PROCEEDINGS

OF THE

ROYAL SOCIETY OF VICTORIA

VOLUME 93

ROYAL SOCIETY'S HALL
9 VICTORIA STREET, MELBOURNE 3000

CONTENTS OF VOLUME 93 NUMBER 1

CONTENTS OF VOLUME 93 NUMBER 2

INSTRUCTIONS TO AUTHORS

Detailed lists of Instructions are available from the Executive Officer. The following is an abbreviated version only.

Papers considered for publication may be Reviews, Reports of experimental or descriptive research, or Short Communications. Length of Papers may vary; Short Communications should not be longer than 1,500 words.

Two copies of the manuscript, with any accompanying Plates and Figures, should be submitted initially to the Executive Officer at the Society's Hall, 9 Victoria Street, Melbourne, 3000.

Manuscripts must be typed on quarto or A4 paper, double-spaced on one side of paper only, and with ample margins. Captions to Text Figures and Explanations of Plates must be attached to the Ms as final pages. Underlining should be restricted to generic and specific names of biological taxa. Measurements must be expressed in the metric system (SI units).

References should be listed alphabetically at the end of the paper. Abbreviations of titles of periodicals must conform with those in *A World List of Scientific Periodicals* (1963-4, 4th ed., London, Butterworth). References to books should give the year of publication, number of edition, city of publication, name of publisher. Titles of books and (abbreviated) names of periodicals should be underlined, in the typed list of references.

Maximum size for **Plates** is 15·5 cm x 21 cm. Do not mount photographs. These must have clear definition, may be submitted as either glossy or flat prints, at actual size. The Plate number should be clearly labelled on the back of the photograph.

Line drawing for **Text Figures** should be made in black ink on white card or drawing linen. Maximum size (full page) is 15·5 cm x 21·0 cm: single column width 7·5 cm. Figures are preferably submitted **at actual size**: they may well be drawn larger and photographed by the author to be submitted as glossy prints of required size. Graphic scales must be included with the drawings, and on maps and geographical plan views, compass directions should be indicated. Lettering on Figures must be inserted by the author, and special care is needed to ensure that all letters and numerals are still readable when the Figure is reduced.

Oversized illustrations, tables or maps are accepted for publication as **Foldouts** only with the understanding that the author meet any additional costs involved in their production. Maximum size for **Foldouts** is 21 cm x 31·5 cm.

Short **Tables** will be typeset within the text. Extensive Tables which are likely to cover one page of print should be typed, on an electric typewriter to ensure clarity and evenness, within the dimensions 27·9 cm x 22·5 cm. They should then be photographed to reduce them to full page size, 15·5 cm x 21 cm, and submitted as glossy prints. They will be reproduced photographically, not type-set, and hence must be finally correct when submitted, since they cannot be corrected at the proof stage.

The Society supplies authors with 25 **Reprints** free of charge; joint authors receive a total of 30. Additional reprints may be ordered by returning the order blank which accompanies the galley proofs.

The author of a paper or the Institution from which a paper is received may be requested to contribute towards the cost of publication 15% of the cost of printing that paper.

COASTAL TREE FERN COMMUNITIES AT WESTERN PORT, VICTORIA

By Fiona Ferwerda, R. J. Williams, and D. H. Ashton

School of Botany, University of Melbourne, Parkville, Australia 3052

Abstract: An occurrence of the rough tree fern, *Cyathea australis*, on coastal bluffs near Point Leo, Western Port, is described. The presence of this species, normally found as an understorey component in cool, humid forests in Victoria, is unusual. It is concluded that the establishment and survival of *Cyathea australis* in a coastal environment is dependent upon the existence of suitable micro-habitats, offering sufficient soil moisture and protection from salt laden S and SE winds. Such micro-habitats are created by small-scale rotational slumping, which occurs frequently in the study area. The slumping is in turn related to a probable rise in water table levels, exacerbated by extensive clearing of native forest in the immediate hinterland.

Tree ferns are characteristic of cool humid gullies in Victoria, so it is surprising to find them on coastal bluffs within 50 m of the high tide mark. The rough tree fern, *Cyathea australis*, occurs on basalt bluffs at Shoreham, Coles' Beach, Merricks and Somers (Figs 1 & 2) on Western Port. An isolated occurrence is found at the base of cliffs composed of lateritized Tertiary clays at Freeman's Point on the NE coast of French Island. In all coastal sites it is confined to wet or unstable soils.

The tree fern sites at Somers and Shoreham are at present being overwhelmed by blackberry thickets 2 to 3 m deep. At the main Coles' Beach study site, blackberries had increased upslope alarmingly between 1974 and 1977, from well entrenched colonies at the bluff-dune junction. The need to describe this unusual plant community was therefore urgent and such a project was initiated in June 1977 by a group of second year ecology students—Fiona Ferwerda, Jane Mallen, Wayne Antrobus and Jan Brown.

