primary vessel so that the plasma body does not lose its internal heat.

In the type of device favoured at the present time, this process is set up in a large toroidal vessel of the proportions of a doughnut, but several metres in cross-sectional diameter. This doughnut of electrically-conductive plasma is arranged to form the secondary coil of a very large electrical transformer, through the multi-turn primary winding of which is sent a very powerful pulse of electric current. This induces a huge electric current ('ring of fire') in the plasma in the toroid, which may reach 10 million amperes or more: a hundred times the current in one of Zeus' most powerful terrestrial thunderbolts.

Simultaneously, this produces two effects: first, it constricts & compresses the plasma due to the 'pinch effect' such that it is isolated from the walls of the toroidal vessel, &, secondly, it heats the plasma by ordinary electric resistive heating.

Resistive heating by the transformer action is, alone, insufficient to achieve the hundred million degrees needed for an adequate fusion rate. This is because the heated plasma has a resistivity(comparable with that of copper at room temperature) which decreases with increase of temperature, so the heating effect becomes progressively less effective. Auxiliary heating is therefore needed: atomic beam & micro-wave techniques are employed.

The 'pinch effect' is familiar in engineering as the force which pulls together two parallel wires carrying electric currents in the same direction, due to the interaction of the current in one wire with the magnetic field of the other.

In a plasma, the induced electric current is not 'mechanically' confined within the boundaries of wires, & in fact, as already mentioned, becomes unstable and 'corkscrews' around in many modes of movement. However, this instability can be greatly reduced by imposing a very powerful magnetic field along the bore of the torus by means of a coil of wire wound around it. In practice, this toroidal winding takes the form of a set of separate very powerful magnet-coils (several tesla field-strength at the centre-line) through which the doughnut is threaded. To economise on power they may have superconducting windings: such coils must be shielded from the neutron leakage flux.

A great many other factors have to be considered & provided for, but this is the essence of the Tokamak Fusion Reactor concept. Very large experimental machines are now in operation, and a demonstration reactor will no doubt be built early in the next century. The great advantages offered by a fusion reactor as compared with a fission reactor include: an effectively infinite supply of fuel with very small environmental effect to obtain it; no inventory of fission products or other radioactive material release-prone in an accident (but tritium needs care); no possibility of a 'reactivity' accident; & less total radioactivity production. The neutrons do produce considerable activity in structure etc, but this is a more tractable problem than fission products; & there are no transuranium elements.

The development of magnetic-confinement nuclear fusion reactors is a very complex & demanding technical problem, but it will be solved, & may well, in the long run, supersede fission power & greatly contribute to solving the World's stationary-plant energy problems: they may well also help to solve some aspects of the transport power problem.

A cross-section view of a fusion reactor would be a bit like Aristotle's Universe: this is indicated in the final figure.

EPIMETHEAN CONFINEMENT

Just as Epimetheus' 'sledge-hammer' method with the fission chain reaction was highly successful in producing a bomb, and would have been feasible even had Prometheus' steady-state fission chain reactor proved impossible, so once again the Epimethean approach was successful in producing an enormous yield of energy from the deuterium-tritium reaction in the form of an explosion long before a net energy gain had been achieved with a steady-state nuclear fusion device. The shackles used to confine the deuteron-triton mixture so as to achieve this took the form of an Epimethean fission bomb.

The simplest method of doing this would seem to be to place a 50:50 mixture of deuterium and tritium in suitable chemical form inside the hollow core of the fission bomb. When the fission bomb detonates, the tritium and deuterium are immediately compressed, vapourised & then ionised to form a plasma at a very high density and temperature, sufficient to initiate the fusion reaction. This is quite analogous to the compression-ignition of protium (hydrogen) in a newly-forming star, except that it is a very transient process, depending on 'inertial confinement' rather than an effectively 'steady-state' process, (in reality a very long-term transient) as is established in stars.

It is believed that large fusion bombs are much more complex devices, with a multi-stage operation involving various different zones of fusile material and indirect methods of confinement using the powerful X-ray emissions from the fission core.

Schemes have been studied whereby useful, steady-state energy might be generated using a regular series of nuclear fusion explosions (eg. several times per day), in a huge, steam-filled underground cavern. The steam is heated by the energy released by the explosion & drawn off at the surface for operating a power plant. Such a scheme is no doubt feasible in principle, but has so many tremendous technical difficulties & political implications that it seems most unlikely ever to be developed.

However, there still remains a slight possibility that nuclear explosives may become useful for major civil engineering.

SHACKLES of LIGHT

Finally, mention must be made of another approach to shackle & fetter deuterons & tritons, in which extremely powerful pulses of light, or perhaps of nuclear particles, are used to compress & heat small (several-millimetre-size) spherical pellets containing the fusile mixture. Several beams, perhaps several tens of beams, would converge on to the pellet from all directions to illuminate its surface very uniformly. The beam-power would be trillions of watts for a few billionths of a second ('nanoseconds') and would compress the fusile material to very high densities & resultant temperatures. The energy release from each pellet would be equivalent to a few kilograms of explosive, which would be withstood by a reaction chamber several metres in diameter. As for the case of the magnetic fusion reactor, the fusion energy would mostly be transferred by the neutrons into a lithium blanket in which heat would be generated (for eventual power production) & tritium would be manufactured for recycling for use as fuel.

To constitute a useful power plant several such pellets would have to be exploded each second. This would require extremely powerful lasers capable of a very high average power output. Such lasers are being developed, but on balance it would seem that the magnetic fusion techniques are further ahead & likely to be the first to generate useful power.

The JUDGEMENT of the GODS

The whole human experiment has been based upon proton power. The reactions between protons energise the stars and manufacture multi-proton nuclei to make the great variety of chemical elements. The planets spawned by stars are warmed by a tiny fraction of their output power. In the case of the Earth, an internal furnace, based on proton power manifested as radioactivity, keeps the upper mantle plastic, drives the motion of continental plates & so forms mountains which proton-(ie Sun-)-driven weather can erode to form soils. Hence the development of the great land-kingdoms of plant and animal life. Prometheus seems to have had a hand in creating human life and in endowing humankind with the gift of both chemical & nuclear fire. To survive into the far future mankind is going to need the gift of nuclear fire, & must redouble efforts to develop safe & economic power systems acceptable to the public,& to avoid its application in wars.

Perhaps the corner is being turned.Perhaps the nuclear swords we have crafted will be disassembled and turned to better use. We should be able to make inherently safe nuclear fission reactors and to develop means for safely storing their waste products. Eventually, nuclear fusion will undoubtedly become feasible, economic and safe, but it is a long & complex road and we may have to use uranium fission power for much if not all of the 21st century and perhaps well beyond.

NOTES, FURTHERS READING, REFERENCES, ILLUSTRATION & TEXT ACKNOWLEDGEMENTS

POWERS of TEN

eg: 10exp3: reads "ten exponent three":means 10x10x10 = 1,000; ie 1 followed by three 0's
10exp(-3) means 1/1,000 (ie one-thousandth); (this notation is easy to type)
10exp6 is 1,000,000 ie a million (mega-); 10exp9 is 1,000,000,000 = a billion (giga-)
10exp12 is a trillion = a million million (tera-); 10exp80 is 1 followed by 80 zeros
10exp11 stars/galaxy x 10exp11 gaxies/universe = 10exp22 stars in observable universe
10exp33 grams/star x 10exp24 protons/gram = 10exp57 protons/star: hence c.10exp79 p/u

FURTHER READING

Note: * means hard to access or rare; other references are to popular books & journals, readily available in libraries, or in print

Mythology & Antiquity:
* Bullfinch (1897):The Age of Fable (13 of 16 text illustrations): Henry Altemis 1903
Larousse Encyclo. Myth. 1959/66 & New ed. 1968/86:(ill.of Pandora's Box):Hamlyn 1966
Sherwood Taylor: Science Past & Present (ill. Aristotelian Universe): Heinemann 1949

Poetry:
Aeschylus (Tran.Murray): Prometheus Bound: Allen & Unwin 1931
Virgil (Tran. Lewis): The Georgics (w. Eclogues): OUP World Classics 1983
Hesiod (Tran.Lattimore): Works & Days, Theogony, Shield of H.: U of Michigan 1959
Milton (Ed.Beeching): Poetical Works of John Milton: Oxford University Press 1916
Byron (Ed.Page): Byron: Poetical Works (Childe Harold C III cvi): OUP 1970

Proton, Neutron, Nuclei: (Note: SA = Scientific American; NS = New Scientist)
Kendall & Panofsky: The Structure of the Proton & the Neutron: SA Jun 1971
Jacob & Landshoff: The Inner Structure of the Proton: SA Mar 1980
Weinberg: The Decay of the Proton: SA Jun 1981
Dicus et al: The future of the Universe (on proton decay): SA Mar 1983
Greiner & Sandulescu: New Radioactivites (on deformation & ejection): SA Mar 1990

Cosmology:
Hoyle: Frontiers of Astronomy: Heinemann 1955/61
Weinberg: The First Three Minutes: Flamingo/Fontana 1977/83
Narlikar: The Primeval Universe: Opus/OUP 1988
Narlikar: What if the Big Bang Never Happened?: NS 2 Mar 1991
Lerner: The Big Bang Never Happened: Times Books 1991

Stars:
Boss: Collapse and Formation of Stars: SA Jan 1985
Stahler: The Early Life of Stars: SA Jul 1991
Cox: The Elements: origin, abundance & distribution: OUP 1989

The Sun:
Mitton: Daytime Star: Faber & Faber 1981
Menzel: Our Sun: Harvard University Press 1959
Foukal: The Variable Sun: SA Feb 1990

Formation of Solar System:
Clark & Cook: Perspectives of the Earth: Aust Academy of Science 1983
Wetherall: The Formation of the Earth from Planitesimals: SA June 1981
Henbest: Rocky Dwarfs & Gassy Giants: NS 10 Feb 1990
Henbest: Birth of the Planets: NS 24 Aug 1991

