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Chiral Metal Complexes. 15*. Alanine and Proline Complexes of [*N,N'*-Di(2-picolyl)-1*R*, 2*R*-diaminocyclohexane] cobalt (III)

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ABSTRACT. When Co(II) ions are oxidised in HCl solution in the presence of *N,N'*-di(2-picolyl)-1*R*,2*R*-diaminocyclohexane, *R,R*-picchxn (*L*), the diastereoisomer Λ-β-[Co *L* Cl_2] ClO_4.½H_2O is isolated from the reaction mixture as the least-soluble perchlorate salt. Λ-β-[Co *L* Cl_2]$^+$ reacts with retention of absolute configuration with a variety of ligands including oxalate, nitrite, *S*- and *R*-alaninate and *S*-prolinate ions. The products of the reactions have been isolated and characterised using circular dichroism and high-resolution ^{1}H NMR techniques. Both β_1 and β_2 isomers are formed in the reaction of the parent complex with *S*-proline and *S*-alanine. Only the β_1 isomer is formed with *R*-alanine and no ternary complexes are formed with *R*-proline. The reasons for this pattern of reactivity are discussed and means of distinguishing between the β_1 and β_2 isomers described. The reactions are compared with similar ones in related systems.

INTRODUCTION

Recently the synthesis and characterisation of a number of *S*-alanine complexes of the Co(III) chelate with *R*- and *S*-picpn† were reported (Chambers *et al*, 1984b; Mulqi *et al*, 1984). Only β_1 isomers were obtained, and it could be shown that the complexes isolated had resulted from a radical redistribution of the Co(III) coordination sphere in that Λ-β isomers of *S*-ala were obtained from Λ-α-[Co(*R*-picpn)Cl_2]$^+$ and corresponding Δ-β isomers with one exception, from Δ-α-[Co(*S*-picpn)Cl_2]$^+$. The other reported reactions of Λ-α-[Co(*R*-picpn)Cl_2]$^+$ have revealed that the complex can undergo a variety of inversions of absolute configuration with respect to the metal centre (Chambers *et al*, 1983; 1984a). Thus it emerges that the optically active picpn ligand is not as highly stereospecific as was first thought (Cragel and Brubaker, 1972). In order to study further the chiral discriminations important in these kinds of complexes we turned our attention to related species containing *R,R*-picchxn, which were expected to be somewhat more stereoselective. We report below the results of our investigations, which have included several kinds of monodentate and bidentate ligands.

EXPERIMENTAL

R,R-Picchxn.4HCl (*L* . 4HCl)

This ligand was prepared using a method modified from that of Häfeli (1975). A solution of freshly distilled pyridine-2-aldehyde (24.0g, 0.224mol) in DMF ($50cm^3$) was mixed quickly with a solution of 1*R*,2*R*-diaminocyclohexane, prepared using Whitney's (1980) method (12.3g, 0.108mol) in DMF ($50cm^3$) and then left to stand overnight at room temperature. The resulting colourless crystals of the Schiff base were collected at the pump, washed with DMF ($20cm^3$) and then water ($10cm^3$), then air-dried { Yield: 27.1g }. The diimine (27.0g) was dissolved in absolute ethanol ($150cm^3$) and was transferred to a Paar low-pressure hydrogenation flask. To the solution was added 5% platinum on carbon catalyst (0.5g) and the mixture was shaken under hydrogen (ambient pressure) until uptake of that gas had ceased (3 days). The catalyst was filtered off and concentrated HCl ($35cm^3$) was added to the filtrate. The mixture was evaporated to dryness under reduced pressure to yield a pale green solid which was recrystallised from boiling ethanol { Yield: 31.1g. *Anal.*: Found C, 48.8; H, 6.1; N, 12.8%. Calc. for $C_{18}H_{28}N_4Cl_4$: C, 48.9; H, 6.4; N, 12.7% }.

Λ-β-|Co(*R,R*-picchxn)Cl_2|ClO_4. ½H_2O

A method similar to that of Bosnich and Kneen (1970) was employed. To a mixture of *R,R*-picchxn. 4HCl (5.20g, 11.8mmol) and $LiOH.H_2O$ (1.98g, 47.2 mmol) in water ($50cm^3$) was added $CoCl_2.6H_2O$ (2.75g, 11.6mmol). The resulting brown solution was adjusted to pH 9.0 with aqueous LiOH and oxidised in a stream of air for 3 hr. The pH of this solution was readjusted to 9.0 as above and the oxidation continued for 24 hr, after which time concentrated HCl ($1.25cm^3$) and concentrated $HClO_4$ ($2.5cm^3$) were added slowly with stirring. The reaction mixture was reduced slowly in volume on a steam bath and the oily layer which formed was continuously dispersed by stirring. A red-violet precipitate formed slowly. After the mixture had been reduced to about $20cm^3$ it was cooled to room temperature, with continuous stirring, and the crystals were collected at the pump, washed with water and then a little ethanol, and air-dried. { Yield: 4.17g. *Anal.*: Found C, 40.6; H, 4.7; N, 10.2; H_2O, 2.3%. Calc. for $C_{18}H_{25}N_4Cl_3O_{4.5}Co$: C, 40.4; H, 4.7; N, 10.5; H_2O, 1.7% }.

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* Part 14 is Chambers *et al*, 1984b.

† picpn = 2,5-diaza-3-methyl-1,6-di(2-pyridyl)hexane, *R,R*-picchxn = *N,N'*-di(2-picolyl)-1*R*,2*R*-diaminocyclohexane, alaH = alanine, proH = proline, en = 1,2-diaminoethane, trien = 1,4,7,10-tetraazadecane, picbn = 2,5-diaza-3,4-dimethyl-1,6-di(2-pyridyl)hexane.

Λ-β-[Co(*R*,*R*-picchxn)$(NO_2)_2$]$ClO_4.3H_2O$

Sodium nitrite (0.15g, 2.17 mmol) was added to a stirred solution of Λ-β-[Co(*R*,*R*-picchxn)Cl_2]$ClO_4.\frac{1}{2}H_2O$ (0.50 g, 0.94 mmol) in water ($30cm^3$) at 60°C, and the solution was warmed on a steam bath for 5 minutes to yield a golden yellow solution. This was cooled to room temperature and the golden needles which had formed were filtered off, washed with water and air-dried { Yield: 0.45g, 80% }. The filtrate was evaporated in a stream of air to yield a further crop of needles which were isolated as above { Yield: 0.06 g , 11% } . The filtrate had the same circular dichroism (CD) spectrum as the isolated crystals, which were shown to contain no nitrito- species by their infrared spectra, which also confirmed the identity of the two crops (Nakamoto, 1970) . { *Anal.*: Found C, 35.7; H, 4.5; N, 14.4; H_2O, 10.1%. Calc. for $C_{18}H_{30}N_6O_{11}ClCo$: C, 36.0; H, 5.0; N, 14.0; H_2O, 9.0% } .

Λ-β-[Co(*R*,*R*-picchxn)(ox)]$ClO_4.2H_2O$

Sodium oxalate (0.13 g , 0.97 mmol) was added to a stirred solution of Λ-β-|Co(*R*,*R*-picchxn)Cl_2| $ClO_4.\frac{1}{2}H_2O$ in water ($30cm^3$) at 60°C . Once dissolution of the sodium salt was complete the reaction mixture was allowed to cool to room temperature and then reduced in volume in a vacuum dessicator over silica gel to about $10cm^3$. The reddish-orange crystals which had formed were collected at the pump, washed sparingly with ice-cold water and air-dried, { Yield: 0.31g, 57% } . A further crop { Yield: 0.08g, 15% } was obtained in the same way as above after reduction of the volume of the filtrate remaining to 5 cm^3 . The final filtrate had the same CD spectrum as those of the two crops of the solid product. { *Anal.*: Found C, 42.0; H, 5.7; N, 9.0; H_2O, 5.5%. Calc. for $C_{20}H_{28}N_4O_{10}ClCo$: C, 41.5; H, 4.9; N, 9.7; H_2O, 6.2% } .

Λ-$β_1$-[Co(*R*,*R*-picchxn)(*S*-ala)]$(ClO_4)_2.3H_2O$ and
Λ-$β_2$-[Co(*R*,*R*-picchxn)(*S*-ala)]$(ClO_4)_2$

S-Alanine (0.42 g , 4.72 mmol) was added to a stirred solution of Λ-β-[Co(*R*,*R*-picchxn)Cl_2]$ClO_4.\frac{1}{2}H_2O$ (0.50g , 0.94 mmol) in water ($30cm^3$) at 60°C . When dissolution was complete 1.0 mol dm^{-3} aqueous NaOH (1.0 cm^3, 1.0 mmol) was added slowly. The orange solution thus formed was cooled to room temperature, diluted five-fold with water and applied to a column (35 x 1.5 cm) of CM-Sephadex C-25 cation exchange resin in the Na^+ cycle with deionised water as the supporting solvent. The column was washed thoroughly with water and then elution was carried out using 0.1mol dm^{-3} aqueous sodium perchlorate. Two orange bands separated cleanly, and these were collected in fractions using an LKB 2070 Ultrorac II fraction collector. Electronic and CD spectral measurements confirmed that each band consisted of only one isomer. The fractions from the first eluted orange band were combined, concentrated *in vacuo* at 40°C, and the solution ($20cm^3$) evaporated slowly over silica gel. After a week the orange crystals of this $β_2$ perchlorate salt which had formed were collected at the pump, washed with ice-cold water and air-dried. { Yield: 0.1g . *Anal.* : Found C, 39.2; H, 4.7 ; N, 11.1% . Calc. for $C_{21}H_{30}N_5O_{10}Cl_2Co$: C, 39.3; H, 4.7, N, 10.9% } . The $β_1$- perchlorate trihydrate complex was isolated from the second eluted band in a manner analogous to that above. { Yield: 0.34g. *Anal.*: Found C, 36.3; H, 5.4; N, 10.0; H_2O, 8.6% . Calc. for $C_{21}H_{36}N_5O_{13}Cl_2Co$: C, 36.2 ; H, 5.2; N, 10.1; H_2O, 7.8% }.

Λ-$β_1$-[Co(*R*,*R*-picchxn)(*R*-ala)]$(ClO_4)_2.3H_2O$

The reaction to form this compound, and its subsequent isolation, was carried out using *R*-alanine in the same quantity and mole ratio as that employed in the *S*-alanine reaction described above. Development of the cation exchange column gave rise to one main orange band preceeded by an extremely faint one which contained only a trace of cobalt complex, insufficient to allow isolation, but with a positive CD spectrum in the visible region. Using the same techniques as above, the main band was shown to contain only one isomer, and was concentrated to yield the $β_1$ perchlorate trihydrate. { Yield: 0.12g. *Anal.*: found C, 36.3 ; H, 4.3; N, 10.5; H_2O, 8.2%. Calc. for $C_{21}H_{36}N_5O_{13}Cl_2Co$: C, 36.2; H, 5.2; N, 10.1; H_2O, 7.8% } . The low hydrogen analysis obtained is due to the loss of the water of crystallization in the gas stream prior to combustion. This was confirmed thermogravimetrically; the calculated H analysis for the anhydrate is 4.3% .

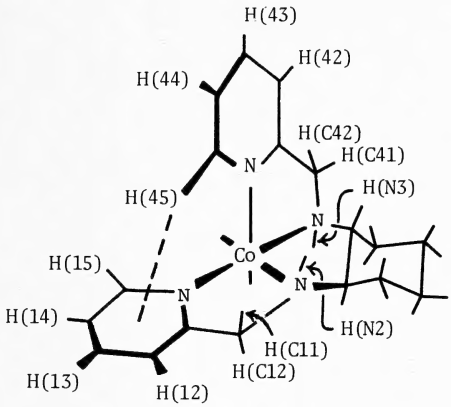
Λ-$β_1$-[Co(*R*,*R*-picchxn)(*S*-pro)]$(ClO_4)_2.2H_2O$ and
Λ-$β_2$-[Co(*R*,*R*-picchxn)(*S*-pro)]$(ClO_4)_2.2H_2O$

These compounds were synthesised using the same weights of Λ-β-[Co(*R*,*R*-picchxn)Cl_2]$ClO_4.\frac{1}{2}H_2O$ starting material and mole ratio of amino acid and base and under the same conditions as those employed for the synthesis of the alanine complexes. The two $β_1$ and $β_2$ isomers separated into clean bands on the column, the $β_2$ diastereoisomer eluting first, and the perchlorate salts were isolated as described above. { For the $β_1$ isomer; Yield: 0.21 g . *Anal.*; Found C, 38.4; H, 4.0; N, 10.0; H_2O, 5.3% . Calc. for $C_{23}H_{36}N_5O_{12}Cl_2Co$: C, 39.2; H, 5.2; N, 10.0; H_2O, 5.1% .
For the $β_2$ isomer; Yield: 0.04 g . *Anal.*: Found: C, 39.2; H, 5.2; N, 10.0% }.
Several attempts to isolate isomers containing *R*-proline gave reaction mixtures containing various decomposition products of the starting materials and which gave only transient trace amounts of orange coloured species when separation by chromatographic means was attempted.

Microanalyses were carried out by Mrs A. Dams in the Department of Chemistry, Cardiff, and the water of hydration analyses were performed using a Stanton-Redcroft TG750 programmed thermobalance. Infrared spectra were recorded using a Perkin Elmer 257 grating spectrometer and electronic and CD spectra measured using a Beckman DK2A ratio recording spectrophotometer and a Jobin Yvon CNRS Dichrographe III respectively. Proton NMR spectra were recorded at 360MHz using a Bruker WM 360 spectrometer at 298.2 K . These spectra were recorded in D_2O and DMSO-d_6 using DSS or TMS as internal standards, or in acetone-d_6 using its d_5 impurity as internal standard (2.17 ppm) .

RESULTS AND DISCUSSION

The numbering scheme for the protons is shown in (*I*), and is based on that used in previous crystallographic determinations (Mulqi *et al*, 1984). 360 MHz ^1H NMR data for the complexes are tabulated in Tables 1 and 2 and electronic and CD spectral data are presented in Table 3. For reference purposes the ^{1}H NMR spectra of the aromatic regions for the various complexes are shown in the Figure.



(*I*)

Häfeli (1975) first reported the synthesis of Λ-β-[Co(*R*,*R*-picchxn)Cl_2]$^{+}$ and the perchlorate salt we have prepared gives a CD spectrum in concentrated HCl which is qualitatively similar to his. All three transitions in the visible region of the spectrum of this ion in HCl solution have positive CD absorption and this confirms the absolute configuration of the complex as Λ. The basis for this assignment has been discussed previously (Bosnich and Kneen, 1970), and has been confirmed now by a number of crystallographic analyses including that of Δ-α-[Cr(*S*-picpn)Cl_2]ClO_4 (Hata *et al*, 1981) which is isomorphous with the Co(III) complex (Yamamoto and Shimura, 1980), and other analogues of en and trien with Co(III) (Saito, 1979). It is interesting to note that the CD spectrum of the complex reported here is nearly enantiomorphous to that of the perchlorate salt β-[Co(*S*,*S*-(+)-picbn)Cl_2]$^{+}$ which was assigned the Δ absolute configuration on the basis of its CD spectrum (Bosnich and Kneen, 1970). The reason given for the preference of hand in this latter complex was that interactions between methyl groups of the central ring with the *cis*-terminal chelate arm were minimized. Since the ligand in our work is of opposite absolute configuration, that the opposite hand of the complex was obtained suggests that such steric interactions may also be important in the *R*,*R*-picchxn complex. On the basis of a number of crystallographic studies of absolute configurations (Saito, 1979), and with reference to known CD spectra, all of the other complexes whose preparations are given here may also be assigned the Λ absolute configuration, and thus Λ-β-[Co(*R*,*R*-picchxn)Cl_2]$^{+}$ reacts with retention of hand in all of the substitution reactions reported here.

We do however wish to draw attention to the CD spectra of the two Λ-complexes of *S*-ala and *S*-pro which have β_2 topology. In both cases the dominant CD band in the visible region of the spectrum is positive in sign, as expected, but a small negative absorption is observed at longer wavelengths. A similar spectral feature was found for the complex Λ-β_2-*S*,*S*-[Co(trien)(*S*-pro)]$^{2+}$, whose absolute configuration also is known from crystallographic

TABLE 1

360 MHz ^{1}H NMR DATA† FOR COMPLEXES IN WHICH CARBOXYLIC GROUPS SHIELD AROMATIC PROTONS

	Complex¶			
	1	*2*	*3*	*4*
H(12)	7.772	7.926	7.869	7.912
H(13)	8.250	8.366	8.341	8.368
H(14)	7.796	7.881	7.902	7.923
H(15)	8.444	8.278	8.408	8.456
H(42)	7.762	7.761	7.801	7.783
H(43)	8.120	8.183	8.154	8.160
H(44)	7.436	7.567	7.479	7.452
H(45)	7.358	7.014	7.235	7.198
$J_{12,13}$	7.60	8.02	8.31	7.66
$J_{13,14}$	8.04	6.61	7.34	7.63
$J_{14,15}$	5.50	5.48	5.62	6.11
$J_{42,43}$	7.93	7.76	7.81	7.89
$J_{43,44}$	7.56	7.88	7.00	7.30
$J_{44,45}$	5.82	5.69	5.80	5.91
H(N2)	exchanged	7.536	exchanged	exchanged
H(N3)	exchanged	6.926	exchanged	exchanged
H(C11)	4.408	4.398	4.363	4.509
H(C12)	4.623	4.454	4.482	4.570
H(C41)	4.382	4.311	4.423	4.458
H(C42)	4.708	4.456	4.602	4.619
$J_{C11,C12}$	-15.92	-15.80	-16.81	-18.62
$J_{C41,C42}$	-16.97	-16.75	-17.17	-17.25
$J_{C11,N2}$		7.90		
$J_{C12,N2}$		8.03		
$J_{C41,N3}$		<0.02		
$J_{C42,N3}$		5.91		
CH_3		1.277§	1.162§	
α-*H*		3.190§	3.894§	4.401§
$J_{CH_3,\alpha H}$		6.80§	7.28§	
N*H*		5.382§	exchanged	exchanged
N*H*'		4.877§	exchanged	exchanged

† At 298.2 K ; Chemical shifts are ± 0.002 ppm, coupling constants ± 0.02 Hz .

¶ Complex *1* : Λ-β-[Co*L* (ox)]$^{+}$ in D_2O ;
2 : Λ-β_1-[Co*L* (*R*-ala)]$^{+}$ in DMSO-d_6 ;
3 : Λ-β_1-[Co*L* (*S*-ala)]$^{+}$ in D_2O ;
4 : Λ-β_1-[Co*L* (*S*-pro)]$^{+}$ in D_2O .

§ These data refer to the coordinated amino acidate groups .

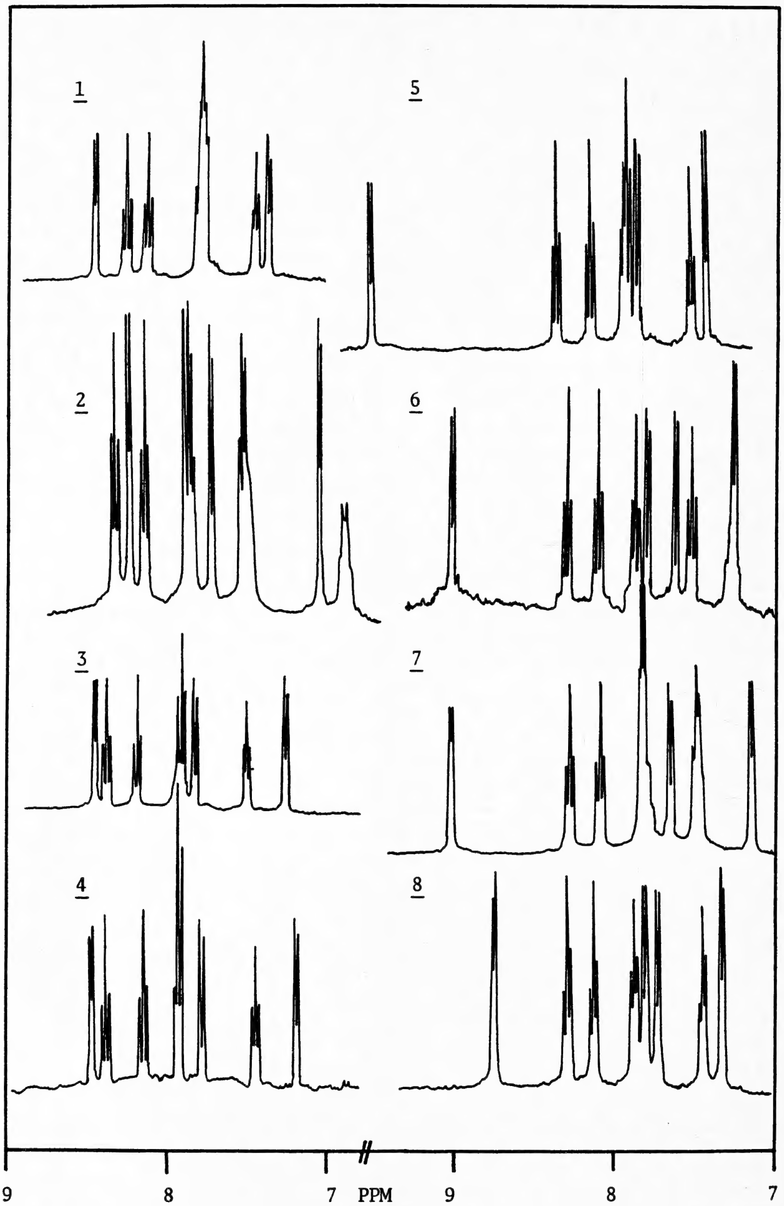


Figure . 360 MHz ^1H NMR spectra of the aromatic regions of the complexes.
1 : Λ-β-[Co(*R*,*R*-picchxn)(ox)]$^+$; *2* : Λ-β_1-[Co(*R*,*R*-picchxn)(*R*-ala)]$^{2+}$;
3 : Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-ala)]$^{2+}$; *4* : Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-pro)]$^{2+}$;
5 : Λ-β-[Co(*R*,*R*-picchxn)Cl_2]$^+$; *6* : Λ-β-[Co(*R*,*R*-picchxn)$(NO_2)_2$]$^+$;
7 : Λ-β_2-[Co(*R*,*R*-picchxn)(*S*-ala)]$^{2+}$; *8* : Λ-β_2-[Co(*R*,*R*-picchxn)(*S*-pro)]$^{2+}$.
Solvents are the same as those given in Tables 2 and 3 .

studies (Lin and Douglas, 1968; Freeman *et al*, 1970). This spectral pattern may occur frequently in β_2 complexes of this type. These results are in contrast with those found for analogous reactions of Λ-α-[Co(*R*-picpn)Cl_2]$^+$ mentioned above and the high degree of stereoselectivity is most probably due to steric and conformational requirements imposed by the 1,2-diaminocyclohexane fragment of the ligand in conjunction with steric interactions between it and the *cis* picolyl group.

All of the complexes are indeed of β-topology,

TABLE 2

360 MHz ^{1}H NMR DATA† FOR COMPLEXES IN WHICH CARBOXYLIC GROUPS DO NOT SHIELD AROMATIC PROTONS

	Complex ¶			
	5	*6*	*7*	*8*
H(12)	7.918	7.809	7.862	7.810
H(13)	8.371	8.304	8.314	8.288
H(14)	7.945	7.881	7.852	7.873
H(15)	9.530	9.018	9.043	8.742
H(42)	7.866	7.635	7.686	7.732
H(43)	8.161	8.115	8.124	8.123
H(44)	7.535	7.541	7.527	7.448
H(45)	7.449	7.271	7.173	7.328
$J_{12,13}$	7.66	7.88	7.46	7.76
$J_{13,14}$	7.82	7.51	7.92	7.50
$J_{14,15}$	4.32	5.18	5.54	5.80
$J_{42,43}$	7.73	7.82	7.76	7.67
$J_{43,44}$	7.62	7.57	7.49	8.08
$J_{44,45}$	5.74	5.74	5.70	4.92
H(N2)	6.670	6.702	7.509	exchanged
H(N3)	6.971	7.270	7.818	exchanged
H(C11)	4.561	4.123	4.469	4.478
H(C12)	4.832	4.293	4.528	4.695
H(C41)	4.611	4.132	4.207	4.298
H(C42)	5.370	4.451	5.127	5.059
$J_{C11,C12}$	-15.53	-16.48	-15.80	-16.40
$J_{C41,C42}$	-16.17	-17.20	-17.72	-18.45
$J_{C11,N2}$	5.32	6.06	6.71	
$J_{C12,N2}$	9.65	4.76	6.71	
$J_{C41,N3}$	<0.02	<0.02	<0.02	
$J_{C42,N3}$	5.20	5.36	4.50	
CH_3			1.357 §	
α-*H*			3.233 §	4.051 §
$J_{CH_3,\alpha H}$			6.62 §	
N*H*			6.666 §	exchanged
N*H*'			4.630 §	exchanged

† At 298.2 K ; Chemical shifts are ± 0.002 ppm , coupling constants are ± 0.02 Hz .

¶ Complex *5* : Λ-β-[Co*L* Cl$_2$]$^+$ in acetone-d_6 ;
6 : Λ-β-[Co*L* (NO$_2$)$_2$]$^+$ in DMSO-d_6 ;
7 : Λ-β$_2$-[Co*L* (*S*-ala)]$^+$ in DMSO-d_6 ;
8 : Λ-β$_2$-[Co*L* (*S*-pro)]$^+$ in D$_2$O .

§ These data refer to the coordinated amino acidate groups .

as is revealed by the ^{1}H NMR studies. Reasons for this have been outlined previously (Chambers *et al*, 1984b) on the basis of symmetry considerations. The *H*(45) resonances occur at higher field than those of *H*(15) due to shielding by a pyridyl ring, as indicated in (*I*). Reference to the Tables and Figure confirms this suggestion. The assignments given were made on the basis of spin-decoupling experiments and by analogy to related picpn complexes (Chambers *et al*, 1984b) .

An important result of the ^{1}H NMR studies is that a convenient way to distinguish β_1 and β_2 isomers of the complexes β-[Co(tetradentate)(amino-acidate)]$^{n+}$ emerges. In the complexes Λ-β-[Co*L*(ox)]$^+$, Λ-β_1-[Co*L*(*R*-ala)]$^{2+}$, Λ-β_1-[Co*L*(*S*-ala)]$^{2+}$ and its *S*-proline analogue, the proton *H*(15) experiences some electronic shielding effects from the coordinated oxalate or amino acid carboxylic groups. In D$_2$O or DMSO-d$_6$ solutions this proton is observed in the NMR spectra between 8.27 and 8.46 ppm . The position of these resonances in such complexes appears to have little spread. The range 8.31-8.40 ppm in D$_2$O and 8.23-8.27 in DMSO-d$_6$ solutions was found for five β_1 isomers of [Co(*R*,*S*-picpn)(*S*-ala)]$^+$ (Chambers *et al*, 1984b), four of whose molecular structures have been established crystallographically (Mulqi *et al*, 1984) .

A marked contrast is noted (Table 2) for those complexes in which such shielding does not take place . The position of the *H*(15) resonance is displaced some 0.3 to 1.2 ppm downfield from those of the oxalate and β_1 amino acidate complexes, and thus the assignment of geometrical isomers is entirely consistent. Further support for the assignment is lent by the positions of the CH_3 resonances in the alanine diastereoisomers. The methyl group in Λ-β_1-[Co(*R*,*R*-picchxn)(*S*-ala)]$^{2+}$ is somewhat shielded by a pyridyl ring of the tetradentate, as revealed by molecular models, but does not experience the same interaction in either the β_2 analogue *or* in the β_1 isomer containing *R*-alanine.

The question then remains as to the absolute configuration of *N*2 in the Λ-β complexes. Molecular models suggest that it has *S* configuration. Because of the coordination and conformational requirements of the 1,2-diaminocyclohexane group the alternative *R*- configuration would enforce unacceptable strain in the coordination sphere. Therefore, all of the complexes are Λ-β-*S*,*S*- forms . Furthermore, the coupling constants between *H*(N2) and *H*(C11) or *H*(C12), in solutions where the *H*(N2) proton had not exchanged with the solvent, are in accord with this assignment.

No β_2 isomers of Co(*R*-picpn)(ala)$^{2+}$ were found in the reactions of *R*- or *S*-alanine with the complex Λ-α-[Co(*R*-picpn)Cl$_2$]$^+$ (Mulqi *et al* , 1984). The isolation in this study of diastereoisomers with this topology may be due to kinetic factors, in that the Λ-β-[Co(*R*,*R*-picchxn)X$_2$]$^{n+}$ nucleus is apparently reluctant to rearrange. The absence of some isomers however, appears to be due to other steric factors. Molecular models of appropriate diastereoisomers indicate that the β_2 of these *R*-alanine and *R*-proline complexes have considerable non-bonded interactions with *H*(15) and the β_1 isomer of *R*-proline also would contain unfavourable intramolecular interactions involving the cyclohexane ring. It thus becomes obvious why these species were not isolated from the appropriate reaction mixtures.

TABLE 3

ELECTRONIC AND CD SPECTRAL DATA FOR THE COMPLEXES AT 298 K IN AQUEOUS SOLUTIONS

Complex	λ (nm)	ε x 10^{-3} ($dm^2 mol^{-1}$)	Δε ($dm^2 mol^{-1}$)
Λ-β-[Co*L* Cl_2]$^+$ ¶	534	1.78	
	590		+6.8
(*5*)	516		+6.0
	403		+10.1
Λ-β-[Co*L* $(NO_2)_2$]$^+$	447	3.11	
	464		+22.2
(*6*)	352		-18.9
	324		-25.6
Λ-β-[Co*L* (ox)]$^+$	483	1.99	
	356	2.30	
(*1*)	490		+11.5
	364		-4.2
Λ-$β_1$-[Co*L* (*R*-ala)]$^{2+}$	480	2.23	
	347	1.75	
(*2*)	506		+28.1
	357		-2.2
	310		+1.2
Λ-$β_1$-[Co*L* (*S*-ala)]$^{2+}$	480	2.44	
	348	1.79	
(*3*)	492		+20.6
	351		-4.5
	306		+0.8
Λ-$β_1$-[Co*L* (*S*-pro)]$^{2+}$	490	2.07	
	355	1.55	
(*4*)	477		+29.8
	355		-7.4
	280		-17.1
Λ-$β_2$-[Co*L* (*S*-ala)]$^{2+}$	472	1.88	
	346	1.73	
(*7*)	537		-8.3
	483		+34.0
	346		-5.7
Λ-$β_2$-[Co*L* (*S*-pro)]$^{2+}$	492	1.91	
	358	2.12	
(*8*)	543		-18.0
	487		+59.3
	355		-10.3
	284		-38.0

¶ Recorded in concentrated HCl solution

The high degree of stereoselectivity found in these complexes has encouraged us to extend our studies to other related chiral tetradentate systems and to explore these kinds of species with a view to using them for stereoselective synthetic catalysts. We hope to report our results on this work in the near future.

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Stratigraphic Revision of the Early Carboniferous Flagstaff Formation, Southern New England Belt, N.S.W.

I. D. LINDLEY

ABSTRACT. Recent stratigraphic studies of the expanded Early Carboniferous marine sequences in the southern New England Belt, New South Wales, have indicated the need for a revision of the Flagstaff Sandstone of Roberts (1961). Because of lithological diversity, the unit is renamed the Flagstaff Formation. Within the Salisbury-Brownmore district five new members are defined: the Allyn River, Underbank Mudstone, Brownmore Sandstone, Bandon Grove Limestone and Lostock Sandstone Members. These are indicative of a transition from deep water turbidite deposition (Allyn River Member), to shallow marine-shelfal deposition (Lostock Sandstone Member). The five members are correlated with the upper part of the Woolooma Formation and part of the Isismurra Formation in the Rouchel district, and the Boolambayte Formation in the Gloucester-Myall Lakes district. The uppermost unit, the Lostock Sandstone Member, is disconformably overlain by ash-flow tuff and conglomeratic lateral equivalents of the Gilmore Volcanic Group, representing a complete marine regression in the southern New England Belt during the Early Carboniferous.

INTRODUCTION

During the past twenty years the original stratigraphic subdivisions used by Roberts (1961) in the Gresford district (Fig. 1) have been applied to a large portion of the southern New England Belt. While Roberts's (1961) terminology continues to be useful, the diversity of lithologies mapped away from the type section of the Flagstaff Sandstone in the Gresford district warrants revision, and is the purpose of this paper.

The Flagstaff Formation, here renamed because of internal lithological diversity, is one of the most extensive Early Carboniferous units in the southern New England Belt, outcropping over an area of at least 1000 km² (Fig. 2). This paper concentrates on the definition of units in the expanded marine sequences present in the Salisbury-Brownmore district. Revision has been facilitated by the detailed geological mapping of McDonald (1972), Gordon (1972), Southgate (1972), Sparke (1972), O'Neil (1972), Hamilton (1972), Hall (1972), Parker (1973) and Lindley (1976).

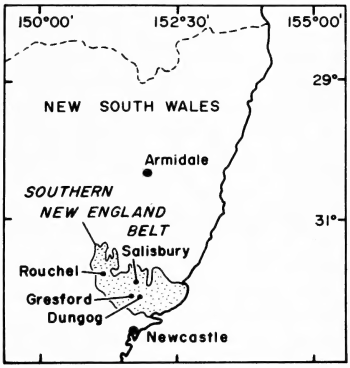


Fig. 1. Locality map.

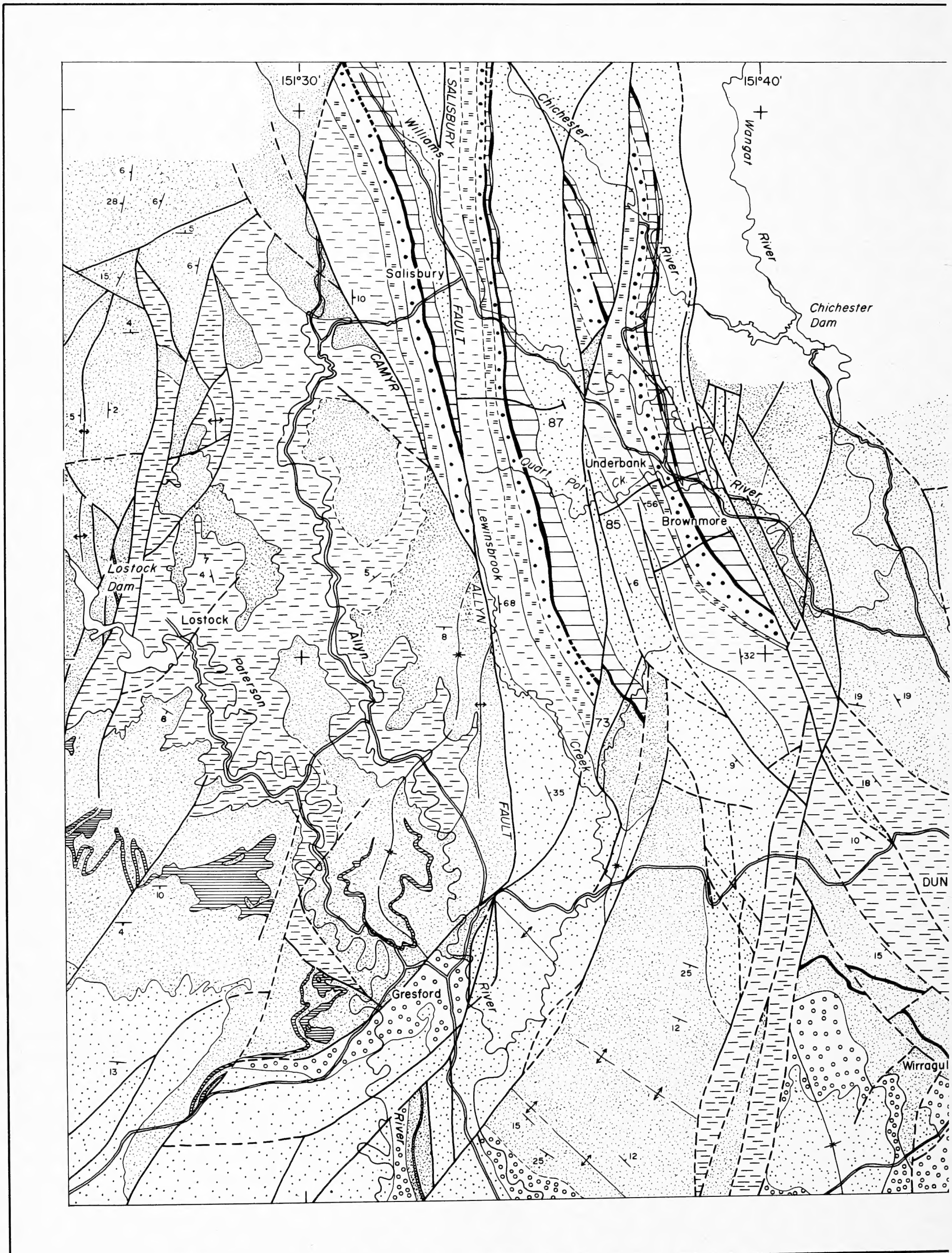
STRATIGRAPHY

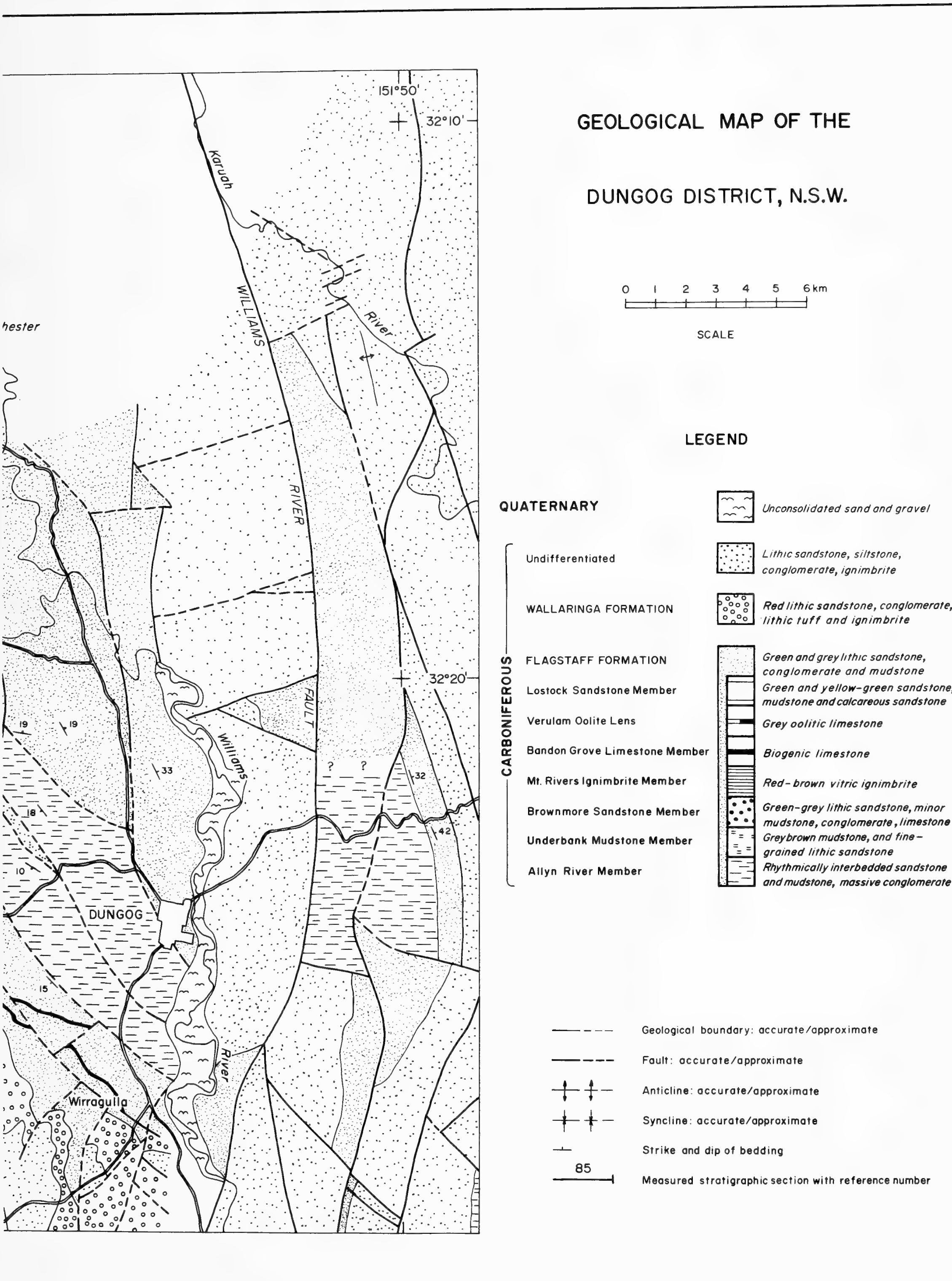
The Carboniferous sequence in the Gresford district has been described by Roberts (1961) and Hamilton *et al* (1974). In the vicinity of Gresford, and essentially restricted to the west of the Camyr Allyn Fault, Hamilton *et al* (1974) defined the Mount Rivers Ignimbrite Member. South-southeast of Gresford they described an informal unit, Member A, comprising interbedded sandstone and mudstone.