DISTRIBUTION OF *Cyathea australis*

This tree fern ranges from Queensland to the NW tip of Tasmania. In Victoria its distribution is generally restricted to areas receiving an annual rainfall of over 750 mm. It is therefore most commonly found in hilly highland regions up to altitudes of approximately 900 m (Fig. 3). Where annual rainfall exceeds 1000 mm, it is found as an understorey component in forests on valley sides or even on ridge tops. In areas of lower rainfall, however, it is confined to sheltered, moist habitats. An interesting example of this in the Creswick area is its occurrence along the moist sides of shallow mine shafts abandoned since the late 1800's (R. Hately pers. comm. 1980).

The occurrence of *C. australis* along the coastal slopes of Western Port lies close to its general annual rainfall limit in Victoria, and as a consequence it is found only on the cooler east to south aspects and where there is moderate protection from salty onshore winds (Fig. 4a, b). It is absent from the taller bluffs on the Bass Strait coast at Flinders, where there are similar aspects, rainfall and microtopography, but where there are probably rougher seas and stronger and more salt-laden S and SE winds. The tree fern communities at Shoreham and Somers are protected by the canopies of *Eucalyptus* and *Banksia* forests and woodlands, or by thickets of coast tea-tree (*Leptospermum laevigatum*) nearer the shore.

At Western Port, *Dicksonia antarctica* is rare, and single specimens only have been found in two localities at Coles' Beach. One occurs in the incised course of Short Creek and the other, although salt burnt, grew in a seepage area of *Melaleuca ericifolia*, 10 m from the beach sand. In 1976 it was cut down and removed, presumably by a gardener.

ENVIRONMENT OF THE WESTERN PORT SITES

Climate

The climate of the Western Port coastal region is typically temperate and maritime. The well distributed annual rainfall ranges from 750-900 mm and is relatively reliable (Fig. 5a, b). Frosts are neither common nor severe. Very wet years (1 standard deviation above the mean) have occurred this century nine times.

Geology and Soils

Accounts of the geology of the Mornington Peninsula and Western Port region by numerous authors were summarized by Spencer-Jones *et al.* (1975). The Shoreham, Coles' Beach, Point Leo area is dominated by the Thorpdale Volcanics of Eocene age which are locally overlain by veneers of Tertiary sands, sandy clays and silts. Shore platforms may be variably covered by calcareous dune and beach sand.

Grey to yellow podzolic soils are formed on Tertiary sediments, whereas brown podzolic and brown earth soils have developed from basalts. The degree of leaching and texture differentiation in the profile is dependent on topography and proximity to the sea.

METHODS

At Coles' Beach, three transects were located at right angles to the shore line, on a 300 m sector of the coast. Transect I was established on a steep, exposed cliff; Transect II on the unstable bluff supporting *Cyathea*

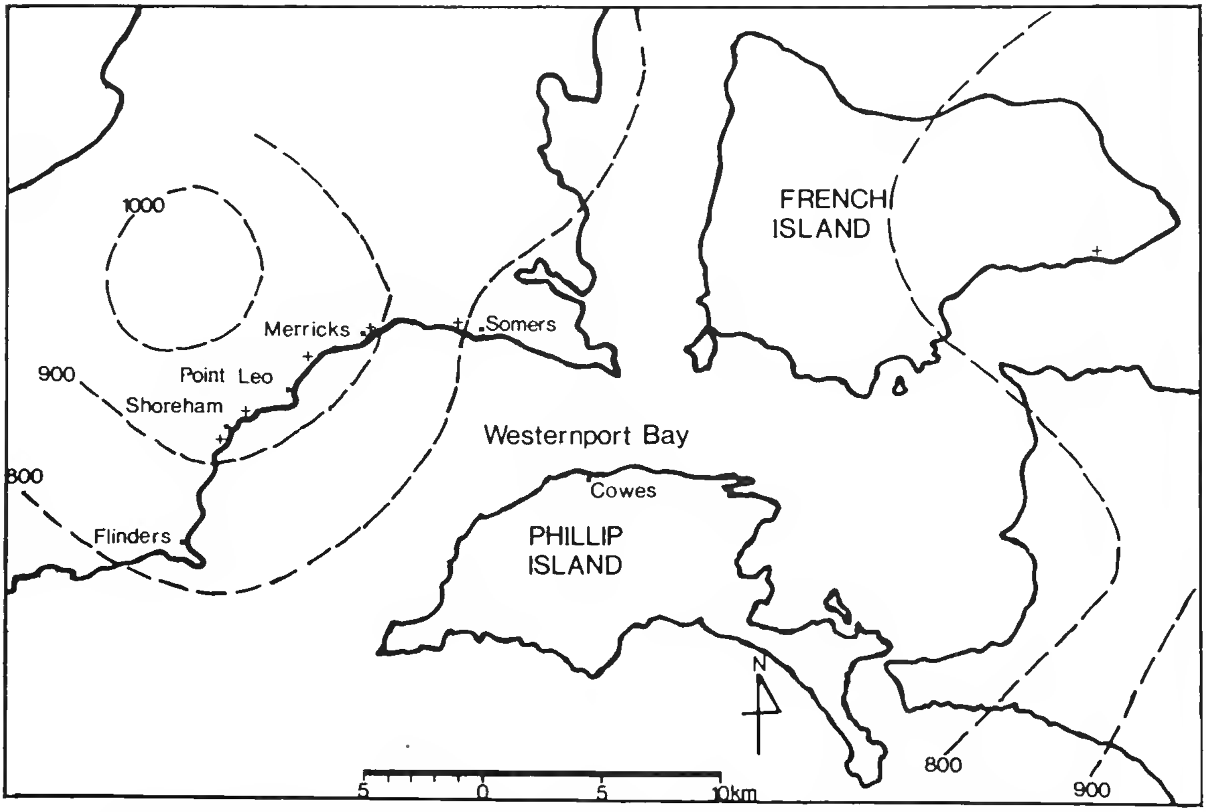


Fig. 1 — Map of Western Port showing tree fern localities (+) on the coast. Coles' Beach is between Merricks and Point Leo; the French Island occurrence is at Freeman's Point. Rainfall isohyets (mm) are shown by the dashed lines. Rainfall data from Shapiro (1975).