Formation & Development of the Earth:
O'Nions et al: The Chemical Evolution of the Earth's Mantle: SA May 1980
Brimhall: The Genesis of Ores: SA May 1991
White & McKenzie: Volcanism at Rifts: SA Jul 1989
Deffeyes & MacGregor: World Uranium Resources: SA Jan 1980

Heating of Earth due to Radioactive Elements:
McKenzie: The Earth's Mantle: SA Sep 1983
* Gabelman: Migration of U & Th: Amer.Assn.Petroleum Geologists 1977
* Clark & Turekian: Thermal cnstrnts. on distrib. r/a elements: R.Soc.Lond.1979

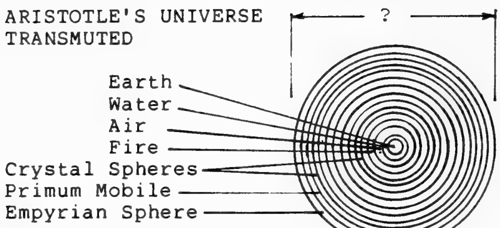
Nuclear Fission Reactors:
Leachman: Nuclear Fission (on physics of fission): SA Aug 1965
Cowan: A Natural Fission Reactor (on Oklo reactor): SA Jul 1976
* IAEA: Dir.Nu.Reac.vol.II: Chicago Pile (CP-1): IAEA Vienna 1959
Golay & Todreas: Advanced Light Water Reactors: SA Apr 1990
Seaborg & Bloom: Fast Breeder Reactors: SA Nov 1970
Hafele: Energy from Nuclear Power: SA Sep 1990

Nuclear Explosives:
Rhodes: The Making of the Atomic Bomb: Penguin Books 1988
Wilkie: Old Age can Kill the Bomb (on fusion bomb): NS 16 Feb 1984

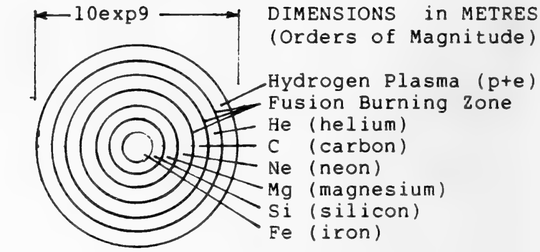
Nuclear Fusion Reactors:
Conn: The Engineering of Magnetic Fusion Reactors: SA Oct 1983
Craxton et al: Progress in Laser Fusion: SA Aug 1986
Rafelski & Jones: Cold Nuclear Fusion (muon catalysed fusion): SA Jul 1987

ARISTOTLE'S UNIVERSE TRANSMUTED

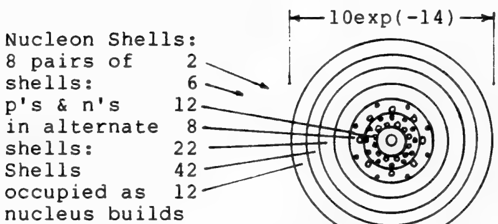
DIMENSIONS in METRES (Orders of Magnitude)



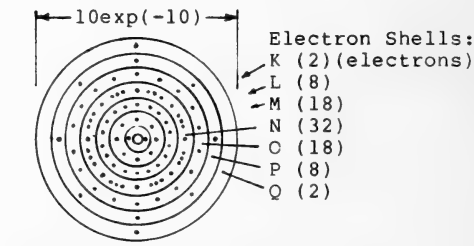
Aristotle's Universe



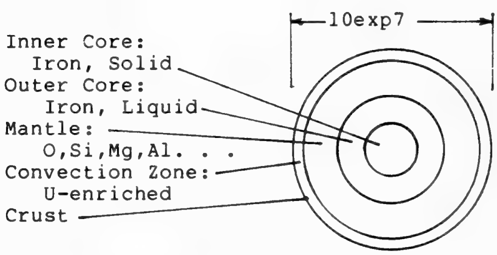
Large Star: 7 Fusion Zones



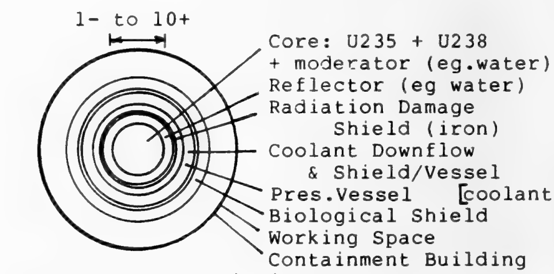
Shell Model of Nucleus



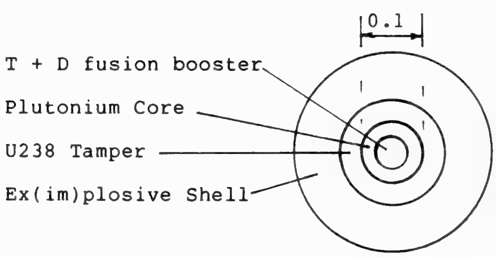
Rutherford/Bohr Nuclear Atom



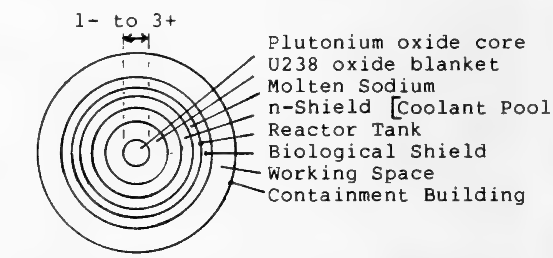
Earth



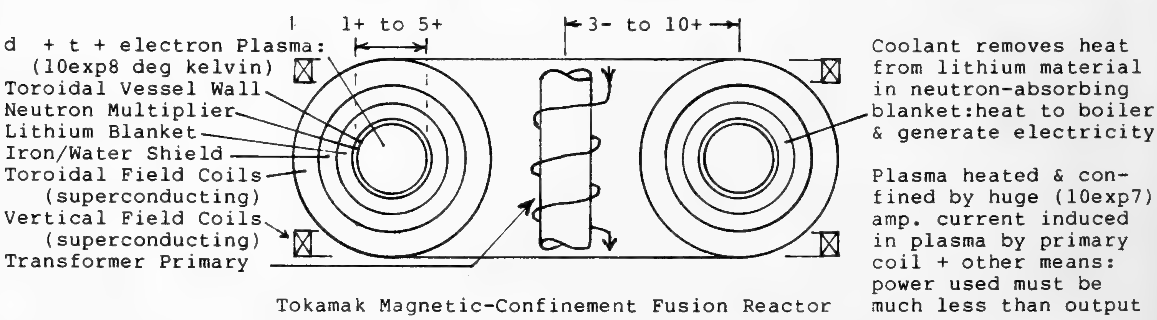
Thermal-neutron Fission Reactor



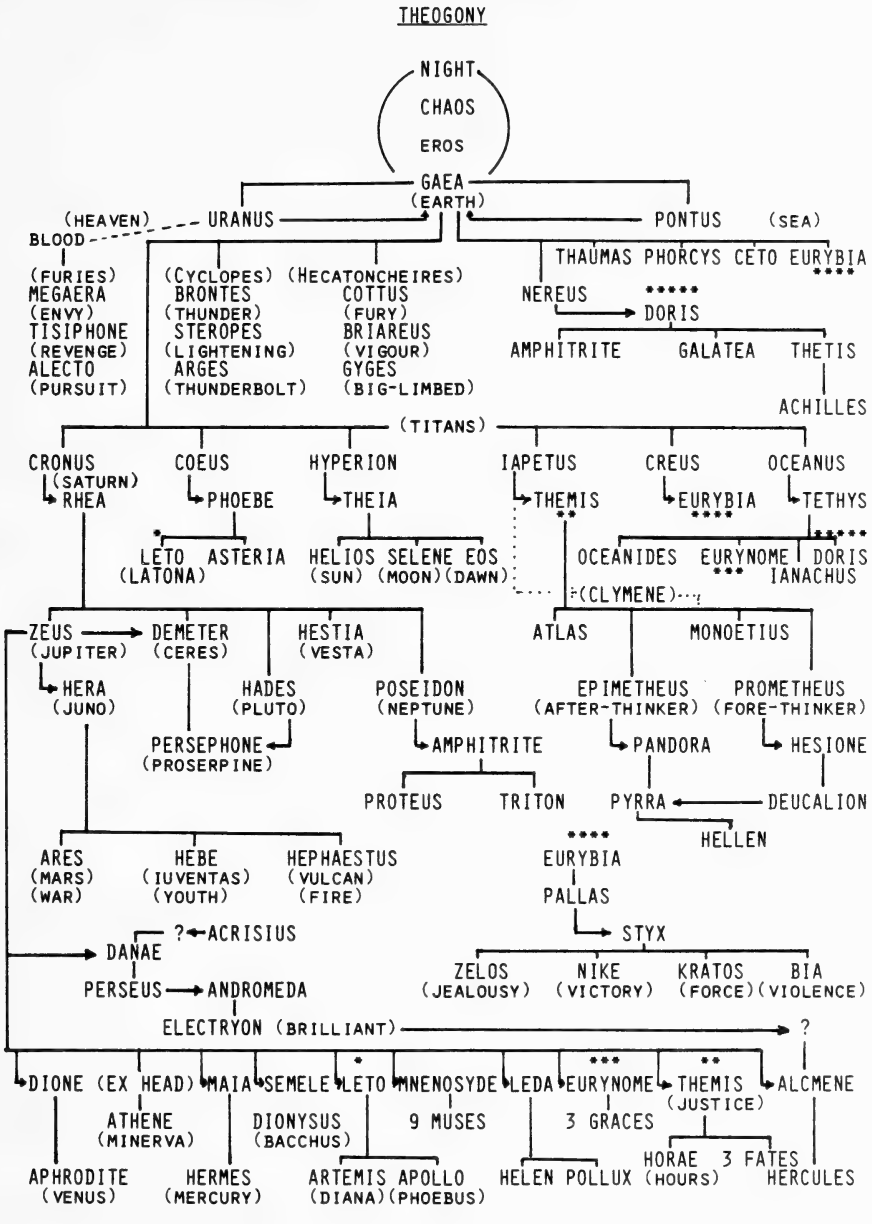
Nuclear Bomb



Fast-neutron-fission Breeder Reactor



Tokamak Magnetic-Confinement Fusion Reactor



Expansion of a Presidential Address delivered before the Royal Society of New South Wales on the 3rd April, 1991.