In the type section in the Lewinsbrook Syncline, the Flagstaff Formation consists of a thick sequence of medium to coarse grained lithic sandstone with minor grey siltstone (Roberts, 1961). East of the Camyr Allyn Fault, in the Salisbury-Brownmore district, it is possible to divide the Flagstaff Formation into five dominantly marine members. The lowermost member is turbiditic and is succeeded by a well-bedded lithic sandstone and mudstone sequence which may contain interbeds of coal and carbonaceous shale. The boundary between these two mudstone dominated members in their type section is gradational. The upper members are dominated by thickly bedded units of sandstone with several interbedded limestone horizons.

West of the Camyr Allyn Fault it is impossible to map the boundary between the lower mudstone dominated units because of its gradational nature, and/or lateral facies changes within the units. A lower turbidite unit is recognisable, and is overlain by an upper unit of coarse grained sandstone, similar to that of the Flagstaff Formation in its type section.

South of Gresford the Flagstaff Formation is undifferentiated. There is, however, a lower unit of interbedded mudstone and sandstone which Hamilton *et al* (1974) refer to as Member A, forming the subdued countryside beneath the escarpment of Mt. Ararat. This informal unit is overlain by an upper unit of thickly bedded lithic sandstone and conglomerate, which to the south interfingers with the Wallaringa Formation.


151°30'
151°40'
SALISBURY
Williams
Chichester
Wangat
River
Chichester
Dam
Salisbury
FAULT
CAMYR
Quart Pot Ck.
Underbank
River
Brownmore
Lewinsbrook
ALLYN
FAULT
Lostock
Dam
Lostock
Paterson
Allyn
Creek
Gresford
River
River
DUN
Wirragul


GEOLOGICAL MAP OF THE
DUNGOG DISTRICT, N.S.W.
0 1 2 3 4 5 6 km
SCALE
LEGEND
QUATERNARY
Unconsolidated sand and gravel
CARBONIFEROUS
Undifferentiated
Lithic sandstone, siltstone, conglomerate, ignimbrite
WALLARINGA FORMATION
Red lithic sandstone, conglomerate, lithic tuff and ignimbrite
FLAGSTAFF FORMATION
Green and grey lithic sandstone, conglomerate and mudstone
Lostock Sandstone Member
Green and yellow-green sandstone, mudstone and calcareous sandstone
Verulam Oolite Lens
Grey oolitic limestone
Bandon Grove Limestone Member
Biogenic limestone
Mt. Rivers Ignimbrite Member
Red-brown vitric ignimbrite
Brownmore Sandstone Member
Green-grey lithic sandstone, minor mudstone, conglomerate, limestone
Underbank Mudstone Member
Greybrown mudstone, and fine-grained lithic sandstone
Allyn River Member
Rhythmically interbedded sandstone and mudstone, massive conglomerate
Geological boundary: accurate/approximate
Fault: accurate/approximate
Anticline: accurate/approximate
Syncline: accurate/approximate
Strike and dip of bedding
85
Measured stratigraphic section with reference number
151°50'
32°10'
32°20'
Karuah
River
WILLIAMS
RIVER
FAULT
Williams
River
DUNGOG
Wirragulla
hester
19
19
33
32
42
18
10
15

East and southeast of Dungog the lower turbidite unit is overlain by medium grained, grey-brown lithic sandstone, containing interbeds of conglomerate in the uppermost units. Brachiopods from the upper part of the *Delepinea aspinosa* Zone are present in the sandstone unit (952001, Clarence Town 1:25 000 sheet).

Flagstaff Formation

Synonymy: Flagstaff Sandstone, Roberts (1961)

Derivation: Named by Roberts (1961) after a prominent hill known as 'Flagstaff Hill'; the hill has since been formally named Lords Pillar (675236, Allynbrook 1: 25 000 sheet).

Type section: Measured along Brandy Creek from its confluence with Lewinsbrook Creek (690172) to a ridge crest at 701208 (Allynbrook 1:25 000 sheet). Measured by J. Roberts and referred to as Section 73.

Thickness: 1220m.

Lithology: The Flagstaff Formation in its type section is dominated by thickly bedded, medium and coarse grained lithic sandstone. The lower (0-270m) and upper (650-1220m) parts of the section comprise almost continuous outcrop of green and brown lithic sandstone, with occasional interbeds of siltstone. The interval between 270 and 650m is poorly exposed, and contains thickly bedded, coarse to medium grained lithic sandstone. Unexposed parts of the sequence are probably mudstone.

An interbedded impure limestone identified as the Bandon Grove Limestone Member is present 949m above the base of the section.

Remarks: The Flagstaff Formation in its type section conformably overlies the Bonnington Siltstone and is apparently conformably overlain by mudstone of the Chichester Formation (Roberts *et al*, 1984).

Age: Brachiopod faunas of the Flagstaff Formation belong to the *Delepinea aspinosa* Zone (Roberts, 1975; Jones and Roberts, 1976; Roberts and Engel, 1980). Hamilton *et al* (1974) and Roberts (1975) considered that the oldest faunas, from the core of the Hilldale Anticline at Greenhills, may be transitional between the *Orthotetes australis* and *Delepinea aspinosa* Zones. The unit is entirely of late Visean age.

Allyn River Member

Derivation: The Allyn River (Allynbrook 1:25 000 sheet), where the member is well exposed.

Type section: The type section is measured along Quart Pot Creek from 696273 to 704278 (Allynbrook 1: 25 000 sheet). Section 85 (Roberts, 1975), Fig. 2.

Thickness: 740m.

Lithology: In the type section, the Allyn River Member consists of thinly interbedded sandstone and mudstone. The lower 138m of the section contains sandstone units whose thickness ranges from 2cm to over 11m (average 117cm), and mudstone units ranging in thickness from 2cm to 380cm (average 33cm). The sand/mud ratio of this interval is 2.67. The remainder of the section is comprised of similar lithologies. The sandstone is typically medium to coarse grained and exhibits sedimentary structures typical of turbidites, including graded, massive, parallel and convolute laminated bedding in various combinations (typically graded, massive, parallel), as well as dish structures. Mudstones are grey-brown and well laminated.

Remarks: Considerable regional variation is present in the Allyn River Member because of its mode of deposition. A large proportion of the member is characterised by interbedded fine and very fine-grained sandstone typical of classical distal turbidites of the outer fan facies (Rupke, 1978). Best exposures of these sequences are present along most of the Allyn River valley, particularly at 601243 (Allynbrook 1: 25 000 sheet). Medium-fine to coarse sandstone, and conglomerate, interpreted as examples of proximal turbidites characteristic of the middle and upper fan facies (Rupke, 1978) intercalate with the distal turbidite sandstone and mudstone sequences. Coarse upper fan channel conglomerates and levee deposits are well exposed on the Dungog to Gloucester Road in the vicinity of 873173, 880170 and 902171 (Dungog 1: 25 000 sheet). In the roadside exposure at the latter locality the channel conglomerate discordantly rests on sparsely fossiliferous mudstone. Pebble sandstones with injection structures and lithic sandstone with disturbed bedding and dish structure, interpreted as part of the middle or upper fan facies, are common in units of the Allyn River Member at many localities. Sparse fragments of brachiopod valves and other fossil debris in tyick massive sandstone also indicate rapid transport.

East of the Camyr Allyn Fault, the member is characterised by considerable variations in thickness. Maximum recorded thickness of the Allyn River Member measured along the Williams River at Salisbury, is in excess of 1000m. The unit appears to decrease in thickness away from Salisbury. In the flat-lying sequences west of the Camyr Allyn Fault thicknesses of the unit are unobtainable because the base of the member is not exposed, and there is difficulty in separating the uppermost units of the member from those of the overlying sandstone dominated sequences. Within the type section of the Flagstaff Formation, the lower 270m of lithic sandstone may be laterally equivalent of the Allyn River Member. These sandstones may represent a proximal turbidite deposit.

Age: The type section is unfossiliferous. The unit directly overlies the Bonnington Siltstone containing faunas of the *Orthotetes australis* Zone and is in turn overlain by the Underbank Mudstone Member containing the *Inflatia elegans* Subzone. The Dunvegan fauna (Roberts, 1961), which occurs northwest of Gresford in the flat-lying sequences west of the Camyr Allyn Fault, is assigned to the *Inflatia elegans* Zone by Roberts (1975). The unit is thus entirely late Visean in age.

Underbank Mudstone Member

Synonymy: Wiragulla Beds (in part), Roberts (1964).

Derivation: Underbank village (Allynbrook 1: 25 000 sheet).

Type section: The type section overlies that of the Allyn River Member, and is measured along Quart Pot Creek from 704278 to 708281 (Allynbrook 1: 25 000 sheet). Section 85 (Roberts, 1975), Fig. 2.

Thickness: 430m.

Lithology: The unit consists of mudstone and interbedded fine-grained sandstone. The mudstone is olive-grey to black and contains abundant well-preserved faunas at various levels throughout the type section. The base of the unit is gradational with the interbedded sandstone and mudstone of the underlying Allyn River Member.

Remarks: The Underbank Mudstone is restricted in outcrop to east of the Camyr Allyn Fault. In the vicinity of Salisbury and to the west of the Salisbury Fault, continental sediments intertongue with the Underbank Mudstone Member. Sections in the fault block wedged between the Camyr Allyn and Salisbury Faults contain up to 11m of coal, carbonaceous shale and white lithic sandstone. On the Salisbury to Dungog road, 1.5km south of Salisbury, interbeds or coal and carbonaceous shale are present over a stratigraphic interval of at least 115m. This is the easternmost exposure of continental sediments which intertongue with the Underbank Mudstone Member. West of the Camyr Allyn Fault, interbedded coal-bearing sediments are present in many exposures immediately overlying the Allyn River Member, and mapped as undifferentiated Flagstaff Formation. Carbonaceous sediments are present north of Halton on the Salisbury Gap Road, and at 630248 (Allynbrook 1:25 000 sheet). Carbonaceous sediments are also present in the vicinity of the type section of the Flagstaff Formation, on Parkes Creek Road at 705153 (Allynbrook 1:25 000 sheet).

The poorly exposed interval between 270 and 650m in the type section of the Flagstaff Formation is possibly laterally equivalent to the Underbank Mudstone Member. Similarly, part of Hamilton *et al's* (1974) Member A south of Gresford, which includes the Torryburn fauna (*Inflatia elegans* Subzone fauna, Roberts, 1975), and is here mapped as undifferentiated Flagstaff Formation, is a lateral equivalent of the Underbank Mudstone Member. Underbank Mudstone equivalents, mapped as Flagstaff Formation, also outcrop at Wiragulla and contain faunas assigned to the *Inflatia elegans* Subzone (Roberts, 1975).

Age: Prolific brachiopod faunas of the member are assigned to the *Inflatia elegans* Subzone of the *Delepinea aspinosa* Zone. The member is therefore late Visean in age.

Brownmore Sandstone Member

Derivation: Brownmore village (Allynbrook 1:25 000 sheet).

Type section: The type section of the Brownmore Sandstone Member is measured from 718251 to 725256 (Allynbrook 1: 25 000 sheet) along a northeasterly trending ridge 2km southwest of Brownmore and 1.25km east of Black Camp Creek (Fig. 2).

Thickness: 830m.

Lithology: In the type section, the lowermost part of the member consists of 210m of resistant massive and parallel bedded lithic sandstone with conglomeratic bands. The remainder of the lower half of the section consists of fine-grained lithic sandstone, interbedded friable mudstone and three shelly limestone lenses. The upper 250m is a massively bedded medium to coarse grained sandstone. The entire section is fossiliferous. At the base of the member there is a sharp boundary between mudstone of the Underbank Mudstone Member and lithic sandstone of the Brownmore Sandstone Member.

Remarks: Thickest development of the Brownmore Sandstone Member is in the Salisbury-Brownmore district, where over 900m of sediment are recorded. The member rapidly decreases in thickness away from this area, and intertongues with undifferentiated units of the Flagstaff Formation. Lateral equivalents of the member are possibly represented in the type section of the Flagstaff Formation by lithic sandstone in the interval between 650m and the base of the overlying Bandon Grove Limestone Member at 949m.

Age: Brachiopods from the sandstone are assigned to the *Gigantoproductus tenuirugosus* Subzone of the *Delepinea aspinosa* Zone indicating a late Visean age.

Brandon Grove Limestone Member

Derivation: Bandon Grove village (Allynbrook 1:25 000 sheet).

Type locality: The type locality of the Bandon Grove Limestone Member is in the vicinity of a small dam in the headwaters of Quart Pot Creek (671252, Allynbrook 1:25 000 sheet).

Thickness: 13m.

Lithology: The Bandon Grove Limestone Member is a biogenic limestone composed of crinoid fragments, minor solitary corals and rare brachiopods. The limestone is usually pure, occasionally contains large rounded volcanic pebbles, and at the type locality contains interbeds of fine-grained calcareous sandstone. In places it grades into a cross-bedded calcareous sandstone.

Remarks: Maximum thickness of the member is 15m, recorded in the Salisbury district. The member decreases in thickness away from the type locality, and grades into calcareous sandstone which is often cross-bedded. The sandstone contains angular and sub-angular grains of quartz, feldspar and rock fragments cemented by micrite.

Geographically, the Bandon Grove Limestone Member is restricted to the eastern side of the Camyr Allyn Fault. The member is present in the type section of the Flagstaff Formation and is also mappable in the Wiragulla district, south of Dungog.

The Mount Rivers Ignimbrite Member in the Gresford district is considered to be an approximate time equivalent of the Bandon Grove Limestone Member because of the mutual exclusiveness of the two members in terms of their distribution. Stratigraphically, the members are not recorded together in the same section, and both occur at similar stratigraphic levels, several hundred metres above the *Inflatia elegans* Subzone.

Age: Brachiopods collected from both above and below and within the Bandon Grove Limestone Member belong to the late Visean *Gigantoproductus tenuirugosus* Subzone.

Lostock Sandstone Member

Derivation: Lostock village (Carrow Brook 1:25 000 sheet).

Type section: The type section of the Lostock Sandstone Member is measured from 657304 to 664304 (Allynbrook 1:25 000 sheet) along a ridge immediately north of Bullee Coggee Creek, 4km west of Underbank Section 87 Roberts, 1975), Fig. 2.

Thickness: 475m.

Lithology: The lowermost 30m of the member consists of coarse grey calcareous sandstone. The remainder of the lower half of the section is poorly exposed grey mudstone. The upper 315m of the Lostock Sandstone Member is represented by thickly bedded medium and coarse grained green and yellow-green sandstone.

Remarks: The Bandon Grove Limestone Member and its calcareous lateral equivalents separates the Lostock Sandstone Member from the underlying Brownmore Sandstone Member. Unlike the underlying sandstone, the Lostock Sandstone Member in most sections is characterised by a fining upwards sequence. In the type section the upper boundary of the member is defined by a disconformable ash-flow tuff unit. North and east of the type section the ash-flow tuff is replaced by conglomerate and conglomeratic sandstone. The first occurrence of conglomeratic sandstone in sections 90 and 85 (Roberts, 1975) marks the upper boundary of the Lostock Sandstone Member and the Flagstaff Formation.

Mapping of the Verulam Oolite Lens in the upper part of the member, 1km east of Chichester village (Chichester 1:25 000 sheet), suggests that there may have been a short hiatus following deposition of the Lostock Sandstone Member. This resulted in localised erosion of the lens and uppermost units of the member.

In the Gresford district, mapping (Hamilton *et al*, 1974; this work, Figs. 2 and 3) indicates that the Martins Creek Ignimbrite Member, at the base of the Gilmore Volcanic Group, overlies either the Flagstaff Formation or the Wallaringa Formation. The latter unit intercalates with and overlies the Flagstaff Formation south of Gresford. The Martins Creek Ignimbrite Member lies between the

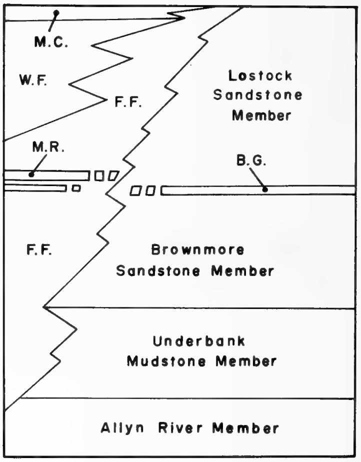


Fig. 3. Composite stratigraphic column showing members of the Flagstaff Formation in the Dungog district: B.G. - Bandon Grove Limestone Member; M.R. - Mount Rivers Ignimbrite Member; F.F. - Flagstaff Formation (sediments similar to those of the type section); W.F. - Wallaringa Formation; M.C. - Martins Creek Ignimbrite Member (of the Gilmore Volcanic Group).

Gigantoproductus tenuirugosus Subzone and the *Rhipidomella fortimuscula* Zone (Roberts and Engel, 1980), and thus it is considered that the ash-flow tuff at the top of the type section of the Lostock Sandstone Member is a correlative of the Martins Creek Member.

The Lostock Sandstone Member is variable in thickness and a short distance southeast of the type-section consists of up to 930m of fossiliferous sandstone interbedded with mudstone. Away from the type area, the member decreases rapidly in thickness and intercalates with the uppermost part of the Flagstaff Formation. Sections north and east of the type section are characterised by several limestone horizons, one named the Verulam Oolite Lens.

Age: Faunas from the member are assigned to the *Gigantoproductus tenuirugosus* Subzone, indicating a late Visean age.

Verulam Oolite Lens

Synonymy: Verulam Oolite Member, Campbell and McKelvey (1972).

Remarks: The Verulam Oolite Lens is a massive, grey, cross-bedded oolite. Brachiopods from within as well as above and below the lens have been assigned to the *Gigantoproductus tenuirugosus* Subzone. The unit occurs at a similar stratigraphic level to the type Verulam Oolite Member mapped by Campbell and McKelvey (1972) in the Barrington district, 20km east-northeast of the Salisbury-Brownmore district. Because of the stratigraphic position of the unit within the Lostock Sandstone Member it is regarded as a lens for the purpose of this revision. The Verulam Oolite Lens is not recorded in section west of the Salisbury Fault.

REGIONAL CORRELATION

The Flagstaff Formation is characterised by brachiopod faunas of the *Delepinea aspinosa* Zone, and within the expanded marine sequences of the Salisbury-Brownmore district, Roberts (1975) has identified two subzones. The *Inflatia elegans* Subzone characterises the Underbank Mudstone Member, and there is some evidence that it is present in lateral equivalents of the unfossiliferous Allyn River Member. The *Gigantoproductus tenuirugosus* Subzone is present in the Brownmore Sandstone, Bandon Grove Limestone, and Lostock Sandstone Members. The *Inflatia elegans* Subzone succeeds the *Orthotetes australis* Zone, present in the Bonnington Siltstone.

Rouchel district: Measured sections of the Woolooma Formation (Roberts and Oversby, 1974) contain faunas of the *Orthotetes australis* Zone in the lower part and *Inflatia elegans* Subzone in the upper part. On biostratigraphic grounds, the sediments containing the *Inflatia elegans* Subzone are considered to be lateral equivalents of the Underbank Mudstone Member and possibly part of the Allyn River Member. Similarly, the *Orthotetes australis* Zone sequence is laterally equivalent to the Bonnington Siltstone.

The Isismurra Formation,which intercalates with and overlies the Woolooma Formation, contains four informal ash-flow tuff units in its upper part (Roberts and Oversby, 1974). The uppermost of the informal units, Cli-d, is correlated with the Martins Creek Ignimbrite Member by Osborne (1928) and Roberts and Oversby (1974) on both lithological and geochronological grounds. Ash-flow tuff unit Cli-c of the Isismurra Formation has been mapped south of the Rouchel district towards Westbrook, where it splits into two units of red ash-flow tuff separated by coarse lithic sandstone. East of Westbrook and in the Gresford district, these two units are mapped as the Mount Rivers Ignimbrite Member. It would therefore appear that the Flagstaff Formation is equivalent to the upper half of the Woolooma Formation and upper (but not uppermost) part of the Isismurra Formation in the Rouchel district.

Gloucester-Myall Lakes District: In this region the Boolambayte Formation is of Visean age (Crane and Hunt, 1980). The unit is overlain by the Nerong Volcanics which are considered by Roberts and Engel (1980) and Roberts (in press) to be a lateral equivalent of the Gilmore Volcanic Group. A poorly preserved brachiopod fauna collected near the base of the Boolambayte Formation in the underlying Wallanbah Formation may belong to the *Orthotetes australis* Zone (Crane and Hunt, 1980), suggesting that a greater part of the Boolambayte Formation is possibly a correlative of the Flagstaff Formation.

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Multiple Karstification in the Lachlan Fold Belt in New South Wales: Reconnaissance Evidence

R. A. L. OSBORNE

ABSTRACT. The Lower Palaeozoic limestone terrains of the Lachlan Fold Belt in New South Wales have complex petrography, elusive structure and enigmatic karst landforms. The geological history of these terrains suggests that they have been exposed to subaerial conditions and thus karstification on a number of occasions, most importantly during Middle Devonian, Permo-Carboniferous and latest Cretaceous to Recent times.

Palaeokarst deposits exposed in caves, quarries and at the surface have been truncated by more recent karst processes. In some cases many generations of cave sediments and palaeokarst deposits can be recognized. This indicates that the limestone terrains have been subjected to multiple periods of karstification. The geomorphology and commonly also petrography of these terrains results from the imprinting of features developed during each period of karstification.

Multiple karstification offers the possibility that limestone terrains may contain information about events during poorly understood parts of the geological record.

INTRODUCTION

Upper Ordovician to Lower Devonian limestones, many of which are massive and recrystallized, occur in the Lachlan Fold Belt in New South Wales commonly associated with silicic/intermediate volcanics and shallow water marine facies. Some karstification has occurred in all but the most thinly bedded and impure limestones. Significant karsts with well developed caves are reported from 39 localities within the Fold Belt (Matthews, 1979) (Fig. 1). The sequence and timing of karstification in these terrains is problematical. Jennings (1982) proposed that the karsts incorporate relic, buried and exhumed components indicating a compound history of landform development.

Limestones may be exposed to subaerial conditions at an early stage in their diagenesis. Studies of caves in coral islands (Ollier, 1975) have shown that significant speleogenesis can occur in poorly cemented limestones. These syngenetic karst features are the product of what can be the first of many periods of subaerial exposure and karstification in the post-depositional history of limestones. Each period of karstification will produce or modify landform features and may deeply penetrate the fabric of the limestone, producing caves or smaller solution cavities and depositing sediments within them.

PALAEOKARSTS AND MULTIPLE KARSTIFICATION

Palaeokarsts, produced where karst features have been protected by burial and revealed by later exhumation, provide evidence for karstification in the past. Multiple karstification is indicated by the presence of palaeokarst features, most often sediments, in limestone terrains that have been subjected to geologically more recent periods of karstification.

Multiple karstification has been recognized in the Carboniferous limestones of the United Kingdom. For example Halstead and Nicoll (1971) describe palaeokarst deposits containing Triassic reptile fossils in Carboniferous limestones of the Mendip Hills, Sommerset, England where significant caves and karst features, believed to have originated in the early Pleistocene, are also developed. Further evidence, summarized by Drew (1975), indicates that "there is considerable evidence that the Mendips were a true karst area possessing some degree of subterranean drainage in Triassic times". Ford (1976), using the Permian and Lower Carboniferous limestones of the United Kingdom as examples, recognized that "any limestone of appreciable geological age may have gone through more than one cycle of karstification" and that "the possibility of the control of present-day karst drainage by fossilized systems should not be overlooked". Buchbinder et al. (1983) have recognised five episodes of karstification ranging in age from Turonian to Neogene in the Cretaceous limestones of central and northern Israel.

Little study has been made of palaeokarsts in the Lachlan Fold Belt (or indeed elsewhere in Australia); however, the literature of the Lachlan Fold Belt indicates that palaeokarsts of supposedly Cainozoic age may be fairly common features of its Lower Palaeozoic limestone terrains. Palaeokarsts have been reported from Canowindra, Molong and Wellington Caves by Carne (1919), in the deep leads of the Gulgong Goldfield by Jones (1940) and in Steeley's Quarry at Wombeyan by Hope (1982). Cainozoic palaeokarst can be inferred from the report on the Cargo Goldfield of Andrews and Morrison (1915) and is suggested as a possibility in the Cliefden Caves area by Webby and Packham (1982).

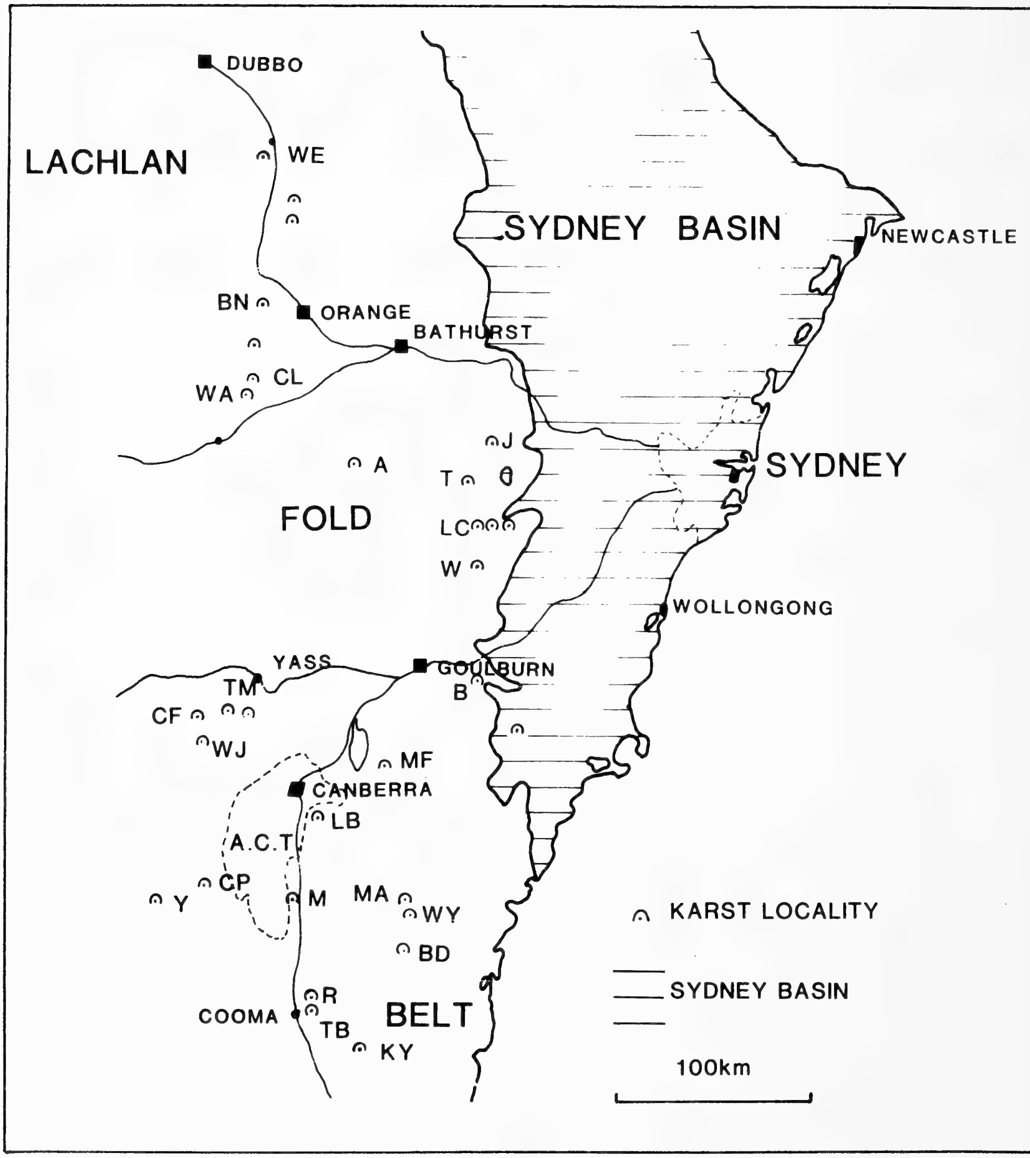

Fig. 1 Some significant karsts developed on Lower Palaeozoic limestones of the eastern Lachlan Fold Belt in New South Wales. A, Abercrombie; B, Bungonia; BD, Bendithera; BN, Borenore; CF, Cave Flat; CL, Cliefden; CP, Cooleman Plain; J, Jenolan; KY, Kybean; LB, London Bridge; LC, Colong; M, Michelago; MA, Marble Arch; MF, Mount Fairy; R, Rosebrook; T, Tuglow; TM, Taemas; W, Wombeyan; WA, Walli; WE, Wellington WJ; Wee Jasper; WY, Wyanbene; Y, Yarrangobilly.

Palaeozoic palaeokarst has been reported in New South Wales by Conaghan (in Crook and Powell 1976) in reference to a "palaeocave" at the boundary between the late Lower Devonian Garra Formation and the Upper Devonian Catombal Group at Mountain View, near Wellington.

EVIDENCE FOR MULTIPLE KARSTIFICATION IN SOME LIMESTONES OF THE LACHLAN FOLD BELT IN NEW SOUTH WALES.

A reconnaissance of seven Lower Palaeozoic limestone terrains in the Lachlan Fold Belt in New South Wales has shown them to contain evidence for multiple periods of karstification. The seven limestones - the Borenore Limestone (at Borenore Caves), Bungonia Limestone (at Bungonia Caves), De Drack Formation (at Mt. Fairy), Garra Formation (at Wellington Caves), Jenolan Caves Limestone (at Jenolan Caves), Rosebrook Limestone (at Toll Bar) and Wombeyan Limestone (at Wombeyan Caves) (Fig. 1) - all contain massive recrystallized facies (metamorphosed in the case of the Wombeyan Limestone) in which significant karstification has taken place. With the exception of the Garra Formation in which Osborne (1983) recognized two periods of phreatic speleogenesis at Wellington Caves and Conaghan (in Crook and Powell (1976) recognized the presence of Devonian palaeokarst, the evidence for multiple periods of karstification presented below has not yet been the subject of detailed investigation.

1. Borenore Limestone

The Upper Silurian Borenore Limestone (Carne & Jones, 1919) is a highly altered, massive, crinoidal limestone - in places extensively brecciated - that has been used as a source of marble. At Borenore Caves, west of Orange, three major karst features - Arch Cave, Tunnel Cave and Verandah Cave - are developed in the Borenore Limestone.

Arch and Tunnel Caves were described by Frank (1972, 1973) who noted (Frank, 1973) that "there is some evidence for fossil karst that has been exhumed during the development of the Tunnel Cave". Frank has recognized here the essential characteristics of multiple karstification, an ancient karst feature truncated by the development of a more recent one.

Current investigations by the author have confirmed Frank's observations and suggest that the post-depositional history of the Borenore Limestone may involve at least four periods of karstification. The earliest period of karstification (which may be syngenetic) is indicated by the presence of cement-filled vugs within the limestone. These (Fig. 2 A) truncate fossils and may be syngenetic or early diagenetic in origin. A second period of karstification is indicated by the presence of laminated sediment that occurs in vertical zones within the limestone (Fig. 2 B). These sediments are unconformable with bedding in the limestone and appear to have been deposited with a high initial inclination such as occurs in a nothephreatic cave environment.

The ferruginized sediments in Tunnel Cave which have been truncated by the development of the present cave as described by Frank (1973) represent a third period of karstification. These sediments are similar to surficial deposits in the area which underlie basalts and have been interpreted by Partridge (1976) as Tertiary in age. A fourth period of karstification was responsible for the development of the present caves. In Arch Cave, there is evidence of a later period of speleogenesis as speleothems have been dissolved away by an apparently fairly recent period of phreatic speleogenesis. How this correlated with the events in Tunnel Cave is as yet unclear.

The Borenore Limestone is overlain by basalt flows from Mt. Canobolas which have been dated by Wellman and McDougall (1974) at 12 Ma. Relationship between the basalt and Arch Cave suggest that at least some of the cave development seen today pre-dates extrusion of the basalt: the southern end of Arch Cave is terminated by a plug of basalt (Fig. 2 C) which shows an ophitic texture in thin section.

2. Bungonia Limestone

A significant karst with many dolines, caves and a major limestone gorge is developed at Bungonia Caves, near Marulan, in the Upper Silurian Bungonia Limestone (Carne & Jones, 1919).

The limestone forms a plateau into which Bungonia Creek has cut a gorge 400 m deep (Fig. 3). Caves developed within the limestone mass of the plateau have horizontal and vertical elements and are among the deepest known on the Australian Mainland, extending to 148 m below the plateau surface.

The age and developmental history of the Bungonia karst has been the subject of much study and speculation. Jennings et al. (1972) and James et al. (1978) attempted to relate the development of shafts in the caves and the incision of the gorge to then current ideas of the timing of uplift of the eastern highlands. Jennings et al. (1972) unwillingly inferred that the upper levels of the caves may extend in age to the early Tertiary with formation of the shafts and gorge taking place in the early Miocene, their unwillingness being due to "the freshness of the cave forms and the absence of demonstrably ancient fill". James et al. (1978) faced with further evidence as to the antiquity of uplift in the Bungonia area were able to cite geological barriers to cave development to break the nexus between development of the gorge and the caves and concluded "that most of the caves could be considerably younger than the rejuvenation which formed the gorge".

Notwithstanding the conclusions of James et al. (1978) there is good evidence to suggest that cave development at Bungonia has taken place in two distinct phases and that the older phase, represented by shallow horizontal cave development close to the plateau surface, may be of considerable antiquity.

James et al. (1978) describe a "ferruginous silcrete" in the B.74 doline (Fig. 3) which is developed at the contact between argillites and limestone. Its presence, apparently in situ, suggests that doline development preceeded

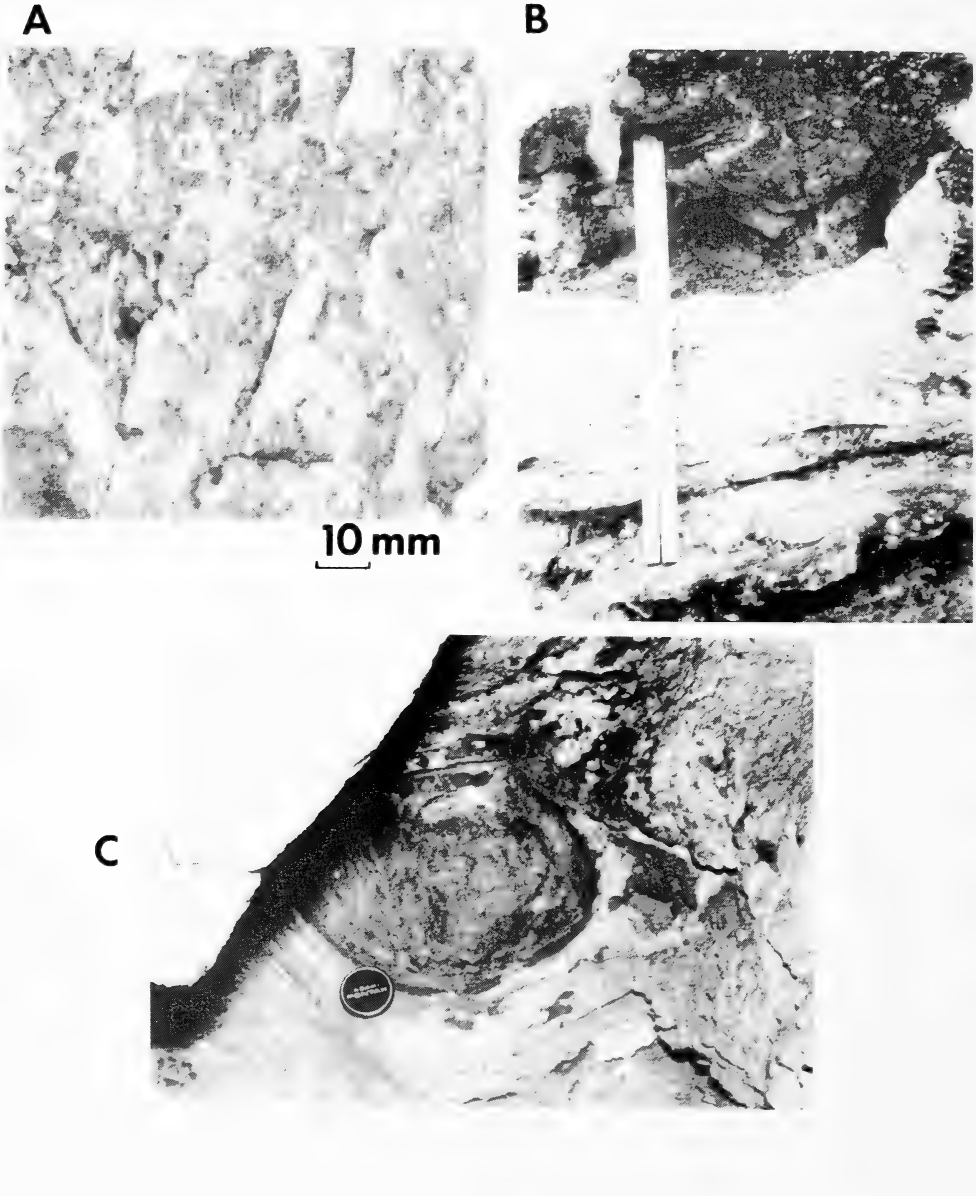

Fig. 2 A: Polished block of Borenore Limestone showing cement-filled vugs that truncate fossils. B: Laminated sediments in "pockets" within the Borenore Limestone that are unconformable with bedrock. Rule 500 mm long.

C: Basalt plug at termination of Arch Cave. Lens cap 55 mm diameter.

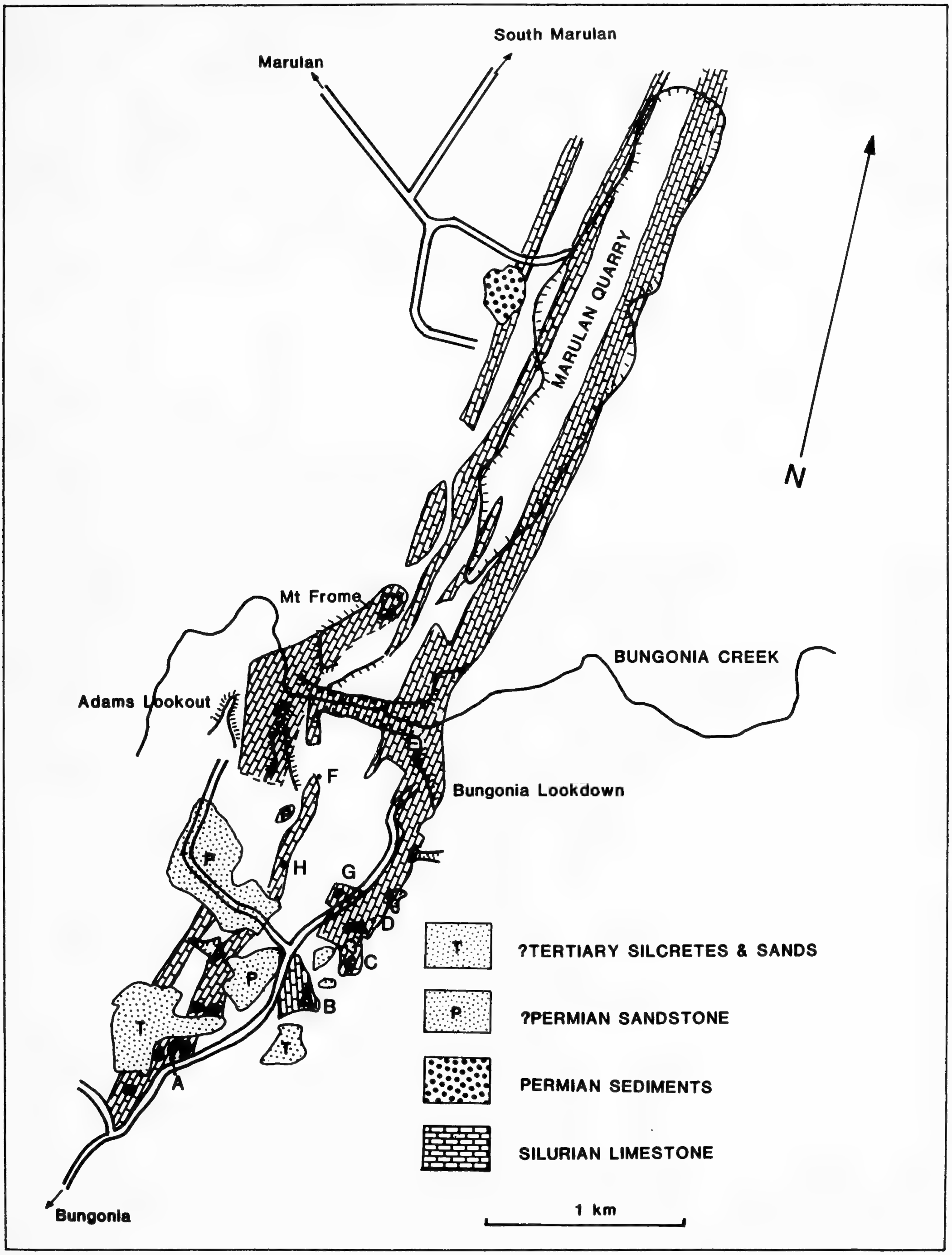

Fig. 3 The Bungonia karst. Limestone outcrop map after James et al. (1978) and Carr et al. (1980). Permian and Tertiary sediments south of Bungonia Creek after Carr et al. (1980). Permian sediments north of Bungonia Creek after Wass and Gould (1969). A, B.74 doline; B, Grill Cave; C, Drum Cave; D, B.50 Cave; E, Cooeeing Point; F, The Efflux; G, Argyle Hole; H, Odyssey Cave.