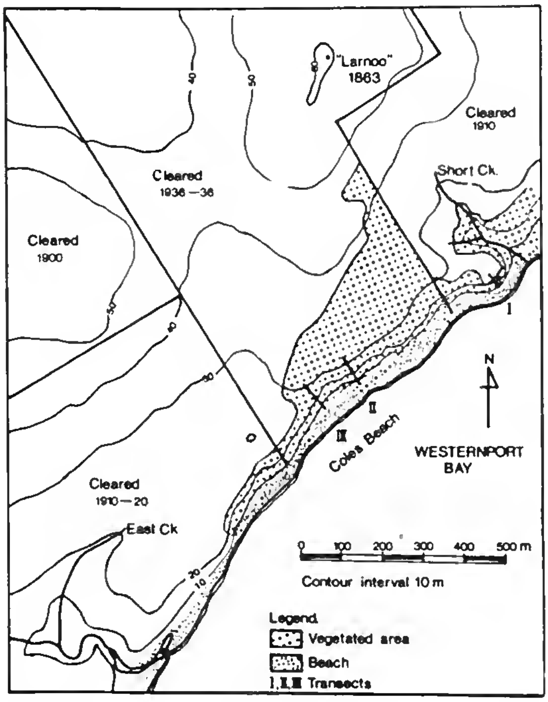


Fig. 2 — General map of the Coles' Beach area showing the land use of the hinterland since 1863.

australis; and Transect III on a stable bluff (Fig. 2). Along each transect, 4 × 1 m quadrats were established at 5 m intervals. In the tree fern community, a further 10 random quadrats were sampled. Within each quadrat, Braun-Blanquet cover values were recorded for each species. Soil holes were augered every 5 m, and soil texture and colour were recorded. Slope profiles at each site were surveyed with tape and clinometer or dumpy level.

TOPOGRAPHY OF THE COLES' BEACH SITE

This area, up-thrown by the nearby Tyabb Fault, slopes gently seaward, the rolling terrain terminating abruptly at a height of 8-10 m above mean high tide level. The coastal features are the product of marine attack and sub-aerial denudation from surface and subsurface water. Gravitational displacement is clearly important where internal resistance has been overcome by water lubrication.

On the more exposed headlands (e.g. Transect I), where sand sheets are absent, marine erosion has produced wide shore platforms and reefs (Hills 1976, Bird 1976). The bases of cliff slopes are subject to marine attack by high tides and storm waves. Due to the local resistance of less decomposed basalt, almost vertical cliffs are produced which suffer frequent rock-falls and slumps after heavy rains (Fig. 6). In this paper, 'cliffs' are defined as those slopes greater than 35° on which there is substantial exposure of underlying rock. The vegetal cover of such cliffs decreases dramatically with increase of slope (Fig. 7). 'Bluffs' are regarded as those vegetated slopes less than 35°, which rise sigmoidally from the beach. They may be further stabilized and degraded to gentler slopes by the combined action of soil creep and hill-wash (Bird 1977).

Stabilized bluffs are common between Merricks and Point Leo where they reach slopes of up to 21° (Fig. 8). At Coles' Beach there is little evidence of slumping at this relatively low angle of slope, and soil profiles at the base reflect a general mixture of wind-blown dune sand with clays, silts and loams washed down from above. The original beach at this point occurs at a depth of 100 cm, where sand is mixed with flat, waterworn basalt pebbles 2 to 15 cm in diameter.

Steeper bluffs of 30° to 33° are frequently unstable, and complex slumping is a conspicuous feature which has reduced the local slope angle to 10° to 20°. The major tree fern occurrences are associated with this diverse microtopography (Fig. 9). At Coles' Beach, judging from prolific seepage and 0.5 m deep cracks in sloppy clay, some areas are still moving. At many sites in this area, mixtures of subsoil, basalt fragments and topsoil have collected against the upper sides of tree trunks and logs to depths of 30 to 40 cm (Fig. 10). Headward erosion from some slumps has now reached the top-soils of the plateau edge, although others have ceased movement and the arcuate clifflets at their upper limits have grassed over.

Due to the rotational nature of the slumps (Selby 1970), back-walls (1 to 3 m high) of decomposed basalt have remained after the tongues of mud and debris have extended out over areas 20 to 30 m long and 5 to 10 m wide. The protected cirque-like basins which are so-formed, are wet and hummocky and some incipient drainage lines have been deflected by later flows. In some places muds have extended out over the dune for up to 4 m. The original slope surfaces, which are often reduced to narrow interfluves by lateral erosion from adjacent slumps, frequently display incipient instability by the presence of terracettes 1 to 10 m long and 10 to 30 cm high.