G.W.K.Ford M.B.E.,
C/- Royal Society of New South Wales,
P.O.Box 1525
Macquarie Centre, N.S.W. 2113

(Manuscript received 6.11.1991)

Annual Report of Council

FOR THE YEAR ENDED 31 MARCH 1991

PATRON

The Council was saddened by the death on 10 August 1990 of the Society's Patron, His Excellency Rear Admiral Sir David Martin, KCMG, AO, Governor of New South Wales. Council wishes to express its gratitude to Sir David Martin's successor as Governor, His Excellency Rear Admiral Peter Sinclair, AO, who kindly agreed to become patron in August 1990.

MEETINGS

Eight General Monthly Meetings and the 123rd Annual General Meeting were held during the year. The average attendance was 24 (range 10 to 40). Abstracts of the Addresses were published in the Newsletter. The Annual General Meeting and seven of the General Monthly Meetings were held at the Australian Museum. A summary of proceedings is set out in a report below.

The Liversidge Research Lecture was held in conjunction with the 1013th General Monthly Meeting on 5th September, 1990, in the Nyholm Theatre, University of New South Wales. The Liversidge Lecture was delivered by Professor D. St. C. Black, Professor of Organic Chemistry and Head of the School of Chemistry in the University of New South Wales. The topic was "Some Natural and Unnatural Indoles". The lecture has been published in Volume 123, pp. 1-13 of the Journal and Proceedings.

The Society was a co-sponsor of a joint meeting on 13th February, 1991, with the Institution of Engineers (Australia) Sydney Division's Nuclear Engineering Panel, the Australian Nuclear Association and the Australian Institute of Energy. The meeting was addressed by Dr.R.S.Pease, FRS, visiting Professor of University of New South Wales, on "Nuclear Fusion Power: Prospective and Economic and Environmental Aspects - Some Comparisons".

An Annual Dinner was held on 13th March, 1991, in the Sir Hermann Black Art Gallery, in the Wentworth Building, University of Sydney The guests of honour were His Excellency the Honourable Mr.Justice Gleeson, AO, Lieutenant-Governor of New South Wales, and Mrs. Gleeson. The President, Mr.Kim Ford, welcomed the guests of honour and introduced His Excellency, the Honourable Mr.Justice Gleeson who presented the Society's Medal to Dr.Lin Sutherland (a Vice-President) and the Edgeworth David Medal to Dr.Timothy Flannery. His Excellency, the Honourable Mr.Justice Gleeson then delivered the Occasional Address. Dr.Edmund Potter (President-Elect) responded by proposing a vote of thanks, and presenting His Excellency with a copy of the Society's Centenary Volume. Forty-six persons were in attendance.

Eleven meetings of the Council were held at the Society's office, 134 Herring Road, North Ryde. The average attendance was nine.

PUBLICATIONS

Volume 122, parts 3 & 4, and Volume 123, parts 1 & 2 of the *Journal and Proceedings* were published during the year. They incorporated eight papers, and the Occasional Address by Rear-Admiral Sir David Martin, the Patron, at the Annual Dinner in March, 1990, together with the Annual Report of Council for 1989-90. The Liversidge Research Lecture for 1990 was also included. Council is again grateful to the voluntary referees who assessed papers offered for publication.

Ten issues of the Newsletter were published during the year, and Council thanks the authors of short articles for their contributions.

Council granted permission to reproduce material from the *Journal and Proceedings* in three instances.

MEMBERSHIP

The membership of the Society as at 31st March, 1991, was:

Honorary members	14
Life members	22
Ordinary members	234
Absentee members	13
Associate members	20
Total	303

During the year Council elected one new Honorary Member, Dr. John Paul Wild, distinguished former Head of the Commonwealth Scientific and Industrial Research Organisation and currently Chairman of the Very Fast Train consortium. Mrs. Grace Proctor, former Honorary Assistant Librarian was elected to honorary life membership in recognition of her devoted service to the Society over many years and her contributions to the efficient operation of the Society's library in Sydney and the Royal Society of New South Wales' Collection in the University of New England Library.

The following twelve new Members were elected and welcomed to the Society:-

Charles Victor ALEXANDER
Sydney Allison BAGGS
Ian Lindsay BARNETT
James Lindsay COOK
John Charles GROVER
Norbert Victor Peter KELVIN
David John LAMOND

Gerrit NEEF
Barbara POSTEN-ANDERSON
Graeme Lindsay WHITE
Lyall Richard WILLIAMS
Vicky Wai-Suen YEUNG

With great regret, the Council received news during the year of the deaths of the following members:

John Manning WARD, 6.5.1990
Frederick Noel HANLON
Barbara Joyce McNAMARA, 17.6.1990
Lyndon Charles NOAKES, 29.6.1990
Alice WHITLEY, 6.8.1990

AWARDS

The following awards were made for 1990:

Clarke Medal (in Zoology):-
Professor Barrie Gillean Molyneaux JAMIESON, Department of Zoology, University of Queensland.

Edgeworth David Medal (research under age 35 years):-
Dr. Timothy Fridjof FLANNERY, The Australian Museum, Sydney.

Royal Society of New South Wales Medal:-
Dr. Frederick Linstead SUTHERLAND, The Australian Museum, Sydney.

The Cook Medal and the Olle Prize were not awarded.

SUMMER SCHOOL

This year's Summer School on "Technology, Today and Tomorrow" was fully subscribed and proved to be most successful. It was held from the 14th to 18th January,1991, at Macquarie University. 58 senior high school students from private and public schools statewide attended. Seventeen speakers from universities, government and industry addressed the students, and two half-day excursions for industrial instruction were undertaken. The Summer School was organised by Mrs. M. Krysko on the Society's behalf.

Visits were made to BULL HN Information Systems Australia Pty.Ltd., North Ryde, to Digital Equipment Corporation Australia Pty. Ltd. Rhodes, and to the Commonwealth Special Research Centre for Lasers and Applications, Macquarie University.

The Council wishes to thank the speakers and organisers of visits, whose addresses and demonstrations helped to make the school a success. Council's appreciation is extended to Mrs. Krysko and to the various Councillors who assisted Mrs. Krysko and chaired meetings. Especial thanks go to Mrs. W. Swaine, who so expertly helped during the excursions and to Dr. and Mrs. Lin Sutherland for the hospitality they extended to country students at the Summer School.

OFFICE

The Society continued during the year to lease for its office and library a half share of Convocation House, 134 Herring Road, North Ryde, on the southeastern edge of Macquarie University campus. The Council is grateful to the University for allowing it to continue leasing the premises.

LIBRARY

Acquisitions by gift and exchange continued as heretofore, the overseas and some Australian material being lodged in the Royal Society of New South Wales' Collection in the Dixson Library University of New England. Other Australian material was lodged in the Society's office at North Ryde. The Council thanks Mr. Karl Schmude, University Librarian, for his continuing care and concern in ensuring the smooth operation of the Royal Society Collection and associated inter-library photocopy loans.

After twenty years of expert custodianship of the Library, Mrs. Grace Proctor found it necessary to tender her resignation at the close of 1990. For the last ten years Mrs. Proctor acted in a completely voluntary capacity, during which period she had not only the normal duties of Librarian of a Special Library, but also the complex problems associated with the move of a large part of the Library to form the Royal Society of New South Wales' Collection in the Dixson Library, University of New England. All of this she accomplished with professionalism and a personal charm which endeared her to the many users of the Library through the years. The duties of the Librarian will be continued by the Honorary Librarian, Miss Patricia Callaghan.

NEW ENGLAND BRANCH REPORT

The Branch held five meetings during 1990:-

Tuesday, 10th March,1990:- Professor Trevor Bryce, Professor of Classics and Ancient History at the University of New England spoke on "The Archaeologist at work in the Ancient Near East".

May, 1990:- A function was held at Armidale and a talk given on "Method in Archaeology". Professor Stanton reported also on a proposal for a Chancellor's Medal Competition amongst post-graduate students at New England in order to encourage an interest in the Royal Society of New South Wales, and science in general, by holding a series of public meetings at which post-graduate students would present 10-minute papers on topics of their choosing.

Monday, 11th September, 1990:- Professor J.R. Burton, Head of the Department of Resource Engineering and Foundation Professor of Natural Resources at the University of New England, gave a talk on "The Coronation Hill Fiasco". About 90 were present.

Thursday, 18th October, 1990:- Dr.G.Riley, (Office of the Supervising Scientist), spoke on "Mining and the Environment in Kakadu National Park".

Thursday, 1st November 1990:- Dr.Ian Lowe, Director of the Science Policy Research Centre at Griffith University, spoke on "The Impossible Dream".

ABSTRACT OF PROCEEDINGS

APRIL 4, 1990

(a) The 1008th General Monthly Meeting. Location: Hallstrom Theatre, the Australian Museum. The President, Mr.H.S.Hancock was in the Chair and 22 members and visitors were present.

Election to Membership:-

S.A.Baggs
I.L.Barnett
G.Neef
B.Poston-Anderson
Lyall Richard Williams

Council announced with regret the deaths of the following members:-

Alan Norval Carter (9.11.89)
Michael Duhan Garretty (Life Member) (21.11.89)
Adrien Albert (Life Member) (29.12.89)
Ilse Rosenthal-Schneider (Honorary Member) (6.2.90)
Haddon Forrester King (11.3.90)

(b) The 123rd Annual General Meeting. The Annual Report of Council for 1989-1990 and the Financial Report for 1989 were adopted, and Messrs. Wylie and Pottock were re-elected as Auditors for 1990.