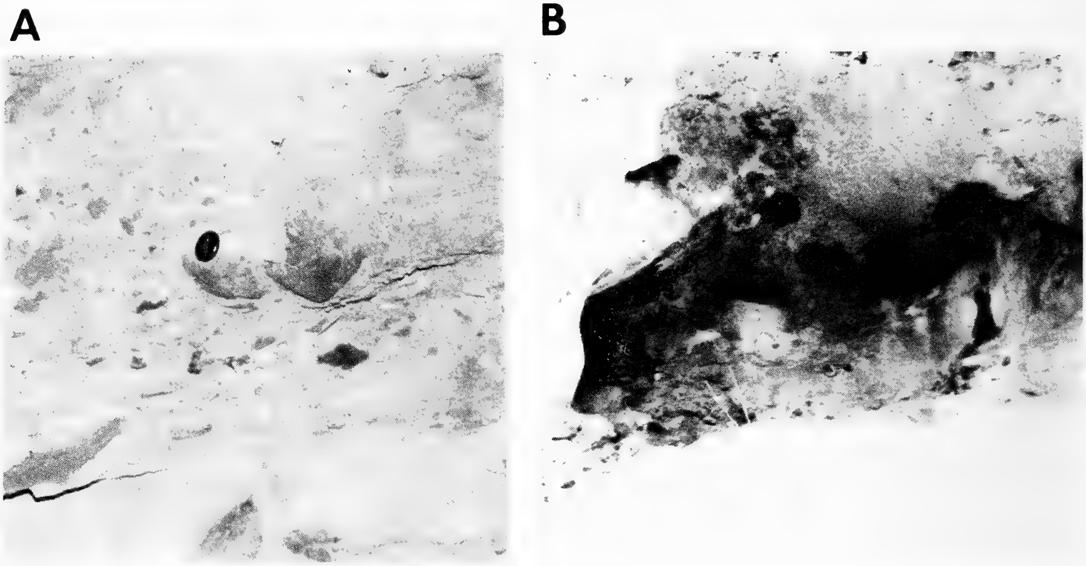

Fig. 4 A: Sediment in B.50 Cave. Note presence of ferruginised sandstone clasts. Lens cup 55 mm diameter B: Cave sediment that has been iron-cemented in situ exposed in "Sharon Loves Glyn" Cave. Pocket knife 100 mm long.

deposition of now ferruginized horizontally bedded sandstones on the plateau. Jennings (1982) describes a remnant of former cave passage, now filled with sediment, exposed in the wall of B.50 Cave. The filled passage (Fig. 4 A) has been eroded away by the formation of the present cave void except for a thin remnant in a blade of rock protruding into the main room of the cave. The sediment, consisting of limestone and ferruginized sandstone cobbles in a sandy matrix, is overlain disconformably by more recent cave loam.

Recent investigations by the author have revealed further evidence for ancient karstification at Bungonia. In a small remnant cave, west of the track from Cardinal View to Cooeeing Point, (identified by the inscription "Sharon loves Glyn") ferruginized cave deposits are exposed. These deposits (Fig. 4 B) appear to have been ferruginized in situ and with the deposit in the B.74 doline are indicative of karstification prior to the ferruginization event.

On the basis of the above evidence it is likely that the Bungonia Limestone has undergone two periods of karstification, one producing dolines and caves in the plateau surface prior to deposition of the sandstones and the incision of the gorge and another, related to the incision of the gorge, during which the deep caves were produced.

3. De Drack Formation

At Mt. Fairy, near Bungendore, sediment-filled caves are exposed in the walls of disused dolomite quarries (Fig. 5 A) which worked the Sandhills Creek Limestone Member of the Upper Silurian De Drack Formation (Felton & Huleatt, 1977).

Sediments filling the caves are unconformable with bedding in the bedrock and have complex unconformable relationships with each other. An unfilled cave is also exposed in the quarry face. Preliminary investigation has indicated the presence of at least five generations of cave sediment being from oldest to youngest:

1. an indurated laminated clay with sandy beds and iron rich horizons, (Fig. 5 D)

2. a polymictic conglomerate

3. an uncemented polymictic gravel

4. a red cave earth, (Fig. 5 C)

5. an uncemented talus, breccia (Fig. 5 B).

Some of the cave sediments have been penetrated by subsequent periods of speleogenesis. This and the presence of so many generations of cave sediment indicates that the dolomite has undergone a number of distinct periods of karstification.

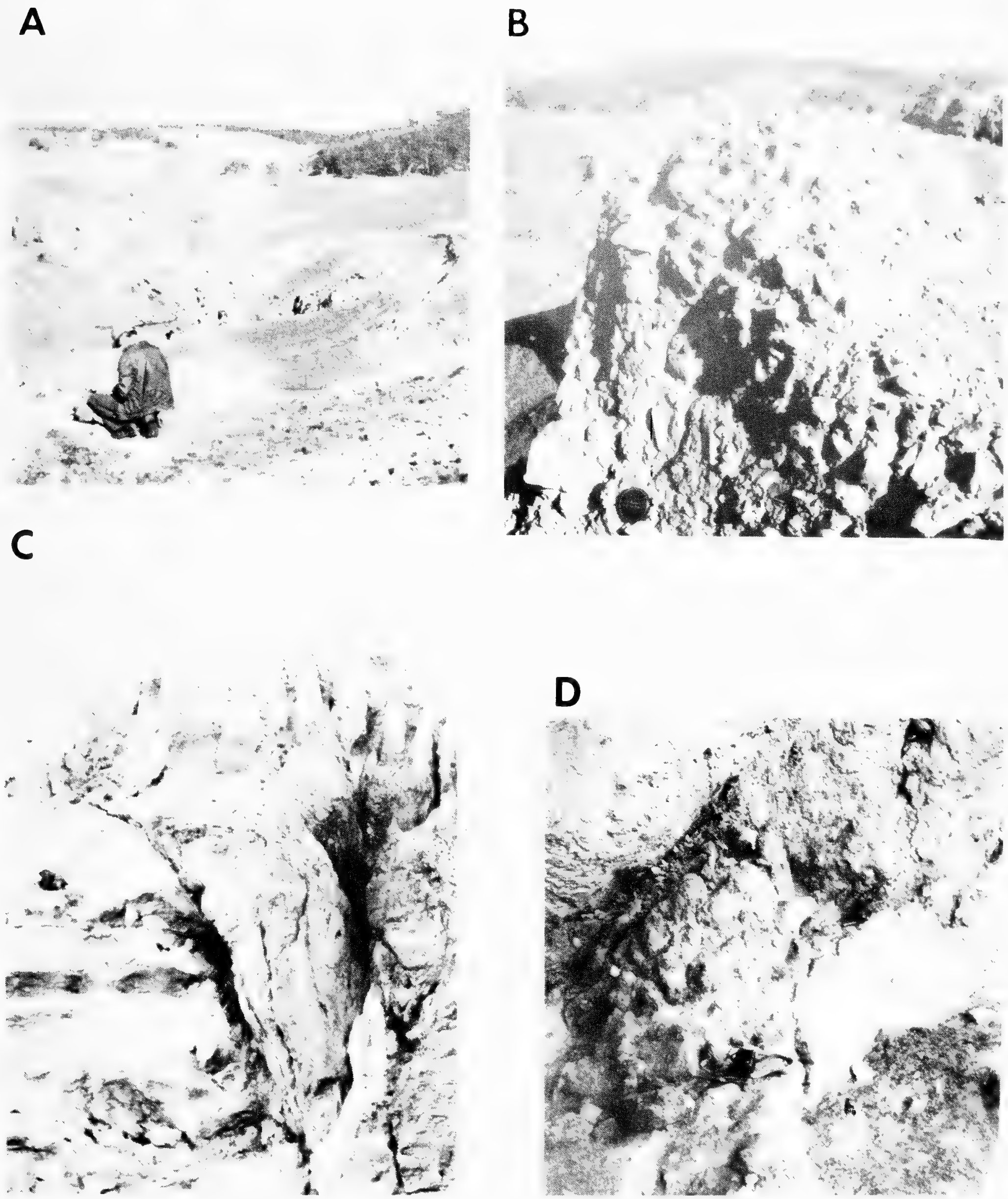

Fig. 5 A: General view of the Mt. Fairy Quarries. Limestone body containing Mt. Fairy Caves can be seen in the distance. B: Angular uncemented talus outcropping at high level in northern quarry at Mt. Fairy GR 368032 BORO 8827-IV-S, 1:25000. Photo, D.F. Branagan. C: Red cave earth filling cavity between older gravel and limestone exposed in southern quarry at Mt. Fairy. Photo, D.F. Branagan. D: Disconformable boundary between gravel and older laminated clay exposed in southern quarry at Mt. Fairy. GR. 368031 BORO 8827-IV-S,1:25000. Photo, D.F. Branagan.

4. Garra Formation

The late Lower Devonian Garra Formation (Strusz, 1965, Johnson, 1975) crops out in the limbs of a syncline on the eastern and western flanks of the Catombal Range in central western New South Wales. Significant caves are developed in the Garra Formation at Wellington Caves, 8 km south of the town of Wellington. The stratigraphy of Cainozoic sediments filling these caves, as described by Osborne (1983), indicates that two periods of sedimentation, separated by a period of surface erosion and phreatic speleogenesis took place following the initial development of the caves.

Further evidence for two periods of phreatic speleogenesis at Wellington Caves is found in Cathedral Cave where speleothem-like deposits have been removed by phreatic solution and now forms roof pendants (Fig. 6 A & B).

The two periods of speleogenesis recognized by Osborne (1983) together with the "palaeocave" of Conaghan (in Crook and Powell, 1976 and pers. comm. 1984) indicate that the Garra Formation has been subjected to three periods of karstification, one during the Late Devonian and two during the Cainozoic.

5. Jenolan Caves Limestone

The Upper Silurian Jenolan Caves Limestone (Chalker, 1971) has developed the best known and most cavernous karst in New South Wales with 262 caves and related karst features presently documented (Welch, 1976).

Imperial Cave, a tourist cave developed in the mass of limestone north of the Grand Arch (Fig. 7), intersects a number of former vugs now filled with subaqueously deposited carbonate crystals (Fig. 8 A & B). These palaeovugs appear to have been part of an old cave system and McClean (1983) considers that this system of infilled cavities has controlled the development of parts of Imperial Cave. The vugs show no sign of major deformation and must have been excavated and filled prior to the phreatic speleogenesis of the present cave.

The evidence from Imperial Cave indicates that two distinct periods of karstification have acted on the Jenolan Caves Limestone.

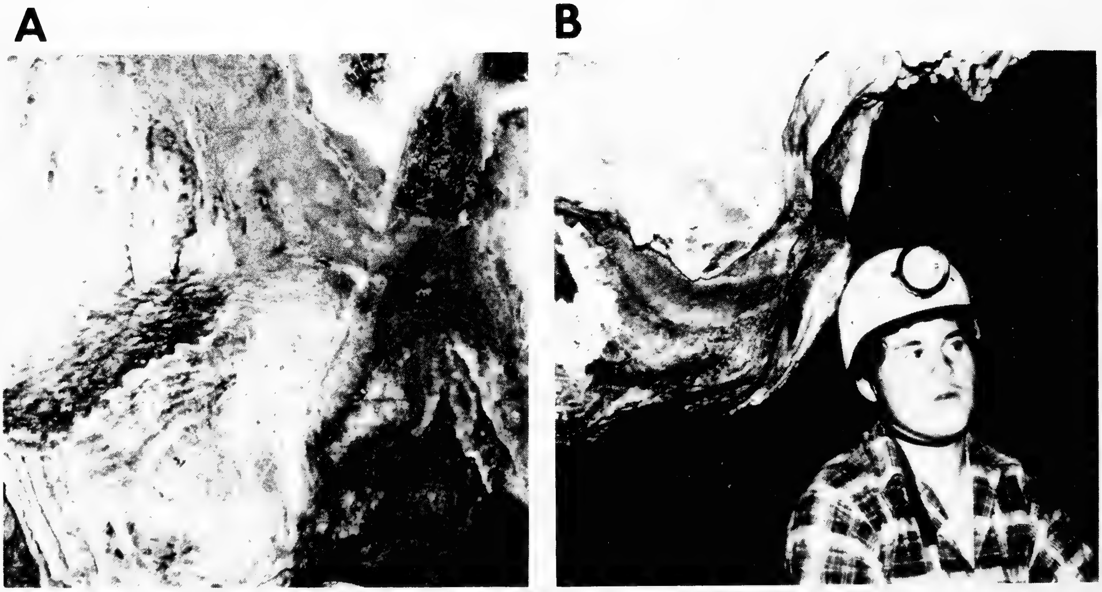

Fig. 6 Palaeokarst deposits exposed in Cathederal Cave, Wellington Caves. A: Speleothem-like deposit covered by more recent flowstone. Match box 53 mm long. B: Speleothem-like deposit now forming part of phreatic roof pendant.

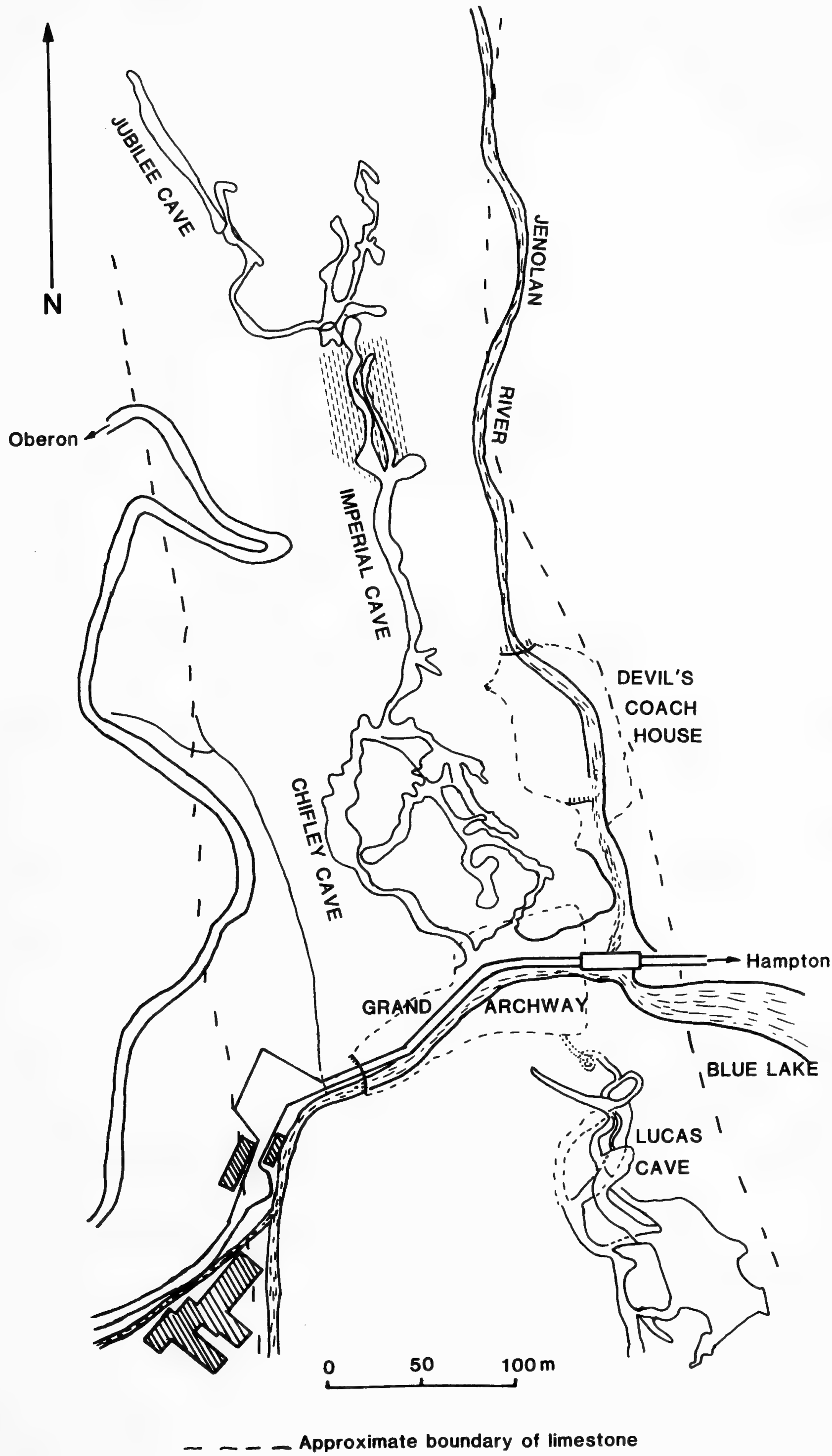

Fig. 7 Tourist caves of the northern limestone, Jenolan Caves, after Trickett (1925). Shaded part of Imperial Cave is where crystalline palaeokarst deposits are exposed in the cave walls.

6. Rosebrook Limestone

The Silurian Rosebrook Limestone (Carne & Jones, 1919) has been mined in two quarries at Toll Bar, 8 km east of Cooma. These quarries expose a number of cavities filled with cave sediments and basalt. Basalt 5 km east of Toll Bar has been dated by Wellman and McDougall (1979) at 38 Ma; however, its relationship with the flow at Toll Bar is yet to be established.

The basalt fills a number of vertical cavities (Fig. 9 A & B) and has the form of pillows (Fig. 9 D), rather than core stones, suggesting that molten basalt flowed into water-filled caves. Laminated sands and muds, interbedded with quartz-pebble-gravels underlie the basalt (Fig. 9 C) and in places mixing has occurred between the sediments and the basalt.

As well as the sediments related to the basalt, red cave earths, which preliminary investigation suggests are post-basaltic, massive clays and bedding-plane fills are also found in cavities exposed in the quarries. Although the relationships at Toll Bar are as yet unclear they do indicate that karstification has occurred there prior to the extrusion of the basalt, and that more recent karstification has taken place resulting in cavities that have been filled with red cave earth. It seems likely that detailed research will show that the Rosebrook Limestone has been subjected to a number of distinct periods of karstification.

7. Wombeyan Limestone

The Silurian Wombeyan Caves Limestone (Brunker & Offenberg, 1970) was metamorphosed by the emplacement of the Devonian Bindook Porphyry Complex and the intrusion of related granites. A significant karst containing 233 caves (Dyson et al. 1982) has developed on the limestone which forms a topographic basin surrounded by hills cf porphyry.

Jennings et al. (1982) discussed the development of the caves and suggested that the cave with the highest elevation in the area, Durrins Tower Cave, may have formed "well back in the Tertiary".

Fig Tree Cave (Fig. 10), a large self-guided tourist cave, through which the often-dry course of Wombeyan Creek flows has features which suggest that the Wombeyan Limestone has been subjected to a number of distinct periods of karstification. A strongly-iron-cemented quartz-lithic-wacke is exposed in the bed of Wombeyan Creek within the cave, downstream of the tourist section. This deposit has an unconformable boundary with the Wombeyan Limestone and a disconformable boundary with overlying cemented coarse gravel fill (Figs. 11 A & B). Its outcrop relationships indicate that it was deposited within a cave passage, eroded and covered by the gravel and then eroded again during the formation of the present cave passage which has removed much of the coarse gravel. The degree of cementation of the quartz-lithic-wacke suggests that it is probably the product of a separate period of karstification to that which is responsible for the development of the present caves.

Further evidence for an ancient period of karstification is found in the eastern non-tourist section of Fig Tree Cave where a laminated clay-filled passage (Fig. 11 C) is exposed in the cave wall. This passage is unrelated to the present development of the cave which truncates it sharply.

The evidence from Fig Tree Cave suggests that there has been more than one period of karstification affecting the Wombeyan Limestone. Fig Tree Cave and many of the other caves in the area contain extensive deposits of sediments whose stratigraphy has not been studied and there are many breccias in the limestone, some of which could be of a karst origin.

MULTIPLE KARSTIFICATION AND THE GEOLOGICAL HISTORY OF THE LACHLAN FOLD BELT IN NEW SOUTH WALES

The geological history of the Lachlan Fold Belt in New South Wales suggests several periods of time during which Lower Palaeozoic limestones may have been exposed to subaerial conditions.

In addition to exposure during subaerial diagenesis, which may have produced syngenetic karsts, a number of orogenies and well-recognized erosional events, during which subaerial exposure could have taken place, have affected the limestone terrains of the Lachlan Fold Belt in New South Wales. The likely post-depositional history of the limestone terrains discussed above is illustrated in Fig. 12.

While Benambran, Quidongan and Bowning events may have resulted in subaerial exposure of the older limestone in the Fold Belt, the earliest period of post-diagenetic subaerial exposures for which there is good evidence took place during the Middle Devonian Tabberabberan Orogeny following the cessation of "geosynclinal" sedimentation within the Fold Belt.

Further exposure would have occurred during Permo-Carboniferous times when much of the Fold Belt had high relief and valley glaciation was taking place, and during Mesozoic to Cainozoic times when the present period of exposure commenced. Each of these periods of possible karstification is discussed below and the limestone terrains where their effects might be recognized are indicated.

a. Syngenetic karstification

The term syngenetic karst was applied by Jennings (1968) to karst processes occurring concurrently with the consolidation of Recent aeolian calcarenites. In relation to the Lower Palaeozoic limestones discussed here, syngenetic karst processes are those associated with the emergence of relatively unconsolidated carbonates and their subaerial diagenesis. This is equivalent to the eogenetic stage of porosity development as defined by Choquette and Pray (1970).

Subaerial diagenesis is widely recognized as being a significant factor in the post-depositional history of limestones (Bathurst, 1975). Unfortunately little study has been made of the petrography and diagenesis of Lower Palaeozoic limestones in New South Wales; however, what is

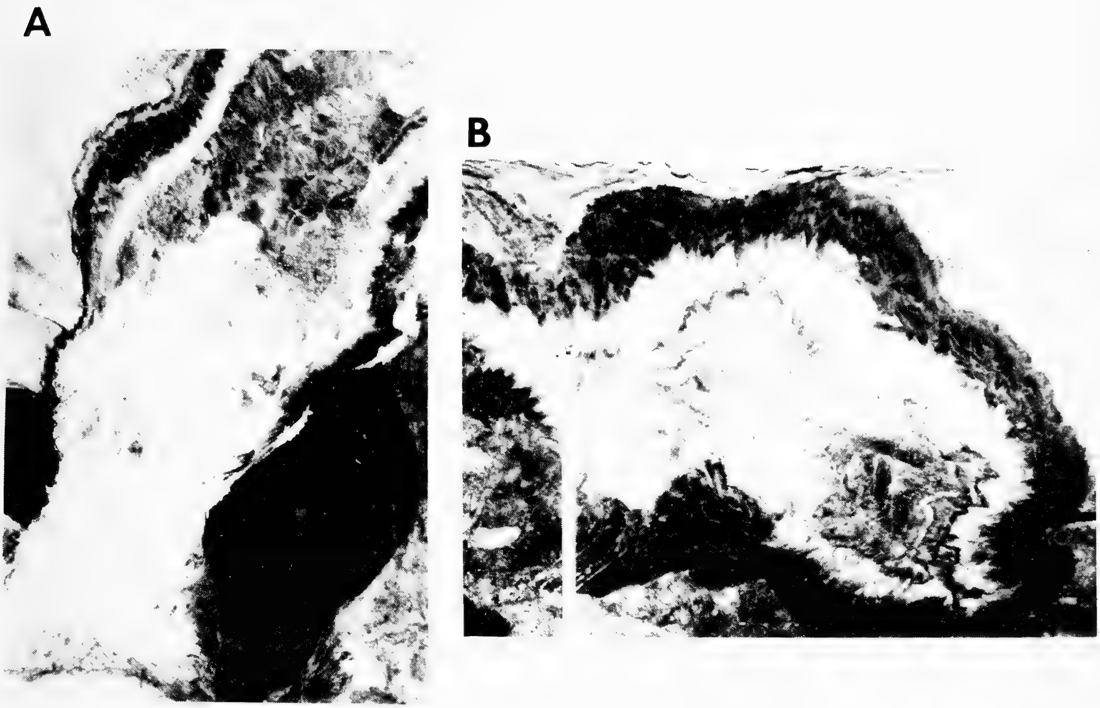

Fig. 8 Crystalline palaeokarst deposits exposed in the walls of Imperial Cave, Jenolan Caves. A: Palaeokarst deposit now forming part of phreatic rock pillar indicating relationship between palaeokarst and present caves. Field of view approx 500 x 750 mm. B: Palaeokarst cavity exposed in cave wall. Note vug-like structure. Tape 320 mm long.

known does suggest that some were exposed to subaerial conditions during their early history.

Wolf (1965) noted solution cavities in Devonian Algal limestones in central New South Wales while Semenuik (1971) identified subaerial solution textures in the Ordovician Bowan Park Group and related them to a vadose or shallow phreatic subaerial environment. Neuhaus (1982) has described internal sediment filled vugs within Silurian limestones at Gleeson's near Cliefden Cave which may also be a result of syngenetic karstification.

Until more study is made of the diagenesis of Lower Palaeozoic limestones in New South Wales it will not be possible to assess the significance of syngenetic karstification.

b. Middle Devonian karstification

The Middle Devonian Tabberabberan Orogeny brought to a close significant carbonate deposition in the Lachlan Fold Belt in New South Wales and was followed by the deposition of quartz-rich terrestrial and marginal marine basinal sediments during the Late Devonian and Early Carboniferous. During the orogeny many of the Lower Palaeozoic limestones could have been exposed to subaerial conditions resulting in the development of Middle Devonian karsts.

Middle Devonian karstification is described by Burns (1964) from Tasmania where the unfolded Eugenana Beds, a sequence of Devonian cave sediments, are enclosed within the folded Ordovician Gordon Limestone. As mentioned previously Conaghan (in Crook and Powell 1976) recognized Middle Devonian karstification in the Garra Formation near Wellington. It is likely that further Middle Devonian palaeokarsts will be found, as many Lower Palaeozoic limestones are unconformably overlain by Upper Devonian sediments (e.g. Bendithera Limestone and Minuma Beds at Bendithera Caves, Narragal Limestone and Catombal Group near Molong, Jesse Limestone and Lambie Group at Limekilns).

The effect of Middle Devonian karstification on later karst development will depend on the intensity of later (e.g. Kanimblan) deformation. Where this has been intense, karst deposits will tend to be sheared and have the effect of changing the petrography of the limestones. Alternatively where little deformation has taken place these old karst features will be more intact and may act as a controlling factor over later karstification.

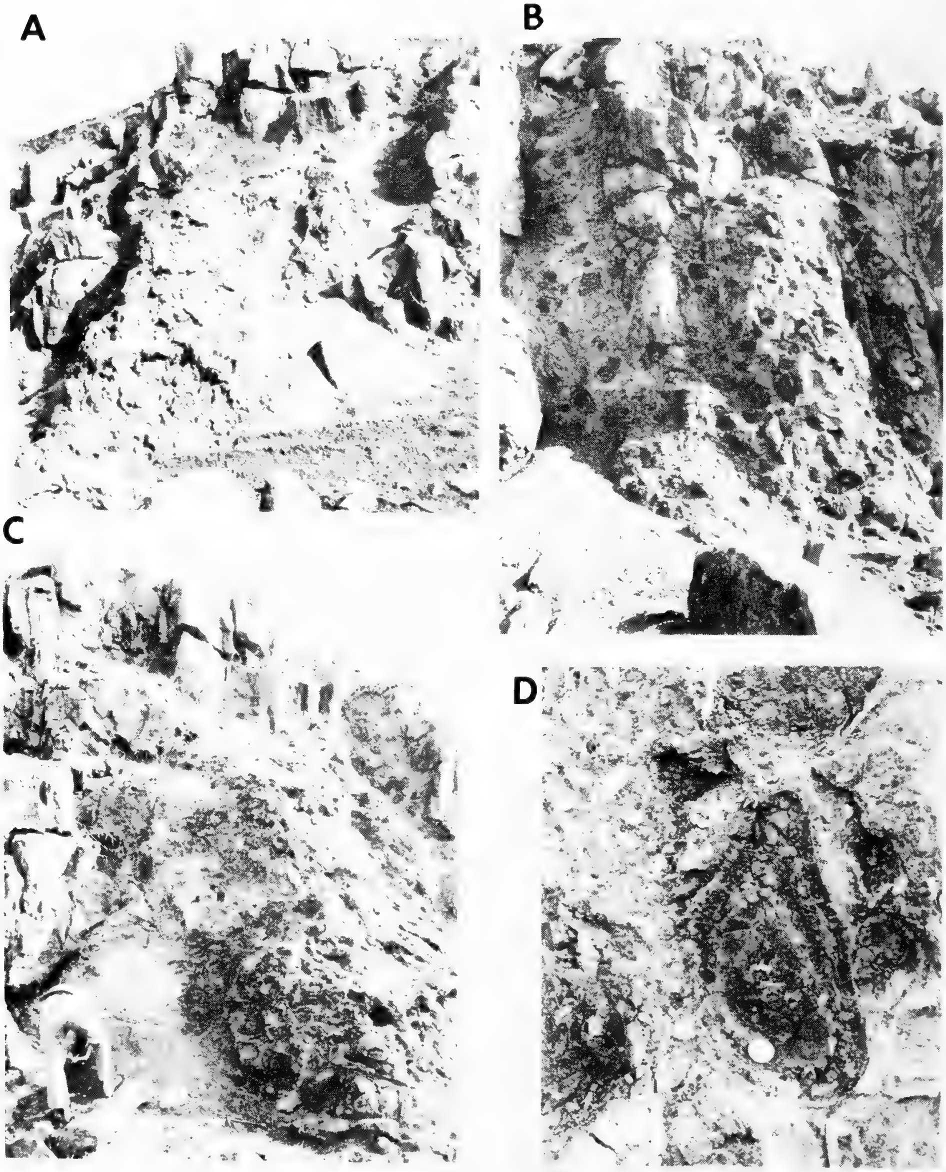

Fig. 9 Basalt-limestone relationships in quarries at Toll Bar, east of Cooma. Exposures in quarry at GR 989916 COOMA 8725-IV-S, 1:25000. A: Basalt filling cavity in limestone. Photo, D.F. Branagan. B: Basalt filling shaft-like vertical cavities in limestone. Photo, D.F. Branagan. C: Basalt filling cavity, overlying and partially mixing with quartz-rich gravel. Boundary between gravel and basalt shown by pick. Photo, D.F. Branagan. D: Detail of basalt showing pillow-like structure. Coin 24 mm diameter. Photo, D.F. Branagan.

c. Permo-Carboniferous karstification

Following the Middle Carboniferous Kanimblan Orogeny terrestrial erosional conditions were established over much of the Lachlan Fold Belt in New South Wales. Relations between rocks of the Fold Belt and the basal strata of the Sydney Basin indicate a pre-Permian relief of at least 600 m in the area that now forms the southwestern edge of the Sydney Basin (Herbert, 1972), and of at least 900 m in the Mudgee district (Dulhunty & Packham, 1962).

The deposition of glacial and periglacial sediments in the Tamworth Trough and at the edges of the Sydney Basin during the Carboniferous and in much of the Sydney Basin during the Permian indicates that valley glaciation was active in the Lachlan Fold Belt during Permo-Carboniferous times (Herbert, 1980). It seems likely that erosion associated with the glaciation was responsible for the removal of much of the previously widespread Upper Devonian and other cover from the Lachlan Fold Belt, exposing its limestones to subaerial conditions. Many of the limestones in the west and southwest of the Fold Belt have probably remained exposed to subaerial conditions since this time (or perhaps for even longer if the ideas of Opik (1958) who interpreted the landforms around Canberra as having Siluro-Devonin origins are correct), their karst development being a product of this long exposure. It may then be difficult to identify karstification of Permo-Carboniferous age in these areas. While it could be possible to argue that karstification in these areas has been essentially continuous since the Palaeozoic, major periods of folding and uplift would ensure that karstification was episodic.

Some limestones to the east of the Fold Belt were exposed in an environment of high relief during Permo-Carboniferous times and then covered by sediments of the Sydney Basin which protected them from further karst action until at least the Late Cretaceous. In these limestones (e.g. possibly the Jenolan Caves Limestone, Bungonia Limestone and the limestones at Billy's Creek, Brogan's Creek, Colong, Church Creek and Portland) it may be possible to identify Permo-Carboniferous karstification.

The proximity of the plateau surface at Bungonia Caves to the level of the basal unconformity of the Sydney Bain exposed in the Shoalhaven Gorge suggests that the plateau surface may be an exhumed Permian landscape (Young, 1977). Wass and Gould (1969) identified Permian sediments overlying the Bungonia Limestone in the South Marulan area, north of Bungonia Gorge. These sediments have a basal elevation of approximately 590 m while the plateau in the caves area has an elevation of about 550 m. Flat lying, often ferruginized quartzarenites overly the Bungonia Limestone in the caves area. These were considered by James et al., (1978) to be Tertiary. However, Carr et al., (1980) suggest that some may be Permian in age by analogy with the sediments described by Wass and Gould (1969). If this is the case then karst features developed during the Permo-Carboniferous could have been preserved by the mantle of the Sydney Basin and then exposed later by erosion and Cainozoic karstification. This view is supported by geological reports on the quarries at South Marulan (Anon, 1972) which state, when discussing the likely effects of cavitation in the limestone on quarrying operations, that "At Marulan much of the cavitation is Permian or pre-Permian in age" and report a cavity in the quarry containing lithified fill which has been intruded by dolerite dykes. As a result of this occurrence Anon (1972) concludes that "The lithified nature of some of the infilling and the fact that it pre-dates the dolerite dykes suggests that it is probably pre-Permian in age". These dykes are likely to be related to basalt flows in the Bungonia area dated by Wellman and McDougall (1974) as Eocene. If this is the case then the cavitation exposed in the quarries is probably Permian in age. The sediments in B.50 Cave, described by Jennings (1982) (see above), have the type of relationships one might expect from Permian cave deposits. However, they contain clasts of ferruginized sandstone and are therefore more likely to be early Tertiary in age.

Jenolan Caves is another area that would have been close to the surface (and possibly exposed) during Permo-Carboniferous times and then covered by the edge of the Sydney Basin. The elevations of the Sydney Basin outliers near Jenolan Caves suggest that the area had a high relief during Permo-Carboniferous times making the Permian surface more difficult to define than in the case of Bungonia. The crystal sediments in Imperial Cave (see above) have the relationship with the present caves that one might expect from a Permian palaeokarst deposit.

d. Cainozoic karstification

During the Cainozoic the Lower Palaeozoic limestone terrains of the Lachlan Fold Belt in New South Wales have been subjected to significant subaerial exposure. This has been punctuated at some localities by the extrusion of Tertiary basalts and by the deposition of thin (?) Tertiary cover which has in places been lateritised. The occurrence of karstification during the Cainozoic has never been in dispute but its timing presents considerable problems.

With the exception of palaeokarsts it has been traditionally accepted that karsts, like other landforms, are a product of events taking place in the most recent part of the geological timescale. This view has been applied by many workers to the Lower Palaeozoic limestone terrains of New South Wales.

Sussmilch and Stone (1915) when discussing the likely age of Jenolan Caves state "it is therefore quite improbable that the age, even of the oldest of the caves can exceed 500,000 years". A similar timescale for Cainozoic karstification has been accepted by many recent workers. Frank & Jennings (1978) have epiphreatic action ceasing in the main Arch at Abercrombie Caves by 15 Ka while Jennings et al. (1972) and James et al. (1978) cite evidence that suggests an old age for karstification at Bungonia Caves but recoil from its implications. Notable exceptions to the idea of young karsts have been Francis (1973) who suggested that phreatic speleogenesis at Wellington Caves may have taken place during the Miocene and Connoly and Francis (1979) who suggested a Cretaceous age for Main Cave at Isaacs Creek (at Timor in New England Fold Belt).

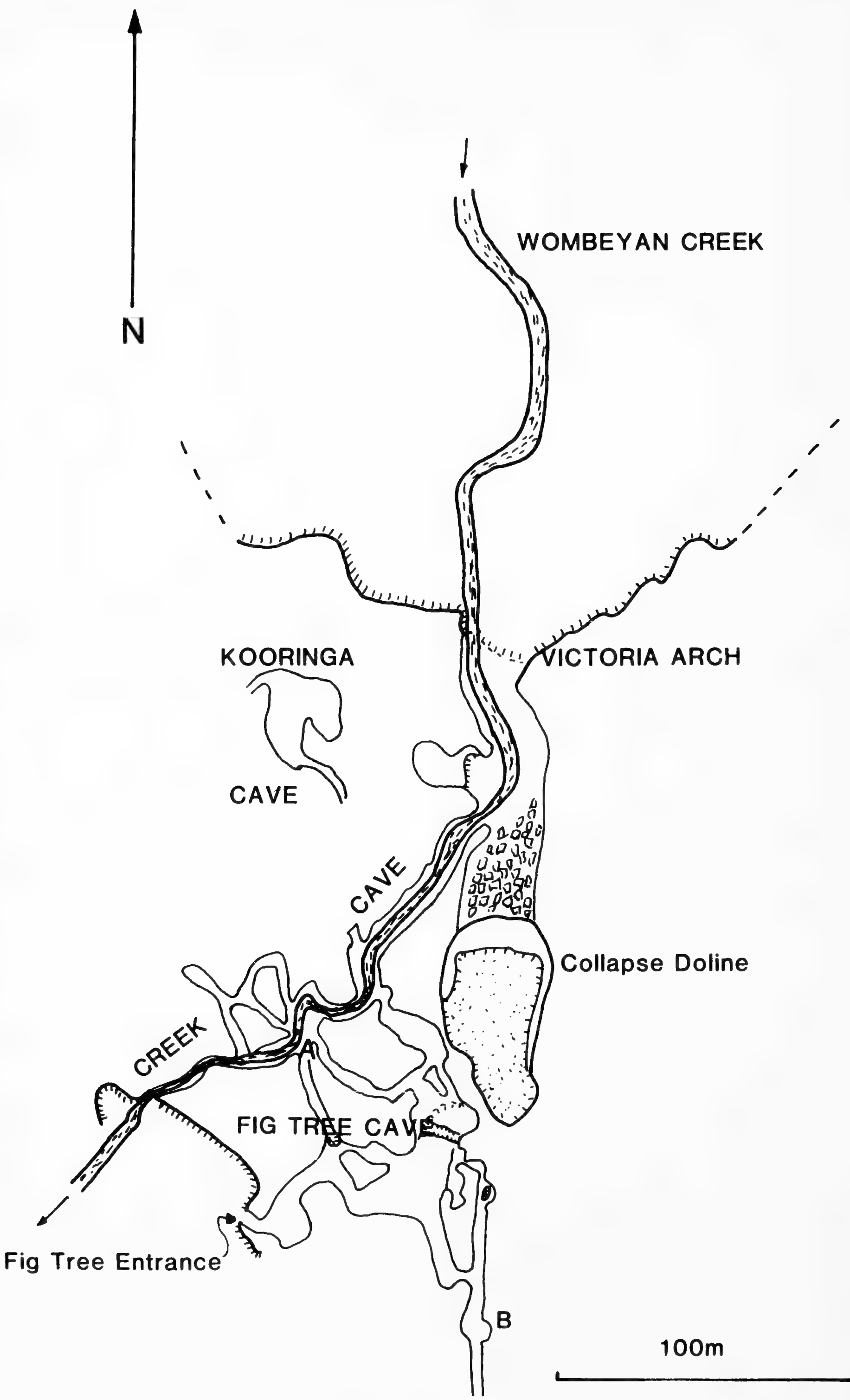

Fig. 10 Fig Tree - Creek Cave System, Wombeyan Caves, after Trickett (1899). A: Location of quartz-lithic-wacke outcrop. B: Location of clay-filled passage.