At the foot of the slope, erratic variations in clay and sand horizons indicate a fluctuating history of earth flows and dune encroachment. The original beach of pebbles and yellow sand occurs at a depth of about 1.3 m. The nature of the slump deposits can be seen in Fig. 4c where truncation has been affected by high tide erosion between Transects I and II.

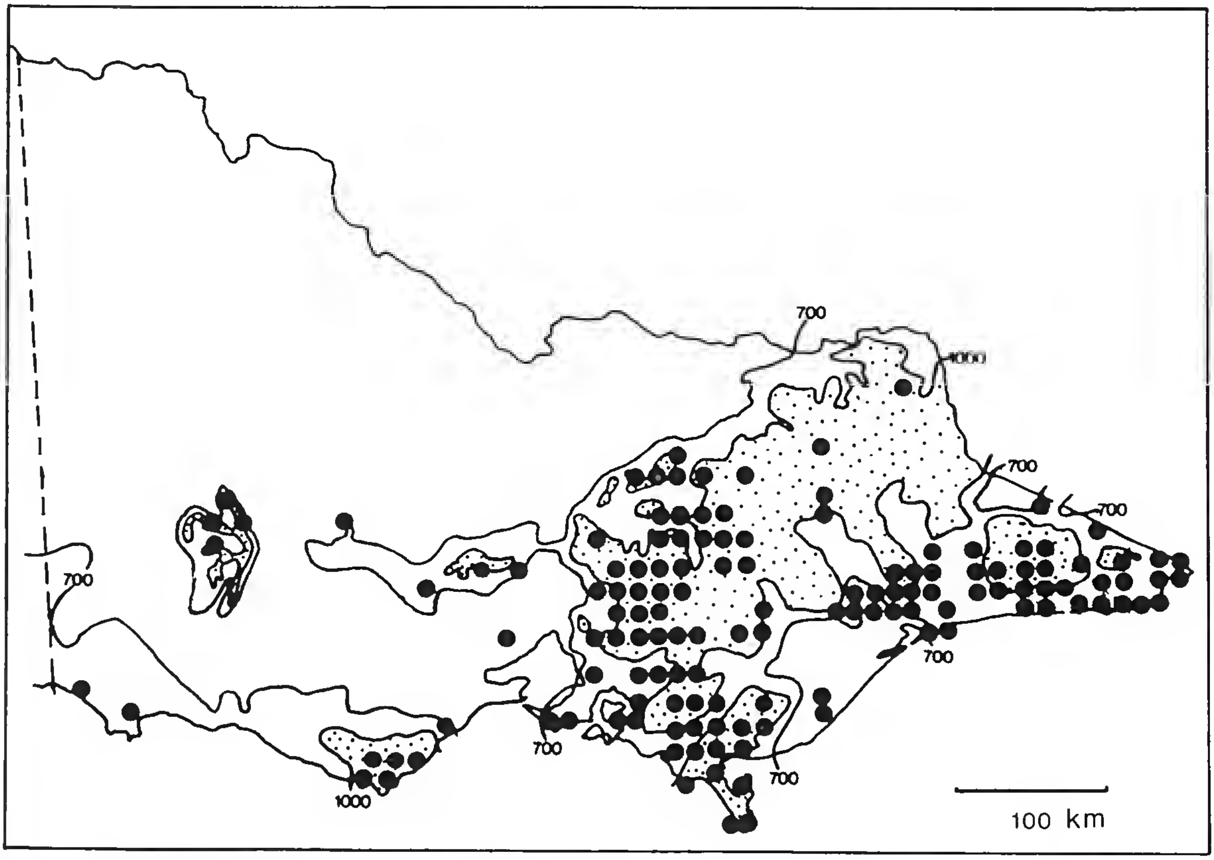


Fig. 3—Victorian distribution of *Cyathea australis* per 10 minute grid. Shaded areas represent those regions receiving greater than 1000 mm annual rainfall. Much of the map was based on data provided by Mrs Betty Duncan, Monash University.