The following Awards for 1989 were announced:-

Clarke Medal:	Professor John Roberts
Society Medal:	Professor John Harold Loxton
Edgeworth David Medal:	Dr.Trevor William Hambley

The Archibald D.Olle Prize, the James Cook Medal and the Walter Burfitt Prize were not awarded for 1990.

The following Office-Bearers and Council were elected for 1990-1991:-

President:	Mr.G.W.K.Ford
Vice-Presidents:	Mr.H.S.Hancock Professor J.H.Loxton Emeritus Professor R.L.Stanton Dr.F.L.Sutherland Associate Professor D.E.Winch
Honorary Secretaries:	Dr.R.S.Bhathal Mrs.M.Krysko(Editorial)
Honorary Treasurer:	Dr.A.A.Day
Honorary Librarian:	Miss P.M.Callaghan
Members of Council:	Mr.J.R.Hardie Mr.E.D.O'Keeffe Mr.T.J.Sinclair Dr.D.J.Swaine Mr.J.A.Welch

The retiring President, Mr.H.S.Hancock, delivered his Presidential Address entitled:- "Some Memories of Computing". The vote of thanks was proposed by A/Professor D.E.Winch

MAY 2, 1990

The 1009th General Monthly Meeting. Location:- Lilac Room, the Australian Museum. The President, Mr.G.W.K.Ford, was in the Chair, and 20 members and visitors were present.

An address on "Radio Astronomy, the Australian Telescope and the Technology behind the Science" was delivered by Dr.Dennis N.Cooper, Chief, C.S.I.R.O., Division of Radiophysics.

Professor T.Cole became a founding member of the Australian Academy of Design, which was funded initially by Australia Council and Federal Government's National Industry Extension Service.

Council announced that Professor David Craig, Honorary Member, was elected President of the Australian Academy of Science at the 36th Annual General Meeting of the Academy in April, and that Dr.Chris Fergusson of the Department of Geology, University of Wollongong, was awarded the inaugural Alan Voisey Medal of the Geological Society of Australia.

Council announced with regret the death of Professor John Manning Ward, who was tragically killed in the train crash at Hawkesbury on 6th May, 1990.

JUNE 6, 1990

The 1010th General Monthly Meeting. Location:- Lilac Room, the Australian Museum. The President, Mr.G.W.K.Ford, was in the Chair, and 18 members and visitors were present.

An address on "Human Temperature Regulation - A Case Study in Interdisciplinary Research" was delivered by Mr.John Welch, Mechanical Engineering Department, North Sydney Technical College. A vote of thanks was offered by Dr.D.J.Swaine.

JULY 4, 1990

The 1011th General Monthly Meeting. Location: Hallstrom Theatre, the Australian Museum. The President, Mr.G.W.K.Ford, was in the Chair, and 22 members and visitors attended.

An address on "State of Science - Research, development and the future of New South Wales" was presented by Mr.David Ellyard, Acting Deputy Director, Technology Subdivision, New South Wales Department of Business and Consumer Affairs. A vote of thanks was proposed by Dr.Alan Day.

Council announced with regret the death of Lyndon Charles Noakes (29.6.1990) and Barbara Joyce McNamara (17.7.1990). Dr.McNamara was the daughter of Dr.Walter Burfitt who generously left a bequest to the Society which established the Walter Burfitt Prize.

AUGUST 1, 1990

The 1012th General Monthly Meeting. Location:- Hallstrom Theatre, the Australian Museum. The President, Mr.G.W.K.Ford, was in the Chair, and 23 members and visitors attended.

An address on "Environmentalists - the New Economic Illiterates?" was given by Dr.David Clark, School of Economics, University of New South Wales, Columnist with the Australian Financial Review. The vote of thanks was offered by Dr.Alan Day.

James Lindsay Cook and Charles Victor Alexander were elected to membership.

Council announced with regret the death of Frederick Nolan Hanlon (2.6.1990), a former President of the Society (1957).

SEPTEMBER 5, 1990

The 1013th General Monthly Meeting. Location:- Nyholm Theatre, School of Chemistry, University of New South Wales. Associate Professor D.Winch was in the Chair, and 40 members and visitors were present.

This meeting was held in conjunction with the Liversidge Research Lecture. Professor D. St.C.Black, Professor of Organic Chemistry and Head of the School of Chemistry, University of New South Wales, delivered the Liversidge Research Lecture entitled "Some Natural and Unnatural Indoles". A vote of thanks was proposed by Associate Professor D.E.Winch.

Council announced with deep regret the passing of Rear Admiral Sir David James Martin,AO Governor of New South Wales and Patron of the Society, on 10th August 1990. The President, Mr.G.W.K.Ford, and Mrs. Ford attended the State Funeral and Service of Thanksgiving at St.Andrew's Cathedral on Thursday 16th August 1990 on behalf of the Council and Members.

OCTOBER 3, 1990

The 1014th General Monthly Meeting. Location:- Hallstrom Theatre, the Australian Museum. In the absence of the President, Mr.G.W.K.Ford, who was overseas attending conferences, the Vice-President, Associate Professor D.E.Winch was in the Chair, and 10 members and visitors were present.

An address "Recent Additions to the Australian Lexicon" was delivered by Sue Butler of Macquarie Library Pty.Ltd. A vote of thanks was proposed by Associate Professor D.E.Winch.

Council announced with great pleasure that His Excellency, Rear Admiral Peter Sinclair, A.O., Governor of New South Wales, had granted the Society Vice-Regal Patronage during his term of Office. Mr.G.W.K.Ford, Mrs.Ford and Mrs.M.Krysko Von Tryst represented the Society at a function on 14th September, 1990 at Government House.

NOVEMBER 7, 1990

The 1015th General Monthly Meeting. Location:- Hallstrom Theatre, the Australian Museum. The President, Mr.G.W.K.Ford, was in the Chair, and 40 members and visitors were present.

An address "Forbidden Music" was delivered by Fred Blanks, AM, Music Critic, Sydney Morning Herald, Music Critic, Australian Jewish News, and Australian Correspondent, Musical Times (U.K.).

As there would be no Meeting in December, President and Council offered members greetings of the Season.

News of Members:- An Honorary Member of the Society, Sir Gustav Nossal, Director of the Walter and Eliza Hall Institute and Professor of Medical Biology at the University of Melbourne, was awarded the Albert Einstein World Award of Science by the World Cultural Council.

Andrew Tink, who is the State Member for Eastwood, has recently been elected Chairman of the State Government Committee on Industrial Relations, Further Education, Training and Employment.

Council Member, Mr.E.D.O'Keeffe, Lecturer in Mathematics at Macquarie University, recently stepped down after 15 years as President of the Macquarie University Sports Association. The Association has now resolved to recognise his outstanding service by the annual award of the Ted O'Keeffe Scholarship for both academic achievement and service to the University and/ or Sports Association.

Honorary Member, Dr.Frederick McCarthy has been elected an Honorary Fellow of the Australian Academy for the Humanities for his distinguished contribution to the creative arts in Australia.

Mr.Barry Jones was appointed a special part-time professorial fellow in the Department of Science and Technology Studies in the University of Wollongong.

FINANCIAL STATEMENTS FOR THE YEAR ENDED 31st DECEMBER

AUDITORS REPORT TO THE MEMBERS

We have audited the accounts set out below in accordance with Australian Auditing Standards.

In our opinion, the accounts are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society as at 31 December 1990 and of the results of the Society for the year ended on that date and are in accordance with Statements of Accounting Concepts, applicable Australian Accounting Standards and applicable Approved Accounting Standards.

The accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provisions of those Rules.

WYLIE & PUTTOCK
Chartered Accountants

By ALAN M. PUTTOCK

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET as at 31st December 1990

1989				1990
	CURRENT ASSETS			
348.25	Petty Cash Imprest		192.05	
1694.00	Debtors for Subscriptions	1175.83		
1694.00	Less Provision For Doubtful Debts	1175.83		
12140.93	Other Debtors & Prepayments		10294.06	
9835.30	Cash at Bank		10788.46	
22324.48	TOTAL CURRENT ASSETS			21274.57
	NON-CURRENT ASSETS			
	Property, Plant & Equipment			
1076.37	Furniture, Office Equipment, etc.- at cost less Depreciation		955.37	
13600.00	Library - 1936 Valuation (note 4)		13600.00	
10.00	Pictures - at cost less Depreciation		10.00	
14686.37			14565.37	
	Investments			
2500.00	Commonwealth Bonds & Inscribed Stock	2500.00		
100000.00	Loans on Mortgage	100000.00		
35843.84	Interest Bearing Deposits	40422.11		
138343.84			142922.11	
153030.21	TOTAL NON-CURRENT ASSETS			157487.48
175354.69	TOTAL ASSETS			178762.05
	CURRENT LIABILITIES			
17044.00	Sundry Creditors & Accruals		20637.96	
25.77	Life Members Subscriptions - Current Portion		23.67	
100.21	Membership Subscriptions Paid in Advance		176.21	
1545.59	Subcriptions to Journal Paid in Advance		1500.00	
18715.57	TOTAL CURRENT LIABILITIES			22337.84
	NON-CURRENT LIABILITIES			
183.08	Life Members Subscriptions - Non-Current Portion		159.41	
183.08	TOTAL NON-CURRENT LIABILITIES			159.41
18898.65	TOTAL LIABILITIES			22497.25
156456.04	NET ASSETS			156264.80
	RESERVES			
7310.57	Library Reserve (note 2(a))			7310.57
7819.35	LIBRARY FUND (note 2(b))			6715.18
21332.22	TRUST FUNDS (note 3)			23078.43
119993.90	ACCUMULATED FUNDS			119160.62
156456.04	TOTAL RESERVES AND FUNDS			156264.80

G.W.K. FORD President

A.A. DAY Honorary Treasurer

ACCUMULATED FUNDS ACCOUNT
For the Year Ended 31st December 1990

(5572.59)	OPERATING DEFICIT for year		2861.53
800.12	Donations & Interest to Library Fund		924.08
13520.54	Proceeds Estate Late Dr G.H. Briggs		0.00
256.91	Transfer from Library Fund		2028.25
100643.86	Accumulated Funds - Beginning of Year		119993.90
120794.02	AVAILABLE FOR APPROPRIATION		120084.70
800.12	Transfer to Library Fund	924.08	
800.12			924.08
119993.90	ACCUMULATED FUNDS - End of Year		119160.62

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1990

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

The accounts have been prepared in accordance with applicable approved accounting standards.
Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1990. Unless otherwise stated, such accounting policies were also adopted in the preceding year

(a) Basis of Accounting

The accounts have been prepared on the basis of historical costs and do not take into account changing money values or, except where stated, current valuations of non-current assets.