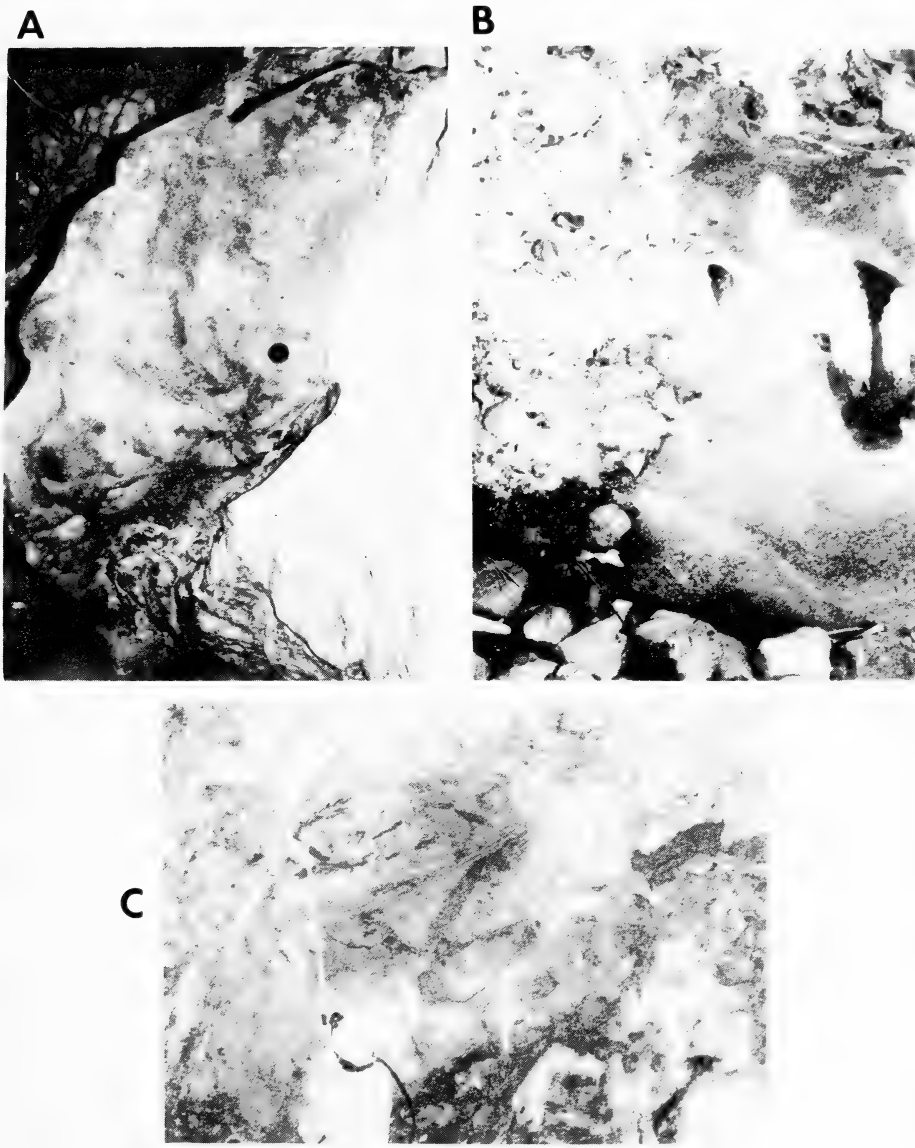

Fig. 11 A: Quartz-lithic-wacke exposed at locality A Fig. 10. Note steep nature of boundary between wacke and limestone (just right of lens cap) and development of scallops on both wacke and limestone. Lens cap 55 mm diameter. B: Disconformable boundary between quartz-lithic-wacke (right) and coarse cemented gravel (left). Note erosional nature of boundary near point of pencil. C: Clay-filled passage exposed in wall of Fig Tree Cave at locality B Fig. 10. End of tape points to outline of passage.

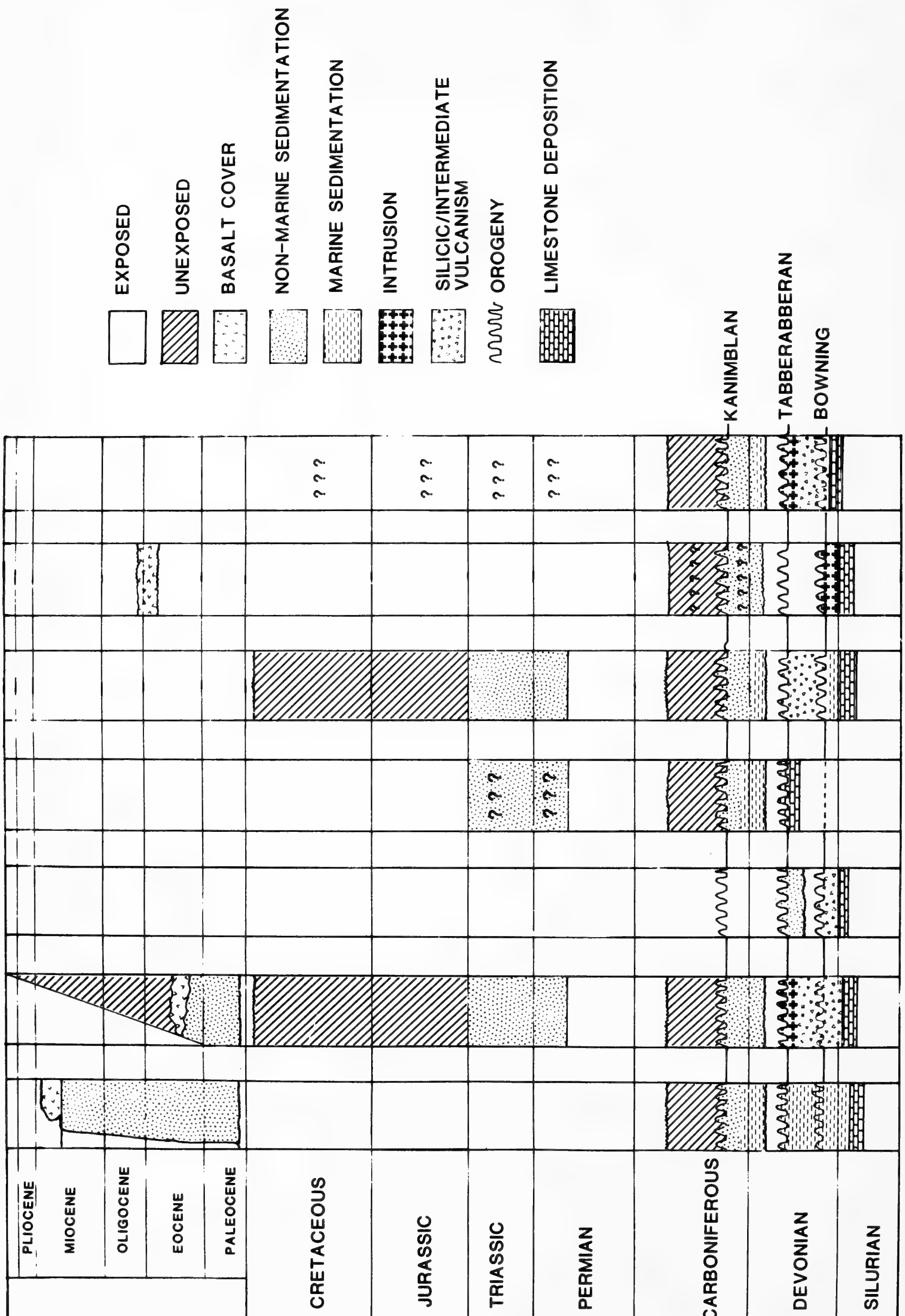

Fig. 12 Time - Event Chart for limestone terrains discussed in this paper. BN, Borenore; B, Bungonia; MF, Mt. Fairy; WE, Wellington; JJ, Jenolan; TB, Toll Bar; W, Wombeyan.

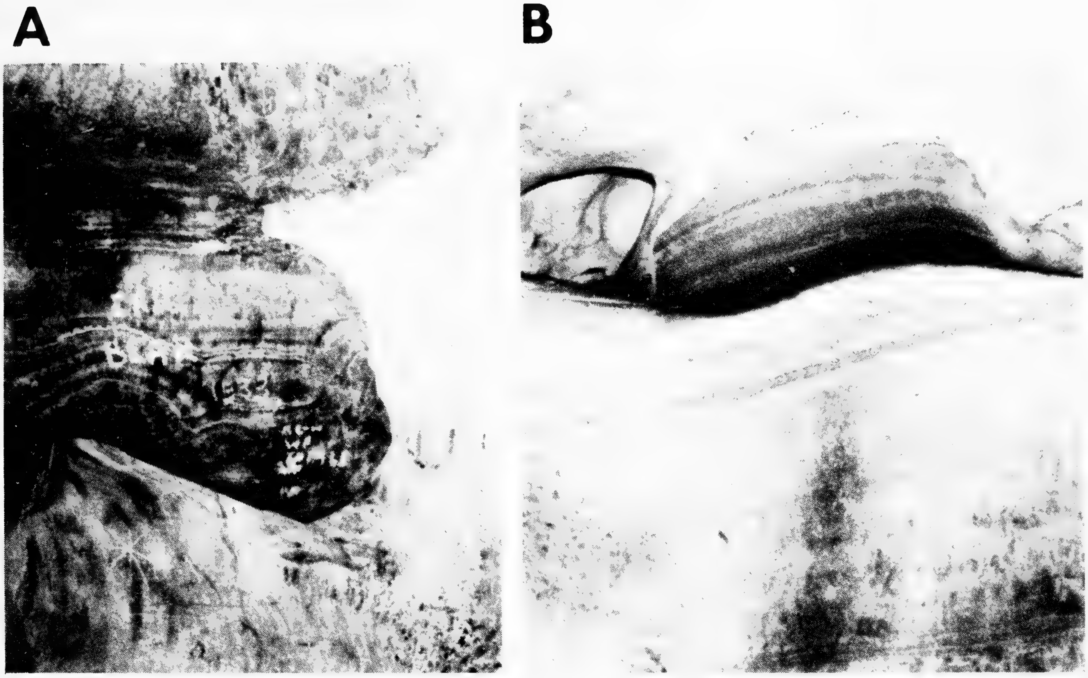

Fig. 13 Palaeokarst deposits exposed in Main Cave (TR.1) Isaacs Creek Caves. A: ? Pool deposits truncated by present cave development. Field of view approx 1.6 x 1.4 m. Photo, T. Allan. B. Flowstone completely truncated by phreatic development. Field of view approx. 2 m x 2.4 m. Photo, T. Allan.

Recent work on the history of the Great Divide and on the age of landforms in southeastern Australia based on the radiometric ages of basalts has brought into question the long accepted concept of a Late Pliocene uplift followed by a period of rapid erosion. Significant work by Wellman (1979), Jones & Veevers (1982) and Bishop (1982) suggests that uplift of the Southeastern Highlands began between 50 - 90 Ma ago and that minimal erosion or change in drainage direction has occurred in the past 40 Ma. Similar reasoning has led Young (1983) to suggest that the rates of denudation in southeastern Australia are much lower than those usually accepted.

If these newer ideas are correct then either the caves and karsts are young features of old landscapes as inferred by James et al. (1978) or there is need for a complete revision of currently accepted views on the timing of Cainozoic karstification. Osborne (1983) has shown that speleogenesis at Wellington Caves involved two distinct phases during the Cainozoic while the features described at Borenore, Bungonia, Mt. Fairy and Toll Bar are indicative of multiple periods of karstification during the Cainozoic. It seems likely that further examination will show this to be the norm.

The relationship between karst features and basalt at Toll Bar and Borenore indicate that significant karstification took place earlier in the Cainozoic than had been usually inferred. Recent work by Goede & Harmon (1983) has shown that some stalagmites deposited on gravelly alluvium in Exit Cave, Tasmania are beyond the range of $^{230}Th/^{234}U$ dating (over 400 Ka) also indicating that extant caves may be older than has been previously thought.

If the Lower Palaeozoic limestone terrains of New South Wales have been subject to multiple periods of karstification within the limits of the Cainozoic and karstification has taken place earlier than the Late Pliocene then existing models for landscape evolution and speleogenesis, based on the concept of a single latest Cainozoic cycle of development, cannot be maintained.

MULTIPLE KARSTIFICATION OUTSIDE THE LACHLAN FOLD BELT

Multiple karstification can occur in any limestone of geologically significant age and is likely to be widepread in the Palaeozoic limestone terrains of Australia. At Torrawangee Quarry, 70 km north of Broken Hill, Branagan (1984) has postulated

Palaeozoic cave sediments occur within the Late Proterozoic limestone of the Wammerra Formation (Cooper & Tuckwell, 1978); much younger cave sediments also occur here within this Formation. Reconnaissance of caves at Isaacs Creek (Fig. 13) in Middle Devonian limestone of the Tamworth Trough (New England Fold Belt) has indicated that multiple karstification has occurred there also.

CONCLUSIONS

The Lower Palaeozoic limestone terrains of the Lachlan Fold Belt in New South Wales have been subjected to multiple periods of karstification. There is good reason to believe that at least some of the limestone terrains were exposed to subaerial conditions and thus karstification during Middle Devonian and Permo-Carboniferous times and that some karst elements produced during these times may survive today.

At least one limestone, the Garra Formation at Wellington Caves, has undergone more than one cycle of karstification during the Cainozoic and it seems likely that this has been the case elsewhere. Relationships between karst landforms and Tertiary basalts and sediment, particularly at Toll Bar, indicate that karstification has occurred much earlier in the Cainozoic than has been generally accepted. This brings the age of karst landforms into line with recent concepts as to the antiquity of uplift and landforms in the Southeastern Highlands of Australia.

The recognition of multiple karstification allows Lower Palaeozoic limestone terrains to be interpreted in a new way. Firstly it introduces a new factor into their post-depositional history, that of multiple subaerial exposure, which may help to explain some of the complexity of their petrography and geomorphology and, secondly, it raises the possibility that evidence may exist, in the form of palaeokarst deposits, of what terrestrial conditions were like during the Tabberabberan Orogeny, the Permo-Carboniferous and during poorly-known parts of the Cainozoic.

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The Stratigraphic Palynology of the Murray Basin in New South Wales. II. The Murrumbidgee Area

HELENE A. MARTIN

ABSTRACT. This report on the stratigraphic palynology of the Murrumbidgee area on the eastern edge of the Murray Basin agrees in a general way with an earlier one (Martin, 1977). However, many more bores have been examined since the first report, including a number of deep bores which extend to basement, so that more precision and detail is presented here.

The basement assemblages are Early and Late Permian and Early Cretaceous.

The oldest Tertiary assemblages are the Mid-Late Eocene Middle *Nothofagidites asperus* Zone. The latest Eocene-earliest Oligocene Upper *N. asperus* Zone reported in Martin (1977) has not been found in any other bore. The thick sections of the Oligocene through Early Miocene *Proteacidites tuberculatus* Zone with almost uniform assemblages have been subdivided using quantitative events of three selected taxa. There are a few occurrences of the Mid-Late Miocene *Triporopollenites bellus* Zone, after which pollen is usually not recovered. There are two records of Pliocene assemblages.

Some dinoflagellates are found in bores near Hay. They indicate channels or low-lying depressions which became flooded by the Early-Mid Miocene high sea levels, rather than truly marine conditions.

The quantitative events (i.e. the high ratios) used here to subdivide the *P. tuberculatus* Zone show a reasonable correspondence to changing sea levels. The species of the more swampy habitats are more abundant at the time of high sea levels whereas the species requiring well drained habitats become more frequent at times of low sea level.

INTRODUCTION

Martin (1977) has described the stratigraphic palynology of the Murray Basin in the Hay-Balranald-Wakool Districts. This report included two deep bores which extended to the Mid-Late Eocene Lower *Nothofagidites asperus* Zone. Most of the bores however were discontinued before reaching the depths of this zone. This study reveals thick sections of the Oligocene through early Miocene *Proteacidites tuberculatus* Zone.

Many bores have been examined since this report, including a number of deep bores which extend to basement below the Tertiary. The thick sections of the *P. tuberculatus* Zone, with no reliable means of subdividing it, have been a problem. The Water Resources Commission of New South Wales requires some stratigraphic control within this zone for groundwater exploration. For this purpose, certain quantitative features have been investigated and found suitable for stratigraphy. This paper presents the stratigraphic palynology of the Tertiary and basement of the Murray Basin in the Hay, Deniliquin and Narrandera districts. None of the results in Martin (1977) have been changed; indeed they have been confirmed with more detail and precision in this report.

GEOLOGY

The Murray Basin is essentially a Cainozoic feature but it overlies infra basins of Palaezoic and Mesozoic age (Bembrick, 1975). Pollen assemblages of Early Cretaceous, Early and Late Permian have been recovered from basement assemblages. The sediments of these ages are hardly any different to those of the Cainozoic and it may be impossible to distinguish between them without a palynological examination.

The Tertiary marine transgression extended as far east as Balranald, and its probable limits are shown on Fig. 1. Dinoflagellates which indicate marine or brackish water conditions have been found in significant numbers in two bores at Hay and very minor occurrences in several other bores elsewhere. Otherwise, the whole of the area is completely non-marine.

A number of stratigraphic units have been described by different authors for different parts of the Basin. For the region under study here, Woolley and Williams (1978) and Woolley (1978) have adopted the units used by Lawrence (1975) for the Victorian part of the basin, with slight modification. The unit formerly known as the Renmark Beds (used in Martin, 1977) has been subdivided into the Warina Sands and Olney Formation. The basal unit encountered in this study is the Mid-Late Eocene Warina Sands which was deposited under generally non-marine conditions. It consists of coarse-grained quartz sands with minor dark grey clay lenses and carbonaceous layers. It is found only in the deeper parts of the basin and does not extend east of Hay. The overlying unit, the Olney Formation, was deposited under deltaic, fluvial and lacustrine environments. It is dominated by thick lignite layers and contains grey carbonaceous clay and extensive sand lenses. The basal part of the Olney Formation is Eocene, and in this non-marine region, extends probably to the Miocene.

The Wunghnu Group (used in Martin, 1977) which overlies the Renmark Beds in the non-marine eastern part of the Basin has been subdivided into three units. One of these, the Torrumbarry Clay, does not form a definite, mappable unit in this area (Woolley and Williams, 1978), so is not discussed further. The Calivil Sand overlies the Olney Formation. This unit is dominated by coarse sand and fine gravel, usually pale grey to white, or pale brown. It also contains very minor bands of carbonaceous clay. The unit becomes more clayey towards the west and is thought to be Late Miocene to Pliocene in age. The Shepparton Formation, the uppermost unit, overlies the Calivil Sand. It is characterised by polymict sand with yellow and brown the dominant colour, and variegated (white, yellow, red-brown, grey) clay. It is thought to be Late Pliocene and Pleistocene in age.

The boundaries between the three units which occur over most of the area are not always clear because of the similarities of the lithologies. The definition of the top and the base of the unit is often rather subjective (Woolley and Williams, 1978). The sequence of carbonaceous, mostly pale grey, then variegated sands and clays, which fits the Olney, Calivil and Shepparton units respectively, is clearly seen in all of the bore logs. Some of the logs have these units marked on them, but when they are compared with the palynology, the boundaries do not always coincide and there is variation from one bore to another. Because of these difficulties in defining the boundaries, no attempt is made to fit the palynology into these units. In any case, the ages assigned to these formations by Woolley (1978) and Woolley and Williams (1978) are based mainly on palynology of Martin (1977, unpubl. and pers. comm).

Framework tectonics are regarded as the primary control of the Murray Basin (Brown, 1983). The basement features of Paleozoic or Mesozoic age are still active and there have been movements along the faults in Tertiary time. The basement highs and lows have retained their relative positions throughout Tertiary time (R.M. Williams, pers. comm.). The basement over most of the Murrumbidgee area is relatively deep, and under these circumstances, the sediments are reasonably well preserved. Sediment accumulation has been sensitive to eustatic changes which, however, is regarded, as a secondary influence (Brown, 1983). Changes in sea level have the greatest influence on deposition close to the sea, but with increasing distance from the sea, the influence decreases. In this non-marine area, the Late Miocene depositional hiatus (in Brown, 1983) is recognised, but the Mid-Oligocene hiatus cannot be identified (R.M. Williams, pers. comm.).

Only the consistently grey clays yield pollen. Once brown, yellow or red colours appear in the section, even in quite minor quantities, the samples are usually barren. The very pale grey clays are frequently barren also. Sands do not yield pollen but very minor clay lenses or sand with a substantial silt and clay matrix may be suitable for palynology. Consequently units mapped as sand may have yielded pollen assemblages.

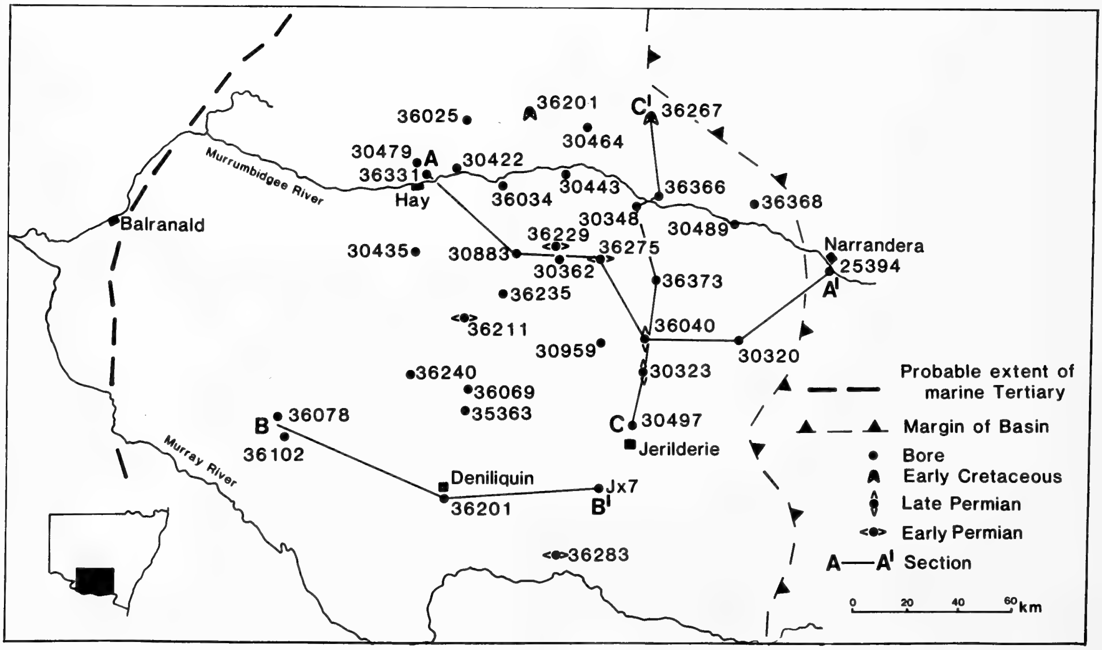

Fig. 1 Locality Map. The probable extent of the marine Tertiary and the margin of the Basin are from Bembrick (1975).

MATERIALS AND METHODS

Samples from some thirty three bores are included in this study. Almost all of the samples are cuttings. Some of the bores have been sunk with the percussion drill which has a limited depth. Bores deeper than 120m are usually sunk with the rotary drill.

The possibility of contamination is greater with cuttings than with cores and the main sources of contamination are discussed in detail in Martin (in press a). However, with care and appropriate procedures (see Martin, in press a) relatively clean cuttings may be obtained. Consistent patterns repeatable in bore after bore and barren samples anywhere in the sequence would not be possible with appreciable contamination. Occasionally, contaminated samples are detected and they are rejected. Cuttings supplied by the Water Resources Commission of New South Wales are suitable for stratigraphic palynology and give a body of internally consistent data.

The samples have been treated with cold hydrochloric and hydrofluoric acids, weak nitric acid and potassium carbonate solutions. Strew samples have been mounted in glycerine jelly.

PALYNOSTRATIGRAPHY

1. Permian

Permian palynostratigraphy follows the scheme set out by Kemp *et al* (1977). The author citations of species names may be found in this reference.

Early Permian assemblages have abundant monosaccate pollen and bisaccates are rare. A number of spores which range through the Early Permian, e.g. *Apiculatisporites cornutus, Microbaculispora tentula, Cyadopites cymbatus* and *Horriditriletes ramosus* are found in these assemblages. *Verrucosisporites psuedoreticulatus* and *Marsupipollenites triradiatus,* which first appear at the base of stage 3a are found in bores 36211 and 36275. *Granulatisporites trisinus,* which first appears at the base of stage 3b, is not found in these two bores, but it is present in bore 36229, in addition to the former two. Consequently, the assemblages in the first two bores are stage 3a and the latter, stage 3b. In addition to most of the spores already mentioned, bore 36283 contains *Praecolpites sinuosus* which first appears at the base of upper stage 4a. Spores diagnostic of the overlying upper stage 4b are not present. Hence this assemblage is upper stage 4a.

In the Late Permian assemblages, bisaccates are dominant with very few monosaccates, and there is a diversity of spores. *Didecitriletes ericanus,* which first appears at the base of lower stage 5b is present in both bores. *Dulhuntyispora parvithola,* which first apeears at the base of upper stage 5 is found in bore 36040 but not in 30323. None of the taxa which characterise the younger *Weylandites* Zone have been found. Thus the former is upper stage 5 and the latter lower stage 5b.

These bores are listed in the Appendix and the distribution of the Permian assemblages is shown on Fig. 1.

2. Triassic ?

A unit identified in bores 30323 and 36040 between Permian and Tertiary (see Figs. 3, 5) failed to yield any pollen. It is thought, however, that this unit is an extension of the Triassic found in the nearby Coorabin Coal Measures (Standing Committee on Coalfield Geology, 1978).

3. Early Cretaceous

Early Cretaceous palynostratigraphy follows Dettmann and Playford (1969) for zonation and Morgan (1980) for time ranges. The citations of

EPOCH	PALYNOLOGICAL ZONES STOVER & PARTRIDGE 1973 PARTRIDGE 1976	APPROXIMATE POSITION OF QUANTITATIVE EVENTS	MODIFIED ZONES
Middle MIOCENE	*T. bellus* Zone		*T. bellus* Zone
Early	Upper	← Dinoflagellates High Myrtaceae ratios ← Upper *N. flemingii* acme	C subdivision
Late	*P. tuberculatus* Zone Middle		*P. tuberculatus* Zone
OLIGOCENE			B subdivision
Early	Lower	← Lower *N. flemingii* acme	A subdivision
Late	Upper *N. asperus* Zone	High *P. mawsonii* ratios	— ? — ? — ? —
	Middle *N. asperus* Zone		Middle *N. asperus* Zone
EOCENE	Lower *N. asperus* Zone		

Fig. 2 Tertiary palynological zones with the modifications adopted for this paper.

species names may be found in these references. The two occurrences in this study are very similar.

Of the gymnosperm pollen, *Podocarpidites* spp. are the most common, with *Alisporites* spp., *Araucariacites australis* and *Microcachryidites antarcticus* frequent. *Classopollis* cf *C. classoides* and *Ginkgocycadophytus nitidus* are infrequent. There is a rich spore flora with *Baculatisporites comaumensis* and *Stereisporites antiquasporites* the most common. *Lycopodiumsporites* spp., *Ceratosporites equalis, Cyathidites* spp. and *Klukisporites scaberis* are seen frequently. *Cicatricosisporites australiensis* is present also, and the presence of *Dictyotosporites speciosus* and *Pilosisporites notensis* place these assemblages in the *Dictyotosporites speciosus* Zone of Neocomian-Aptian age (Dettmann and Playford, 1969) or Aptian-early Albian (Morgan, 1980).

Both assemblages are non-marine with abundant pollen and plant cellular debris. No dinoflagellates have been found, although there are a few of the acritarch *Micrhystridium* sp. in bore 36261.

The bores are listed in the Appendix and the distribution of the Early Cretaceous is shown on Fig. 1.

4. Tertiary

Palynostratigraphy follows Stover and Partridge (1973) with some modifications. The *P. tuberculatus* Zone has been modified by the method in Martin (in press a). The citation of species names follows Stover and Partridge (1973).

The oldest Tertiary assemblages fit the Mid-Late Eocene Lower *N. asperus* Zone, similar to those reported in Martin (1977). Almost twenty species whose ranges terminate at the top of this zone are found here, and any one assemblage may contain up to eight of them. The zone may be divided into an older and a younger part, based on the presence of *Triorites magnificus* in the latter (Stover and Partridge, 1973). Partridge (1976) and Stover and Partridge (1982) use this sub-

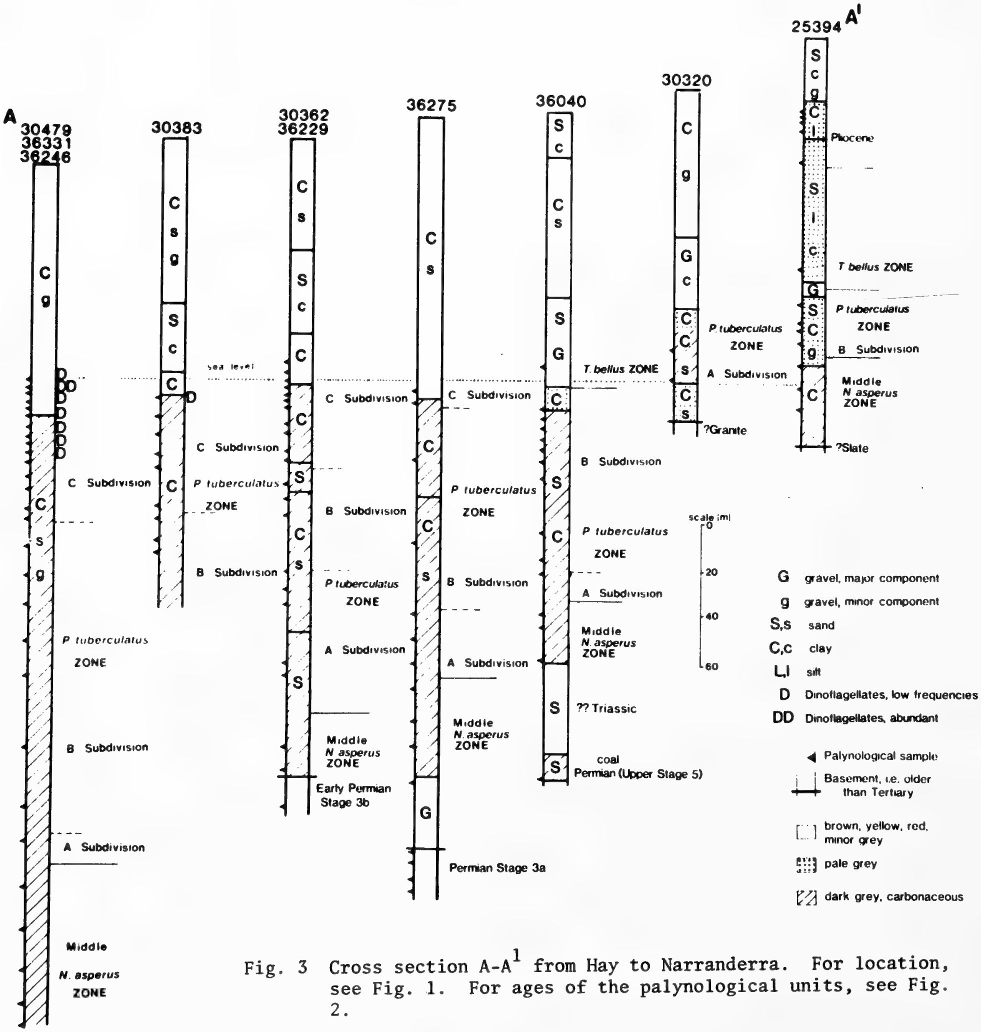

Fig. 3 Cross section A-A[1] from Hay to Narranderra. For location, see Fig. 1. For ages of the palynological units, see Fig. 2.

division to recognise a Middle *N. asperus* Zone. They restrict the Lower *N. asperus* Zone to the lower subdivision of the original Lower *N. asperus* Zone of Stover and Partridge (1973). The presence of *Polycolpites reticulatus, Proteacidites reticulatus* and *Triorites magnificus* in a number of Murray Basin assemblages indicate that they belong to the Middle *N. asperus* Zone.

The Upper *N. asperus* Zone, of Late Eocene-Early Oligocene age, recognised in one bore in Martin (1977), has not been identified in any others of the Murray Basin, if the diagnosis of Stover and Partridge (1973) is followed.

The species whose ranges terminate at the top of the Middle *N. asperus* Zone decrease in number

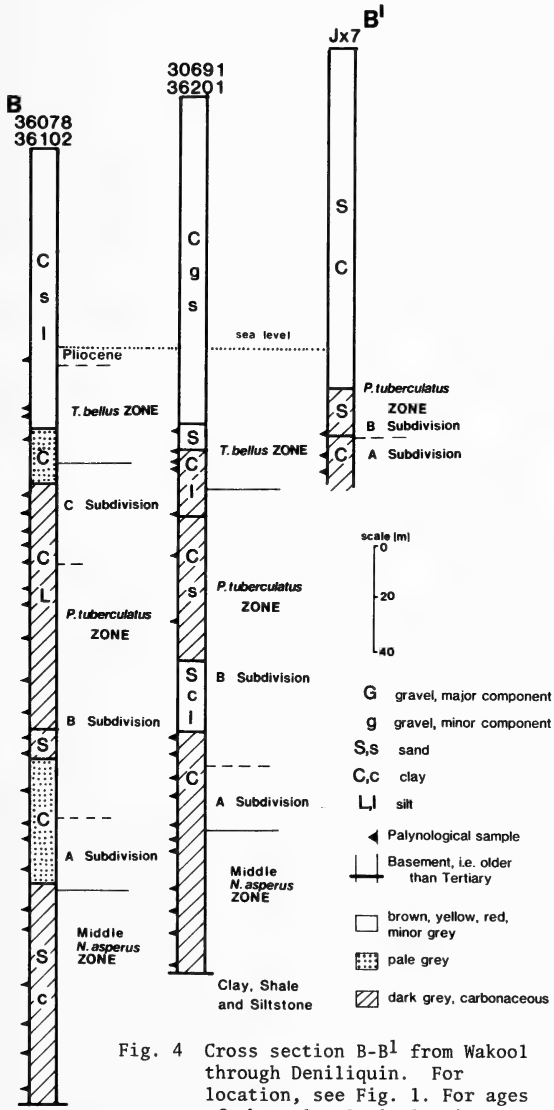

Fig. 4 Cross section B-B^1 from Wakool through Deniliquin. For location, see Fig. 1. For ages of the palynological units, see Fig. 2.

with successively younger assemblages, until none remain. As the several species which first appear at the base of the *P. tuberculatus* Zone are rarely seen in this area, the latter is usually identified on negative evidence, i.e. lack of Middle *N. asperus* Zone species. Other than the diagnostic species, there is little difference between the assemblages of the two Zones. The boundary between the Middle *N. asperus* and *P. tuberculatus* Zones (Fig. 2) in the Murrumbidgee area is thought to approximate the Eocene Oligocene boundary.

Stover and Partridge (1973) have divided the *P. tuberculatus* Zone into lower, middle and upper, but their diagnosis of these subdivisions does not work in this area. The thick sections of *P. tuberculatus* Zone have been subdivided using three taxa showing occasional high frequencies which are defined by constructing a ratio and empirically choosing a cut off value to delimit the high ratios. Table 1 lists the taxa, the ratios and the values of the high ratios used in this study. This method is explained in detail in Martin (in press a).

High ratios of *P. mawsonii* are found in both the upper part of the Middle *N. asperus* Zone and the base of the *P. tuberculatus* Zone. In this position, they are thought to approximate the Upper *N. asperus* Zone which cannot be identified on the original diagnosis. Some of the coals of the Upper *N. asperus* Zone in the Gippsland Basin contain very high frequencies of *P. mawsonii* (Stover and Partridge, 1973). High ratios or acme of *N. flemingii* occurs in two layers in the *P. tuberculatus* Zone, one low down either within the top of the high *P. mawsonii* ratios or just above it, and the other much higher up. It is thought that the lower *N. flemingii* acme approximates the true base of the *P. tuberculatus* Zone. The high Myrtaceae ratios start about the level of the upper *N. flemingii* acme layer and continue into the Mid Miocene *Triporopollenites bellus* Zone. *Polyadopollenites myriosporites* first appears in the beginning of the Miocene. It is rare in this area, but it has found with the high Myrtaceae ratios, above the upper *N. flemingii* acme layer. Consequently, the upper *N. flemingii* acme layer is thought to approximate the Oligocene-Miocene boundary and the high Myrtaceae ratios are Early Miocene. These stratigraphic positions of the high ratios are shown in Fig. 2.

The dinoflagellates *Operculodinium centrocarpum, Lingulodinium machaerophorum, Hystrichokolpoma rigaudiae* and *Systematophora placacantha* (for citation of species see Lentin and Williams, 1977) are found in several bores near Hay. *Operculodinium centrocarpum* is by far the most common, and all of these species are found in the Miocene (Deflandre and Cookson, 1955). Dinoflagellates indicate marine or brackish water, and it is thought that their occurrence at Hay indicates the Miocene high sea level, when channels or low lying areas would have been flooded. For the southern Australian margin, the peak of the Miocene marine transgression occurs about the Early-Mid Miocene boundary (Loutit and Kennett, 1981). The dinoflagellates are stratigraphically within the high Myrtaceae ratios, above the upper *N. flemingii* acme. Their position is thus in agreement with the other palynological events in the upper part of the *P. tuberculatus* Zone (see Fig. 2).

For convenience, the *P. tuberculatus* Zone has been divided thus:

A subdivision,	high *P. mawsonii* and lower *N. flemingii* acme layer
B subdivision,	without high ratios
C subdivision,	upper *N. flemingii* acme layer and high Myrtaceae.

These subdivisions are shown on Fig. 2 and their occurrence in the bores are listed in the Appendix.

The *Triporopollenites bellus* Zone is identified by several diagnostic species which first appear at the base of the zone (Stover and Partridge, 1973). Assemblages of this zone are found in a few bores. See Appendix.

Pliocene assemblages (Martin, 1973) occur in only two bores. See Appendix.