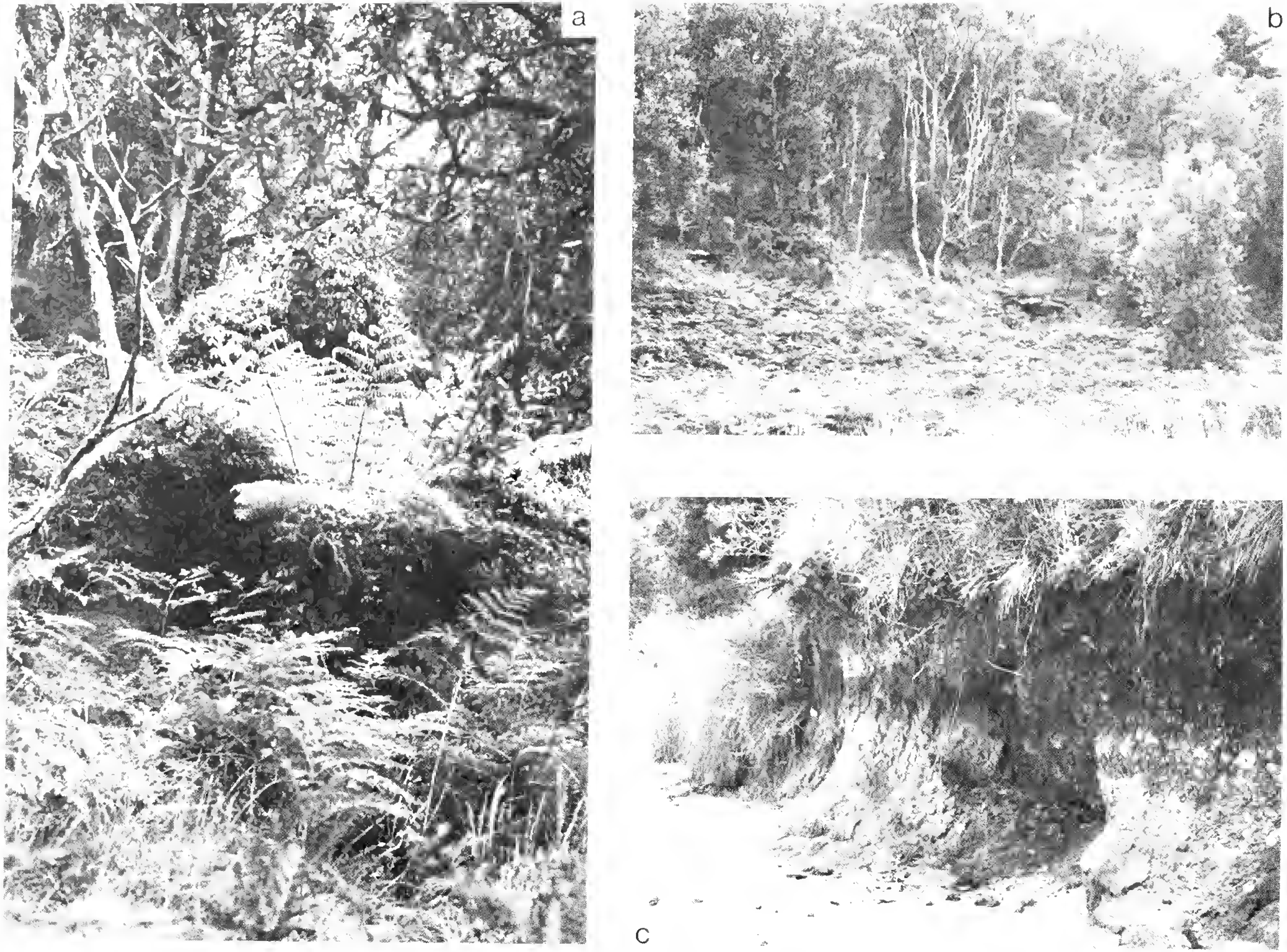


Fig. 4 – Interior of a woodland of (a) *Cyathea australis* – *Acacia melanoxylon* and *Clematis aristata* at Coles' Beach. (b) A relatively large tree fern of *C. australis* 120 cm tall, on a grassy slope facing SE at Coles' Beach. This fern is often 'salt burnt' following on-shore winds from this quarter. *Eucalyptus viminalis* woodland is in the background. (c) Alternating top soil bands and clay rubble in an earth flow truncated by high tides at Coles' Beach north.