(b) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

Furniture	7.50%
Office Equipment	15.00%

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1990

2. MOVEMENTS IN PROVISIONS AND RESERVES

(a) Library Reserve

7310.57	Balance at 1st January		7310.57
7310.57	Balance at 31st December		7310.57

(b) Library Fund

7276.14	Balance at 1st January		7819.35
800.12	Add Donations and bank interest		924.08
8076.26			8743.43
256.91	Less Library purchases and expenses	28.25	
0.00	Transfer to general fund re costs exchange jnls for library	2000.00	
256.91			2028.25
7819.35	Balance at 31st December		6715.18

3. TRUST FUNDS

Clarke Memorial Fund - Capital

5000.00	Balance at 1st January	5000.00		
5000.00	Balance at 31st December		5000.00	

Clarke Memorial Fund - Revenue

743.64	Revenue Income for Period	965.70		
1409.73	Less Expenditure for Period	85.89		
(666.09)		879.81		
709.72	Balance at 1st January	43.63		
43.63	Balance at 31st December		923.44	
5043.63				5923.44

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1990

1989				
	Walter Burfitt Prize Fund - Capital			
3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	
	Walter Burfitt Prize Fund - Revenue			
446.19	Revenue Income for Period	459.40		
446.19		459.40		
3034.24	Balance at 1st January	3480.43		
3480.43	Balance at 31st December		3939.83	
6480.43				6939.83
	Liversidge Bequest Fund - Capital			
3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	
	Liversidge Bequest Fund - Revenue			
446.19	Revenue Income for Period	834.40		
4.80	Less Expenditure for Period	1040.00		
441.39		(205.60)		
384.05	Balance at 1st January	825.44		
825.44	Balance at 31st December		619.84	
3825.44				3619.84
	Olle Bequest Fund - Capital			
4000.00	Balance at 1st January	4000.00		
4000.00	Balance at 31st December		4000.00	
	Olle Bequest Fund - Revenue			
594.91	Revenue Income for Period	612.60		
594.91		612.60		
1387.81	Balance at 1st January	1982.72		
1982.72	Balance at 31st December		2595.32	
5982.72				6595.32
21332.22	Total Trust Funds			23078.43

4. LIBRARY

During the 1983 year the Society gifted the serials collection component of the library to the University of New England. The Society has retained that section of the library which is of historical significance. At the 31st December, 1990 a current valuation of the library had not been obtained.

STATEMENT OF SOURCE AND APPLICATION OF FUNDS
For the Year Ended 31st December 1990

1989			1990
	SOURCE OF FUNDS		
5572.59	Operating surplus for the year	0.00	
	Add:		
	Items not involving the outlay of funds in the current period:		
112.00	Depreciation of fixed assets	0.00	
509.37	Provision for doubtful debts	0.00	
6193.96	Funds derived from operations		0.00
800.12	Donations and interest to library fund		924.08
2230.93	Trust fund income		2872.10
0.00	Reduction in working funds		4740.85
13520.54	Proceeds Estate Late G.H. Briggs		0.00
22745.55			8537.03
	APPLICATION OF FUNDS		
0.00	Operating deficit for the year	2861.53	
	Less:		
	Items not involving the outlay of funds in the current period:		
0.00	Depreciation of fixed assets	121.00	
0.00	Provision for doubtful debts	(68.67)	
0.00	Funds applied to operations		2809.20
25.77	Reclassification of life members subscriptions in advance		23.67
301.71	Acquisition of Equipment		0.00
14840.24	Increase in investments		4578.27
1414.53	Trust fund expenses		1125.89
6163.30	Increase in working funds		0.00
22745.55			8537.03

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31st December 1990

1989				1990
	INCOME			
7235.00	Membership Subscriptions - Ordinary			7288.50
35.37	Membership Subscriptions - Life Members			25.77
31.00	Application Fees			57.00
7301.37				7371.27
13344.17	Subscriptions and Contributions to Journal Publication Costs			8137.74
20645.54	Total Membership and Journal Income			15509.01
17899.36	Interest Received			18404.80
0.00	Sale of Reprints			37.70
0.00	Sale of Back Numbers			266.20
87.00	Sale of Other Publications			10.00
4.00	Photocopying Refunds			27.50
1224.44	Summer School Surplus			0.00
375.00	Annual Dinner Surplus			
4.00	Other Income			0.00
40239.34				34255.21
	Less:EXPENSES			
1790.00	Accountancy Fees		1933.00	
	Annual Dinner Deficit		116.86	
895.00	Audit Fees		967.00	
30.75	Bank Charges & Government Duties		30.70	
200.00	Branches of the Society		0.00	
112.00	Depreciation		121.00	
326.00	Entertainment Expenses		271.80	
80.15	Insurance		80.80	
	Journal Publication and Distribution Costs			
15776.00	Printing	14294.85		
2673.51	Wrapping & Postage	4046.99		
18449.51			18341.84	
256.91	Library Expenses		28.25	
103.80	Miscellaneous Expenses		2727.43	
219.80	Monthly Meeting Expenses		100.00	
1932.07	Newsletter Printing & Distribution		1982.39	
373.30	Postage		305.36	
403.03	Printing & Stationery - General		226.97	
509.37	Provision for Doubtful Debts		(68.67)	
2000.00	Rent		2000.00	
0.00	Repairs & Maintenance		400.00	

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31st December 1990

1989			1990
6745.15	Salaries	6435.83	
0.00	Summer School Deficit	845.90	
239.91	Telephone	270.28	
34666.75			37116.74
(5572.59)	DEFICIT for the year		2861.53

CLARKE MEDAL FOR 1990

The Clarke Medal for 1990 is in the field of Zoology and is awarded to Professor Barrie Gillean Molyneux Jamieson, BSc., PhD., DSc. who is a graduate of the University of Bristol. After working in Uganda and Tanganyika, he came to the University of Sydney in 1961 and in 1965 he joined the Department of Zoology in the University of Queensland.

Professor Jamieson's research interests include spermatology, reproductive biology and invertebrate ultrastructure, primate phylogeny, bioluminescence, oligochaete taxonomy, zoogeography and trematode life cycles. He has published widely in these fields, as attested by more than 100 papers and 5 books. In particular, his pioneering research on the biology and systematics of earthworms has yielded major insights into the biology and importance of these significant animals.

His current research on the evolutionary relationships of animal phyla is one of the most important works in zoology being carried out in Australia. The basis of this research is a unique method of analysis for comparing these relationships using the detailed structure of animal spermatozoa, mainly determined by transmission electron microscopy. Professor Jamieson's Australia studies in this field are a major contribution to invertebrate zoology and his approach using sperm ultrastructure, is challenging ideas about the evolution of animal phyla. The results and relevance of these studies are encapsulated in 2 books, one on "The Ultrastructure and Phylogeny of Insect Spermatozoa" published in 1987, and another on "Fish Evolution and Systematics:Evidence from Spermatozoa", published on 3rd April, 1991, the day on which he received the Medal at the Annual General Meeting.

Professor Jamieson has proposed a taxonomic system for oligochaetes, based on extensive studies involving morphological, evolutionary and zoogeographical components. He has named about 100 new species, many genera and 2 families of the Oligochaeta, and other scientists in Australia and overseas have named genera and species after him. He is a member of several scientific societies and editorial boards, and he has received invitations to work in overseas laboratories and to speak at various international conferences.

There is no doubt that Professor Jamieson's research work is outstanding and the ramifications of his current studies are very significant in zoology. He has established a world reputation on the basis of distinguished work carried out in Australia, and hence he deservedly merits the award of the Clarke Medal for 1990.

EDGEWORTH DAVID MEDAL

The Edgeworth David Medal for excellence of research in any area of science or applied science by a worker under 35 years of age, is awarded to Dr. Timothy Fridtjof Flannery.

Dr.Flannery began his systematic studies of fossil and recent kangaroos and potoroos whilst at Monash, where he wrote his MSc. thesis describing and analysing the fossil kangaroos from the Morwell Open-Cut Coal Mine. At the same time he published several other papers on the same group from other fossil sites. This interest has continued until the present time as one of his major research topics and he is at present the leading systematist of this group in terms of his knowledge of them as both living and extinct organisms.

His work has been particularly important in the field of the taxonomy and phylogeny of the Macropodidea. The kangaroos and their allies have a rich fossil record and Dr.Flannery has done more than anyone ever has to utilise this material to prepare a history of the group. For many years to come his monumental *'Phylogeny of the Macropodidea: a study of convergence'* and the supporting works on the homology of the molar cusps and on the polarity of morphological features in the Macropodidae, will be a primary source of challenge to those working in the area.

As his training advanced, Dr.Flannery came to realise the importance of the New Guinea mammalian fauna for illuminating the origin and evolutionary history of the Australian fauna. Whilst a student at the University of New South Wales, he made the first of several trips to New Guinea and although his training had emphasised vertebrate palaeontology, his naturalist outlook resulted in a much broader approach to his research programme. This can clearly be seen in his 1990 book *'Mammals of New Guinea'* which is not only a valuable scientific document but is evidence of his ability to communicate the significance of his studies to his fellow scientists and to the general public.