DISCUSSION

The Middle *N. asperus* Zone underlies most of the Basin. It is, however, lacking from bores 30320, JX-7 and 30497 where the *P. tuberculatus* Zone directly overlies the basement. In the first two bores, the A subdivision of this zone rests on the basement, whereas in the latter, the B overlies basement. There is a considerable displacement between the A subdivision of the first

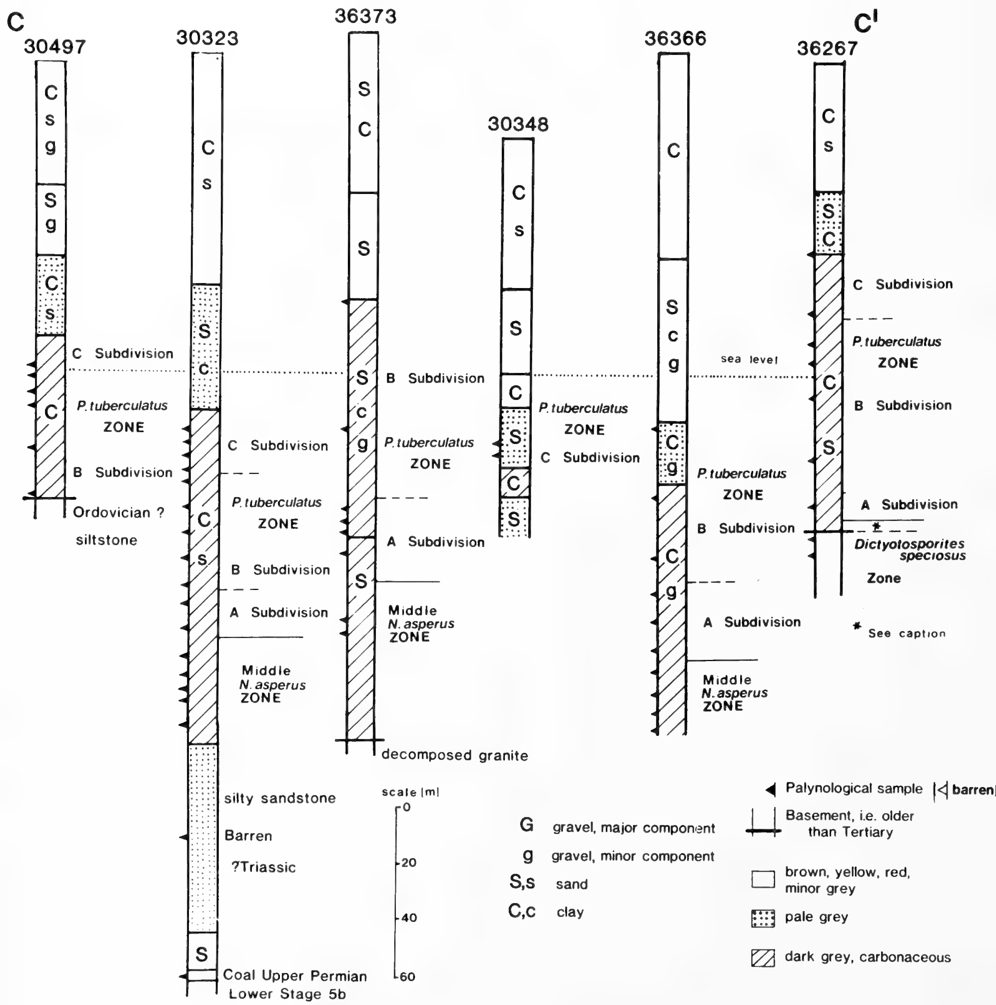

Fig. 5 Cross section C-C[1] from Jerilderie across the Murrumbidgee River. For location, see Fig. 1. For ages of the palynological units, see Fig. 2. *The top sample in the *Dictyotosporites speciosus* Zone is a mixed assemblage and contains species diagnostic of the Middle *N. asperus* Zone. Therefore, this latter zone must be present although it has not been sampled.

two bores and their neighbouring deep bores, 36040 and 30691/36201 respectively (see Figs. 3, 4). This indicates movement along a fault, sometime after the deposition of the A subdivision. If the questionable identification of the C subdivision in 30323 is accepted, then the displacement of this subdivision between this bore and 30497 would suggest that movement along the fault occurred after the deposition of the C subdivision (Fig. 5). Unfortunately, this subdivision is not well developed in the southern and south-easterly deep bores so the evidence of the precise timing of movement is inconclusive. The two deep bores are situated in the Ovens Valley Graben (Yoo, 1982), a basement feature and this evidence shows that Tertiary movement has occurred along one of the basement faults.

The middle *N. asperus* Zone sediments at Narrandera occur in a narrow valley a few kilometers upstream from the Basin margin. This long, narrow embayment extended into the highland flanking the Eocene plain and is the earliest recognisable stage of the Murrumbidgee River System (Woolley, 1978). The Early-Mid Miocene dinoflagellates at Hay probably may mark another, but later, embayment of the Murrumbidgee River, which became flooded by the rising sea level.

It is curious that the Upper *N. asperus* Zone as described by Stover and Partridge (1973) cannot be identified in this area. As discussed previously, there is a gradual change from the Middle *N. asperus* to *P. tuberculatus* Zones in successive assemblages, and apart from the diagnostic species, the assemblages of the two zones are very similar. It is thought that the A subdivision with the high *P. mawsonii* content, which is the only character in agreement with the original description of the Upper *N. asperus* Zone, might be the time equivalent (more or less) of the one occurrence of this zone, found further to the west (Martin, 1977). An alternative explanation is non-deposition in the Murrumbidgee area during the time of the Upper *N. asperus* Zone. This possibility is considered unlikely, since the latest Eocene - earliest Oligocene was a time of high sea level (Loutit and Kennett, 1981).

The three quantitative events used here to subdivide the *P. tuberculatus* Zone are based on taxa which form a palaeoecological series: *P. mawsonii* in the wettest habitat, *N. flemingii* intermediate, and Myrtaceae in the driest (Martin, in press a). The sediment type associated with the high ratios and the ecology of the living taxa both confirm this series (Martin, in press a). The degree of wettness may be controlled by climate and/or hydrology, i.e. the efficiency of drainage. Thus the high *P. mawsonii* ratios indicate more swampy conditions and the two *N. flemingii* acme layers periods of improved drainage. The high Myrtaceae ratios indicate the start of a climatic change which heralds the beginning of the trend to aridity and which continues into the Mid-Late Miocene and is associated with the disappearance of *Nothofagidites* and the rise to dominance of Myrtaceae (Martin, 1982).

If the quantitative events and their stratigraphic positions (see Fig. 2) are compared with the sedimentary cycles for the southern margin of Australia (Loutit and Kennett, 1981) there is a reasonable correspondence. High sea levels in latest Eocene time correspond to the high *P. mawsonii* ratios. Drainage would have been very inefficient at this time with a consequent increase in swampy habitats conducive to *P. mawsonii*. There is a large drop in sea level, with the lowest level in Early Oligocene time corresponding to the lower *N. flemingii* acme. Lowered sea levels would have created better drainage. Sea levels rise throughout the Oligocene, but there is a minor drop to a lower level about the Oligocene-Miocene boundary, corresponding to the upper *N. flemingii* acme. Sea levels rise further to their highest levels about the Early-Mid Miocene, when the low lying areas at Hay were flooded, creating the habitats for dinoflagellates. No doubt the terrestrial environment became more swampy, but *P. mawsonii* does not increase in abundance, for the climate had become drier. The swamp habitat was probably occupied by species of Myrtaceae which tolerate a much drier climate.

It is suggested that changing sea levels have largely controlled the stratigraphic distribution of the high ratios through the Oligocene. However, the Murrumbidgee area is a special case, for the same high ratios are identified in the Lachlan area but they do not show the same patterns as those of the Murrumbidgee (Martin, 1984).

If eustatic changes have had such an influence on the palynology then one may expect them to have had an influence on sediment deposition and preservation as well. As discussed previously, the further the distance from the sea, the less marked the effects of eustatic changes. The Mid Oligocene hiatus shown in the interpretation of the Murray Basin by Brown (1983) is not recognisable here. There is no evidence in the palynology to suggest a hiatus either. Subtle changes, however, such as the raising or lowering of the water table by a few metres would make a great difference to plant growth. Thus although the influence of eustatic changes is not recognisable in the sedimentary record, it registers in the palynologic record through changes in the relative abundance of the pollen types.

The failure to recover pollen from most samples above 100m is striking. Simple lack of deposition and/or erosion is unlikely to be the cause of this failure for there is 100m of sediment above the level of the pollen bearing deposits. It is thought that the climate had become too dry to support an abundance of the permanently wet sites required for pollen preservation. The occasional occurrence of the *T. bellus* Zone and Pliocene assemblages are viewed as representing an occasional body of permanent water in the landscape of the time. The permanently wet sites started decreasing during the subdivision of the *P. tuberculatus* Zone, were much reduced by the time of the *T. bellus* Zone and extremely rare in the Pliocene. The frequency of permanently wet sites in a landscape is largely dependant on rainfall, either over the area itself or the catchment that feeds it. By the same token, if the rainfall is insufficient to support widespread permanently wet sites, the climate is dry enough to allow cycles of wetting and drying which are most destructive to pollen. Under such circumstances, pollen preservation would require rapid burial, to depths beyond the fluctuating water table, an unlikely proposition given the generally low rates of sedimentation in this area (R.M. Williams, pers. comm.).

TABLE 1.

Selected taxa showing occasional high frequencies and the definition of high ratios. For a full explanation of the method, see Martin (in press a).

Taxon	Ratio	High ratio
Phyocladidites mawsonii	*P. mawsonii* / Total gymnosperms	⩾0.25
Nothofagidites flemingii	*N. flemingii* / Total *Nothofagidites*	⩾0.25
Myrtaceae	Myrtaceae / Total *Nothofagidites*	⩾ 0.80

CONCLUSIONS

The palynologic record shows that Tertiary deposition occurred from Mid-Late Eocene through Early Miocene time over most of the area under study. An hiatus corresponding to lowered sea levels cannot be recognised during this time. Lowered sea levels, however, have influenced the palynologic record. Plants require specific ecologic conditions, and the lowering of the water table by only a few metres, as would occur with more efficient drainage during times of low sea level, could make a great difference to the vegetation. The quantitative events (high ratios) of the *P. tuberculatus* Zone show a reasonable correspondence with eustatic changes.

Pollen assemblages are only occasionally recovered from Mid Miocene time onwards. The climate had become too dry to support more than an occasional permanently wet site which is required for pollen preservation.

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APPENDIX.

Bores are arranged from W to E, then N to S. See Fig. 1 for location. For the ages of the palynological zones see Fig. 2. All bores have been sunk by the Water Resources Commission of New South Wales except for one, JX-7, a Mines Administration Pty. Ltd. bore.

36078		
	76.2 - 77.7m	Pliocene
	94.4 - 108.2m	*T. bellus* Zone
	114.3 - 152.4m	C subdivision, *P. tuberculatus* Zone
	155.4 - 250.0m	B subdivision, *P. tuberculatus* Zone
	254.5 - 266.7m	A subdivision, *P. tuberculatus* Zone
	280.4 - 349.0m	Middle *N. asperus* Zone
30479		
	109.7 - 135.6m	C subdivision, *P. tuberculatus* Zone with maximum dinoflagellates at 112.8-114.3m.
	137.1 - 198.1m	B subdivision, *P. tuberculatus* Zone
36331/36246		
	120.0 - 154.0m	C subdivision, *P. tuberculatus* Zone
	164.0 - 277.0m	B subdivision, *P. tuberculatus* Zone
	291.0 - 292.0m	A busdivision, *P. tuberculatus* Zone
	307.8 - 370.3m	Middle *N. asperus* Zone
30435		
	109.7 - 146.2m	C subdivision, *P. tuberculatus* Zone
	150.9 - 184.4m	B subdivision, *P. tuberculatus* Zone
	196.6 - 198.1m	A subdivision, *P. tuberculatus* Zone
36240		
	115.8 - 253.0m	B subdivision, *P. tuberculatus* Zone
	326.1 - 335.3m	Middle *N. asperus* Zone
36025/2		
	105.1 - 106.6m	*T. bellus* Zone
	109.7 - 138.6m	C subdivision, *P. tuberculatus* Zone
30422		
	109.7 - 155.4m	C subdivision, *P. tuberculatus* Zone
36211		
	112.8 - 137.8m	C subdivision, *P. tuberculatus* Zone
	147.8 - 195.0m	B subdivision, *P. tuberculatus* Zone
	280.4 - 281.9m	Mixed A subdivision, *P. tuberculatus* Zone and Stage 3a of the Early Permian
36069		
	120.0 - 129.5m	C subdivision, *P. tuberculatus* Zone
	135.6 - 137.2m	B subdivision, *P. tuberculatus* Zone

25363
125.9 - 129.5m C subdivision } *P. tuberculatus* Zone
134.1 - 185.9m B subdivision }
36201/30691
123.7 - 124.3m Early *T. bellus* Zone
131.1 - 138.4m C subdivision } *P. tuberculatus* Zone
140.2 - 245.4m B subdivision }
256.0 - 271.3m A subdivision }
274.3 - 323.1m Middle *N. asperus* Zone
36261
94.5 - 117.3m C subdivision } *P. tuberculatus* Zone
121.9 - 216.4m B subdivision }
224.0 - 236.2m A subdivision }
248.3 - 273.5m Lower *N. asperus* Zone
278.1 - 289.6m *Dictyotosporites speciosus* Zone of the Early Cretaceous
36034
103.6 - 105.1m *T. bellus* Zone
106.7 - 132.6m C subdivision, *P. tuberculatus* Zone
30883
111.2 - 158.5m C subdivision } *P. tuberculatus* Zone
164.6 - 178.2m B subdivision }
36235
105.2 - 135.6m C subdivision } *P. tuberculatus* Zone
155.4 - 205.7m B subdivision }
210.3 - 243.8m A subdivision }
246.1 - 259.8m Middle *N. asperus* Zone
30443
102.1 - 103.6m *T. bellus* Zone
105.1 - 121.9m C subdivision } *P. tuberculatus* Zone
123.5 - 207.0m B subdivision }
36229/30362
96.0 - 134.1m C subdivision } *P. tuberculatus* Zone
137.2 - 185.9m B subdivision }
193.5 - 230.1m A subdivision }
259.1 - 260.6m Middle *N. asperus* Zone
285m Stage 3b of the Early Permian
30464
97.5 - 134.1m C subdivision } *P. tuberculatus* Zone
137.2 - 138.7m B subdivision }
36275
118.8 - 125.9m C subdivision } *P. tuberculatus* Zone
148.1 - 185.3m B subdivision }
214.3 - 238.6m A subdivision }
246.3 - 288.9m Middle *N. asperus* Zone
322.7 - 334.7m Stage 3a of the Early Permian
30959
130.5 - 156.0m C subdivision } *P. tuberculatus* Zone
168.0 - 184.0m B subdivision }
36283
142.6 - 144.2m Upper Stage 4a, Early Permian
JX-7 (Mines Administration Pty. Ltd.)
140.2 - 141.7m B subdivision } *P. tuberculatus* Zone
149.3 - 158.5m A subdivision }
30348
117.3 - 121.9m C subdivision, *P. tuberculatus* Zone

36267
66.1 - 89.0m C subdivision } *P. tuberculatus* Zone
105.8 - 140.8m B subdivision }
154.5 - 156.0m A subdivision }
166.7 - 168.2m Middle *N. asperus* Zone
172.5m *Dictyotosporites speciosus* Zone of the Early Cretaceous
36366
122.0 - 150.0m B subdivision } *P. tuberculatus* Zone
158.0 - 192.0m A subdivision }
198.0 - 221.0m Middle *N. asperus* Zone
36373
94.0 - 140.0m B subdivision } *P. tuberculatus* Zone
166.0 - 184.0m A subdivision }
206.0 - 212.0m Middle *N. asperus* Zone
36040
109.7 - 111.2m Upper *T. bellus* Zone
128.0 - 195.1m B subdivision } *P. tuberculatus* Zone
196.6 - 201.2m A subdivision }
216.4 - 237.7m Middle *N. asperus* Zone
289.6 - 307.8m Upper Stage 5 of the Early Permian
30323
131.1 - 146.3m ? C subdivision } *P. tuberculatus* Zone
149.3 - 187.4m B subdivision }
192.0 - 204.2m A subdivision }
211.8 - 239.3m Middle *N. asperus* Zone
276.0 - 278.0m Barren, ? Triassic
330.7m Lower Stage 5b of the Late Permian
30497
105.0 - 106.7m C subdivision } *P. tuberculatus* Zone
108.2 - 152.4m B subdivision }
30489
96.0 - 115.8m C subdivision, *P. tuberculatus* Zone
36368
136.0 - 138.0m Middle *N. asperus* Zone
30320
112.8 - 126.5m A subdivision, *P. tuberculatus* Zone
25394
32.3 - 55.5m Pliocene
100.6 - 101.2m Upper *T. bellus* Zone
115.2 - 134.4m B subdivision, *P. tuberculatus* Zone
143.6 - 160.6m Middle *N. asperus* Zone

Note:

The Narranderra bore in Martin (1973) is 25394. This report was written before the zonation scheme of Stover and Partridge (1973) became available and everything below 100m is incorrectly designated as Miocene. This report supersedes that in Martin (1973).

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The Stratigraphic Palynology of the Murray Basin in New South Wales. III. The Lachlan Area

HELENE A. MARTIN

ABSTRACT. The geology and palynology of the Lachlan area of the eastern edge of the Murray Basin is generally similar to that of the Murrumbidgee area. The oldest Tertiary sediments are the Mid-Late Eocene Middle *Nothofagidites asperus* Zone. The Oligocene-Early Miocene *Proteacidites tuberculatus* Zone may form thick sections which require subdivision. The Mid-Late Miocene *Triporopollenites bellus* Zone is not found here. In the southwestern region of the Lachlan area, the basement is deeper and the sedimentary sequence thicker. Here the *P. tuberculatus* Zone may be subdivided using the quantitative events (i.e. high ratios), similar to that of the Murrumbidgee area. Elsewhere, the pre-Tertiary basement is shallower and the sedimentary sequence thinner. Here, the quantitative events show different patterns to those of the Murrumbidgee area. It is thought that better drainage over the shallower basement is the likely cause of the different patterns.

The two records of basement assemblages are both the Early Cretaceous *Dictyotosporites speciosus* Zone.

INTRODUCTION

Tertiary deposition in the Lachlan area (see Fig. 1) is generally similar to that of the Murrumbidgee (Martin, 1984). The oldest Tertiary sediments are the Mid-Late Eocene Middle *Nothofagidites asperus* Zone, like those of the Murrumbidgee area. The *Proteacidites tuberculatus* Zone may form thick sections also, and the problems of subdividing them are encountered here as well. In the Murrumbidgee area, these problems have been solved by the use of quantitative events (i.e. high ratios). However, this solution does not work over most of the Lachlan area for while the high ratios may be identified, they do not form similar patterns to those seen in the former.

This paper presents the stratigraphic palynology of the Tertiary and basement of the Lachlan area. The differences between it and the Murrumbidgee are discussed and the likely causes suggested.

GEOLOGY

The geology of the Murrumbidgee area presented in Martin (1984) is applicable in general to the Lachlan area. The discussion below concentrates

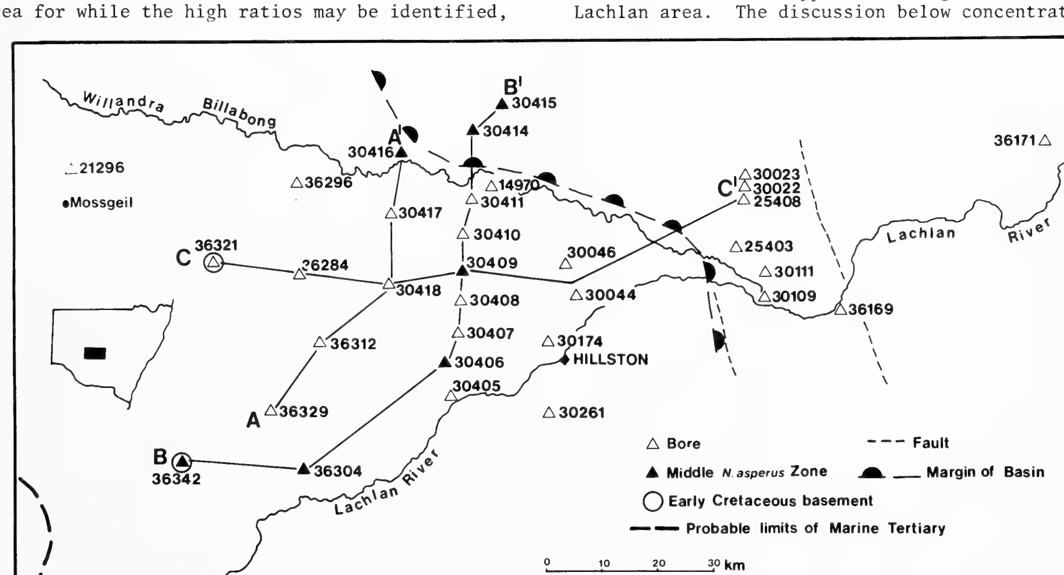

Fig. 1 Locality map. The probable extent of the marine Tertiary and the margin of the Basin are from Bembrick, 1975. The faults are from the 1:250,000 Geological Series, Cargellico SI 55-6.

on the differences between the two areas.

The pre-Tertiary basement of the Lachlan is shallower over most of the area. It deepens towards the south west and the bores in this region are situated on the Ivanhoe Trough, a basement feature (R.M. Williams, pers. comm.). As a consequence of this shallower basement, which has been relatively shallow throughout the Tertiary the section is not as thick as that of the Murrumbidgee area, with the exception of the south west region where the section is much deeper.

The sediments in the Lachlan area are generally not as carbonaceous as those of the Murrumbidgee area. The dark grey clays are not as common and pale to mid-grey clays may be encountered low down in the sequence. At the top of the sequence, barren pale grey sediments may extend above the pollen bearing beds before the change to brown, yellow, red and minor grey sediments.

Overall, sands are more common in the Lachlan area than in the Murrumbidgee area (R.M. Williams, pers. comm.).

These differences in the geology are relatively slight but they are thought to be important for palynology.

MATERIALS AND METHODS

All of the bores have been sunk by the Water Resources Commission of New South Wales and most reach basement. The methods are the same as those described in Martin (1984).

PALYNOSTRATIGRAPHY

(1) Early Cretaceous.

Early Cretaceous assemblages are found in two bores and palynostratigraphy follows Dettmann and Playford (1969) for zonation and Morgan (1980) for time ranges. The citations of all species below follow these references. All of the assemblages are similar. The gymnosperms *Microcachryidites antarticus* and *Podocarpidites* spp. are the most common. *Araucariacites australis* is relatively abundant and *Alisporites* spp., *Ginkgocycadophytus nitidus,* and *Classopollis* of *C. classoides* are present also. There is a rich spore flora of *Cyathidites* spp., *Lycopodiumsporites* spp., *Leptolepidites* spp., *Baculatisporites comaumensis, Stereisporites antiquasporites* and others. Four diagnostic species are present and their ranges are shown on Fig. 1. The ranges of Morgan (1980) are preferred for they are based on more comprehensive data than that of Dettmann & Playford (1969). Thus these assemblages fit the *Dictyotosporites speciosus* assemblage of Aptian into early Albian age (Morgan, 1980).

All of the assemblages contain abundant plant debris. No dinoflagellates have been found in Bore 36342, indicating wholly non-marine environments. A few dinoflagellates have been found in Bore 36321. Several species are present, but usually only one specimen of each. Most are broken or lack the definitive diagnostic features so reliable identification is not possible. However, the distinctive genus *Odontochitinia* which is known from the *D. speciosus* Zone (Morgan, 1980), is present. These few dinoflagellates indicate near shore conditions, perhaps the head of an estuary. The bores are listed in the Appendix and the distribution of the Early Cretaceous basement is shown on Fig. 1.

(2) Tertiary

For the main part, Tertiary palynostratigraphy follows Stover and Partridge (1973) with the modifications adopted in Fig. 2 of Martin (1984). The citations of species names follow Stover and Partridge (1973).

The oldest Tertiary assemblages found here are placed in the Middle *Nothofagidites asperus* Zone of Mid-Late Eocene age, similar to those of the Murrumbidgee area (Martin, 1984). Its distribution is restricted, as shown on Fig. 1.

The Late Eocene-Early Oligocene Upper *N. asperus* Zone, as described by Stover and Partridge (1973) has not been found in this area. Once the species restricted to the Lower *N. asperus* Zone disappear, the assemblages are those of the *Proteacidites tuberculatus* Zone. The Lachlan area is similar to the Murrumbidgee in this respect.

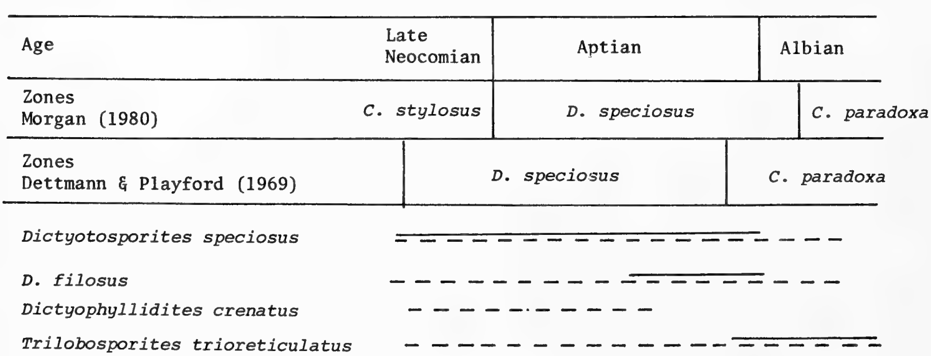

Fig. 2 The time ranges of Early Cretaceous diagnostic species. Solid lines, time ranges from Dettmann & Playford (1969). Broken lines, time ranges from Morgan (1980).

The *P. tuberculatus* Zone of Early Oligocene through Early Miocene age is found in almost every bore, sometimes in thick sections. The subdivisions of the *P. tuberculatus* Zone described by Stover and Partridge (1973) cannot be recognised on their diagnosis, but some subdivision of these thick sections is necessary. Three quantitative events have been used to subdivide the thick sections of the *P. tuberculatus* Zone in the Murrumbidgee area and their stratigraphic position is shown in Fig. 2 of Martin (1984). The same quantitative events are recognised in the Lachlan area, but their stratigraphic positions show some differences, viz:

1) High *Phyllocladites mawsonii* ratios in the base of the *P. tuberculatus* Zone in the Murrumbidgee area are not found in this position in the Lachlan area, with the exception of one bore on the basin edge.

2) High *Nothofagidites flemingii* ratios may not form two distinct layers here, as it does in the Murrumbidgee area. In many bores, high ratios may be found more or less continuously through the *P. tuberculatus* Zone, or sporadically, showing no definite pattern of distribution. In a few bores, the high ratios are concentrated at the base of the zone.

3) High Myrtaceae/*Nothofagus* ratios are not as common as in the Murrumbidgee area, but most are found in the top part of the *P. tuberculatus* Zone, so they may be used to define the C subdivision (see Fig. 2 in Martin, 1984). Some high ratios may be found lower down in the B subdivision. A few high Myrtaceae/*Nothofagus* ratios may be found well down in the *P. tuberculatus* Zone in the Murrumbidgee area also, but not as many as in the Lachlan area.

As a consequence of these differences in expression of the quantitative events, the three subdivisions of the *P. tuberculatus* Zone may be distinguished in a few bores, they are questionable in many, and in some bores, the *P. tuberculatus* Zone cannot be divided at all.

There is one occurrence of the Mid- Late Miocene *Triporopollenites bellus* Zone in the most easterly bore. Older assemblages do not occur here. Pliocene assemblages are found above the

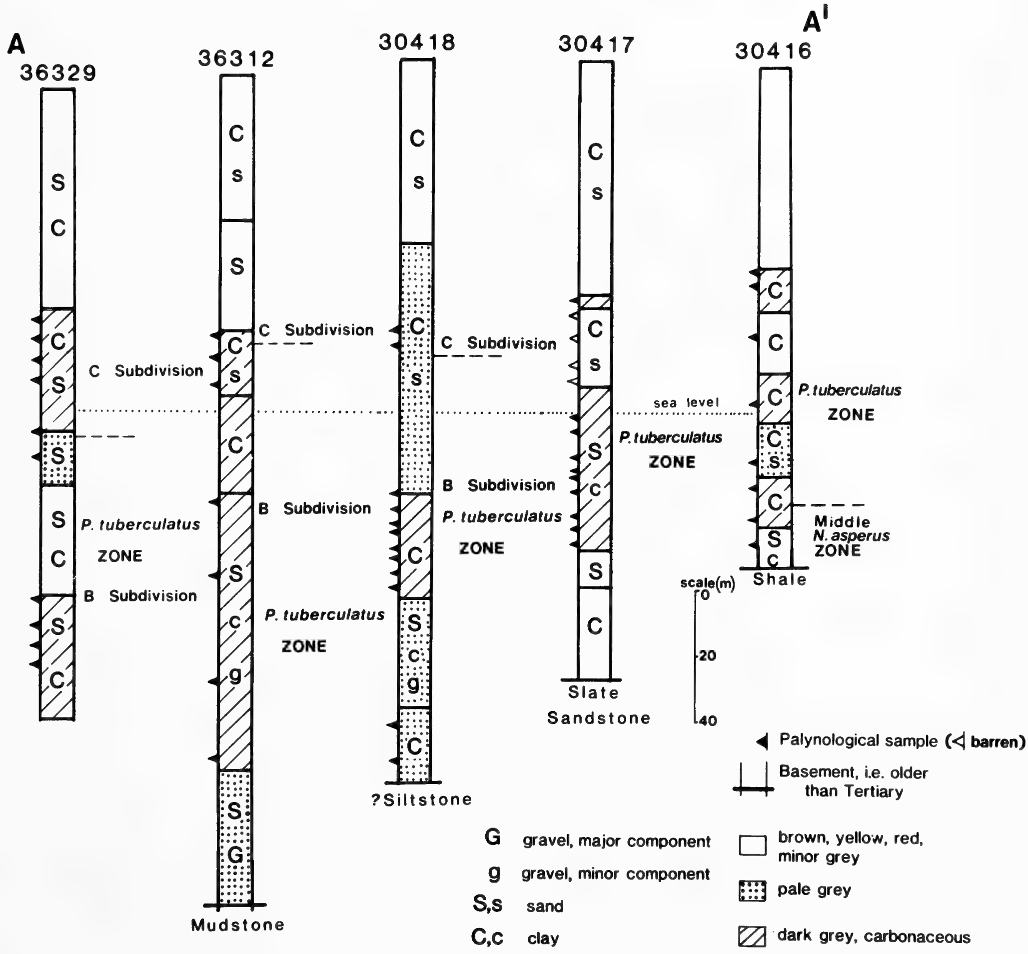

Fig. 3 Cross section A-A[1]. For location of bores see Fig. 1.

T. bellus Zone.

No dinoflagellates have been found in the Tertiary. This deposition is entirely non-marine.

The distribution of the zones and their subdivisions in the bores are listed in the Appendix. Three cross sections are shown in Figs. 3-5.

DISCUSSION

The Early Cretaceous assemblages were probably deposited at a time of high sea level which would have induced more swampy conditions on the land. Some slight influence of the sea is indicated in the most northerly bore which contains a few dinoflagellates. These deposits would have been a southerly extension of the Great Australian Basin.

The Middle *N. asperus* Zone is not encountered very often in the Lachlan area. Some may have been removed by channelling, e.g. Bores 30407 and 30411 (see Fig. 4) where the *P. tuberculatus* Zone extends well below the level of the Middle *N. asperus* Zone in the neighbouring bores. However, the basement is somewhat irregular with highs, e.g. Bores 30410 (Fig. 4) and 36321 (Fig. 5) which would have been above the swampy areas at the time the Middle *N. asperus* Zone was being deposited. The topography need not have been more than a few metres.

The Upper *N. asperus* Zone as described by Stover and Partridge (1973) is not found here, similar to that of the Murrumbidgee area. The high *P. mawsonii* ratios in the latter are thought to be the time equivalent of this zone (Martin, 1984). However, these high ratios are not found in the Lachlan area hence the identification of any time equivalent is impossible. As the Upper *N. asperus* Zone was a time of high sea level its preservation is expected. It is thought that the shallower basement coupled with more sands and a greater irregularity of the terrain produced better drainage so that the swampy environment required by *P. mawsonii* was insufficient to produce the high ratios. The general lack of carbonaceous sediments when compared with the Murrumbidgee area supports this interpretation.

The diffuse nature of the high *N. flemingii* ratios, running through most of the *P. tuberculatus* Zone is the most striking difference when compared with the Murrumbidgee area. This difference is not seen in the three southern-most bores where the basement deepens. Here the *P. tuberculatus* Zone may be divided into the three subdivisions used in the Murrumbidgee area. Elsewhere, over the shallower basement, the better drainage would have been conducive to *N. flemingii* high ratios through most of the *P. tuberculatus* Zone, so that they are not confined to the times of lowered sea levels. This interpretation based on the difference in drainage is in accord with that for

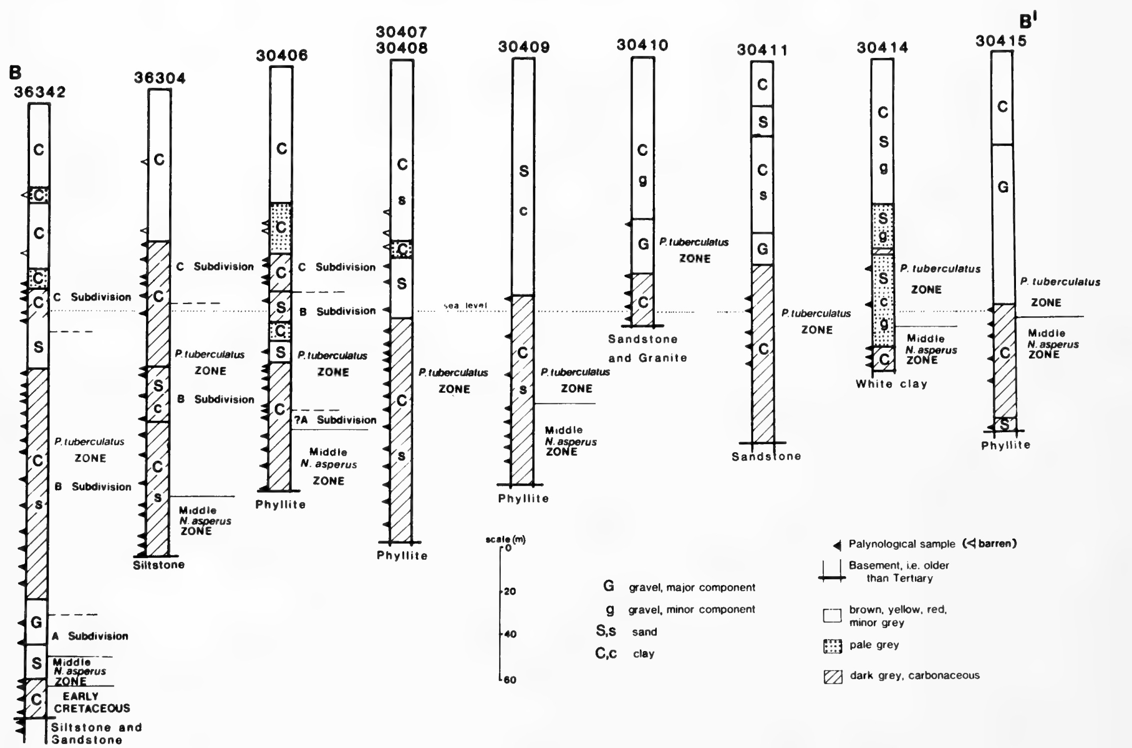

Fig. 4 Cross section B-B[1]. For location of bores see Fig. 1. *The palynology of bores 30407 and 30408 is almost identical but the lithology is different, especially in the distributions of the sands. The log of 30407 is presented here.

P. mawsonii.

In the Murrumbidgee area, the greatest thickness of any *N. flemingii* acme is 30m. There is only one occurrence of this thickness and all the rest are 20m or less. The lower *N. flemingii* acme, where it occurs, only consists of one sample, so the total thickness of the two *N. flemingii* acmes combined approximate the thicknesses above. In the Lachlan area, *N. flemingii* high ratios may be found through a thickness of up to 60m. There are two occurrences of thickness and a number are greater than 30m. Thus the total thickness of *N. flemingii* high ratios in the Lachlan area is up to twice that of the Murrumbidgee area. This evidence supports the interpretation that the *N. flemingii* high ratios in the Lachlan are not the strict time equivalent of the *N. flemingii* acmes in the Murrumbidgee, and that they are found in the time equivalent of the B subdivision which occurs between the two acmes of the latter area.

The Mid-Oligocene hiatus of the Murray Basin (Brown, 1983) cannot be recognised here (R.M. Williams, pers. comm.), similar to that in the Murrumbidgee area. The palynologic evidence does not suggest an hiatus either. The subdivision of the *P. tuberculatus* Zone using quantitative events relies on the ecologic requirements of the selected species. The difference in habitat, viz. better drainage accounts for the observed differences when compared with the Murrumbidgee area.

The high Myrtaceae/*Nothofagus* ratios, diagnostic of the upper part of the *P. tuberculatus* Zone are found consistently in the deeper, southernmost part of the area where the C subdivision is clearly identified. Elsewhere, the distribution is patchy and probably represents small, isolated swamps. This contrasts with the Murrumbidgee area where the C subdivision is well represented over most of the area. Thus the thinner C subdivision is in keeping with the whole sequence being thinner.

The *T. bellus* Zone is not found in the Lachlan area of the Murray Basin itself, unlike that of the Murrumbidgee area. There is one occurrence in Bore 36171 (see Fig. 1), but it is well beyond the eastern limits of the Basin edge. Older sediments do not occur here. There is one occurrence of Pliocene assemblages in the same bore.

There is a barren section above the pollen bearing beds, similar to that of the Murrumbidgee area. However, it is thinner, about 80m in thickness compared with 100m in the latter, and this is in accord with the whole sequence being thinner. The likely reasons for this section being barren are probably the same as those for the Murrumbidgee area (Martin, 1984).

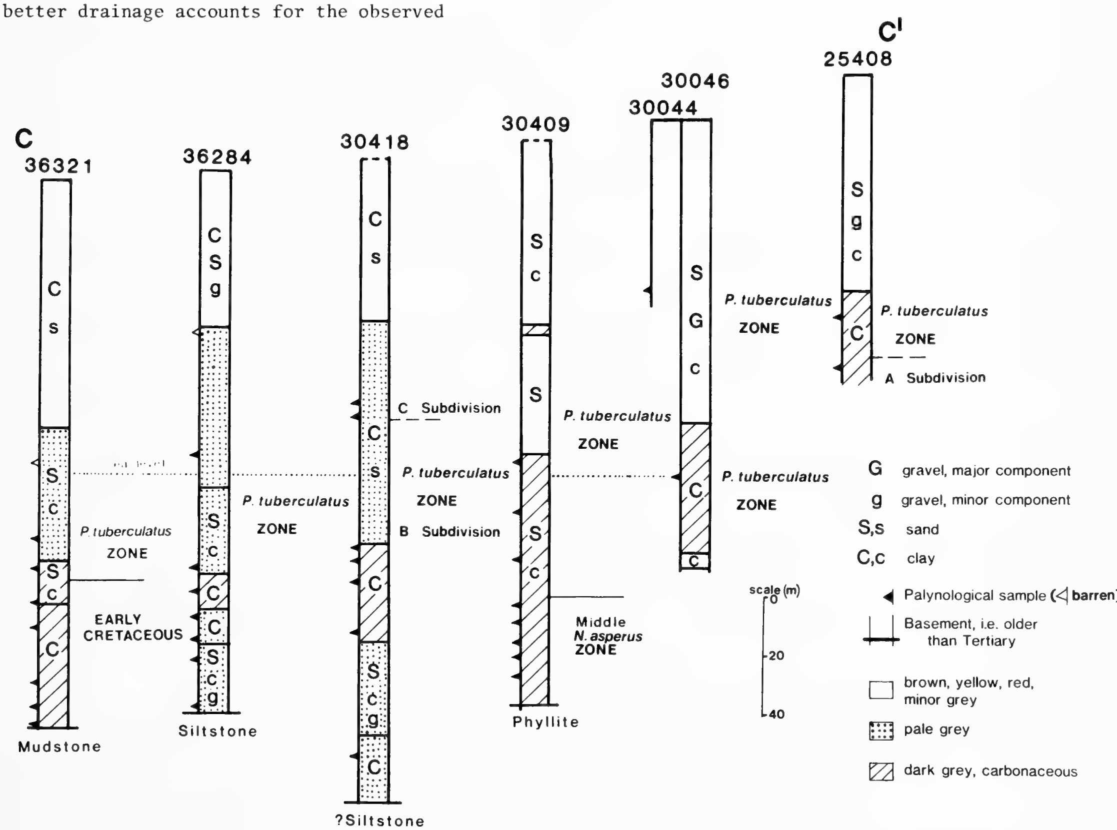

Fig. 5 Cross section C-C[1]. For location of bores see Fig. 1.

CONCLUSIONS

The palynologic record shows that Tertiary deposition occurred from Mid-Late Eocene into Early Miocene time, and this is similar to that of the Murrumbidgee area. The Lachlan area may be divided in two:

1) The southwestern part where the basement deepens and the sedimentary sequence is of a comparable thickness to that of the Murrumbidgee area. The *P. tuberculatus* Zone may be subdivided in a similar way also.

2) Elsewhere, the basement is shallower and the sedimentary sequence thinner. Here the quantitative events (i.e. high ratios) of the *P. tuberculatus* Zone show different patterns to those seen in the Murrumbidgee area. It is thought that better drainage is the cause of the difference.

Pollen assemblages are not recovered from Early Miocene time onwards, similar to that in the Murrumbidgee area. The barren section is thinner over the shallower basement.

ACKNOWLEDGEMENTS.

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APPENDIX

Bores arranged W to E then N to S. For location, see Fig. 1. For the age of the palynological zones, see Fig. 2 in Martin (1984). All bores have been sunk by the Water Resources Commission of New South Wales.