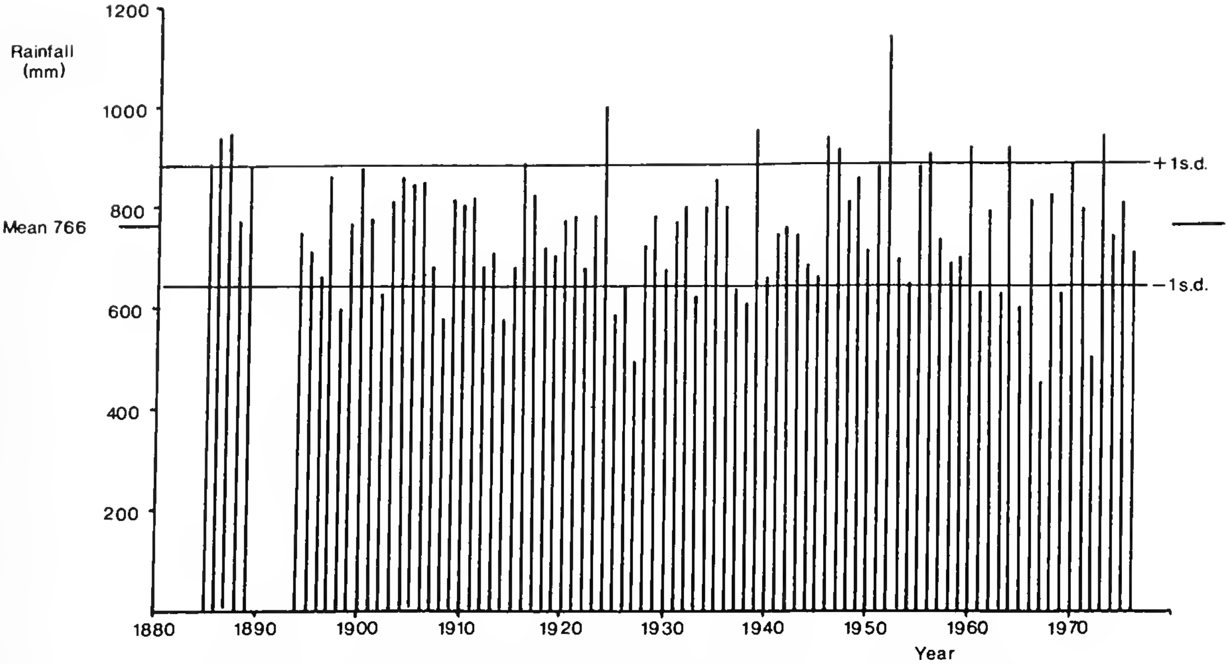


Fig. 5a—Variation of the annual rainfall at Cowes, Phillip Island, 10 km east of Coles' Beach.

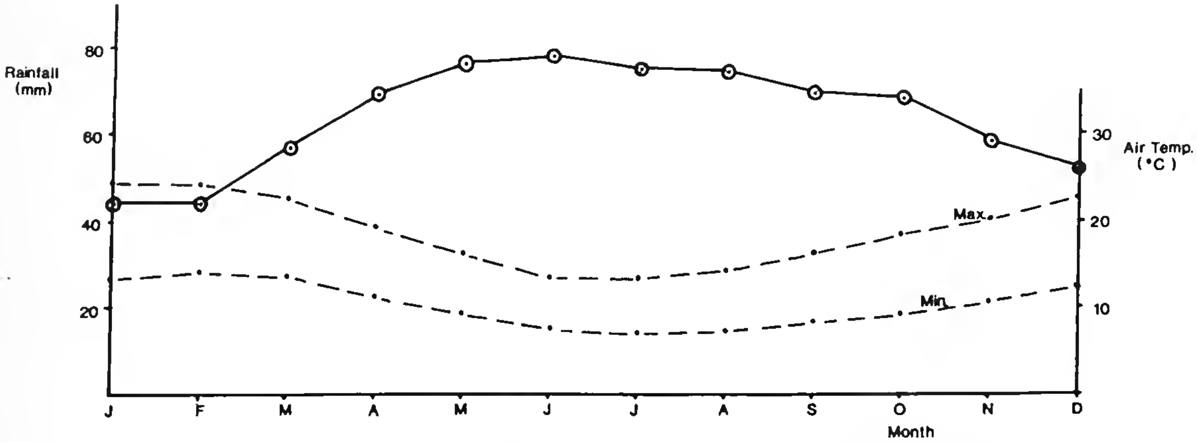


Fig. 5b—Seasonal distribution of rainfall (solid line) and air temperature (broken line) at Cowes. Cowes has the most complete set of rainfall statistics of any recording station near the study area. Annual rainfall figures for the years 1954-1957 were missing from the record. These figures were interpolated from a regression line correlating annual rainfall data from Cowes and Frankston over the period 1919-1975.

The occurrence of landslides in Victoria appears to be primarily controlled by the rock or soil type. The seasonal distribution of rainfall may be broadly related to landslide activity, but heavy rains are usually only a 'catalyst' (Evans & Joyce 1974). Another factor causing instability on the Coles' Beach bluffs is likely to be the behaviour of ground water, especially its depth fluctuations. A dumpy level survey of Short Creek indicated that the water table spring at its source was 21 m above high tide mark on 12/12/1979 at a distance of 210 m from the beach (Fig. 11). This intersection of the water table was about 2 m above the junction of the basalt flows and the Tertiary sands and silty clays. The creek was brackish near its source with a salinity of 5.1%t.d.s.—a value only 1/7th of that of sea water. The water tables in the Coles' Beach bluffs are likely to be of shallow origin and intake recharge may be derived from areas such as the broad sand-capped hill, 60 m above sea level and 1 km inland, which was cleared for the original 'Larnoo' homestead in 1863. A very broad divide extends directly from this hill along a 2° slope to the small forested area on the 'hinterland plateau' above the unstable bluff site (Fig. 2). It seems probable that ground-water discharge occurs down this slope and is in-

TABLE 1

THE PERCENTAGE FREQUENCY OF SPECIES OCCURRENCE IN 10 RANDOM QUADRATS (1+4 m) IN THE UNUSUAL WOODLAND OF TREE FERN (*Cyathea australis*)—BLACKWOOD (*Acacia melanoxylon*) ON SLUMPED CLAYS ON THE COLES' BEACH SITE, 1978. Figures in brackets indicate the frequency where cover exceeds 5%.