He has also contributed to policy discussions in the area of conservation. In particular he has encouraged a return to frequent deliberate burning of bush in order to maximise the survival of the remaining small native animals. He observed that the cessation of burning-off of the vegetation in historic times and in the absence of large herbivorous marsupials which became extinct thousands of years ago, gave recent habitat changes which have resulted in the extinction of several small native Australian mammals during the past century and a severe reduction and endangerment of others.

With 66 scientific publications including three books, Dr.Flannery has clearly demonstrated an outstanding ability to produce pioneering research. His planned and future work on the living and extinct mammals of the southwest Pacific region promises to shed light, not only on the composition and history of that fauna, but also to significantly augment the knowledge of Australia's mammals.

He is indeed a worthy receipient of the Edgeworth David Medal, awarded to distinguished scientists under 35 years of age.

THE ROYAL SOCIETY OF NEW SOUTH WALES MEDAL

The Society's Medal for contributions to the progress of the Society and to Science is awarded to Dr.Frederick Linstead Sutherland, MSc., PhD. Dr.Sutherland is a graduate of the University of Tasmania and of James Cook University. After some years with the Queen Victoria Museum, Launceston and with the Tasmanian Museum, Hobart, he was appointed Curator of Minerals at the Australian Museum, where he is currently a Principal Research Scientist. Dr.Sutherland's research on minerals, rocks and geological structures in eastern Australia is unravelling some aspects of the ancient topography which preserves a record of 200 million years of continental movements, uplists and volcanism. Amongst his past and ongoing research are studies of high pressure minerals, of hot spot volcanoes, on age-dating of volcanic fields, on the origin of gem minerals and on zeolitic minerals. The breadth of his interests is enshrined in his presidential address on the "Demise of the Dinosaurs and Other Denizens by Cosmic Clout, Volcanic Vapours or Other Means".

Lin Sutherland joined the Society in 1977 and has been Vice-President and President and continues as an active member of Council. His research is recognised nationally and internationally, as evidenced by his many publications and frequent participation in scientific meetings. Dr.Sutherland has made his mark on our Society and on the field of earth sciences, thereby becoming a worthy recipient of the Society's Medal.

Speech by the Honourable Mr. Justice Gleeson, A.O., Lieutenant-Governor of New South Wales at Annual Dinner and Presentation of Medals, Royal Society of New South Wales, 13th March 1991

I thank you for the welcome that you have given to me and my wife. It is an honour to be amongst you on the occasion of your Society's annual dinner and to have the pleasure of presenting the awards this evening.

To equip me for this occasion I was provided with some historical matter concerning the Royal Society, including a speech made by Professor Elkin on the occasion of the Society's Centenary in 1966. I read it with great interest.

I was especially interested in Professor Elkin's account of some of the personalities connected with the Society and its predecessor, the Philosophical Society of Australasia. It is apparent that this organisation has been a meeting place from the earliest days of New South Wales for persons of wide ranging interests, with a particular attraction to natural sciences. Even lawyers, it seems, were in former times active in such matters.

According to Professor Elkin a founding member of the Philosophical Society, and a contributor to its papers, was one of the Colony's earliest judges, who rejoiced in the ambiguous name of Barron Field. His interests extended well beyond the law.

He published the following works:

Narrative of a Voyage to New South Wales;
Narrative of a Voyage from New South Wales;
Journal of an Excursion across the Blue Mountains;
Journal of an Excursion to the Five Islands and Shoalhaven;
Glossary of the Natural History of New South Wales.

The reports of his character vary widely. He was appointed a judge of what was then called the Supreme Court of New South Wales. It was the immediate predecessor of the existing court, which was established in 1824. On his arrival the Governor made reference to his "mild, modest and conciliating manners". On the other hand, in 1830, after he had left the Colony of New South Wales and had been appointed Chief Justice of Gibraltar, he met Benjamin Disraeli upon whom he made a distinctly unfavourable impression. Disraeli referred to him as a "noisy, obtrusive, jargonic judge, ever illustrating the obvious, explaining the evident and expatiating on the common place."

He was one of Australia's earliest and least meritorious poets. There is a record of a dinner invitation that he sent to one Captain Piper in the following terms:

"Dear Piper should be either willing or able
To forget the delights of a Governor's table
Tomorrow at five we'll be glad if you'd trudge
To Macquarie Place and dine with the Judge."

Both his poetry and his intellectual capacity were criticised by his successor Mr. Justice Therry in the following terms:

"Thy poems, Barron Field, I've read
and thus adjudge their meed -
so poor a crop proclaim thy head
a barren field - indeed".

I also noted with interest from Professor

I also noted with interest from Professor Elkin's speech that the first paper, delivered to your Society of New South Wales after it was named the Royal Society of New South Wales, was a paper entitled "Non-Linear Coresolvents", (Cockle, 1867) The author of the paper was the Chief Justice of Queensland. I would have to acknowledge that my acquaintance with non-linear coresolvents is slight. On the other hand, the Chief Justice of Queensland of 1866 could not have been experiencing much difficulty with court delays if he had time to write and deliver papers of that kind.

It is impossible to read Professor Elkin's speech without being impressed by the interest which, in the early days of this Society, was taken in the Society by men of public affairs who by no means specialised in the pursuit of the natural sciences. Just as men of science took an interest in matters of philosophy, religion, and public affairs, the reverse also operated. This strikes me as a very healthy situation. In that connection I might mention that, a little later this year, Oxford University Press will publish a work on mathematics and philosophy the author of which is Mr. Justice Hodgson, (1991), a member of the Equity Division of our Court.

Many people outside the occupations more immediately concerned with scientific matters are attracted by the honesty and integrity of the scientific method. The word "science" is now frequently used in connection with a very wide variety of disciplines. These disciplines are not always characterised by a rigorous and uncompromising pursuit of the scientific method. In those cases where they are, those, who adhere to that method, shine like beacons and compel admiration. It would be a pity however, if those directly involved in science were to retreat from the imperfections of the rest of the world and seek a kind of shelter or haven in their own areas of particular interest. Just as people of public affairs should be encouraged to pursue an interest in science, so scientists should be encouraged to pursue an interest in public affairs. The history of your Society demonstrates a most desirable interaction in that regard, and we all benefit from it.

We all become despondent about the limits of our knowledge and intellectual capacity. Alexander Pope described Man as one who is

> "In doubt his mind or body prefer,
> Born but to die, and reasoning but to err."

Our great and distinctive gift, however, is curiosity. When that is coupled with intelligence, energy, and honesty it produces marvellous achievements, as the advance of scientific knowledge shows.

I congratulate your Society upon its achievements, and in particular I congratulate those whose achievements are being especially honoured tonight. Thank you for your hospitality.

REFERENCES

Reference for quotation re. Barron Field: "Barron Field. His Associations with New South Wales", published in 1948, *Australian Law Journal, 22,* 305.

Cockle, 1867. On "Non-Linear Coresolvents." *Transactions, Royal Society of New South Wales, 1,* 27-30.

Elkin, A.P., 1966. Centenary Oration. *Journal of the Royal Society of New South Wales, 100, (3/4)* 105-118.

VOTE OF THANKS TO LT.GOVERNOR BY DR.EDMUND C.POTTER, PRESIDENT-ELECT.

The Honourable Mr. Justice Gleason, Lieutenant Governor and Chief Justice of New South Wales, Mrs. Gleason, Mr. President, Distinguished Guests, Ladies and Gentlemen:-

It is a privilege and a pleasure for me to accept our President's request that I propose our vote of thanks to the Lieutenant Governor for being among us this evening and presenting the Royal Society's Awards for the past year. He not only did this with fitting grace and fervour, but also addressed us with admirable erudition and warmth. You may be sure, Sir, that we listened attentively; for even a Society as long established as ours benefits from words of encouragement, especially in these turbulent and unpredictable times. We have also very much appreciated Mrs. Gleason's presence here this evening, and, on behalf of the Royal Society of New South Wales, I ask that both of you convey to their Excellencies, when they return, our pleasure at your acting in their stead this evening.

The recipients of the Society's Awards represent their respective extremes of professional achievement in their chosen fields of endeavour. It occurs to me to remind the Lieutenant Governor that he is associated with another, less familiar, professional extreme. I refer to the principal High Court Building at Taylor Square, Sydney, where the message incised on the lintel over the entrance signifies that the edifice was built in 1888. Considering the building's purpose this may seem brief enough, except that 1888 assumes the extreme of length when written in Roman numerals. So at Taylor Square, as the passer-by can easily observe, the stonemason was obliged to fashion a record thirteen letters on the lintel to mark completion of the building, and his record will not be broken before 897 years from now.

Such matters aside, it has been an extreme pleasure for us to entertain the Lieutenant Governor and Mrs. Gleason, and I ask you all to join me in our vote of thanks to them this evening. (After the acclamation Dr. Potter presented the Lieutenant Governor with a copy of the Society's Centenary Volume as a momento of the occasion.)

EXPLANATORY NOTE FOR READERS

1888 in Roman numerals is MDCCCLXXXVIII, which will gain another M in 2888. Fortunately, we can enhance the Latin distinction of Taylor Square long before then; since, if a modest annex were completed in IX years time, its lintel could be inscribed MM - as brief as we've had in a millenium.

Biographical Memoirs

DR. ALICE WHITLEY.

Alice Whitley, M.B.E., B.Sc (Syd.), Ph. D. (Lond.), A.R.A.C.I., F.A.C.E., and member of the Royal Society since 1951, died suddenly at her home in Burwood on 6th August 1990. Perhaps most widely known as Headmistress of the Methodist Ladies College at Burwood, N.S.W., her influence reached far beyond the schools in which she taught, for she applied her very considerable talents to a wide spectrum of educational, social and administrative issues, both within N.S.W. and federally.