21296	
71- 90m	C subdivision, *P. tuberculatus* Zone
114-115m	*P. tuberculatus* Zone
36321	
122-134m	*P. tuberculatus* Zone
144-148m	Mixed *P. tuberculatus* Zone and Early Cretaceous
152-190m	*Dictyotosporites speciosus* Zone of the Early Cretaceous
36342	
84-100m	C subdivision
122-230m	B subdivision *P. tuberculatus* Zone
236-248m	A subdivision
262-266m	Middle *N. asperus* Zone
270-286m	*Dictyotosporites speciosus* Zone of the Early Cretaceous
36296	
78- 80m	C subdivision, *P. tuberculatus* Zone
122-184m	*P. tuberculatus* Zone
36284	
136-188m	*P. tuberculatus* Zone
36329	
70-106m	C subdivision *P. tuberculatus* Zone
112-178m	B subdivision *P. tuberculatus* Zone
36312	
78- 80m	C subdivision *P. tuberculatus* Zone
86-212m	B subdivision *P. tuberculatus* Zone
36304	
70- 98m	C subdivision *P. tuberculatus* Zone
104-182m	B subdivision *P. tuberculatus* Zone
190-214m	Middle *N. asperus* Zone
30416	
62-130m	*P. tuberculatus* Zone
138-148m	Middle *N. asperus* Zone
30417	
74-146m	*P. tuberculatus* Zone
30418	
84- 90m	C subdivision *P. tuberculatus* Zone
134-219m	B subdivision *P. tuberculatus* Zone
30415	
118-120m	*P. tuberculatus* Zone
124-174m	Middle *N. asperus* Zone
30414	
86-114m	*P. tuberculatus* Zone
132-142m	Middle *N. asperus* Zone

14970	
76- 77m	*P. tuberculatus* Zone
30411	
108-140m	*P. tuberculatus* Zone
30410	
74-120m	*P. tuberculatus* Zone
30409	
108-158m	*P. tuberculatus* Zone
164-184m	Middle *N. asperus* Zone
30408	
94-138m	*P. tuberculatus* Zone
30407	
102-220m	*P. tuberculatus* Zone
30406	
88- 89m	C subdivision } *P. tuberculatus* Zone
96-148m	B subdivision }
156-162m	? A subdivision
168-194m	Middle *N. asperus* Zone
30405	
90-156m	*P. tuberculatus* Zone
30158	
72- 74m	*P. tuberculatus* Zone
30157	
84- 87m	*P. tuberculatus* Zone
30046	
103-149m	*P. tuberculatus* Zone
30044	
70- 72m	*P. tuberculatus* Zone
30174	
96- 97m	*P. tuberculatus* Zone
30261	
70- 73m	*P. tuberculatus* Zone
30023	
76- 88m	*P. tuberculatus* Zone
30022	
74- 83m	*P. tuberculatus* Zone
25408	
74- 98m	*P. tuberculatus* Zone
98-103m	A subdivision, *P. tuberculatus* Zone
25403	
74-107m	*P. tuberculatus* Zone
30111	
56- 64m	*P. tuberculatus* Zone
30109	
69- 79m	*P. tuberculatus* Zone
36169	
23- 70m	Pliocene
36171	
61-73m	Pliocene
78- 79m	Late *T. bellus* Zone

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Computation of Reaction Matrix Parameters by Perturbation Theory

J. L. Cook, E. K. Rose and B. E. Clancy

ABSTRACT. The forward problem of computing phase shifts, or the equivalent reaction matrix parameters, directly from an interaction potential is investigated. Ordinary perturbation theory provides an excellent way to compute the parameters to high accuracy. A quadrature scheme is given which allows the computation of high orders of the interaction matrix. The scheme takes into account rapid oscillations in the wave functions at high orders and agrees well with test cases where analytical results are derived. Finally, a wide range of interior potentials in the s-wave case is considered and analytic results are given for the interaction matrix.

INTRODUCTION

There is an extensive literature on methods for solving the inverse scattering problem. Attempts to determine a local or non-local potential that reproduces these data have been based on a knowledge of the scattering phase shift. Most approaches are very formal and a general review of these methods has been given by Chadan and Sabatier (1977). In a paper by Hartt (1980), the new technique of using Padé approximants to compute the scattering function F = k cotα, where α is the phase shift, has been used formally to solve both the forward and inverse problem for nucleon-nucleon scattering. Cook (1972) employed a much older method in which the intermediate calculation of reaction matrices, which are essentially Padé approximants, were used to solve the inverse problem. Despite an extensive literature search, we were unable to locate any recent publications on the solution to the forward problem with the aid of reaction matrix parameters. Such calculations are important to understand the behaviour of overlap and interaction matrices.

For a review of reaction matrix theory we refer the reader to the article by Lane and Thomas (1958). In our discussion of the interaction and overlap matrices, we use the notation of Cook (1972). The purpose of this paper is to establish the connection between perturbation series (Newton 1966) and the reaction matrix. The usual Born approximation fails at energies close to a bound state energy or a resonance pole energy. On the other hand, the reaction matrix formalism remains valid, no matter what the size of the coupling constant might be or how close the energy is to the bound state or resonance poles. This led us to surmise that it may be possible to calculate the poles and residues of the reaction matrix directly from the series. We discovered a set of recurrence relations for the n^{th} order overlap matrix and energy eigenvalue which relates them to lower orders of the same quantities. In terms of numerical computation, this has afforded a very rapid means of computing the reaction matrix parameters up to high orders of perturbation.

We tested the method by applying it to a computation of poles and residues of the reaction matrix for the n-p system in the triplet s-state. The correct binding energy was obtained using Yukawa, Gaussian, exponential and square well nuclear potentials with coupling constants and shape parameters derived from the effective range approximation (Preston, 1965). Heaviside units are used with the nucleon mass unit throughout this paper.

We also discuss general power law potentials and the Woods-Saxon potential in the s-wave case. A quadrature scheme is derived which allows accurate computation of overlap and interaction matrices for high order harmonics, in which the Bessel function components oscillate very rapidly, so that ordinary integration schemes do not work adequately.

A big advantage of reaction matrix theory over optical model theories is that the behaviour of a many-channel s-matrix can be investigated using the old theory of Wigner and Eisenbud (1947). We are evolving a theory based on this early work that should prove suitable for pion-nucleon reaction channels and should also permit the determination of interaction potentials in non-elastic pion and associated production channels. A further advantage of reaction matrix theory is that it permits an excellent local energy approximation to the scattering matrix. Truncation of the sum over poles in the reaction matrix leads to an acceptable accuracy in restricted regions; this is always limited by the fact that all data have to be fitted over restricted energy ranges.

The general philosophy of the reaction matrix approach is that Wigner-Eisenbud theory always allows for real internal wave functions and potentials which are analytically decoupled from channel to channel. It can be shown formally that such a scheme will allow only the real part of the scattering phase shift above inelastic thresholds to be used independently to compute a decoupled interaction. This work has been reported by Clayton (1972). Relativistic corrections can be incorporated in the effective interaction.

PERTURBATION THEORY

The derivation of the first two orders follows closely that given by Schiff (1949). For the reaction matrix eigenfunctions $U_\lambda(r)$, the total

Hamiltonian H is introduced which, in the presence of an interaction gV(r), satisfies:

$$HU_\lambda(r) = k_\lambda^2 U_\lambda(r) \quad (1)$$

and

$$H = H_o + gV \quad (2)$$

where H_o is the free particle Hamiltonian satisfying

$$H_o W_\mu(r) = k_\mu^2 W_\mu(r)$$

$$H_o \equiv -\frac{\partial^2}{\partial r^2} + \frac{\ell(\ell+1)}{r^2} \quad (3)$$

and $W_\mu(r)$ are free particle eigenfunctions with V = 0 and the same boundary conditions. The overlap matrix for a force of range a is defined as

$$B_{\lambda\mu} = \int_o^a dr\, U_\lambda(r) W_\mu(r) \quad (4)$$

We now expand $U_\lambda(r)$ into a perturbation series of the form

$$U_\lambda(r) = W_\lambda(r) + \sum_{n=1}^{\infty} g^n U_\lambda^{(n)}(r) \quad (5)$$

where $U_\lambda^{(n)}(r)$ is the n^{th} order perturbation to $U_\lambda(r)$. Hence, from equation (4) we find

$$B_{\lambda\mu} = \sum_{n=0}^{\infty} g^n B_{\lambda\mu}^{(n)} \quad , \quad (6)$$

and

$$U_\lambda^{(n)}(r) = \sum_{\mu=1}^{\infty} B_{\lambda\mu}^{(n)} W_\mu(r) \quad . \quad (7)$$

Similarly, k_λ^2 is the position of the pole in the reaction matrix $R(k^2)$, i.e.

$$R(k^2) = \frac{1}{a} \sum_{\lambda=0}^{\infty} \frac{U_\lambda^2(a)}{k_\lambda^2 - k^2} \quad , \quad (8)$$

so we expand k_λ^2 into a similar series

$$k_\lambda^2 = K_\lambda^2 + \sum_{n=1}^{\infty} g^n \left(k_\lambda^{(n)}\right)^2 \quad . \quad (9)$$

We substitute equations (9) and (5) into equation (1) and get

$$(H_o + gV)\left(\sum_{n=0}^{\infty} g^n U_\lambda^{(n)}\right) =$$

$$= \left[\sum_{n=0}^{\infty} g^n \left(k_\lambda^{(n)}\right)^2\right]\left[\sum_{m=0}^{\infty} g^m U_\lambda^{(m)}\right] \quad (10)$$

and equate corresponding coefficients of g^n. For example:

(a) Coefficients of g^o

$$H_o U_\lambda^{(o)} = \left(k_\lambda^{(o)}\right)^2 U_\lambda^{(o)} \quad , \quad (11)$$

that is

$$U_\lambda^{(o)} = W_\lambda \quad ; \quad k_\lambda^{(o)} = K_\lambda \quad .$$

(b) Coefficients of g

$$H_o U_\lambda^{(1)} + VW_\lambda = K_\lambda^2 U_\lambda^{(1)} + \left(k_\lambda^{(1)}\right)^2 W_\lambda \quad (12)$$

which yields

$$\sum_\mu H_o B_{\lambda\mu}^{(1)} W_\mu + VW_\lambda = K_\lambda^2 \sum_\mu B_{\lambda\mu}^{(1)} W_\mu + \left(k_\lambda^{(1)}\right)^2 W_\lambda \quad . \quad (13)$$

Multiplying by W_ν and integrating over the range $0 < r < a$, we use the orthonormal property of W_λ to get

$$\text{(i)} \quad B_{\lambda\mu}^{(1)} = \frac{V_{\lambda\mu}}{K_\lambda^2 - K_\mu^2} \quad \text{for } \lambda \neq \mu$$

$$\text{(ii)} \quad \left(k_\lambda^{(1)}\right)^2 = V_{\lambda\lambda} \quad (14)$$

$$\text{(iii)} \quad V_{\lambda\mu} = \int_o^a dr\, V(r) W_\lambda(r) W_\mu(r) \quad .$$

As in Schiff's derivation, we substitute equation (5) into the orthonormal conditions

$$\text{(i)} \quad \int_o^a dr\, U_\lambda(r) U_\nu(r) = \delta_{\lambda\nu}$$

$$\text{(ii)} \quad \int_o^a dr\, W_\mu(r) W_\rho(r) = \delta_{\mu\rho} \quad (15)$$

and obtain for the coefficient of g

$$B_{\lambda\lambda}^{(1)} = 0 \quad . \quad (16)$$

(c) Coefficients of g^2

$$\text{(i)} \quad B_{\lambda\mu}^{(2)} = \frac{1}{K_\mu^2 - K_\lambda^2}\left\{\frac{V_{\lambda\lambda} V_{\lambda\mu}}{K_\lambda^2 - K_\mu^2} - \sum_\nu B_{\lambda\mu}^{(1)} V_{\nu\mu}\right\} \text{ for } \lambda \neq \mu$$

$$\text{(ii)} \quad B_{\lambda\lambda}^{(2)} = -\frac{1}{2}\sum_\mu |B_{\lambda\mu}^{(1)}|^2 \quad , \quad (17)$$

$$\text{(iii)} \left(k_\lambda^{(2)}\right)^2 = \sum_\mu B_{\lambda\mu}^{(1)} V_{\mu\lambda} \quad .$$

(c) Coefficients of g^3

$$\text{(i)} \quad B_{\lambda\mu}^{(3)} = \frac{1}{K_\mu^2 - K_\lambda^2}\left\{-\sum_\nu B_{\lambda\mu}^{(2)} V_{\nu\mu} + \left(k_\lambda^{(1)}\right)^2 B_{\lambda\mu}^{(2)} + \left(k_\lambda^{(2)}\right)^2 B_{\lambda\mu}^{(1)}\right\} \quad \text{for } \lambda \neq \mu$$

$$\text{(ii)} \quad B_{\lambda\lambda}^{(3)} = -\sum_\mu B_{\lambda\mu}^{(1)} B_{\lambda\mu}^{(2)} \quad (18)$$

$$\text{(iii)} \left(k_\lambda^{(3)}\right)^2 = \sum_\mu B_{\lambda\mu}^{(2)} V_{\mu\lambda} - \left(k_\lambda^{(1)}\right)^2 B_{\lambda\lambda}^{(2)} \quad .$$

By examining increasing orders of n, we find the general recurrence relations:

$$\text{(i)} \quad B_{\lambda\mu}^{(n)} = \frac{1}{K_\mu^2 - K_\lambda^2}\left\{-\sum_\nu B_{\lambda\nu}^{(n-1)} V_{\nu\mu} + \sum_{p=1}^{n-1} \left(k_\lambda^{(p)}\right)^2 B_{\lambda\mu}^{(n-p)}\right\} \quad \text{for } \lambda \neq \mu$$

$$\text{(ii)} \quad B_{\lambda\lambda}^{(n)} = -\frac{1}{2}\sum_{p}^{n-1}\sum_{\mu=0}^{\infty} B_{\lambda\mu}^{(p)} B_{\lambda\mu}^{(n-p)} \quad , \tag{19}$$

$$\text{(iii)} \quad \left(k_{\lambda}^{(n)}\right)^2 = \sum_{\mu=0}^{\infty} B_{\lambda\mu}^{(n-1)} V_{\mu\lambda} - \sum_{p=1}^{n-1} \left(k_{\lambda}^{(p)}\right)^2 B_{\lambda\lambda}^{(n-p)} \quad .$$

Thus we have a method for calculating $\underline{B}$, the $U_{\lambda}(a)$ and k_{λ}^2 which determines $R(k^2)$. The scattering phase shifts are then found from the relationship (Preston 1965):

$$S(q^2) = e^{2i\delta(q^2)} = \Omega\left(\frac{1-R(q^2)(L^*-B)}{1-R(q^2)(L-B)}\right) \tag{20}$$

where Ω is the hard sphere phase factor, $L = s+ip$, $\delta(q^2)$ is the scattering phase shift, $s(q^2)$ and $p(q^2)$ are the level shifts and penetration factors respectively, as completely tabulated by Lane and Thomas (1958) and by Preston (1965), and $B = -\ell$, where ℓ is the orbital angular momentum of the partial wave considered.

COMPUTATIONS

The definitions of $W_{\mu}(r)$ for free particles in an s-state yield

$$\text{(i)} \quad W_{\mu}(r) = \sqrt{\frac{2}{a}}\,\sin(\mu+\tfrac{1}{2})\,\frac{\pi r}{a}$$

$$\text{(ii)} \quad W_{\mu}(a) = \sqrt{\frac{2}{a}}\,(-1)^{\mu} \tag{21}$$

$$\text{(iii)} \quad K_{\mu} = (\mu+\tfrac{1}{2})\,\frac{\pi}{a} \quad .$$

We now consider the four potentials fitted by Preston to the n-p system in the triplet state.

(a) The Yukawa Potential

$$gV(r) = Gr_n \frac{e^{-r/r_n}}{r} \tag{22}$$

which, when substituted into equation 14 (iii), gives for large a (Gradshteyn and Ryzhik 1965):

$$\text{(i)} \quad V_{\lambda\mu} = \frac{1}{2a}\,\ell n\left\{\frac{a^2+(\lambda+\mu+1)^2\pi^2 r_n^2}{a^2+(\lambda-\mu)^2\pi^2 r_n^2}\right\} \tag{23}$$

$$\text{(ii)} \quad g = Gr_n$$

where G is the dimensionless coupling constant. Preston's parameters give:

$$g = -0.3330 \quad , \quad r_n = 7.53 \quad .$$

We varied the value of 'a' for the calculation of $B_{\lambda\mu}$, $U_{\lambda}(a)$ and k_{λ}^2 to study the convergence of the series and found that 'a' must be large enough for equation (23) to be valid. On the other hand, since the convergences became slower as 'a' increased, we settled for a value around 'a' 50 to satisfy the criterion $V(a) < 0.01\ k_o^2$, which required the maximum value of $n = N \sim 90$. This computation took less than half a minute on the AAEC's IBM3031 computer. From equation (2) we see that the poles of the s-matrix, denoted by q_{λ}^2, occur when

$$R(q_{\lambda}^2)\,\left(L(q_{\lambda}^2)-B\right) = 1 \tag{24}$$

The values of $U_{\lambda}(a)$, k_{λ}^2 and q_o^2 are shown in Table 1.

For the triplet s-state

$$L = -|q_o|a \quad , \quad B = 0$$

and

$$|q_o| \sum_{\lambda=0}^{10} \frac{U_{\lambda}^2(a)}{k_{\lambda}^2+|q_o|^2} = -1 \tag{25}$$

This is the most difficult case in which to obtain suitable convergence, but the convergence rate improves rapidly as λ increases and, for the 10^{th} order, N = 3 is satisfactory for both $U_{10}(a)$ and k_{10}^2. The convergence is always slowest for $\lambda = 0$. Nevertheless, it is important to determine $U_{\lambda}(a)$ and k_{λ}^2 accurately, since the value of $U_{\lambda}(a)$ comes close to $W_{\lambda}(a)$ when the cut-off radius is large, and round-off can occur when the scattering matrix is calculated, owing to cancellations between Ω and the multiplying term.

(b) The Gaussian Potential

We use

$$gV(r) = ge^{-(r/r_n)^2} \tag{26}$$

For this case

$$V_{\lambda\mu} = \frac{r_n}{2a}\sqrt{\pi}\left\{\exp\left[-(\lambda-\mu)^2\frac{\pi^2 r_n}{4a^2}\right] - \exp\left[-(\lambda+\mu+1)^2\frac{\pi^2 r_n}{4a^2}\right]\right\} \tag{27}$$

and Preston's parameters are:

$$g = -0.07727 \quad , \quad r_n = 7.003 \quad .$$

Satisfactory convergence was obtained for a $\sim$20 and N, the maximum required order, about 13; the values are listed in Table 2. The discrepancies are more likely due to the errors in the effective range approximation, which we estimate to be at least 10%. Naturally, we could obtain a perfect fit to q_o by varying our parameters, but we chose to compare the two methods.

(c) The Exponential Potential

The potential is:

$$gV(r) = ge^{-r/r_n} \tag{28}$$

with parameters

$$g = -0.2016 \quad , \quad r_n = 3.193 \quad .$$

The resulting interaction matrix is:

$$V_{\lambda\mu} = ar_n\left[\frac{1}{a^2+(\lambda-\mu)^2\pi^2 r_n^2} - \frac{1}{a^2+(\lambda+\mu+1)^2\pi^2 r_n^2}\right] \tag{29}$$

Suitable convergence was achieved with a $\sim$30 and N $\sim$40. The reaction matrix parameters are shown in Table 3.

(d) The Square Well Potential

This satisfies

TABLE 1
REDUCED WIDTHS AND POLES OF THE R-MATRIX FOR THE n-p SYSTEM WITH THE YUKAWA POTENTIAL

λ	$U_\lambda(a)$	k^2_λ	q^2_o (calc.)
0	0.0837	-2.565×10^{-3}	-2.418×10^{-3} ±10%
1	-0.3187	2.839×10^{-3}	
2	0.2294	1.655×10^{-2}	
3	-0.2137	3.870×10^{-2}	
4	0.2085	6.905×10^{-2}	
5	-0.2051	0.1075	
6	0.2042	0.1540	
7	-0.2025	0.2085	
8	0.2027	0.2710	
9	-0.2012	0.3414	
10	0.2021	0.4198	

q^2_o (experiment) = -2.37×10^{-3}

TABLE 2
REACTION MATRIX PARAMETERS FOR THE GAUSSIAN POTENTIAL IN THE n-p SYSTEM

λ	$U_\lambda(a)$	k^2_λ	q^2_o (calc.)
0	0.2263	-4.081×10^{-3}	-2.179×10^{-3} ±10%
1	-0.3631	0.03349	
2	0.3280	0.1314	
3	-0.3223	0.2789	
4	0.3199	0.4760	
5	-0.3187	0.7227	
6	0.3180	1.0187	
7	-0.3176	1.3641	
8	0.3173	1.7588	
9	-0.3171	2.2029	
10	0.3169	2.6964	

TABLE 3
REACTION MATRIX PARAMETERS FOR THE EXPONENTIAL POTENTIAL IN THE n-p SYSTEM

λ	$U_\lambda(a)$	k^2_λ	q^2_o (calc.)
0	0.1587	-3.045×10^{-3}	-2.255×10^{-3} ±10%
1	-0.3217	0.01132	
2	0.2746	0.05240	
3	-0.2659	0.1166	
4	0.2629	0.2033	
5	-0.2614	0.3123	
6	0.2607	0.4434	
7	-0.2601	0.5966	
8	0.2598	0.7719	
9	-0.2594	0.9691	
10	0.2593	1.1883	

$$gV(r) = V_o = g \quad , \quad r \le a$$

$$V(r) = 0 \qquad r > a \tag{30}$$

$$V_{\lambda\mu} = \delta_{\lambda\mu}$$

We do not tabulate $U_\lambda(a)$ and k_λ^2 for this potential, as the recurrence relations (equation 19) show that with the form (equation 30), the values are exact in the zeroth order for the reduced width and exact to first order in the energy eigenvalue, i.e.

$$\text{(i)} \quad U_\lambda(a) = W_\lambda(a)$$

$$\text{(ii)} \quad k_\lambda^2 = K_\lambda^2 + V_o \quad , \quad \text{and} \tag{31}$$

$$\text{(iii)} \quad B_{\lambda\mu}^{(0)} = B_{\lambda\mu} = \delta_{\lambda\mu} \qquad B_{\lambda\mu}^{(n)} = 0 \text{ for } n > 0.$$

Preston's values, slightly modified for g, are:

$$g = -0.3826 \quad , \quad a = 9.62$$

which gave $q_o^2 = -2.37 \times 10^{-3}$, the exact result.

It is important to note how different the higher order values are for $U_\lambda(a)$ and k_λ^2 for each potential. This illustrates that the effective range approximation does not contain enough information to determine higher energy parameters.

COMPUTATION OF INTERACTION MATRICES BY QUADRATURES

Perturbation theory allows the calculation of bound state wave function and energy eigenvalues, as well as the scattering phase shifts for most commonly used potentials. As part of this theory, it is necessary to evaluate integrals of the form:

$$\text{(i)} \quad V_{\lambda\mu}^{(\ell)o}(a) = N_\lambda N_\mu \int_o^a dr\, V(r) j_\ell\left(X_{\lambda\ell}\frac{r}{a}\right) j_\ell\left(X_{\mu\ell}\frac{r}{a}\right)$$

where

$$\text{(ii)} \quad j_\ell(z) = \sqrt{\frac{\pi z}{2}}\, J_{\ell+\frac{1}{2}}(z) \quad ,$$

$$N_\lambda = \sqrt{\frac{2}{a}}\, \frac{1}{|j_\ell(X_\lambda)|} \tag{32}$$

and $J_{\ell+\frac{1}{2}}(z)$ is the ordinary Bessel function. The $X_{\lambda\ell}$ are the infinite set of solutions to the eigenvalue equation

$$j_{\ell-1}(X_{\lambda\ell}) = 0 \tag{33}$$

and 'a' is the usual matching radius of the reaction matrix theory. V(r) is a local potential with restrictions on its behaviour near r = 0, or 'a'. We call quantity (32) the 'interaction matrix'.

For some commonly used potentials, such as the Woods-Saxon, analytic results are not available for $\underline{V}^o$, so numerical methods must be used. We have discovered that ordinary schemes, such as the trapezoidal rule, Simpson's rule and Gaussian quadrature, give satisfactory results in test cases for small λ and μ. However, for $\lambda,\mu \ge 10$, the Bessel functions in integral (32) oscillate with increasing speed and conventional schemes fail to give accurate answers unless a superfine integration increment is used. As this is costly in computer time, we have developed a quadrature scheme which makes use of the particular form of (32).

The interaction matrix (32) is basically different to that defined by Cook (1972) in that if $U_\lambda(r)$ is the reaction matrix wave function evaluated in the presence of the interaction V(r), Cook's matrix is

$$V_{\lambda\mu} = \int_o^a dr\, V(r) U_\lambda(r) W_\mu(r) \; ; \; W_\mu(z) = N_\mu j_\ell(z) \tag{34}$$

which is related to equations (32) by the transformation

$$\underline{V} = \underline{B}\, \underline{V}^o \quad , \tag{35}$$

where $\underline{B}$ is the overlap integral

$$B_{\lambda\mu} = \int_o^a dr\, U_\lambda(r) W_\mu(r) \tag{36}$$

The physical significance of equation (35) is that $\underline{V}^o$ is the 'bare' interaction matrix which, analogous to quantum field theory, is the transition energy between vacuum states $|\lambda\rangle$ and $|\mu\rangle$. The transformation (4) 'clothes' the bare interaction matrix and gives the transition energies between vacuum states $|\mu\rangle$ and interacting states $|\lambda\rangle$.

THE QUADRATURE SCHEME

It is assumed that the potential is given at a set of M points such that

$$\text{(i)} \quad V(r) \approx V_m \quad , \quad r_{m-1} \le r \le r_m$$

where (37)

$$\text{(ii)} \quad V_m = V\left(\frac{r_m + r_{m-1}}{2}\right) \quad .$$

Dropping the ℓ superfix, the integral (32) becomes

$$V_{\lambda\mu}^o = N_\lambda N_\mu \sum_m^M V_m\, a \int_{u_{m-1}}^{u_m} du\, j_\ell(X_\lambda u) j_\ell(X_\mu u) \tag{38}$$

To proceed further we need to evaluate the integrals in (38) analytically.

Consider the integral (Abramowitz and Stegun (1964):

$$\int_o^z (X_\lambda^2 - X_\mu^2) t\, J_\nu(X_\lambda t) J_\nu(X_\mu t)$$
$$= z\{X_\lambda J_{\nu+1}(X_\lambda z) J_\nu(X_\mu z) - X_\mu J_\nu(X_\lambda z) J_{\nu+1}(X_\mu z)\} \; . \tag{39}$$

Changing the notation to the functions $j_\ell(z)$ and using (8), we find that

$$V^{o}_{\lambda\mu} = N_\lambda N_\mu \frac{a}{(X^2_\lambda - X^2_\mu)} \sum_{m=1}^{M-1} (V_m - V_{m+1}) \tag{40}$$

$$\{X_\mu j_{\ell-1}(X_\mu u_m) j_\ell(X_\lambda u_m) - X_\lambda j_\ell(X_\mu u_m) j_{\ell-1}(X_\lambda u_m)\}$$

for $\lambda \neq \mu$

and, employing l'Hopital's rule, the diagonals become

$$V^{o}_{\lambda\lambda} = V_M + \frac{a}{2} N^2_\lambda \sum_{m=1}^{M-1} (V_m - V_{m+1}) u_m \{j^2_\ell(X_\lambda u_m) - j_{\ell+1}(X_\lambda u_m) j_{\ell-1}(X_\lambda u_m)\} \quad . \tag{41}$$

COMPUTATIONAL RESULTS

The above quadrature scheme was checked against the exact formulae for the Yukawa, Gaussian and exponential potentials. A 500 point scheme gave excellent agreement (to within 0.5% for $\lambda,\mu \leq 20$) for values of $a \leq 500$. The error in this scheme increases with increasing 'a', but decreased with increasing number of points. For errors less than 2%, 500 points gave satisfactory results up to a = 1000, 1000 points up to a = 2000 and 2000 points up to a = 4000. Extending the λ,μ range up to 40 increased the discrepancies to about 1.5% for $a \leq 500$.

It seems that doubling the number of points in the quadrature scheme extends the a-range by a factor of two, however, this is at the expense of computing time which is also doubled. We feel confident that the quadrature scheme with 500 points is good enough to predict $V^{o}_{\lambda\mu}$ to within 0.5% of the exact value for any potential V(r) and $a \leq 500$. Potentials with a singularity at the origin can also be handled by setting u_1 very small, but not zero, which leads to negligible error.

INTERACTION MATRICES

(a) Linear Potential

Let V(r) = gr, where g is a coupling constant. Then for s-waves

$$V^{oo}_{\lambda\mu} = \pm ga \frac{2}{(X_\lambda \pm X_\mu)^2} \qquad \text{for } \lambda \neq \mu \tag{42}$$

where the plus sign is taken for (λ,μ) even-even or odd-odd, and the minus sign for (λ,μ) even-odd and odd-even. For $\lambda = \mu$, one gets

$$V^{oo}_{\lambda\lambda} = ga \left[\frac{1}{2} + \frac{1}{2X^2_\lambda} \right] \quad , \tag{43}$$

in which $X_\lambda = K_\lambda a$. These formulae were checked with the quadrature scheme which gave a difference of less than 0.2% for a 1000 point and 0.5% for a 500 point quadrature.

(b) Harmonic Oscillator

For this case

$$V(r) = gr^2 \tag{44}$$

and

$$V^{oo}_{\lambda\mu} = \pm ga^2[(X_\lambda - X_\mu)^{-2} + (X_\lambda + X_\mu)^{-2}] \text{ for } \lambda \neq \mu \tag{45}$$

$$V^{oo}_{\lambda\lambda} = ga^2 \left[\frac{1}{3} + \frac{1}{2X^2_\lambda} \right] \quad . \tag{46}$$

This was also checked with the quadrature scheme ($\leq$0.5% for 500 point quadrature).

(c) General Power Law Potential

This example has

$$V(r) = gr^n \tag{47}$$

for which

$$V^{\ell o}_{\lambda\mu} = V(a) \int_0^1 du\, u^n\, j_\ell(X_\lambda u) j_\ell(X_\mu u) = V(a)\, G^{n\ell}_{\lambda\mu} \tag{48}$$

in which $G^{n\ell}_{\lambda\mu}$ is independent of 'a'.

Although a general form for this quantity is not reported elsewhere, it can be seen that the perturbation series generates an expression in which each term is a power of V(a) and is an ordinary power series.

(d) Inverse Power Law for Large Radius

$$V(r) = gr^{-\rho-1} \qquad 0 < \rho \leq 1 \tag{49}$$

We use the approximation

$$V^{\ell o}_{\lambda\mu} \approx \int_0^\infty dr\, V(r) N_\lambda j_\ell(K_\lambda r) N_\mu j_\ell(K_\mu r) \quad ; \tag{50}$$

the resulting integral is given by Erdélyi et al. (1953) as

$$\text{(i)} \quad V^{\ell o}_{\lambda\mu} = g \frac{C}{M}\, {}_2F_1(a';b';c';z) \tag{51}$$

in which a' is not the cutoff radius, but

(ii) $a' = \ell+1 - \frac{\rho}{2}$,

(iii) $b' = \frac{1}{2}(1-\rho)$,

(iv) $c' = \ell + \frac{3}{2}$,

(v) $z = \frac{K^2_\lambda}{K^2_\mu} = \frac{X^2_\lambda}{X^2_\mu}$ and is independent of 'a' where $\lambda \leq \mu$

${}_2F_1$ is the usual hypergeometric function,

(vi) $C = \frac{\pi}{2} N_\lambda N_\mu \sqrt{K_\lambda K_\mu}\, K_\lambda^{\ell+\frac{1}{2}}\, \Gamma(a')$

(vii) $M = 2^\rho (K_\mu)^{\ell+\frac{1}{2}-\rho} \Gamma(c')\Gamma(c'-a'-b')$.

For the s-wave case, and 'a' large, the numerical results from these equations for $\rho = 1$ agree with Coulomb scattering results, the Yukawa case with zero shielding coefficient and the quadrature scheme.

(e) Generalised Yukawa for Large Radius

$$\text{Let } V(r) = g r^{\alpha-2} e^{-\beta r} \quad , \quad \alpha \geq 0 \tag{53}$$

Erdélyi et al. reported the result

(i) $V^{\ell o}_{\lambda\mu} = g \frac{C}{M} \mathcal{J}$,

in which $K_\mu \geq K_\lambda$

(ii) $C = \frac{\pi}{2} N_\lambda N_\mu \sqrt{K_\lambda K_\mu}$,

(iii) $M = 2^{2\nu}(K_\lambda K_\mu)^{-\nu} \beta^{\alpha+2\nu} \Gamma(c')$,

$$\text{(iv)} \quad \mathcal{J} = \sum_{m=0}^{\infty} \frac{\Gamma(\alpha+2\nu+2m)}{m!\,\Gamma(\nu+m+1)} \left(\frac{-K_\mu^2}{4\beta^2} \right)^m \times \; {}_2F_1(a';b';c';z) \tag{54}$$

(v) $a' = -m$,

(vi) $b' = -(\nu+m)$,

(vii) $c' = \nu+1 = \ell + \frac{3}{2}$,

(viii) $z = \frac{K_\lambda^2}{K_\mu^2} = \frac{X_\lambda^2}{X_\mu^2}$ and is independent of a; $X_\lambda \leq X_\mu$.

The series (54) is numerically useful for only very large 'a' and converges specifically for $|K_\mu/2\beta| < 1$, i.e. $a > (X_\lambda/2\beta)$. Thus it does not converge for high order λ or μ.

(f) Generalised Gaussian for Large Radius

We write

$$V(r) = g r^{\alpha-2} e^{-\beta r^2} \quad , \tag{55}$$

and use the Erdélyi et al. result

$$\text{(i)} \quad V^{\ell o}_{\lambda\mu} = g \frac{C}{M} \mathcal{J} \quad , \tag{56}$$

(ii) $C = \frac{\pi}{2} N_\lambda N_\mu \sqrt{K_\lambda K_\mu}$,

(iii) $M = 2^{2\nu+1}(K_\lambda K_\mu)^{-\nu} \beta^{\frac{\alpha}{2}+\nu} \Gamma(c')$

$$\text{(iv)} \quad \mathcal{J} = \sum_{m=0}^{\infty} \frac{\Gamma\left(\frac{\alpha}{2} - b'\right)}{m!\,\Gamma(c'+m)} \left(\frac{-K_\mu^2}{4\beta} \right)^m \times \; {}_2F_1(a';b';c';a) \quad ,$$

(v) $z = \frac{K_\lambda^2}{K_\mu^2} = \frac{X_\lambda^2}{X_\mu^2}$, $X_\lambda \leq X_\mu$,

(vi) $a' = -m$,

(vii) $b' = -(\nu+m)$,

(viii) $c' = \nu+1 = \ell + \frac{3}{2}$.

Again, this series fails if λ or μ are large. It was checked satisfactorily with the quadrature scheme and the exact formula (26) for $\alpha = 2$.

(g) Ordinary Gaussian for Large Radii

For this case

$$V(r) = g\, e^{-\beta r^2} \tag{57}$$

and Erdélyi et al found that

$$V^{\ell o}_{\lambda\mu} = g \frac{\pi}{2} N_\lambda N_\mu \sqrt{K_\lambda K_\mu} \frac{1}{2\beta} e^{-\frac{K_\lambda^2+K_\mu^2}{4\beta}} I_{\ell+\frac{1}{2}} \left(\frac{K_\lambda K_\mu}{2\beta} \right) \tag{58}$$

This case provides a good test example for general quadrature schemes. $I_\nu(z)$ is the associated Bessel function.

THE WOODS-SAXON POTENTIAL

The contribution of Coulomb fields to the region external to the matching radius 'a' of reaction matrix theory was first derived by Wigner and Eisenbud (1947). Normally, one takes 'a' to be equal to the finite range of the strong nuclear interaction. The collision matrix $\underset{\sim}{S}_\ell$ for each partial wave is then given for elastic scattering and one channel open by

$$\text{(i)} \quad S_\ell = \Omega_\ell \left(\frac{1-R_\ell L_\ell^*}{1-R_\ell L_\ell} \right) = e^{2i\delta_\ell} \tag{59}$$

where R_ℓ is the reaction matrix,

(ii) $L_\ell = s_\ell + ip_\ell - B_\ell$,

(iii) $s_\ell = \frac{1}{2} a \frac{d}{dr} [G_\ell^2(kr)+F_\ell^2(kr)]_{r=a}$,

and

(iv) $P_\ell = ka[G_\ell^2(ka)+F_\ell^2(ka)]^{-1}$,

k is the centre of mass momentum and F_ℓ and G_ℓ are the Coulomb regular and irregular wave functions respectively. We have

(v) $\Omega_\ell = e^{-2i\phi_\ell}$, $B_\ell = -\ell$,

where

$$\phi_\ell = \tan^{-1} \left(\frac{F_\ell(ka)}{G_\ell(ka)} \right)$$

is the Coulomb hard sphere phase shift. Such a formalism can be extended to include any long-range force and poses no problem in nuclear reaction theory.

A typical optical potential was used by Moake and Debevec (1980) to fit data from elastic proton scattering on ^{6}Li, ^{12}C and ^{14}N at 144 MeV proton energy. If we try to derive a reaction matrix from their potentials, particular interest in the convergence of the series is paid to

(a) internal Coulomb fields,

(b) the Woods-Saxon potential, and

(c) the $\underset{\sim}{L}\cdot\underset{\sim}{S}$ coupling contribution.

First we discuss (a) and (b) in general and avoid the complication of having to deal with a two-component wave function.

No analytic results have been found for the bare interaction matrix V^o in the case of the Woods-Saxon potential. This has the local form

$$V(r) = \frac{-V_o}{1+e^x} \tag{60}$$

where $x = (r-r_oA)/\gamma$

r_o = a basic nuclear radius parameter,

A = the atomic mass of the target nucleus,

γ = the diffusivity of the nuclear surface,

V_o = the depth of the potential well within the nuclear volume

and we define

$$R_o = r_oA \tag{61}$$

as the nuclear radius.

The form (60) was substituted into the quadrature formula given in section 4 and the bare interaction matrix evaluated for the s-wave case. The Moake and Debevec parameters in the Heaviside units are, for ^{14}Ni,

$$\begin{aligned} &\text{(i)} \quad V_o = 0.03337 \\ &\text{(ii)} \quad \gamma = 5.5618 \\ &\text{(iii)} \quad R_o = 28.865 \end{aligned} \tag{62}$$

The resulting matrix was substituted into our perturbation series with a = 50 and the higher order terms of the wave function and energy eigenvalues in the case of the first ten resonances. Beyond order N = 2, the series began to diverge rapidly and no realistic combination of 'a' and N gave convergence. This result is surprising, and the Woods-Saxon form is very like a square well for which our series gives exact results to zero order in the reduced widths and to first order in the R-matrix poles. Tracing through the terms in our series, we found that the interaction between surface and volume contributions appeared to produce the divergence.

We then tried separating the surface contribution from the volume contribution by defining the surface potential as

$$\begin{aligned} V(r) &= -V_o\left[\frac{1}{1+e^x}\right] + V_o\,, \qquad r < R_o \\ &= \frac{-V_o}{1+e^x}\,, \qquad\qquad\quad r > R_o \end{aligned} \tag{63}$$

This form converged after twelve iterations. From the knowledge that addition of a square well contribution to any potential does not change the eigenfunctions $U_\lambda(a)$ and shifts the energy eigenvalues k_λ^2 by V_o, we can subtract V_o from the final converged values of k_λ^2 to obtain the correct eigenvalues for the Woods-Saxon case. Using the Moake-Debevec parameters (62), we obtain the resonance parameters shown in Table 4 for the first six terms.

TABLE 4
RESONANCE PARAMETERS FOR A WOODS-SAXON POTENTIAL

λ	U_λ	k_λ^2
0	0.2139	-0.0350
1	-0.1618	-0.0219
2	0.2291	-0.00975
3	-0.1782	0.0158
4	0.2104	0.0473
5	-0.1947	0.0856

With this simplified version of the Moake-Debevec potential we did not try to patch the bound levels with those of ^{16}O as the internal Coulomb field, the L·S contribution and the imaginary part of the optical potential were not included. The chief aim was to test the convergence of our series for a reasonable nuclear potential.