LIFE FORM AND STRATA	SPECIES	FREQUENCY
Tree and shrub strata		
Trees	*Eucalyptus viminalis*	20
	Acacia melanoxylon	40 (30)
	Banksia integrifolia	20
Shrubs	*Helichrysum dendroideum*	10
	Bursaria spinosa	10
Tree fern	*Cyathea australis*	30 (20)
Lianes	*Clematis aristata*	80 (50)
Field and ground strata		
Ground ferns	*Pteridium esculentum*	90 (40)
	Adiantum aethiopicum	90 (10)
Graminoids	*Poa labillardieri*	100 (70)
	Lepidosperma laterale	40
	Holcus lanatus	30
	Microlaena stipoides	20
	Echinopogon ovatus	10
Dicotyledon forbs and scramblers	*Geranium potentilloides*	100
	Galium parisiense	70
	Acaena anserinifolia	40
	Senecia jacobaea	40
	Epilobium glabellum	30
	Rubus ulmifolius	20
	Stellaria pungens	20
	Sonchus asper	20
	Dichondra repens	20
	Lobelia alata	20
	Oxalis corniculata	10
	Glycine clandestina	10
	G. latrobeana	10
	Hypochoeris radicata	10
	Rubus parvifolius	10
	Cirsium vulgare	10
	Gnaphalium japonicum	10
Bryophytes	*Fissidens asplenifolius*	50
	Ptychomnion aciculare	10
	Sematophyllum amoenum	10
	Lophocolea semiteres	10

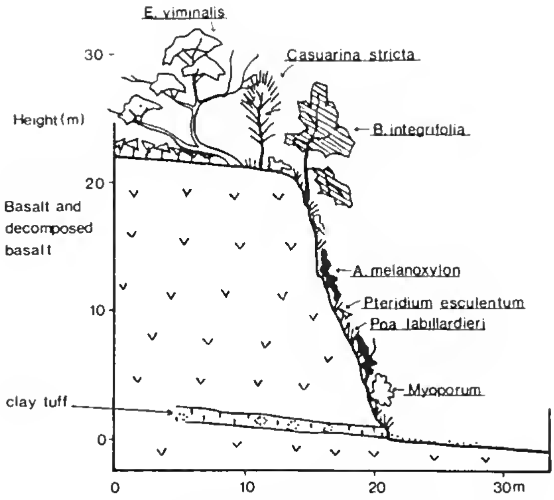


Fig. 6—Vegetation and land profile of the cliff and shore platform at Transect 1.

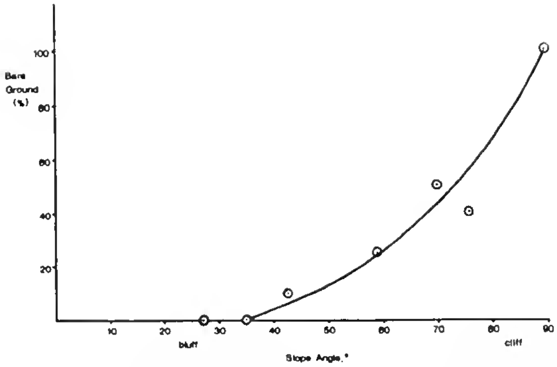


Fig. 7—The relationship between the amount of bare ground and the angle of slope in the Coles' Beach area. Bare ground cover was subjectively assessed and the curvilinear relationship estimated by eye.

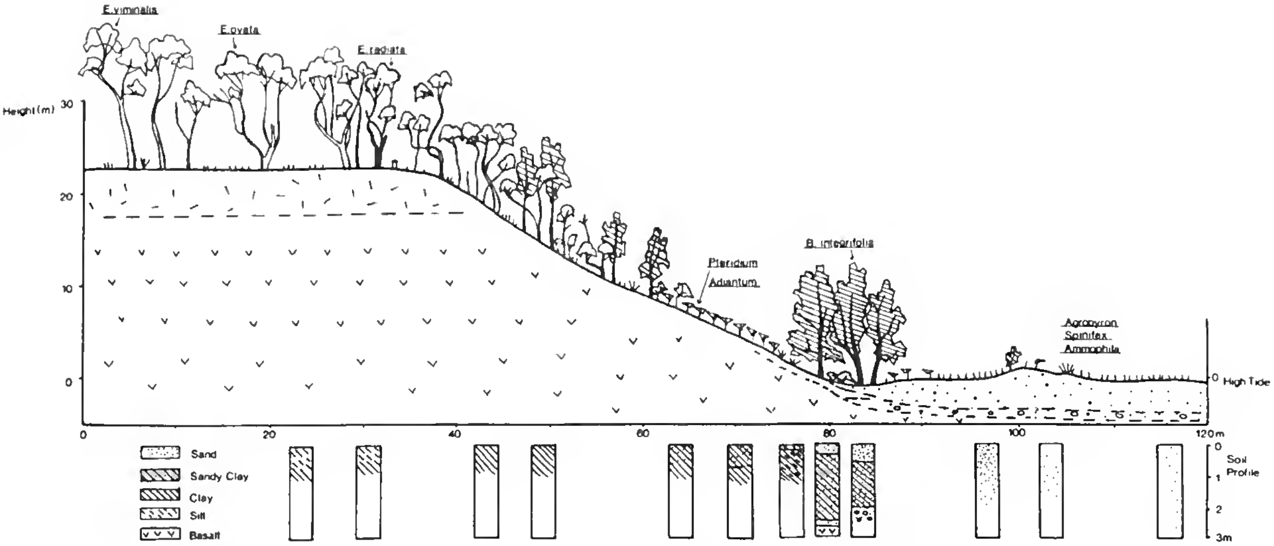


Fig. 8—Vegetation and land profiles of the stable bluff along Transect III, Coles' Beach. B = *Banksia*; E = *Eucalyptus*.

tersected by the slumping bluff surface about 20 m above high tide approximately at the junction of the decomposed basalt and the Tertiary sediments. The relative stability of the bluffs to the north and south of the central area may be preserved by a deflection of ground water discharge along the lateral drainage lines which run parallel to the coast along slopes of 3 to 5° in this area.