Born in Sydney on 6th February 1913, she received her schooling at M.L.C. Burwood, becoming Dux of the school in 1930. After completing her Science degree at the University of Sydney, she taught at Brighton College, Manly and S.C.E.G.G.S., Moss Vale, before renewing her association with M.L.C. Burwood, first as a teacher of Science and Mathematics (1941 - 1952) then as Deputy Headmistress and Head of the Science Department (1955 - 1959). The culmination of her career in education came with her appointment as Headmistress of M.L.C. (1960 - 1972) during which term (in 1966) she was awarded an M.B.E. for "Services to Education". Her retirement in 1972 came after a 50 year association with the school.

Her interest in chemistry led her to study with Prof. D. Bradley at Birbank College in the University of London where she was awarded a Ph.D. in 1954. The thesis, titled 'New Metal Alkaloids', was followed by several papers which she co-authored. On her return to Sydney and M.L.C. in 1955 she regularly taught night classes in Chemistry at the University of N.S.W. for several years and undertook further research there with Dr. S.E. Livingstone on ligands. This work was also published jointly.

Continuing commitment to chemistry, coupled with a flair for administration resulted in her appointment to - and an almost inevitable term as president of - innumerable committees. These included the N.S.W. Science and Teachers Association (President, 1966 - 67), the Association of Girls Independent Schools (President, 1961) as well as membership of the Council of the Guild Teachers College from 1976 to 1981 (Vice President 1979 - 81). Her constructive and energetic input was also evident in her membership of the State Development Committee for In-Service Teacher Training, the Commonwealth Advisory Committee on Standards for Science Facilities in Independent Schools, and as a Council Member of the Teacher's Guild of N.S.W. (Vice President, 1975). After her retirement from M.L.C., she was appointed to the Interim Committee of the Australian Schools Commission in 1973 and as a Building Consultant to the Commonwealth Department of Education and Training. When this body was replaced in 1987 by the Department of Employment, Education and Training, she continued in the same capacity until the time of her death. She co-authored *A New Approach to Chemistry* (William Brooks,1958) and a widely used booklet on *Design in Science Rooms* (A.G.P.S. 1965). Her work with the A.S.C. actively involved her in the construction of Science wings and classrooms in many of the States Independent Schools in N.S.W. where she frequently surprised building foremen by her knowledge of their trade and her insistence that half measures were not acceptable!

Alice was particularly concerned with the role of women in the community and sought to emphasize that education and privilege bring special responsibilities. She actively supported the programmes of the Australian Federation of University Women (Vice President 1979 - 82) over three decades, involving herself particularly with the award of prizes and scholarships. She also wholeheartedly supported programmes of aid to the needy abroad and consistently sought to persuade women to contribute their professional skills to local social issues, as indeed she herself did most generously. In the 1940's she ran a Guide Company in Chippendale for the Sydney University Settlement as part of its welfare work.

Her love of the simple pleasures of nature found expression in her life long involvement with the Guide Association of N.S.W. and she greatly enjoyed its various activities. She was a most experienced camper, a brilliant improviser and able to make herself snug and comfortable in a tent anywhere. In the Guiding Movement as elsewhere she played a most active role, being a highly accredited Trainer of Guiders, serving on the State Council and State Executive (as a

member of the Finance Sub-Committee, 1975 - 79) for many years, and acting as the Commandant of the Australia wide Centenary Corroboree Camp, in 1957.

In what little time she could call her own, she indulged her love of travel, frequently acting as a delegate for some organisation along the way. She was an accomplished needlewoman and her tapestries are used and enjoyed by friends and by churches in many countries. She read widely - though perhaps not as often as some - and still found time to enjoy music and the companionship of her many friends.

Alice Whitley was a born leader, but it was not only her contribution to committees nor the awards she won which gained her so much affection and respect. She was never afraid to espouse a cause or course of action,if she felt it to be right. She never came to a decision without reference to personal standards based on the ultimate good of society, a kindly concern for, and genuine interest in, other people and on her own personal faith. Those of us who knew and worked with her can envy the legacy she has left - a legacy of example and influence and a heightened awareness of our own social responsibilities.

J.J.C.

* Further details of Alice Whitley's career are available in:-

1. Who's Who of Australian Women, (Comp. A Lofthouse) North Ryde: Methuen. 1982.
2. Notable Australians, Sydney: Hamlyn. 1978
3. Excelsior, (M.L.C. Magazine). Burwood. M.L.C. 1972.

RESEARCH WORK (1952-1971)

Apart from her Ph.D. Thesis (1954) on "New metal alkoxides", Alice Whitley published the following:-

Bradley, D.C.,Wardlaw, W., and Whitley, A. Normal alkoxides of quinquevalent Ta_{49}.
Journal of the Chemical Society, 1955.

Bradley, D.C.,Wardlaw, W., and Whitley, A. Effects of solvents on the molecular complexities of Ta alkoxides.
Journal of the Chemical Society, 1956.

Anderson, J.R.A., and Whitley, A. Determination of R_f values of metal cation using di-ethyl ether as a solvent.
ANAL. CHEM. ACTA, 6.

Martin, R.L., Whitley, A. Magnetic studies of copper salts ^{III}. Constitution of Copper ^{II} alkanoates in solution.
Journal of the Chemical Society, 1958.

Bradley, D.C., et al. Niobium and tantalum mixed alkoxides.
Journal of the Chemical Society, 1958.

Livingstone, S.E., and Whitley, A.
Interaction of various ligands with halogen-bridged anionic complexes of bivalent platinum v palladium.
Australian Journal of Chemistry, 15, 1962.

HADDON RYMER FORRESTER KING

Dr. Haddon King, member of the Society and its Clarke Medallist in 1974, died quite suddenly in Brisbane on 11th March 1990. Although he had been retired for some years and, during his last three or four years, had been of indifferent health, he had remained very active as a scientific thinker and died having just half completed a letter on geological matters to his old colleague and friend, Dr. E.S.T. O'Driscoll.

Haddon Rymer Forrester King was born on 4th February 1905 and began his career as a surveyor's assistant in the Geological Survey of British Guiana in 1926. His immediate supervisor in the Survey was H.J.C. (Terence) Conolly - a man who was later to become very well known in Australian mineral exploration - from whom he received much early help and encouragement and towards whom he was always to feel a deep gratitude.

From British Guiana - having obtained his surveyor's licence in 1929 - Haddon King moved to Canada, receiving his degree in Mining Engineering from the University of Toronto in 1933. During the period 1929-1934 he obtained experience in mineral exploration in the Timmins and Sudbury districts of Canada, and then in 1934 he was invited to join a distinguished group - including D.H.McLaughlin and H.E. McKinstry of Harvard, J.K. Gustafson and H.J.C. Conolly - being gathered together by the then newly-established Western Mining Corporation to apply the latest ideas in geology, geophysics, geochemistry and aerial photography to the scientific search for new mineral deposits in Australia. His move to Western Australia later in 1934 set the course of the rest of his life. He became senior geologist of Western Mining Corporation in 1936, and remained with the firm until 1941 when he joined the Royal Australian Engineers, with whom he served (in the sixth-west) until 1945. After the war he moved to the Zinc Corporation at Broken Hill where he was concerned first with extensions to the orebody then with the regional search for a new Broken Hill deposit and finally - with Zinc Corporation's successor firm Conzinc Rio Tinto of Australia (CRA) - Australia - and then world-wide exploration for a wide range of mineral deposits. During this period of 35 years with ZC-CRA he became a director of CRA and of a number of its subsidiaries, and a famous figure in the world of economic geology and mineral exploration.

Haddon King's name first came to international attention when, in 1953 and at the age of 48, he and his younger colleague Brendan Thomson published the now-famous paper on "The Geology of the Broken Hill District" in "The Geology of Australian Ore Deposits" volume of the Fifth Empire Mining and Metallurgical Congress. This, with concurrent work carried out by Garlick and others on the stratiform copper deposits of Rhodesia, was highly influential in provoking the post-war questioning of replacement as the principal process of stratiform ore formation, and in giving support to the idea that the sulphides might have been deposited during sedimentation.

In 1970 Haddon King was awarded the Penrose Medal of the Society of Economic Geologists "for unusually original work in the earth sciences" and in 1973 he received the Clarke Medal of this society. In 1974 he received the Institute Medal of the Australasian Institute of Mining and Metallurgy and in 1975 the degree of Doctor of Science (honoris causa) from the University of New England and an Honorary Fellowship of the Institution of Mining and Metallurgy, London. In 1984 he received the Browne Medal of the Geological Society of Australia.

Haddon King was both an intensely practical man, and an intellectual who relished unconventional ideas. The first characteristic led to his development of one of the finest mineral exploration groups in the world, and thus to the discovery of deposits such as those of Bougainville and the Hammersley iron province and just a few months after his death - the new "Century" deposit of north-west Queensland. The second led to many new ideas and approaches to problems of ore formation and the relationships of ore deposits to the geological terrains in which they occurred.

In his quiet and unobtrusive way Haddon King was an inspiration to all who worked with him. Although he achieved world renown and the highest honours in his profession, he remained a shy, modest man, a superb - and wonderfully kind and gentle - mentor, and a staunch friend to those who knew him well.

Haddon King was a member of the Royal Society of New South Wales from 1973 until his death.

R.L.S.

LYNDON CHARLES NOAKES

Lyndon Charles Noakes, OBE, died in Canberra on 29 June, 1991, aged 76.

Born 9 March 1914, he was educated at Fort Street Boys' High School in Sydney, and at the University of Sydney, graduating in 1935 with a BA degree, Geology having been a major subject.

In July of the same year he beg began his professional career as Assistant Government Geologist in the New Guinea Administration, stationed at Wau in the Australian Mandated Territory of New Guinea, a position he held until 1941. He commenced under the supervision of Dr. Norman Fisher, and these two were to work together not only in the New Guinea region but in later years in the Bureau of Mineral Resources.