Such potentials as the Moake-Debevec usually alter the Coulomb potential to a charge-distribution potential at radii corresponding to the edge of the nuclear charge distribution. However, the value of 'a' corresponding to the limit of the strong interaction is often considerably larger than this; consequently, there is interest in the perturbation produced by the Coulomb component of the interior potential. This can be computed in two ways.

(a) The original technique of Born (Schiff 1949) wherein a screened potential is used

$$V(r) = \frac{2Ze^2}{r}\exp\{-\beta r\} \quad , \quad e = \text{electric charge} \tag{64}$$

to produce an interaction matrix for s-wave and large 'a' of

$$V_{\lambda\mu}^{oo} \approx \frac{2Ze^2}{a}\,\ell n\left\{\frac{a^2\beta^2+(\lambda+\mu+1)^2\pi^2}{a^2\beta^2+(\lambda-\mu)^2\pi^2}\right\} \quad . \tag{65}$$

The factor 2 comes from the coefficient 2M, where M = reduced mass. Substituting this matrix into our series and allowing the screening coefficient β to tend to zero produces the limit

$$V_{\lambda\mu}^{oo} \to \frac{2Ze^2}{a}\,\ell n\left\{\frac{\lambda+\mu+1}{|\lambda-\mu|}\right\} \quad , \tag{66}$$

resulting in a logarithmic divergence for the self-interaction terms of V_o. This is raised to the nth power in the expression for the nth order perturbation to the wave-function and energy eigenvalue. Renormalisation of the coupling constant could be introduced, as in quantum electrodynamics, for the diagonal terms alone, but this procedure gives an incorrect answer.

(b) The exact expression for the Coulomb interaction matrix for s-waves and any value of 'a' is

$$V^{oo}_{\lambda\lambda}(a) = \frac{2Ze^2}{a}\left[C_i\big((2\lambda+1)\pi\big)-\gamma-\ell n\big((2\gamma+1)\pi\big)\right]$$

$$= \frac{2Ze^2}{a} G_{\lambda\lambda} \quad ,$$

$$V^{oo}_{\lambda\mu}(a)(\lambda\neq\mu) = \frac{2Ze^2}{a}\left\{C_i\big((\lambda-\mu)\pi\big)-C_i\big((\lambda+\mu+1)\pi\big)\right.$$

$$\left.\ell n\left(\frac{\lambda+\mu+1}{|\lambda-\mu|}\right)\right\} \qquad (68)$$

$$= \frac{2Ze^2}{a} G_{\lambda\mu} \quad ,$$

where γ = Euler's constant and

$$C_i(z) = -\int_z^\infty \cos t \frac{dt}{t} \qquad (69)$$

as defined by Abramowitz and Stegun (1964). The logarithmic singularity apparent in (66) is explicitly subtracted in (68). If a Coulomb radius r_c is introduced to define the edge of the charge distribution, the interior Coulomb interaction is just

$$V^{oo}_{\lambda\mu} = 2Ze^2 G_{\lambda\mu} \qquad (70)$$

in which

$$G_{\lambda\mu} = \int_0^1 \frac{du}{u} j_o(X_\lambda u) j_o(X_\mu u) \quad ,$$

$$X_\lambda = (\lambda+\tfrac{1}{2})\pi \quad , \qquad (71)$$

and $$j_o(z) = \sqrt{\frac{\pi z}{2}}\, J_{\frac{1}{2}}(z)$$

$$= \sin z \quad .$$

A useful method for spot checking the s-wave interaction matrix elements is as follows. An approximation to the integral is taken from the general form of the s-wave interaction matrix:

$$I(K) = \int_0^a \frac{\cos Kr\, dr}{1 + e^{\frac{r-r_o}{\gamma}}} \quad . \qquad (72)$$

This may be written as

$$I(K) = \frac{\sin Kr_o}{K} - \int_0^{r_o} \cos Kr \left[\frac{e^{\frac{r-r_o}{\gamma}}}{1 + e^{\frac{r-r_o}{\gamma}}}\right] dr + \int_0^a \frac{\cos Kr}{1 + e^{\frac{r-r_o}{\gamma}}} dr$$

Substituting $v = r-r_o$ in the first integral and $u = r-r_o$ in the second integral, we get

$$I(K) = \frac{\sin K r_o}{K} - \int_0^{r_o} \frac{\cos K (r_o-v)du}{1 + e^{v/\gamma}} + \int_0^{a-r_o} \frac{\cos K (r_o+u)}{1 + e^{u/\gamma}} du$$

$$\approx \frac{\sin K r_o}{K} - \sin K r_o \int_0^\infty \frac{\sin Ku\, du}{1 + e^{u/\gamma}} \quad .$$

The integral is a tabulated standard form given in Gradshteyn and Ryzhik (1965) and leads to the final result:

$$I(K) = \frac{\pi\gamma \sin K r_o}{\sinh(K\pi\gamma)} \quad , \qquad a \gg r_o \quad . \qquad (73)$$

The s-wave interaction matrix becomes

$$V^{oo}_{\lambda\mu} = \frac{2g}{a}\left[I\Big((\lambda-\mu)\ \frac{\pi}{a}\Big) - I\Big((\lambda+\mu+1)\ \frac{\pi}{a}\Big)\right] \quad . \qquad (74)$$

CONCLUSION

The mathematical framework for computing the reaction matrix from a given potential has been presented from the point of view of perturbation theory. Although entirely numerical methods could be used to compute the relevant parameters, this is very time-consuming, even on modern computers. In such a technique, the wave equation has to be integrated many times to search for the eigenvalues, then integrated to r = a to find the $U_\lambda(a)$, followed by similar procedures for each partial wave. Our method of mostly analytical solutions is much faster.

The concept of the interaction matrices, both bare and clothed, is much clearer in the forward problem than in the inverse one. From this theory one finds the following:

(i) The interaction matrices and the overlap matrix are completely determined by the local or non-local potential. There is no manifestation of phase equivalence.

(ii) The bare interaction matrix is always symmetric. In general, the overlap matrix is not.

Ongoing investigations based on this work have allowed us to find a simple way of representing local potentials from the above matrices.

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Notes on Freshwater Zooplankton Found in Central Province, Papua New Guinea, 1981-2

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ABSTRACT. The study reported on was carried out on three water bodies in Central Province of Papua New Guinea between 1981 and 1982. They were Lake Surinumu, a hydroelectric reservoir on the Sogeri Plateau, which was ascertained to be warm polymictic and oligotrophic, Waigani Swamp in Port Moresby, and the artificial pond at Varirata National Park. The following zooplankton are discussed in terms of their local ecology and zoogeography: the Rotifers *Brachionus falcatus*, *Asplachna brightwelli*, *Trochosphaera aequitorialis*, and *Filinia opoliensis*; the Crustaceans *Diaphanosoma sarsi*, *Diaphanosoma excisum*, *Ceriodaphnia cornuta*, *Eodiaptomus lumholtzi*, *Thermocyclops crassus*, *Mesocyclops leuckarti* and the genus *Phyllognathopus*; and the Dipteran planktonic larva *Chaoborus*.

INTRODUCTION

Prior to 1980 very few species lists for the Papua New Guinea limnetic fauna had been put together. Between 1980 and 1982 I collected zooplankton samples from three water bodies in Central Province and also some physicochemical data. With the exception of one rotifer all species were identified by Professor C.H. Fernando of Waterloo University, Canada, and Dr. N.N. Smirnov of the Academy of Sciences, USSR.

The water bodies sampled were:

(i) Lake Surinumu, a hydroelectric reservoir on the Sogeri Plateau, an impoundment of the Laloki River at an altitude of 538 m.a.s.l. The lake is shallow (I recorded a maximum depth of 14 m) with a complex perimeter. Petr (1976) reported a fall in nutrient ion concentration between 1970 and 1975 and commented on the lake's very low calcium concentration, in the range of 0.075 - 0.090 m.eq.l^{-1}, having been raised to its present level in 1971.

(ii) Waigani Swamp, a shallow tropical body at sea level in Port Moresby, which has been a site of sewage effluent disposal since 1975.

(iii) The artificial pond at Varirata National Park, altitude approx. 750 m.a.s.l. It was no deeper than 2.25m at any time when I sampled it.

METHODS

A standard silk-bolt net was used for all zooplankton sampling. Lake Surinumu was sampled regularly between October 1981 and December 1982 at various points throughout the lake. Littoral samples were taken at Waigani Swamp on three occasions in 1982 in response to a request from Dr. R. Hamond of Melbourne University while a surface tow was taken in December 1982. The pond at Varirata was visited twice in 1982.

Physicochemical parameters were measured at Lake Surinumu only. Water levels and surface temperatures were recorded throughout 1982 while surface water samples were submitted to the University of Papua New Guinea in June 1982 for nutrient and photosynthetic pigment analyses.

RESULTS

(i) Lake Surinumu - Physicochemical: The lake's water level was observed to peak at 13.5m as measured at the dam wall in March following the wet season influx, while the lowest watercolumn at the same site was 6.5m in December. At the same time surface temperatures generally rose from 27^{o}C to 31.5^{o}C. Nutrient concentrations in March were found to be consistently low throughout the lake, featuring Soluble Reactive Phosphorus concentrations of 3 μg.L^{-1} while NH_4-Nitrogen readings ranged from 120 - 215 μg.L^{-1}. Nutrient levels in the May and June surface water samples were much lower (maximum NO_3-Nitrogen recorded was 25 μg.L^{-1}) although there was an increase in S.R.P. concentrations to a maximum of 8 μg.L^{-1}.

(ii) Lake Surinumu - Productivity: Only the March samples were analysed. The maximum chlorophyll-a pigment concentration measured was 7.14 μg.L^{-1} while the maximum carotenoid concentration was 7.00 m.s.p.u.

(iii) Lake Surinumu - Colonial Cyanophytes: Two genera were regularly found in samples, namely *Microcystis* and *Oscillatoria*. *Microcystis* was found to be most abundant from July to December 1982 while *Oscillatoria* was very abundant from March to July 1982.

(iv) Zooplankton Found: (at Lake Surinumu only unless specified)

Rotifers:

Brachionus falcatus, perenially present in low abundances.

Asplachna brightwelli, perenially present in low abundances, peaking in November 1981, with a relatively high abundance recorded in March 1982 in a shallow basin in which many ephippial and juvenile cladocerans were also present.

Trochosphaera aequitorialis, found at all times except June to September 1982, very abundant October to December 1982 (maximum relative abundance 0.64 in November, 1982.

Filinia opoliensis, present in very low abundances between June and December 1982. Owing to the species' similarity in appearance to *B. falcatus* and to the fact that sample analysis could not begin until October 1982, by which time earlier samples had been stored in formalin for several months, it is quite possible that specimens in those samples were not recognized.

Crustaceans:

Diaphanosoma sarsi and *Diaphanosoma excisum*, at Lake Surinumu and Waigani Swamp. The two species can be distinguished from one another only by the shape of the fold on the exoskeletal margin and this was not possible for most samples due to preservation damage. The diaphanosomids in the December 1982 Waigani Swamp sample were however described as *D. excisum* by Professor Fernando in the apparent absence of its congener, while my own observations of identifiable specimens indicated that *D. sarsi* is the more abundant in Lake Surinumu. The density of diaphanosomids at Lake Surinumu peaked at 2.6 organisms per litre in January 1982 with secondary peaks in May and July 1982 approaching $2.5L^{-1}$, with troughs of about 1 organism per litre from February to May 1982 and fewer than $0.1\ L^{-1}$ from September to December 1982. Fertility in terms of percentage ephippial females featured a single peak in March 1982 of nearly 40%.

Ceriodaphnia cornuta, at all three sites. At Lake Surinumu the species was perennially present, featuring relative abundance peaks of 0.55 - 0.6 from December 1981 to March 1982 with a secondary peak of 0.48 in October 1982, the lowest abundance recorded being 0.1 in July 1982. Ephippial females were perennially present peaking at 38% in March 1982.

Eodiaptomus lumholtzi, at Lake Surinumu and Varirata. At Lake Surinumu this species is normally dominant, a peak relative abundance of 0.82 being recorded in August 1982, though the animal fell to below 0.1 in October 1981 and November to December 1982.

Thermocyclops crassus, at Lake Surinumu and Waigani Swamp, perennially present in the former, and very abundant in the December 1982 Waigani Swamp sample.

Mesocyclops leuckarti, perennially present in low abundances.

Phyllognathopus, a single specimen of which was found in littoral samples at Waigani Swamp.

Insect Larva:

Chaoborus, present in low abundances in all samples except those taken from June to October 1982.

DISCUSSION

Lake Surinumu would appear to be of the warm polymictic type by Hutchinson and Loffler's thermal classification of lakes (1956). Neither thermal stratification nor tropholytic oxygen depletion tend to occur in such lakes (Bayly and Williams, 1973; Finlayson, Farrell and Griffiths, 1980). Both Petr's (1976) and my own nutrient analyses indicate that the Lake is oligotrophic by Finlayson and Gillies (1982) trophic classification for artificial lakes.

B. falcatus is characteristic of tropical lakes in general, and occurs in subtropical and temperate regions (Ruttner-Kolisko, 1974). Specific references to it include the Lower Murray River (Shiel, Walker and Williams, 1982), the Queensland University Pond (Timms, 1967), the Lake Kainji Reservoir and the potamoplankton of the Niger and Swashi Rivers (Clarke, 1978a), and the Eilengele Reservoir in Nigeria (Imevbore, 1967), where it is reported to display an optimal temperature range of 17 - 29^{o}C.

A. brightwelli features a very wide tropical and subtropical distribution, both limnetic and lotic (Fernando et al, 1982). References to it include the Lower Murray River (Shiel, Walker and Williams, 1982), the Queensland University Pond (Timms, 1967c), Eilengele Reservoir (Imevbore, 1967), and the Blue Nile River (el-Moghraby, 1977). A predaceous carnivore, its diet includes *B. falcatus* and juvenile cladocerans (Green and Oey, 1974), consistent with my observations of its high abundance in the basin featuring a high abundance of ephippial cladocerans in March 1982.

The global distribution of *T. aequitorialis* has been poorly mapped (Fernando, 1980). It occurs commonly in the Danube Delta (Ruttner-Kolisko, 1974) and is common in Sri Lankan lakes (Fernando, 1980).

F. opoliensis is a pantropical species (Ruttner-Kolisko, 1974). It is common in India (Koste and Shiel, 1980) and in the Blue Nile (el-Moghraby, 1977).

The distributions of the diaphanosomids are complicated by the fact that a degree of uncertainty exists about 'species' identifications in many reports prior to 1980. Krovchinsky (1981) noted that specimens from New Guinea and Celebes classified as *D. paucispinosum* by Brehms in 1939 were almost certainly *D. excisum* while reports of *D. sarsi* from Sars in 1901 were probably *D. spinulosum*, and suggested that all reports from Africa were particularly suspect. Fernando et al (1982) reported that *D. excisum* is an exclusively tropical species. The species appears to be common in Queensland and New South Wales (Krovchinsky, 1981) and it was reported as being present in Lakes Dakataua and Wisdom in Papua New Guinea's West New Britain Province (Ball and Glucksman, 1982). Krovchinsky (1981) reported *D. sarsi* as definitely occurring in North Queensland and Sumatra. Both species occur in Sri Lanka, *D. excisum* being more common in reservoirs while *D. sarsi* is more common in rivers and ponds (Rajapatska and Fernando, 1982). The genus appears to display a marked preference for calm waters in the temperature range of 27 - 28.5^{o}C in Lake Surinumu, especially in terms of its univoltine reproductive cycle.

Ceriodaphnia cornuta is a pantropical species which extends into subtropical regions (Fernando et al, 1982), being common in tropical Asia, Africa, America and Australia (Rajapatska and Fernando, 1982). It featrues a high abundance in the White Nile Gebel Aulia Dam (Clarke, 1978), Lake Kainji and the Blue Nile (el-Moghraby, 1977). It is a common limnetic species in Australia and normally peaks in spring or summer, though in Tasmania it does so in winter (Bayly and Williams, 1973), and was reported from Lake Dakataua by Ball and Glucksman (1982). It was recorded as being multivoltine in Lake Surinumu, but fertility peaks appeared to correlate inversely with density, suggesting that lowering population densities acted as a parthenogenetic stimulus.

Eodiaptomus lumholtzi is one of two species of a genus present in Australia, inhabiting the open waters of lakes, large ponds and deep pools (Willisms, 1968). Bayley (1966) reported its distribution as being from the north-east of West Australia, across mid-Northern Territory to a southerly latitude of 23°S. This distribution appears to be due to mutually exclusive competitive relationship with *Boeckella triarticulata* (Bayly, 1965). Bayly (1965) claimed a similar relationship exists between *E. lumholtzi* and *Calamoecia* species, but Bayly and Williams (1973) stated that where the two coexist, competition for food is avoided by the two species growing to different average sizes. With the exception of samples in which both *E. lumholtzi* and *C. cornuta* were at a low abundance, the Correlation Coefficient between the relative abundances of the two species as measured at the dam wall in Lake Surinumu was found to be -0.88, indicating intense interspecific competition, *C. cornuta* being relatively the more abundant until June 1982, with *E. lumholtzi* more so from June on. It is possible that temperature is responsible for this change in competitive status, higher temperatures favouring the latter.

T. crassus is a globally widespread species (Fernando et al, 1982).

M. leuckarti is a cosmopolitan species exhibiting considerable ecological diversity though it is seldom dominant (Gophen, 1978b). It is omnivorous but will not eat *Microcystis* (Clarke, 1978b). It preys on both *Ceriodaphnia* and *Diaphanosoma* species. It is common in the Blue Nile (el-Moghraby, 1977), Lake George in Uganda (Burgis, 1974), Lake Kainji and the Swashi and Niger Rivers (Clarke, 1978a), Lake Kinneret in Israel (Gophen, 1978a), and Lake Tjeukemeer in the Netherlands (Vijverberg, 1977), as well as in New South Wales lakes and reservoirs (Bayly and Williams, 1973) and in Victorian waste stabilization ponds (Mitchell and Williams, 1982).

Phyllognathopus occurs in Europe, North America, Northern Africa, the Malay Archipelago, Brazil, Patagonia and New Zealand (Barclay, 1969).

Chaoborus is a pantropical dipteran genus extending into subtropical regions (Fernando et al, 1982) which preys on diaphanosomids, copepodites, and adult cladocerans, cyclopoids and calanoids (Lewis, 1977, 1979).

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Changing Employment Patterns and Truncated Development in Australia*

HON. BARRY O. JONES, M.P., MINISTER FOR SCIENCE AND TECHNOLOGY

I welcome this opportunity to speak to the Royal Society of New South Wales. It seems particularly appropriate to be with you at a time when the Australian Reserve Bank has chosen to commemorate John Tebbutt (1834-1916), a distinguished Fellow of your Society, on the $100 note, a hopeful augury, as I told the Treasurer, of future support for astronomical ventures.

It is commonplace to say that we live in an era of unprecedented technological, social and cultural change. I am inclined to think that ours is one of the two most rapid periods of change, the other being the three decades of the 'belle epoque' before World War I. The French philosopher Charles Péguy argued that 'in the period 1880 to 1913 the world has changed more than in the time since Jesus Christ'.

This period was marked by the development of telephones, electrified cities, motor cars, gramophones, radio, cheap photography, motion pictures, mass circulation newspapers, X-rays, aircraft and aerial bombardment, not to mention post impressionism, Cubism, jazz, Stravinsky's *Rites of Spring*, quantum theory, relativity ($E = mc^2$) and Sigmund Freud.

I want to begin by talking about the changing patterns of work in Australia and then go on to discuss the Canadian concept of 'truncated development' which seems to be, I regret to say, an appropriate description of our situation.

Australia in my view has gone through a 'post industrial revolution' since the 1960s, with a paradigm shift in employment and trade away from the development model of the post-World War II era. In my book *Sleepers, Wake*, my essay 'Industry and Development' and in my Labor Economists Lecture 'Technology, Development and Employment', I have discussed these shifts at length.

In *Sleepers*, I set out in an Appendix what I impertinently called 'Jones' Seven Laws'. If I rewrote the book now, I would add an eighth, although in importance I would place it first.

'Employment levels are culturally determined'.

It is the *culture* which determines whether a 16 year old should be at school or in the labour force or whether the appropriate retirement age is 55, 60, 65 or 70. This is not to discount economic factors (which come first in most analyses) and human psychology as well.

However, I would argue that it is postcodes which determine life-styles and life-changes far more than technology. A recent survey by the N.S.W. Education Department indicated a more than 90% retention rate for high school pupils in the Bligh state electorate, including Woollahra (2025) compared to less than 15% in the electorate which includes Broken Hill (2880) - that is, of Year 1 school entrants, there was a more than 6:1 difference in the numbers who stayed on to Year 12.

Regional, class and ethnic factors are all critical in determining employment aspirations and employment levels.

In "working class" areas it is taken as absolutely axiomatic that the great majority of fifteen to nineteen year olds will be in the labour force competing for work. In "middle class" electorates there are totally different aspirations.

In addition, as Raymond Williams the doyan of English social critics has pointed out we have adopted the very odd principle (that has been built into modern English education) that those who are slowest to learn should have the shortest time to learn, while those who learn quickly will be able to extend the process of learning for as much as a further seven years.

For two hundred years ever since the Industrial Revolution began, we have taught people that life without work is meaningless and when work is withdrawn, not surprisingly, people feel diminished.

"Middle class" people with their adaptability and flexibility, enter the labour force late, often in their 20s, move in and out of careers and localities as easily as they move in and out of marriages, they break continuity with working holidays and overseas travel, and can leave work early or late as it suits them without worrying too much about whether they will have 35, 40, 45 or 50 years of it. They are generally relaxed about adapting to new technology. People employed in the new 'Information' sector are overwhelmingly "middle class". "Working class" people suffer from considerable cultural rigidity, often being anchored to a particular job type and to a specific region. Home ownership is a factor which ties them to declining regions - 'Who would buy my house if I move?', they ask. They often start work at 15, expecting a 50 year end-on stretch (long service leave notwithstanding). They dare not get off the treadmill, even temporarily, for fear of not getting back on. At 65, many self destruct when compulsory exclusion from work means the curtailment of income, some loss of life's purpose and an end to the primary social relationship, often followed by rapid physical deterioration.

Australia's capacity to adopt and pay for an appropriate range of life and work styles for its people will depend to a large extent on whether we are able to take advantage of development opportunities selectively and quickly.

'TRUNCATED DEVELOPMENT' AND THE 'X' INDUSTRY

On a recent visit to Canada (January 1984) I was struck by the almost morbid resemblance between many elements of the Canadian and Australian economies: both of us immensely resource-rich, but with the commanding heights of the economy in foreign hands, manufacturing in long-term decline, a reduced share of world markets and a sense of frustration about failure to match rates of growth in newly developing nations.

I was grateful to be able to discuss these problems in Ottawa with officers of the Science Council of Canada, the equivalent of ASTEC, and in Montreal with members of the GAMMA Institute, a

* Address delivered before the Royal Society of N.S.W. on the occasion of the Annual Dinner on 21st March, 1984 at the University of Sydney.

think-tank comprising staff from the Montreal, McGill and Concordia Universities and the Ryerson Polytechnic. (GAMMA had some parallels with Melbourne University's Institute of Applied Economic and Social Research until its recent changes).

Dr. J.M. Gilmour, Director of Research at the Science Council, delivered a valuable paper 'The Industrial Policy Debate in a Resource Hinterland' at a symposium held by the Academy of Technological Sciences in Canberra in October, 1981 on 'Manufacturing Resources of Australia' (Gilmour, 1982), and I draw heavily on it for what follows in the next section.

The Canadians apply the useful term 'truncated development' to describe a superficial, stunted form of industrialisation, characteristic - at least until very recently - of their economy and still true of ours. As Gilmour says, after World War II, 'tariffs promoted industrialisation by invitation', but this promoted products rather than indigenous firms and to a large extent foreign factors of production - capital, technology and management - substituted for local ones.

'Truncation occurs when a subsidiary does not carry out all the functions - from original research to marketing - necessary for developing, producing and selling its goods' and also describes the general tendencies of foreign firms to allocate roles to subsidiaries which serve the global interest of the parent, such as limitation to an assigned market.

There are several adverse consequences of truncation:

1. Subsidiaries are unable to initiate new products or develop new markets and are increasingly dependent on the parent. Factors which would encourage innovation, flexibility and producing new products for world markets are almost invariably absent.

2. The diminished structure of subsidiaries makes them dependent on the parent for components, subassemblies, designs, services and finished goods for resale with adverse effects on the balance of payments, significantly reducing the multiplier effect of industrial growth.

3. Foreign owned subsidiaries are constrained from exporting, first because they never intended to do so, and second because they are usually assigned products that have no international sales potential. (In Canada when foreign firms export these are predominantly intra-corporate transfers and not part of free-market trading).

4. The range of employment generated in local subsidiaries is limited to management, process work, transport and routine services: there is little if any scope for professional, scientific, assigned and overseas marketing functions.

5. There is a severely dampening effect on technological capacity and innovation. 'Most subsidiaries are technologically dependent, have little or no innovation capability, and are unable to generate products with international sales appeal.' When multinationals transfer technology it is done in such a way that it rarely results in a spin-off of technological capability to other local firms. There is no problem with technology transfer - the products of Ford, Hoechst, Union Carbide or ICI are only a telex or telephone call away - but only the branch office benefits directly.

Canada had the reputation of being the only non-banana republic with a higher degree of foreign economic penetration than Australia.

Certainly the percentage of effective foreign ownership in major industries in Australia was extraordinarily high in the last year they were recorded (1972-73) and there is little to suggest that the pattern has changed since then:

Motor Vehicles	99.8%
Plastics	94.3%
Processing aluminium	91.2%
Petroleum	90.8%
Agricultural chemicals	85.7%
Basic chemicals	78.0%
Pharmaceuticals	77.8%
Industrial chemicals	75.2%
Electronics	69.3%
Construction equipment	59.9%

In Canada, as in Australia, classical economists and free-marketeers have blamed the failure of manufacturing on short production runs and sub-optimal production scales and, as Gilmour says, 'took a theological leap in directly and wholly attributing ... competitive problems to tariff protection'. This was naive and superficial without considering the basic problem of trunction. To condemn as non-competitive industries in Australia which were explicitly programmed not to compete seems to be as unfair and absurb as insisting that non-vertebrates should show some backbone.

Australia has been consistently decreasing its dependence on tariffs but has been unfairly condemned as hard line because it has been frank about honestly declaring its tariff position. Other countries are notorious for applying non-tariff barriers. Even within the ostensibly free-trade European Common Market, the transfer of certain goods from, say, Germany to France can be maddeningly slow, uncertain and frustrating - far more costly than the imposition of a tariff. The problems of placing many of our products in Japan where severe import quotas are imposed are legendary.

In Canada, as in Australia, an alternative economic view to the free-marketeers is being put both inside and outside the Government and public service, that of the economic 'nationalists' who argued that interventionist policies were needed (before all tariff protection disappeared) to prepare for international competition. This meant combatting the combined impact of high costs, low productivity, general technological weakness, lack of innovation and lack of entrepreneurial initiative.

Gilmour identifies five major areas of concern by Canada's economic nationalists (and you will judge for yourselves their relevance here):

1. 'Excessive reliance on the development of natural resources is undesirable. The nature of international trade is changing and the areas of Canada's traditional strength are now facing increasingly sharp competition.

2. 'Resources are not sufficient to offset deficits in secondary manufactures and services', and he points to Canada's total dependence on imported capital equipment in drilling, excavating, mining, oil and gas.

3. 'The high capital intensive nature of resource extraction presents few opportunities for large scale employment growth' and Canada's unemployment rate was consistently the highest in the OECD during the 1970s and is higher than Australia's now.

4. 'Any shift in demand away from Canada's export staples or any bottleneck in supply ... would pose a crucial threat to the Canadian economy'.

5. 'The complement to a large trade surplus in staples is a large deficit in finished manufactured goods. This is the staple trap .. Canada's trade surpluses are generally found in those commodities for which the long-run income elasticity of demand is quite low. This means that as foreign incomes grow, demand for those products grows less than in proportion to income. In contrast, Canada's deficits are in manufactures and service, i.e. items for which the income elasticity of demand is fairly high'.

The Canadians have put a heavy emphasis in the last two years in focussing their efforts in a comparatively few areas, applying the 'niche' approach with success. Being part of that enormous North American economic engine can be both a threat and an opportunity. The danger of overlay by their powerful southern neighbour is always present (the analogy of making love to an elephant has often been used) and for a long time Canadians seemed to have a permanent and massive inferiority complex ('Being Canadian means always having to say you're sorry'). On the other hand the sheer size of the North American market - when opportunities open up - and physical ease of penetration make it potentially very lucrative. The Canadians have gained world markets with telecommunications equipment, specialised computer applications, the impressive 'Telidon' on-line data bank, instrumentation and process controls and some space technology.

Bell Canada, Mitel, Northern Telecom, Infomat, Glenayre, Western Research, Bytec-Conterm and many others have internationally recognised brand names- in Australia we have none. It is not that we have a bad reputation in brand name goods - we simply have no reputation at all.

We used to export Australia's Sunshine Harvester - now the brand name belongs to Canada's Massey-Ferguson.

For Australia and Canada there is a need to recognise the changing international environment, and there are penalties for slow learners.

World markets are approaching saturation for a widening range of products of which cars and TV sets are obvious examples and this has been accompanied by the rapid growth in productive capacity from newly industrialised countries - South Korea, Taiwan, Hong Kong, Mexico and Brazil. The large scale aircraft industry appears saturated with only two firms - Boeing and Airbus - still in contention.

There is another factor which deserves notice. I drew attention to it in *Sleepers, Wake!* and so does Gilmour 'The occurrence of major product innovations with the power to create large and entirely new markets and industrial branches has been slowing down over the last forty years (in part due to the .... cyclical nature of innovation) ... The tremendous expansionary benefits from the last great burst of major product innovations ... have been harvested'. As I wrote in *Sleepers*, where is the 'X' industry which some unthinking technological optimists assert will arise in manufacturing in the same way that cars, planes and electrical industries arose in the past? The inventive peak of what I have called the 'Third' Industrial Revolution' occurred between 1942 and 1970, coinciding with the era of full employment. The 1970s marked a significant decline in major discoveries, although many new technological refinements were produced. In aviation, for example, the jumbo jet dates from 1968 and the supersonic Concorde from 1969: the wide-bodied jets of the 1970s were not innovative. In micro-electronics, large-scale integrated circuits dated from 1969 and the micro-processor from 1971. Magnetic bubble memories were developed in 1966 and the 'Josephson junction' in 1968: since 1970 their capacity has increased enormously, but again few new concepts have emerged. Orbiting space laboratories and communications satellites were put into service in the 1970s based on techniques first used during the space race nearly twenty years earlier. Lasers and radio telescopes were products of the 1960s.

Clearly service employment will continue to be the overwhelmingly dominant employer for the foreseeable future.

In 1780 John Adams, later to become the second President of the United States wrote these words from Paris to his wife Abigail:

> 'I must study politics and war that my sons may have liberty to study mathematics and philosophy. My sons ought to study mathematics and philosophy, geography, natural history, naval architecture, navigation, commerce and agriculture in order to give their children a right to study painting, poetry, music, architecture, statuary, tapestry and porcelain.'

This reflects the concept of the 'hierarchy of needs' which the psychologist Abraham Maslow wrote about in his *Motivation and Personality* and which is abundantly illustrated in the changing nature of our labour force. Humanity starts with basic needs for food, water, shelter and goods on to increasing needs for gourmet cooking, Perrier water, sophisticated and specialised habitations, both stationary and mobile, together with individual demands for information, leisure and culture. We move away from staples towards CD players and Mozart piano concertos.

The option is still open to make the 1980s a creative era in which as Dennis Gabor has said, Mozartian man (or woman) can evolve.

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MEETINGS

Nine general monthly meetings and the annual meeting were held during the year. The average attendance was 23 members and guests (range 11 to 42). Summaries of the addresses were published in the Newsletter and abstracts of the proceedings are appended to this report.

The Clarke Memorial Lecture for 1983 was delivered by Associate Professor R.H. Vernon on "Restite, Xenoliths and Microgranitoid Enclaves in Granites" at Macquarie University on 21st September 1983. The text is published in the Journal and Proceedings, Volume 116, pages 77-103.

Council held 11 ordinary meetings during the year. From April to November 1983, the meetings were held in the Board Room, Science Centre, Sydney; in February and March 1984, they were held at Macquarie University. In addition there were held: one extraordinary meeting of the Council on 15th June, 1983, two extraordinary meetings jointly with the Council of the Linnean Society of New South Wales on 13th April and 27th May, 1983, six meetings of a joint committee of representatives of the two societies on 15th and 30th June, 14th and 28th July and 11th and 25th August, 1983, and one special meeting of the Royal Society Executive on 23rd August. These additional meetings were necessitated by the failure of Science House Pty. Ltd. and the consequent impending loss by both societies of their library and office accommodation upon sale of the Science Centre.

At its meeting on 1st February, 1984, Council established a Working Party to examine the Society's operations and recommend future directions which the Society could realistically pursue. One meeting of the Working Party, on 24th February, had been held by the close of the Society's year.

ANNUAL DINNER

The Annual Dinner was held in the Withdrawing Room, Sydney University Union, on the evening of Wednesday, 21st March, 1984. 59 members and guests were present. The Guest of Honour was Mr. Barry Jones, B.A., LL.B., M.P., Minister for Science and Technology in the Australian Government. Mr. Jones gave an address entitled "Changing Patterns of Employment and Truncated Development". The vote of thanks was moved by Professor T.W. Cole, Vice-President.

PUBLICATIONS

Journal and Proceedings Volume 116, Parts 1 to 4 were published during the year, incorporating 14 papers and the 1982-83 Annual Report. Council is again grateful to the voluntary referees who assessed papers offered for publication.

Every effort is made to ensure the wide availability of the Journal in Australia and overseas. In addition to the copies automatically sent to members 444 copies were distributed as follows: 241 to exchange partners, 115 to subscribers and 88 as donations (mainly to university libraries which do not have suitable exchange publications to offer). Counting these three categories together, 98 copies go to the United States, 52 to Great Britain and Ireland, 23 to Japan, 20 to Canada, 18 to U.S.S.R., 12 to New Zealand, 11 to West Germany and 7 to South Africa; copies also go to 43 other countries.

The Journal is abstracted routinely in Chemical Abstracts, Physical Abstracts, Geological Abstracts, Geoabstracts, Mathematical Reviews, and when relevant, in Biological Abstracts.

Newsletter

Nine issues 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, 1984 was:-

Honorary Members	12
Company Member	1
Life Members	33
Ordinary Members	288
Absentee Members	12
Associates	21
Total	367

AWARDS

The following awards for 1983 were made:

Walter Burfitt Prize: Dr. William Stephen Hancock
Edgeworth David Medal: Dr. Denis Wakefield
Archibald D. Olle Prize: Mr. David S. King and Dr. Nicholas R. Lomb

Citations follow this report

SUMMER SCHOOL

A most successful Summer School on "Sound" was held from 16th to 20th January, 1984, at the CSIRO National Measurement Laboratories, Lindfield. 42 students who had completed high school year 11 attended the School. The program comprised lectures and tutorials on a wide variety of topics, including the physics and mathematics of sound, sonar and sound propagation in the ocean, ultrasonics and its use in measurement and medical diagnosis, noise and noise pollution, earthquake waves, hearing, electronic music and the making of musical instruments. Visits were paid to the Ultrasonics Institute of the Department of Health at Millers Point and the Mastertouch Piano Roll Company at Petersham.

LIBRARY

With the sale of the Science Centre building appearing imminent all reader services and inter-library loans were ceased at 5.00 p.m. on 28th April, 1983. The possible fate of the library was

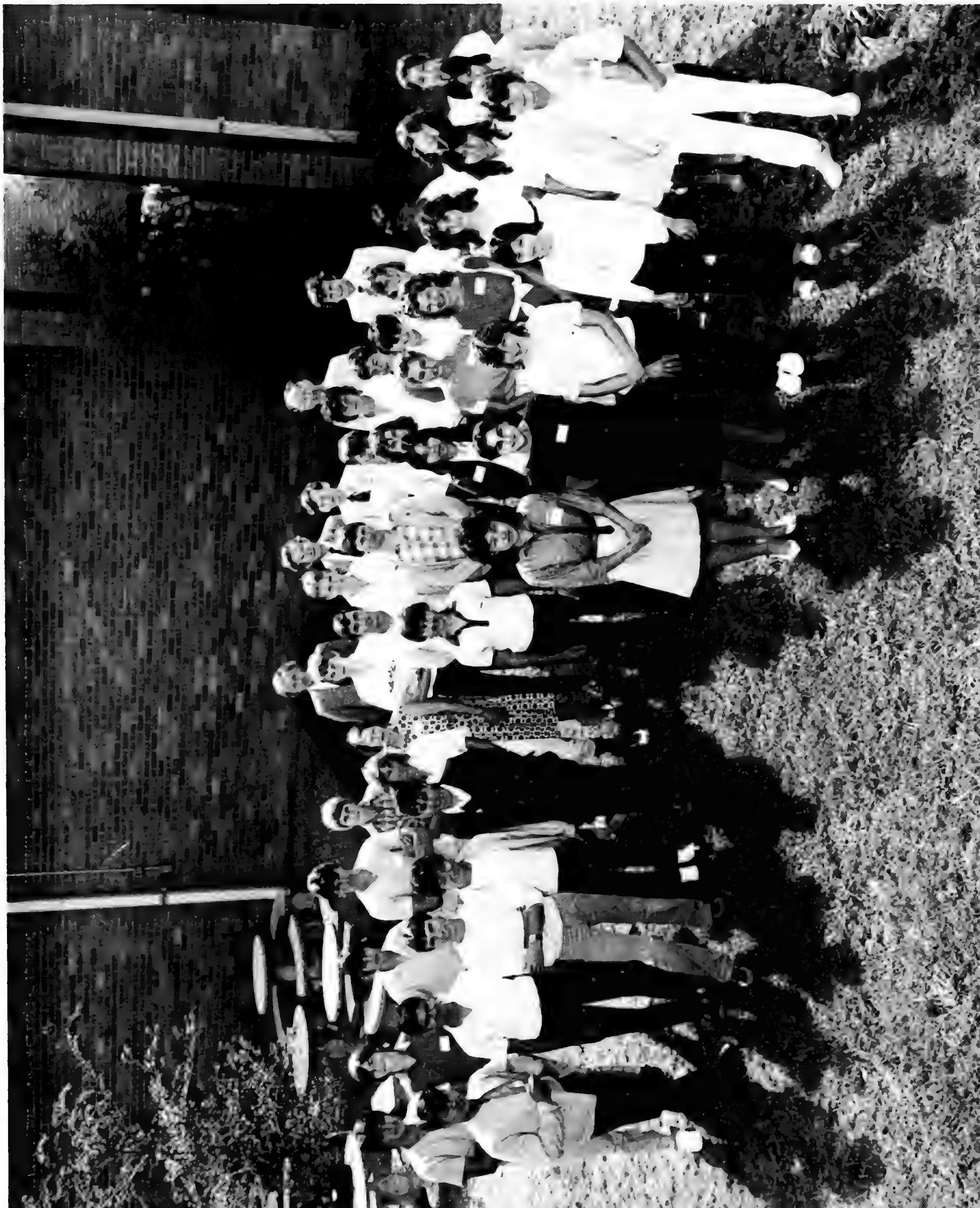


Plate 1. Tutors and students at the Summer School on "Sound" at the National Measurement Laboratories, West Lindfield on 16th January, 1984.

investigated by Council, and it soon became apparent that the Society could not afford to retain the major serials collection as a working library. It was resolved therefore that, if possible, a suitable recipient be sought who would be willing to take over the serials collection as a working unit, make it available for reference within a reasonable time, and make some permanent public acknowledgement of the donation.

In the event offers to take over the collection were received from the N.S.W. Institute of Technology and the University of New England. After lengthy deliberation Council resolved that the collection of serials be donated to the Dixson Library of the University of New England. This decision was confirmed by members at the Ordinary General Meeting of 6th July, 1983. The Society has retained its collection of historic monographs, early scientific journals and some other Australian publications.

Transfer of the collection to Armidale took place in July/August at the University's expense, and involved packing and moving over 1000 boxes. The Dixson Library has reestablished the major unique part of the collection as a separate unit under the title of "The Royal Society of New South Wales Collection" which will be displayed prominately on a brass plate. The Library is producing a catalogue of the 1,100 titles involved in the donation, and every volume will bear the Society's crest stamped in gold and include a bookplate acknowledging its source.

Involvement in the inter-library loans system has recommenced already and the former Journal exchange arrangements will continue.

Council expresses its sincere gratitude to the Honorary Assistant Librarian, Mrs. Grace Proctor, particularly for her valuable assistance with the transfer to the Dixson Library.

OFFICE

A joint committee consisting of the Executives of the Royal and Linnean Societies was established in May with a view to finding suitable joint office assommodation. This committee met several times between June to August, and bodies such as the National Trust, the State Government and various tertiary institutions were approached as well as commercial real estate companies. An offer of the use of space in the Fisher Bookstack was made to this Society by the University of Sydney. After the sale of the building in October the Linnean Society decided to reestablish its office at North Sydney.

The Council of Macquarie University resolved in November to make available to the Royal Society part of Convocation House at 134 Herring Road, North Ryde, which is on the University campus and was being used as a temporary book depositary. This offer was accepted by the Society's Council and it is anticipated that the house will become available and the Society's office be re-established there by the end of May 1984. In the interim period temporary office accommodation has been generously provided for the Society by its Honorary Treasurer and Assistant Secretary, Drs. A. and J. Day, at their home in Lindfield. Council is exceedingly grateful to the Day household for this.

The office at Macquarie University will house the Society's collection of journals and monographs, which have been in commercial storage, and should provide a meeting and reading room for members. Part-time membership of the Macquarie University Club also will be available to Society members.

SCIENCE HOUSE PTY. LTD.

Since the inception of the project the Society's four directors on the Board of Science House Pty. Ltd. have been: Mr. M.J. Puttock (Vice Chairman, and since mid-1979, Chairman), Mr. E.K. Chaffer, Mr. J.W. Humphries, and Associate Professor W.E. Smith. Following his appointment as editor of the Australian Mathematical Society's Journal Professor Smith found it impossible to continue as director and resigned with effect on 31st March, 1983. Dr. A.A. Day was appointed in his place by Council on 27th April. Board meetings were held on 6th, 23rd, 24th and 30th (two) May, and 6th and 15th June. The Board's principal concern was with the serious financial situation of the Company, income being inadequate to cover normal outgoings and the large interest bill on the loans from the Commonwealth Bank. In September 1982, with the Bank's encouragement 3 floors of the Science Centre building had been offered for sale under strata office title, but no sale had eventuated. In March 1983 the whole building was put up for sale by private treaty and on 24th May, 1983, it was offered for auction but without attracting any bids. Concurrently the Board was actively examining possible ways of retaining the secretariat (servicing scientific and other bodies) with or without the meeting room facilities. A detailed report on the room hire operation was obtained from a leading firm of chartered accountants.

Following the unsuccessful attempted sale of the building by auction the Board sought and received detailed advice from the Company's solicitors and auditor. Representatives from the Board met senior management of the Bank on 26th May and 3rd June. On 6th June the Board resolved to proceed to wind up the Company as soon as possible. On 15th June the Society's Council and the Board passed the formal resolutions necessary to achieve a Creditors' Voluntary Winding-Up in the manner specified by the Companies (New South Wales) Code, 1981. Meetings of shareholders and creditors were convened on 1st July. The meeting of shareholders (represented by their Presidents, Dr. R.S. Vagg and Dr. C.N. Smithers) passed the following special resolution:

> "That it has been proved to the satisfaction of this meeting of members of Science House Pty. Limited that the Company cannot, by reason of its liabilities, continue its business, and it is advisable to wind-up, and accordingly that the company be wound-up voluntarily and that Richard John Grellman of 167 Macquarie Street Sydney be nominated as Liquidator for the purpose of winding up."

Mr. E.K. Chaffer attended the meeting of creditors as the appointed director required by the Companies Code, and was elected chairman of that meeting. The Society, as creditor, was represented by Dr. A.A. Day. In addition to the Linnean Society, the Bank, the restaurateur, the Company's employees and the Liquidator were also present. The Society's Proof of Debt (Form 131) was handed in setting out its claim for approximately $420,000. A "Report as to Affairs" (Form 30) was distributed showing (in summary):

Assets:	$4.3 M
Amounts owing:	3.7 M
Net assets:	0.6 M
Claims by employees	0.1 M
Estimated Amount available for unsecured creditors:	0.48M
Unsecured creditors & contingent liabilities:	0.84M
Estimated deficiency, subject to costs of liquidation:	$366,861

A Committee of Inspection representing the creditors, was appointed, consisting of Mrs. R.J. Inall (employees), Dr. A. Ritchie (Linnean Society) and Dr. A.A. Day (Royal Society) to meet with the Liquidator as required. As from the closure of the meeting the Board of the Company ceased to exist, its powers being taken over by the Liquidator.

The Science Centre secretariat was deemed by the Liquidator not to possess any inherent monetary value and in August was transferred to the Science Centre Foundation Ltd. at no charge. A slight improvement in the previously depressed office real estate market having emerged, the Liquidator put the Science Centre building up for sale by auction on 12th October, 1983, and it was sold after brief bidding for $3.775M.

At 31st March, 1984 the liquidation of Science House Pty. Ltd. had not been completed.

FINANCE

The Annual Accounts, prepared as usual by Messrs. Wylie and Puttock, Chartered Accountants, show firstly a loss on the year's operations of $2505, and secondly, a writing off of the assets of the Resumption Reserve of $416,991. The principal factors producing the deficit were the rejection by the N.S.W. Government of our application for a grant (possibly connected with the same policy of reducing support for scientific research indicated by the closure of research at Sydney Observatory), an increase in printing costs due to a welcome increase in the size of the Journal and Proceedings, an unwelcome substantial increase in postal costs of the Journal, and costs associated with the enforced removal of the Society's library, office and Journal back-issues from Science Centre. A substantial increase in investment interest and increased membership subscriptions were insufficient to balance those increases in costs.

The probable writing off of the loan to Science House Pty. Ltd. was foreshadowed in last year's report and was inevitable following the failure of the sale of the Science Centre building to realise sufficient return to cover all outstanding debts to the Bank and other secured creditors. The Society ranked as an unsecured creditor for its loan, as did the Linnean Society.

We are again grateful to Mr. A.M. Puttock of Messrs. Wylie and Puttock for his helpful advice in the resolution of the many financial problems which have arisen during the year.

NEW ENGLAND BRANCH REPORT

Officers:	Chairman:	S.C. Haydon
	Secretary:	R.L. Stanton
	Committee:	T. O'Shea
		H.G. Royle
	Branch Representative on Council:	S.C. Haydon

The following meetings were held:

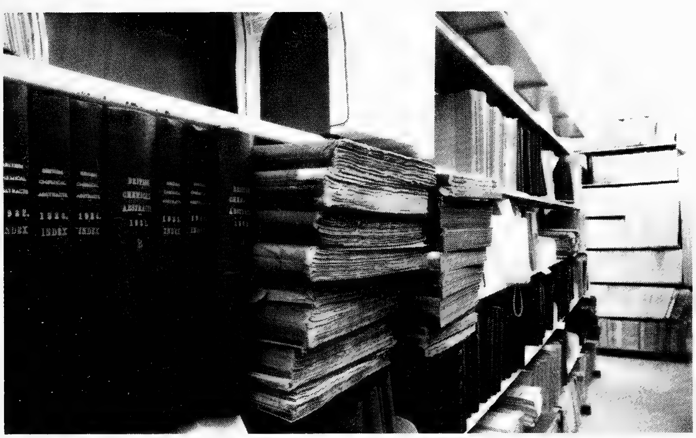
1983	
6th June	Professor E.B. Burnside, University of Guelph, Canada on "The role of genetics in food production - mice, men, computers and cows".
26th June	Professor Ian Falconer, Dr. Maria Runnegar and Dr. Arthur Beresford, University of New England, on "Blue-green algal toxins from Malpas Dam. Their nature, effects and how to remove them from drinking water".
23rd August	Professor E.F.W. Seymor, University of Warwick on "Modern magnetic methods emerge from the laboratory - astronomy, archaeology, anatomy".
14th September	Professor Theresa Brophy, University of Queensland, on "Not only the Broad Street pump".
19th October	Dr. Terry Speed, Chief of the Division of Mathematics and Statistics, CSIRO, on "The assessment of risk; a statistician's view".
14th November	Professor T.W. Cole, University of Sydney, President of the Royal Society, on "Our future in communications and computing".
1984	
29th February	Professor C.N. Watson-Munro, University of Sydney, on "Does the world need nuclear power".
27th March	Professor A.E. Ringwood, Australian National University, on "Disposal of high-level nuclear wastes - a geological perspective".
9th April	Mr. J.O. Reynolds, Manager Corporate Affairs, Western Mining Corporation, on "The Roxby Downs operation: mining methods and precautions".

FINANCIAL STATEMENT OF THE NEW ENGLAND BRANCH

Balance carried forward, 1.4.83			$177.40
Subvention from Royal Society, Sydney			150.00
Bank Interest			8.83
			$336.23
Less Expenses:-			
Meeting	11.10.82	$40.00	
"	14. 9.83	74.00	
"	14.11.83	36.15	
"	29. 2.84	154.55	
"	27. 3.84	51.55	
Federal Govt. Tax		0.40	
			$356.65
Balance carried forward, 31.3.84			$(20.42)

ACKNOWLEDGEMENTS

In conclusion, the Council wishes to express its gratitude to the many people who assisted the Society in the past year, including:- Associate Professor J.H. Loxton, Mrs. M. Krysko and Professor T.W. Cole who organised the Summer School; Professor S.C. Haydon and Professor R.L. Stanton in the New England Branch; Mr. K. Schmude and Mr. W. Callaghan for organising the transfer of the Royal Society Collection to the Dixson Library; and Mrs. Grace Proctor and Mrs. Judith Day for their assistance in the library and office.



Plates 2 and 3. Views of the "Royal Society Collection" on temporary shelving at the Dixson Library, University of New England, Armidale.

Photos: K. Schmude

THE ROYAL SOCIETY OF NEW SOUTH WALES

AUDITORS REPORT

In our opinion:

(a) the attached accounts, 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 1983 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 31/12/83

	RESERVES			
7310.57	Library Reserve (note 2(a))			7310.57
416991.00	Resumption Reserve (note 2(b))			0.00
3039.78	LIBRARY FUND (notes 1(c)(d) and 2(c))			5017.05
18366.59	TRUST FUNDS (note 4)			19875.34
78520.50	ACCUMULATED FUNDS			73322.93
524228.44	TOTAL RESERVES AND FUNDS			105525.89
	Represented by:			
	CURRENT ASSETS			
28.06	Petty Cash Imprest		336.56	
2227.62	Debtors for Subscriptions	2405.60		
2227.62	Less Provision For Doubtful Debts	2405.60		
0.00			0.00	
3291.96	Other Debtors & Prepayments		7044.59	
5013.61	Interest Bearing Deposit		9583.43	
1079.58	Cash at Bank		4508.53	
9413.21				21473.11

BALANCE SHEET as at 31/12/83

	Less: CURRENT LIABILITIES		
6708.33	Sundry Creditors & Accruals	13475.72	
19.37	Life Members Subscriptions - Current Portion	27.37	
53.00	Membership Subscriptions Paid in Advance	43.59	
1115.77	Subcriptions to Journal Paid in Advance	1042.00	
7896.47			14588.68
1516.74	NET CURRENT ASSETS		6884.43
	Add: FIXED ASSETS		
5550.66	Furniture, Office Equipment, etc.- at cost less Depreciation	1568.66	
13600.00	Library - 1936 Valuation (rate 5)	13600.00	
10.00	Pictures - at cost less Depreciation	10.00	
19160.66			15178.66
20677.40			22063.09
	Add: INVESTMENTS		
8700.00	Commonwealth Bonds & Inscribed Stock	8700.00	
60000.00	Loans on Mortgage	60000.00	
15000.00	Interest Bearing Deposits	15000.00	
83700.00			83700.00
	Add: ASSOCIATED CORPORATIONS (note 3)		
1.00	Shares - at Cost	0.00	
419994.61	Advances & Loans - Unsecured	0.00	
419995.61			0.00
524373.01			105763.09
	Less: NON-CURRENT LIABILITIES		
144.57	Life Members Subscriptions - Non-Current Portion		237.20
524228.44	NET ASSETS		105525.89

R.S. VAGG President

A.A. DAY Honorary Treasurer

STATEMENT OF ACCUMULATED FUNDS
For the Year Ended 31st December 1983

1982			1983
614.02	OPERATING DEFICIT for year		2504.57
0.00	EXTRA-ORDINARY ITEM (note 3)		416991.00
614.02	DEFICIT & EXTRA-ORDINARY ITEM		419495.57
381.65	Donations & Interest to Library Fund		382.67
5000.00	Proceeds Estate Late W.F. Poggendorf		0.00
50.00	Transfer from Library Fund		430.00
0.00	Transfer from Resumption Reserve		416991.00
75084.52	Accumulated Funds - Beginning of Year		78520.50
79902.15	AVAILABLE FOR APPROPRIATION		76828.60
381.65	Transfer to Library Fund	3505.67	
1000.00	Transfer to Liversidge Bequest Fund Capital (note 4)	0.00	
1381.65			3505.67
78520.50	ACCUMULATED FUNDS Current Year		73322.93

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1983

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, 1983. 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%

(c) Library Fund

During the 1980 year an amount was transferred from the Library Fund to Accumulated Funds as a contribution to the cost of printing & mailing those copies of the Journal & Proceedings involved in the exchange programme whereby the publications of other Societies are acquired for the Library. This proceedure was not adopted in the current year.

(d) Library Facilities

Certain donations to the Society's Library Fund have in previous years been paid to Science House Pty Limited (see also note 3) towards the cost of providing library facilities for the Society. Such payments represented donations specifically designated by the donor as being for that purpose. No such donations or payments have been received or paid in the current year.

2. MOVEMENTS IN PROVISIONS AND RESERVES

(a) Library Reserve

1982			1983
7310.57	Balance at 1st January		7310.57
7310.57			7310.57
0.00	Transfer to Accumulated Funds	0.00	
0.00			0.00
7310.57	Balance at 31st December		7310.57

(b) Resumption Reserve

1982			1983
416991.00	Balance at 1st January		416991.00
416991.00			416991.00
0.00	Transfer to Accumulated Funds	416991.00	
0.00			416991.00
416991.00	Balance at 31st December		0.00
	Represented by:		
1.00	Shares in Associated Corporation		0.00
416990.00	Loan to Associated Corporation		0.00
416991.00			0.00

(c) Library Fund

1982			1983
2708.13	Balance at 1st January		3039.78
381.65	Add Donations and bank interest		382.67
0.00	Proceeds disposal library fittings		3123.00
3089.78			6545.45
50.00	Less Library purchases	0.00	
0.00	Loss on disposal library fittings	430.00	
0.00	Costs re gift to University of New England	1098.40	
50.00			1528.40
3039.78	Balance at 31st December		5017.05
	Represented by:		
244.13	Cash at Bank		662.80
2900.00	Commonwealth bonds and inscribed stock		2900.00
(104.35)	Owing by general funds		1454.25
3039.78			5017.05

3. LOAN TO ASSOCIATED CORPORATION

In 1974 the Society entered into a joint venture with the Linnean Society for the establishment and operation of a Science Centre for New South Wales to provide facilities for professional, scientific and academic institutions.To facilitate this, a company, Science House Pty Limited, was formed in which each Society had a 50% interest.
Advances and loans to the company were made on an interest free basis repayable at call.
During 1983 Science House Pty Limited entered into a creditors voluntary winding up. The liquidator has advised the Society that there will be insufficient funds to repay the Society's loan and accordingly the amount outstanding has been written off and is shown as an "Extra-ordinary Item" in the Statement of Accumulated Funds.

419994.61	Balance at 1st January		419994.61
419994.61			419994.61
0.00	Repaid during year	3004.61	
0.00	Written off persuant to Science House Pty Ltd winding up	416990.00	
0.00			419994.61
419994.61	Balance at 31st December		0.00
	Representing		
416990.00	Resumption reserve		0.00
3004.61	Accumulated funds		0.00
419994.61			0.00

4. TRUST FUNDS

	Clarke Memorial Fund - Capital			
4800.00	Balance at 1st January	5000.00		
200.00	Capitalisation of Accumulated Revenue	0.00		
5000.00	Balance at 31st December		5000.00	
	Clarke Memorial Fund - Revenue			
651.00	Revenue Income for Period	794.00		
1344.42	Less Expenditure for Period	809.22		
(693.42)		(15.22)		
1243.01	Balance at 1st January	349.59		
549.59		334.37		
200.00	Less Capitalisation	0.00		
349.59	Balance at 31st December		334.37	
5349.59				5334.37
	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			
391.00	Revenue Income for Period	477.00		
0.00	Less Expenditure for Period	65.03		
391.00		411.97		
1233.27	Balance at 1st January	1624.27		
1624.27	Balance at 31st December		2036.24	
4624.27				5036.24
	Liversidge Bequest Fund - Capital			
2000.00	Balance at 1st January	3000.00		
1000.00	Transfer from Accumulated Funds	0.00		
3000.00	Balance at 31st December		3000.00	
	Liversidge Bequest Fund - Revenue			
391.00	Revenue Income for Period	477.00		
474.10	Less Expenditure for Period	0.00		
(83.10)		477.00		
183.64	Balance at 1st January	100.54		
100.54	Balance at 31st December		577.54	
3100.54				3577.54
	Olle Bequest Fund - Capital			
4000.00	Balance at 1st January	4000.00		
4000.00	Balance at 31st December		4000.00	
	Olle Bequest Fund - Revenue			
521.00	Revenue Income for Period	635.00		
224.25	Less Expenditure for Period	0.00		
296.75		635.00		
995.44	Balance at 1st January	1292.19		
1292.19	Balance at 31st December		1927.19	
5292.19				5927.19
18366.59	Total Trust Funds			19875.34

5. LIBRARY

During the 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, 1983 a current valuation of the library has not yet been obtained.

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31st December 1983

	INCOME			
7359.20	Membership Subscriptions - Ordinary			7920.00
19.37	Membership Subscriptions - Life Members			19.37
45.20	Application Fees			44.00
7423.77				7983.37
3061.70	Subscriptions to Journal			2943.62
1000.00	Government Subsidy			0.00
11485.47	Total Membership and Journal Income			10926.99
8872.16	Interest Received			13209.21
386.70	Sale of Reprints			0.00
6.00	Sale of Back Numbers			453.00
25.00	Sale of Other Publications			268.00
0.00	Donations - General			30.10
27.33	Annual Dinner Surplus			0.00
313.67	Summer School Surplus			150.54
186.69	Other Income			124.00
21303.02				25161.84
	Less:EXPENSES			
932.00	Accountancy Fees		1025.00	
0.00	Annual Dinner		322.87	
466.00	Audit Fees		513.00	
0.00	Bank Charges & Government Duties		17.35	
150.00	Branches of the Society		150.00	
176.00	Cleaning		176.00	
523.00	Depreciation		429.00	
460.55	Electric Light & Power		503.66	
374.15	Entertainment Expenses		493.81	
202.91	Insurance		255.73	
	Journal Publication Costs			
4664.83	Printing - Current Year Volume	6442.50		
1002.10	Wrapping & Postage	1784.97		
5666.93			8227.47	
50.00	Library Purchases		0.00	
131.00	Library Accession, Cataloguing & Reader Services		140.00	
0.00	Library and Office Relocation		2657.29	
433.66	Library Insurance		0.00	
29.85	Miscellaneous Expenses		57.67	
744.23	Monthly Meeting Expenses		706.50	
1217.37	Newsletter Printing & Distribution		1328.22	
280.98	Postage		290.39	
468.80	Printing & Stationery - General		432.10	
1348.12	Provision for Doubtful Debts		1000.48	
2781.24	Rent		2781.24	
0.00	Repairs & Maintenance		112.00	
0.00	Reprints - Loss on Sale		81.70	
5149.41	Salaries		5625.17	
330.84	Telephone		339.76	
21917.04				27666.41
614.02	DEFICIT for the year			2504.57

STATEMENT OF SOURCE AND APPLICATION OF FUNDS
For the Year Ended 31st December 1983

	SOURCE OF FUNDS		
381.65	Donations and interest to library fund		382.67
1954.00	Trust fund income		2383.00
5000.00	Proceeds Estate Late W.F. Poggendorf		0.00
0.00	Proceeds disposal library fittings		3123.00
0.00	Loan Science House Pty Limited repaid		3004.61
0.00	Life Membership Subscriptions		120.00
7335.65			9013.28
	APPLICATION OF FUNDS		
614.02	Operating deficit for the year	2504.57	
	Less:		
	Items not involving the outlay of funds in the current period:		
523.00	Depreciation of fixed assets	429.00	
1348.12	Provision for doubtful debts	1000.48	
0.00	Loss on disposal library fittings	430.00	
(1257.10)	Funds applied to operations		645.09
19.37	Reclassification of life members subscriptions in advance		27.37
5600.00	Increase in investments		0.00
2042.77	Trust fund expenses		874.25
930.61	Increase in working funds		6368.17
0.00	Costs re gift library to University New England		1098.40
7335.65			9013.28

ABSTRACT OF PROCEEDINGS 1983 - 1984

The Annual General Meeting and nine General Monthly Meetings were held in the Science Centre, 35 Clarence Street, Sydney. Abstracts of the proceedings of these meetings are given below. In addition the Clarke Memorial Lecture was delivered on 21st September, 1983 by Associate Professor R.H. Vernon at Macquarie University. The title of the Lecture was "The Trouble with Granites".

APRIL 6th

947th General Monthly Meeting. Location: the Auditorium, 1st Floor, Science Centre. The President, Professor T.W. Cole was in the Chair and 42 members and visitors were present. John Huon Brown was elected to membership. Paper read by title only: "Precise Observations of Minor Planets at Sydney Observatory during 1982" by N.R. Lomb.

116th Annual General Meeting. Followed the 947th General Monthly Meeting. The Annual Report of the Council and the Annual Statement of Accounts were adopted.

The Clarke Memorial Medal was awarded to Emeritus Professor Noel Charles William Beadle; the Edgeworth David Medal to Dr. Nhan Phan-Thien; and the Royal Society Medal to William Broderick Smith-White.

Messrs. Wylie and Puttock, Chartered Accountants, were elected Auditors for 1983.

The following Office-Bearers were elected for 1983/84:

President: Dr. R.S. Vagg
Vice-Presidents: Professor T.W. Cole, Dr. G.S. Gibbons, Mr. M.J. Puttock, Professor B.A. Warren.
Hon. Secretaries: Mr. E.K. Chaffer, Mrs. M. Krysko
Hon. Treasurer: Dr. A.A. Day
Hon. Librarian: Mr. J.L. Griffith
Members of Council: Dr. R.S. Bhathal, Mr. D.S. King, Assoc. Professor J.H. Loxton, Assoc. Professor D.H. Napper, Mr. M.A. Stubbs-Race, Dr. F.L. Sutherland, Dr. W.J. Vagg, Professor S.C. Haydon (New England Representative)

The Presidential Address "The Technological Revolution in Communication and Computing" was delivered by Professor T.W. Cole.

The incoming President, Dr. R.S. Vagg was installed and introduced to members.

MAY 4th

948th General Monthly Meeting. Location: the Auditorium, 1st Floor, Science Centre. The President, Dr. R.S. Vagg, was in the Chair and 22 members and visitors were present. Professor John Manning Ward was elected to membership.

An address entitled "The Museum of Applied Arts and Sciences" was delivered by the Director, Dr. L.G. Sharp.

JUNE 1st

949th General Monthly Meeting. Location: Room G, 1st Floor, Science Centre. The President, Dr. R.S. Vagg, was in the Chair, and 27 members and visitors were present. Richard Hoskin Read, Roy Malcolm MacLeod, and Dennis John Frost were elected to membership.

Papers read by title only: "The volatile leaf oils of *Melaleuca armillaris, M. dissitiflora* and *M. trichostachya*" by J.M. Brophy and E.V. Lassak; "Silcretes in the Cobar Area, NSW" by R.A. Glen and J.T. Hutton; "Basement/cover relations and a Silurian I-type intrusive from the Cobar-Lucknow area, NSW" by R.A. Glan, G.L. Lewington and S.E. Shaw; and "Lake Dieri and its Pleistocene environment of sedimentation" by J.A. Dulhunty.

An address entitled "Natural Food Flavours" was delivered by Dr. F. Whitfield, of the CSIRO, Division of Food Research, North Ryde.

JULY 6th

950th General Monthly Meeting. Location: Room E, 2nd Floor, Science Centre. The President, Dr. R.S. Vagg, was in the Chair and 22 members and visitors were present. Richard Arthur Glen, Kylie Maitland Mattocks and Richard Hewitt Christopher Carrington were elected to membership. Paper read by title only: "Astrometric Determination of Mass Segregation and Membership Probabilities in Galactic Clusters" by D.S. King.

Following a resolution of Council made on 15th June, 1983, the Meeting decided that the Royal Society Collection of scientific serials be donated to the Dixson Library, University of England.

An address entitled "Lasers and their applications" was delivered by Dr. K. Crane of the CSIRO, Division of Applied Physics, Lindfield.

AUGUST 3rd

951st General Monthly Meeting. Location: Room J, 2nd Floor, Science Centre. The President, Dr. R.S. Vagg was in the Chair and 11 members and visitors were present.

An address entitled "Cacti in Australia" was given by Mr. W. Harland of "Booalbyn" Orchard, Wedderburn.

SEPTEMBER 7th

952nd General Monthly Meeting. Location: Room J, 2nd Floor, Science Centre. The President, Dr. R.S. Vagg was in the Chair and 20 members and visitors were present.

An address entitled "Offshore Petroleum Exploration - Sydney Basin" was delivered by Dr. T.G. Russell of the Sydney Oil Company Limited.

OCTOBER 5th

953rd General Monthly Meeting. Location: Room H, 2nd Floor, Science Centre. The President, Dr. R.S. Vagg was in the Chair and 20 members and visitors were present. Peter John Derrick and Joseph John Brophy were elected to membership.

NOVEMBER 2nd

954th General Monthly Meeting. Location: Room H, 2nd Floor, Science Centre. The President, Dr. R.S. Vagg was in the Chair and 18 members and visitors were present.

Vincent Chi-Kin Lau and David St. Clair Black were elected to membership.

Papers read by title only: "Stratigraphy and Sedimentation of the Late Permian Illawarra Coal Measures in the Western Coalfield, Sydney Basin, NSW" by C.S. Bembrick; "The Technological Revolution in Communication and Computing" Presidential Address by T.W. Cole; "Lambdarina (Rhynchonellacea) from the Upper Visean of Queensland" by R. Nazer; "The Teaching Hospital: Past Present and Future" by J.B. Hickie; "Sydney Southern Star Catalogue" by D.S. King and N.R. Lomb; and "Dextral Movement on the Demon Fault, Northeastern New South Wales: a Reassessment" by J. McPhie and C.L. Fergusson.

An address entitled "Trace Elements and Coal Combustion" was given by Dr. D.J. Swaine, Leader, Geoscience Section, CSIRO, Division of Fossil Fuels, North Ryde.

DECEMBER 7th

955th General Monthly Meeting. Location: Room H, 2nd Floor, Science Centre. The President, Dr. R.S. Vagg was in the Chair and 25 members and visitors were present.

It was announced that the office on the 6th Floor of the Science Centre had closed at the end of November, and a new office would open at Macquarie University early in 1984.

An address entitled "Minerals, Gems and Volcanoes" was delivered by Dr. F.L. Sutherland, Curator of Rocks and Minerals, Australian Museum, Sydney.

CITATIONS

THE JAMES COOK MEDAL

"In Australia, only three species of arachnids are a serious threat to the life and health of man. These are the red-back spider, the Sydney funnel-web spider and the common bush tick". S. Sutherland, 1976.

Dr. Struan Keith Sutherland has devoted his considerable talents to the investigation of the venoms and toxins present in the Australian environment particularly those provided by spiders. The aim of these investigations is to provide the people of this country with effective treatment should they be bitten by venomous spiders.

From a firm base of the analysis of the effects of spider bite he proceeded in his research with characterizing specific venoms both biochemically and biologically.

Venoms are a peculiarly potent group of agents from a biologist's viewpoint and often provide startling and sometimes lethal effects. Investigations of the activity of venoms have been fruitful in determining the various components of the coagulation cascade and they can act as a tool to nibble away at obdurate problems involving understanding of biochemical functions.

Dr. Sutherland is the Foundation Head of the Immunology Research Department of the Commonwealth Serum Laboratories, Melbourne and has contibuted substantially to our understanding of the mode of action of venoms peculiar to Australia and to the rational formulation of the most effective measures of treatment of the affected persons.

Dr. Sutherland was born in 1936 and educated at Bendigo High School and Melbourne University.

He served in the Australian Navy as a Surgeon Lieutenant from 1962 to 1965 on the HMAS Voyager and Melbourne. Appointment to the staff of the Royal Melbourne Hospital followed and he has held an appointment as Clinical Assistant since 1966.

He won the AMA Prize for Medical Research in 1977 and has been a visiting lecturer at the Universities of Sydney and Melbourne and at Monash University.

He has written extensively in his area of expertise and his more significant publications include *Dangerous Animals and Plants of Australia* (1979), *Venomous Creatures of Australia* (1981) and *Australian Animal Toxins* (1983).

As previously deserted areas of Australia are settled there is the likelihood that diseases and toxins as yet not clearly defined will come to the fore and be recognised. It is essential that we have active Departments such as those headed by Dr. Sutherland to cope with identification and formulation of treatment of previously obscure envenomation.

The James Cook Medal of the Society originates from gifts by Mr. Henry Ferdinand Halloran over the period 1943-44. It is awarded for outstanding contributions to Science and Human Welfare in and for the Southern Herispehre. Dr. Sutherland is a worthy recipient of the James Cook Medal for his work on the venoms peculiar to Australia.

THE WALTER BURFITT PRIZE AND MEDAL

The Walter Burfitt Prize and Medal was founded by Dr. and Mrs. W.F. Burfitt for scientific work done in Australia or New Zealand and was first awarded in 1929.

The recipient of the 1983 award is Dr. William Stephen Hancock. Dr. Hancock is a Reader in the Department of Chemistry, Biochemistry and Biophysics at Massey University, Palmerston North, New Zealand. He heads an active research group concerned with lipoprotein chemistry and the chemical synthesis of peptides and proteins. Over the six year period 1977 to 1982 his research group has published fifty papers associated with these topics and is highly regarded by both the reviewers for the National Heart Foundation of New Zealand and the Medial Research Council of New Zealand.

He has put forward a new concept in the study of the structure-function relationships of proteins which he has called "active site engineering" and his group is the holder of a patent involving an "activated matrix" system. The metabolism of lipoproteins is of great importance in the understanding of coronary atherosclerosis and Dr. Hancock has performed basic work in this field.

THE EDGEWORTH DAVID MEDAL

Dr. Denis Wakefield graduated M.B., B.S. with 1st Class Honours in the University of New South Wales in 1976. Graduation prizes included the Australian College of Ophthalmologists Prize, the Graduation Prize for Surgery and the University Medal for Medicine. He is a member of the Australian Society of Immunology, the Australian Society for Medical Research and is a Fellow of both the Royal Australasian College of Physicians and the Royal Australasian College of Pathology.

During the last four years Dr. Wakefield's research has mainly involved the immunology of the eye and in particular the relationship between certain genetic factors and the role of bacterial infections in causing ocular inflammation. He was the first person to outline the aetiology of uveitis in an Australian population and first to describe the relationship between the blood group HLA B27 and the most common form of uveitis. His was the first description of the HLA antigens and other immunogenetic markers of uveitis and retinal vasculitis in an Australian population. As a result of Dr. Wakefield's work it is now realised that some 50% of patients with anterior uveitis have the HLA B27 blood group antigen.

Dr. Wakefield has made some outstanding scientific discoveries in relation to the immunological mechanisms responsible for controlling the body's immune response to the *Chlamydia trachomatis* micro-organism which is responsible for the epidemic of trachoma in the Aboriginal population of this country. His results have opened up a whole new field of research into the pathogenic mechanisms involved in controlling infections by this organism.

In addition to these achievements in the field of basic medical research Dr. Wakefield also has found time to pursue his interest in medical education and is coauthor of two books on basic aspects of internal medicine. He is at present a Senior Lecturer in Immunopathology in the Department of Pathology in the University of New South Wales.

The Edgeworth David Medal is awarded by the Society for distinguished contributions by young scientists, usually under the age of 35, working in Australia and contributing to the advancement of Australian science. Botn in 1950, Dr. Wakefield has demonstrated already in his career that he has the potential to become one of Australia's great medical researchers, and indeed that he is a worthy recipient of this Award.

ARCHIBALD D. OLLÉ PRIZE

The Archibald D. Ollé Prize is awarded jointly to Mr. David S. King and Dr. Nicholas R. Lomb for their paper entitled "Sydney Southern Star Catalogue".

Mr. King and Dr. Lomb have been astronomers at Sydney Observatory since 1976 and 1979 respectively. From 1964 the Observatory was engaged in a programme of photographing a large section of the southern sky to form an astrometric star catalogue. By 1982 the area from -36° declination to the South Pole had been photographed but only a portion of the plates had been measured.

The decision of the New South Wales Government in 1982 to cease astronomical research at Sydney Observatory made it necessary to terminate the measurement and reduction of the plates by June 1983. The resulting catalogue of positions and proper motions of stars was made possible by the energy and initiative of the two authors, using the New South Wales Public Service computer. The catalogue is available in magnetic tape and microfiche form. It covers the area from -51° to -65° declination and is a very valuable contribution to positional astronomy in the southern sky.

OBITUARIES

ROBERT JOHN WALSH

Emeritus Professor Robert John Walsh the Second Dean of the Faculty of Medicine, University of New South Wales died on 20th July, 1983, at the age of sixty six.

Professor Walsh was born in Brisbane in 1917 and educated at the University of Sydney, graduating M.B., B.S. in 1939. As a young resident medical officer at Sydney Hospital Dr. Walsh was invited to fill the position of Medical Officer-in-Charge in order to supervise the bleeding of donors and preparation of serum for the new Red Cross Society Service while the Hospital granted him three months leave. This temporary situation led to Dr. Walsh being appointed Director of the New South Wales Red Cross Blood Transfusion Service, a post he filled with distinction for a quarter of a century. Under his leadership this fledgling Service grew from small beginnings in 1941 to a service not only collecting thousands of blood donations but also offering widening scope of service in serology, biochemistry and haematology techniques and in the range of blood products supplied. He introduced new modalities of treatment, was the co-author of a book on the subject of blood transfusion and had over a hundred research publications to his credit.

Dr. Walsh enlisted for active service during the last World War, was commissioned in the Army and subsequently posted as the officer commanding the newly created Australian Blood and Serum Preparation Unit of the Army in Sydney. It was here that he served during the remaining war years as Major Walsh. After the War he was invited to become the first Director of the New South Wales Red Cross Blood Transfusion Service.

His formal association with the University of New South Wales commenced in 1962 when he was appointed visiting professor of human genetics which became a full-time appointment in 1967. He was Chairman of the Professorial Board of the University in 1970-1973 and member of its Council 1969-1973. He was appointed Dean of the Faculty of Medicine in 1973, the Second Dean from the foundation of the Faculty of Medicine, a post which he held until his retirement last year on 3rd January, 1982.

He was a Fellow of the Royal Australian College of Physicians (1955), the Royal College of Pathologists of Australasia (1956) and the Australian Academy of Science (1958).

He was active in a large number of organizations and held significant executive positions in committees and societies concerned with haematology and the environment. He was a member of the Council of the Australian Academy of Science 1963-65 and 1966-70, and of Macquarie University since 1976. His advice was sought on many issues by both private institutions and government and he gave time and effort unstintingly to each sector of the community. He served on the advisory committee of the Kanematsu Institute of Sydney Hospital and was a loyal supporter of this Hospital. He contributed to the framework of the Institute of Human Biology, Papua New Guinea as Chairman of the Council.

He married Dr. Helen Tooth on 5th June, 1944 and had three sons and one daughter.

He was appointed an Officer of the Order of Australia in 1976 and raised to the rank of Companion in 1982. For his contribution to the practice and theory of blood transfusion and his work for the improvement of the environment Professor Walsh was awarded the James Cook Medal of the Royal Society of New South Wales in 1980.

B.A. Warren

RAYMOND AUGUSTINE BURG

Raymond Augustine Burg, a member of the Royal Society of New South Wales since 1960, died suddenly on 6th October, 1983, at the age of 59.

Mr. Burg was born at Maitland on 24th January, 1924, was educated at Marist Brothers' High School, Maitland, and was awarded ASTC (Chemistry) from Sydney Technical College in 1947. His first position was as Laboratory Assistant at Elliotts and Australian Drug Company Pty. Ltd., 1942-48. He was appointed Analyst at the Chemical Laboratory, N.S.W. Department of Mines in 1948, and Senior Analyst in 1960. He was in charge of the Ceramic Section of the Chemical Laboratory from 1952 until his appointment as Chief Analyst in 1974, a position he held until his retirement in 1982.

Mr. Burg was an authority in the field of clay and ceramics, his work receiving wide recognition in universities and industry.

Mr. Burg was heavily involved in community activities having an active involvement in school committees, local clubs and Randwich Roman Catholic Church. He is especially remembered for his caring nature and consideration of others.

He is survived by his wife and four children.

John McGlynn

MARCEL AUROUSSEAU

One of Australia's most honoured geographers, Marcel Aurousseau, MC, CdeG, BSc (Hons, Syd), Hon DLitt (Newcastle), died in Sydney on 22nd August, 1983, at the age of ninety-two. Born in Sydney on 19th April, 1891, he graduated in geology from Professor Edgeworth David's department and went to the University of Western Australia as assistant lecturer in geology. After a few months in Perth he enlisted in the A.I.F. and served in Egypt and France. He returned to Perth in 1919 as lecturer in charge of geology but shortly moved to the Carnegie Institution of Washington to engage in petrological research. An interest in geography having steadily grown and displaced that in geology, he began to publish on geographical matters and took a post with the American Geographical Society. In the mid-1920s he travelled considerably, with very limited funds. He walked from Paris to Madrid and wrote a book, 'Highway into Spain', both descriptive and interpretive, from his observations. Later he joined the staff of the Royal Geographical Society in London and then became secretary to the British Permanent Committee on Geographical Names. For more than two decades he investigated the best methods of rendering geographical names until he 'retired' in 1956.

Aurousseau then returned to Australia and a new generation of Australians came to know and appreciate his qualities of mind and personality and draw upon his experience. He contributed substantially to the advancement of Australian academic geography and was from 1964 to 1968 a member of the National Committee for Geography, of the Australian Academy of Science. With unflagging energy he collated, translated and edited the letters of the explorer Ludwig Leichhardt, partly to correct what he considered to have been a misinterpretation by others of Leichhardt's character. The resulting three volumes were published by the Hakluyt Society in 1968.

Mr. Aurousseau was elected a member of this Society on 1st October, 1919, and was thus in his sixty-fourth year of continuous membership when he passed away - a record surpassed by few. He contributed two papers to the Journal, both on ocean temperatures.

He was highly regarded in Australia and overseas and much further information about his life and publications may be read in R. Freestone's "Marcel Aurousseau and the True Tint of Geography" (Australian Geographer, 15(1):1-7, 1981), obituaries in the Geographical Journal, 150(1):149-150 and the Australian Geographer 16(1):1-3, and a full bibliography in the Australian Historical Geography Bulletin.

A.A. Day

NOTICE TO AUTHORS

A "Style Guide to Authors" is available from the Honorary Secretary, Royal Society of New South Wales, PO Box N112, Grosvenor Street, NSW 2000, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarized below.

GENERAL

Manuscripts should be addressed to the Honorary Secretary (address given above).

Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinised by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere, nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgements must be made.

PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Typescripts should be submitted on bond A4 paper. A second copy of both text and illustrations is required for office use. Manuscripts, including the abstract, captions for illustrations and tables, acknowledgments and references should be typed in double spacing on one side of the paper only.

Manuscripts should be arranged in the following order: title; name(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgments; 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'Unites (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 format paper of 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.

Illustrations. When submitting a paper for review all illustrations should be in the form and size intended for insertion in the master manuscript. If this is not readily possible then an indication of the required reduction (such as reduce to ½ size) must be clearly stated.

Note: There is a reduction of 30% from the master manuscript to the printed page in the journal.

Maps, diagrams and graphs should generally not be larger than a single page. However, larger figures can be printed across two opposite pages.

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.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper.

Diagrams, graphs, maps and photographs must be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

References are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow the preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by date.

Abbreviations of titles of periodicals shall be in accordance with the International Standard Organization IS04 "International Code for the Abbreviation of Titles of Periodicals" and International Standard Organization IS0833 "International List of Periodical Title Word Abbreviations" and as amended.

MASTER MANUSCRIPT FOR PRINTING

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