Field work was conducted in the Morobe district in 1935, and at the end of the year Fisher and Noakes went to Bougainville Island where they examined a small gold mine at Kupei, close to the site of the present big copper mine at Panguna. At times working together, and sometimes alone, Noakes and Fisher penetrated areas little known or unexplored, such as the Sepik district of New Guinea in 1937 and the volcanoes of New Britain in 1938. In 1939 Lyn Noakes carried out geological mapping in New Britain, and his report "The geology of the island of New Britain" was published in 1942.

The Second World War (1939-1945) suspended geological activities for Lyn, but he substituted distinguished military service (1941-44) against the invading Japanese forces. He joined the Wau group of the New Guinea Volunteer Rifles and was involved in some action in New Britain. He returned to Australia and was commissioned in the A.I.F., then posted back to New Guinea as a Coast Watcher, positioned on a ridge near Japanese-held Buna. The exploits of Lieutenant Noakes in this hazardous assignment have been well chronicled in the documentary book "The Coast Watchers" by Eric Feldt, who was in command of that special group. Lyn was decorated for that service and received the U.S.A. Legion of Merit.

Returning to Australia at the end of the war, Lyn was appointed in 1945 as Geologist in the Commonwealth Mineral Resources Survey, which in the following year developed into the Bureau of Mineral Resources, Geology and Geophysics (the BMR). He became Assistant Chief Geologist in 1959, Assistant Director, Mineral Resources 1967, Acting Director 1974, and Director 1975. He retired from the Bureau in 1979, and in addition to his leisure pursuits took up an appointed as a director of Cluff Resources.

Lyn Noakes' contributions to geology and the mineral industry during his long tenure with the BMR were varied and significant, particularly in the fields of regional geological mapping, mineral exploration and engineering geology. Some of these activities involved joint ventures with the CSIRO and the Geological Surveys of several States. Apart from his professional duties he also took a keen interest in the social and sporting events of the Bureau.

In the period 1961-63 Lyn was seconded to London as British Commonwealth Geological Liaison Officer, which brought him into contact with many earth scientists from around the globe. He was Secretary to the Technical Committee on Oceanography (United States Development Programme) from 1966, and Special Advisor on detrital mineral deposits to the United Nations Economic and Social Commission for Asia and the Pacific from 1967.

Lyn Noakes was elected to membership of the Royal Society of New South Wales on 2 May, 1945 (his proposers being L.A. Cotton, L.L. Waterhouse and I.A. Brown). He had one paper published by the Society, "A method for determining the distribution of oil in a reservoir rock by means of ultra-violet light" (Journal and Proceedings, Vol. 81, 1947). Lyn was also FAusIMM (being very active in the Canberra branch of that Institute), MIMM and FGS. Other of his publications include "Upper Proterozoic and Sub-Cambrian rocks in Australia" (1956); "Economic placer deposits of the Continental Shelf" (with K.O.Emery, 1968); and "The structure of the Northern Territory with relation to mineralisation"(1953).

He is survived by his wife Margaret, sons Ian and David, and daughter Roslyn.

In the Queen's Silver Jubilee and Birthday Honours List, on 11 June, 1977, Lyndon Charles Noakes was awarded the Order of the British Empire - "for public service". That simple phrase sums up the enthusiasm, integrity and dedication with which he served his country, both in peace and war.

E.O.R.

GERMAINE ANNE JOPLIN

Germaine Joplin, born 26th February 1903, the eldest daughter of a large family of seven, led a remarkable life as a geologist, academic, researcher and an immensely caring person, for famil family, colleagues and students - indeed all who in some way came in contact with her.

Germaine grew up in the suburbs of Strathfield and Eastwood in Sydney. She was educated at the Presbyterian Ladies' College, Croydon where she developed an interest in geology. Her interest grew into a real dedication and feel for geology, particularly for the world of rocks under the ciroscope. This became a major aspect of her life's work, culminating in two text books on Australian Igneous and Metamorphic Rocks. She graduated in science, majoring in geology, from the University of Sydney in 1930, gaining many awards, including a University Medal, for her academic and practical achievements in her geological studies.

After graduating Germaine continued on at Sydney University in various teaching or research fellowship positions, and during this time she began her research and field work in the Hartley area, followed by study of the igneous and metamorphic rocks of Ben Bullen. The latter work resulted in publications in the Journal and Proceedings of the Royal Society of New South Wales in 1935 (the year she joined the Society) and in 1936. Over 50 years later, students from geology departments in universities in the Sydney metropolitan area are still referred to Dr. Joplin's work, as undergraduate excursions are frequently held in these localities. It is remarkable, and indeed a real mark of the value of her research, that her studies have stood the test of such a long period of time.

In 1933 Germaine Joplin was awarded a Junior International Fellowship by the International Federation of University Women. This supported her studies towards a Ph.D. in the Department of Mineralogy and Petrology at Cambridge University. While in Cambridge she resided in Newnham College until the completion of her degree in 1935. She subsequently returned to teacning at Sydney University from 1936-1941, 1946-1949. In the intervening period Dr.Joplin held a Macleay Fellowship of the Linnean Society of New South Wales and her research at this time resulted in the award of a D.Sc. from the University of Sydney in 1950.

Her deep concern for people, together with her interests outside geology, led her to complete a B.A. degree and a Diploma in Social Work and then to full-time work in caring for people in need in Sydney. However, her scientific expertise was again tapped wnen she joined the Bureau of Mineral Resources in 1951, followed by an appointment as Fellow, then Senior Fellow in the Department of Geophysics at the Australian National University. While at ANU Dr. Joplin was a key member of University House, serving in many capacities. After retirement from ANU in 1968 Dr. Joplin continued to contribute to University affairs by serving on Council from 1969-1975, as a member elected by Convocation.

It is, perhaps, indicative of Germaine Joplin's loyalty and gratitude to those organisations with which she had association over the years, and in turn the respect and high regard in which she was held, that she became a Life Member of the Royal Society of New South Wales in 1974, of the Linnean Society of New South Wales in 1970, and of the Australian Federation of University Women. She was also active in fund-raising for her Cambridge College, Newnham.

Dr. Joplin published three books, a number of major BMR Bulletins, and over 50 research papers. Of the latter 10 were published in the Journal and Proceedings of the Royal Society of New South Wales over a period of 30 years, indicating her long and productive research contribution. This was recognised by the scientific community in two prestigious awards. Firstly. the Clarke Medal of the Royal Society of New South Wales in 1962. An excerpt from the citation (J. & Proc. Roy. Soc. NSW., Vol.97, p.129) for this medal points to "her distinguished contributions to Geology, particularly in the field of igneous and metamorphic petrology" and noted she had "always been most generous in her assistance and encouragement to younger geologists". Secondly, the W.R.Browne Medal of the Geological Society of Australia in 1986. This would have brought special pleasure to Germaine, as Dr. Browne was her mentor at Sydney University, and she was the force behind the publication of the special "Browne Volume" of the Royal Society of New South Wales in 1966. The citation for the Browne Medal (Australian Geologist No.58, 1986, pp 8-9) stated that Dr. Joplin was a "lady of great ability and much determination, who contributed significantly to her Science, and thus to the prestige of her Nation, and yet had the time and drive to develop many of her other skills and interests. She achieved all this in a generation when it was not easy for women who wished, as she did, to participate fully in a field-oriented discipline".

Her contribution to her Nation was also recognised in 1986, when she was made Member of the General Division of the Order of Australia (AM).

Dr. Germaine Joplin's fulfilling and rich life ended in Sydney on July 18, 1989. She will be greatly missed by her family and friends, all those she showed such care and concern for over many years.

T.H.G.

Bibliography:

Published in the Journal and Proceedings of the Royal Society of New South Wales:

1935 *Vol.69, pp. 135-158*
The Endogenous Contact-zone of the Magnesian Limestones at Ben Bullen, New South Wales.

1936 *Vol.70, pp. 69-94*
The Ben Bullen Plutonic Complex, New South Wales.

1936 *Vol.70, pp. 327-331*
Evidence of Magmatic Stoping in a Dyke at Hartley, New South Wales.

1937/38 *Vol.71, pp. 267-281*
The Geological Structure and Stratigraphy of the Molong-Manildra District.

1940 *Vol.74, pp. 419-442*
A note on some Leucite-bearing rocks with special reference to an ultra-basic occurrence at Murrumburrah.

1956 *Vol.90, pp. 80-86*
On the association of Albitites and Soda Aplites with Potash Granites in the Precambrian and older Palaeozoic of Australia.

1957 *Vol.91, pp. 120-141*
Basic and Ultra-basic rocks near Happy Jack's and Tumut Ponds in the Snowy Mountains of New South Wales.

Published in the Proceedings of the Linnean Society of New South Wales:

1931 *Vol.56, Part 2 (no.234), pp. 16-59*
The Petrology of the Hartley District. 1: The Plutonic and Associated Rocks.

1933 *Vol.58, Parts 3-4, (nos.247-248), pp. 125-158*
The Petrology of the Hartley District. 2: The Metamorphosed Gabbros and Associated Hybrid and Contaminated Rocks.

General Reference:

1941 Anderson, R.H. Presidential Address. (26.3.41) *The Proceedings of the Linnean Society of New South Wales.*

Further published in the Journal and Proceedings of the Royal Society of New South Wales:

1962 *Vol. 96, pp. 9-13.*
Zircons in some granites from North-Western Queensland.

1966 *Vol. 99, pp. 37-43.*
On Lamprophytes.

Participants in the Summer School on Technology, Today and Tomorrow", January 1991, at Macquarie University. Front row left: Mr.G.W.K.Ford, President of the Society, and front row right: Mrs.M.Krysko Von Tryst, Honorary Convener for the Summer School.

Journal and Proceedings, Royal Society of New South Wales, Vol.124, p.91, 1991
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