Sodium predominance in the clay complexes in this maritime site is certain to render the soils more fluid and dispersable in wet conditions (Leeper 1957). The soils of the basalt areas are brown, friable loams over red/yellow mottled sticky clays, whilst those on the Tertiary deposits are grey fine sandy loams over heavy yellow clay. In both soil types the presence of magnetic buckshot gravel in the lower A horizons suggests periodic waterlogging—a prerequisite of mass soil movement.

It is well known that clearing of eucalypt forest for pasture development can result in reduced water use and a rise in the level of the water table. It seems highly likely therefore that this has been the case in the Coles' Beach area following general clearing from 1910 to 1938. A greater flow of ground water would not only increase the likelihood of slumping but also tend to cause instability higher up the slope of the bluff.

VEGETATION AT THE COLES' BEACH SITE

At this site the largely intact vegetation appears as a moderately low open-forest or woodland which descends from an almost level plateau to a set of 2 or 3

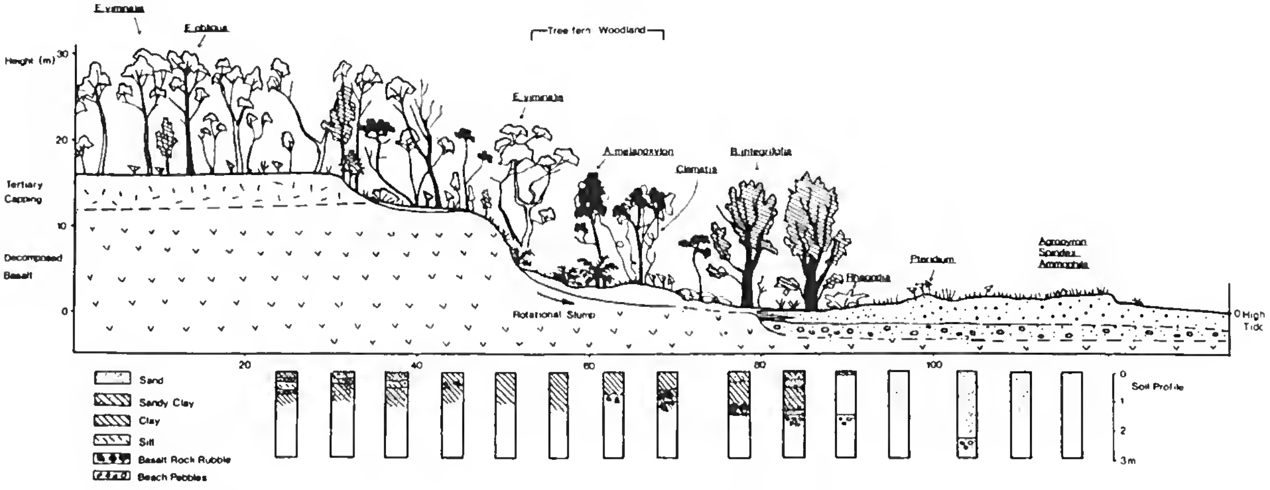


Fig. 9—Vegetation and land profiles of the unstable bluff along Transect II, Coles' Beach. B = *Banksia*; E = *Eucalyptus*; A = *Acacia*.

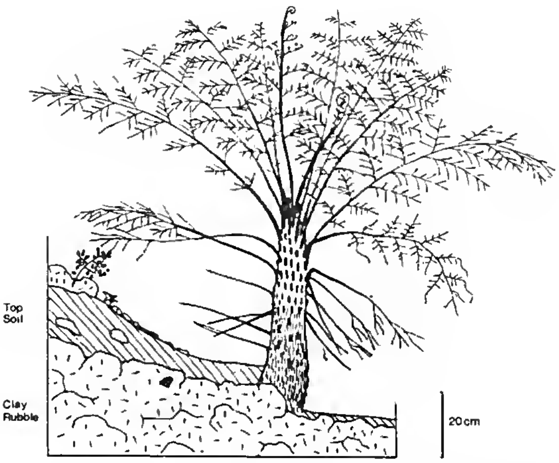


Fig. 10 — Build-up of hill wash against a young tree fern (12 to 13 years old), on the lower slopes of an earth flow, Coles' Beach. The rate of accumulation against the 6 year old trunk could be about 1 cm per year.

grassy dunes 1 to 2 m high and 30 to 40 m broad. It is likely that these deposits with scattered, resistant *Banksia* have protected some of the bluff vegetation from the worst excesses of salt spray. The vegetation has been mapped on a structural basis, and for convenience named according to the dominant plant form. A purely floristic analysis may have grouped the communities differently but it is not likely to have modified the conclusions. The major communities described below are closely correlated with local topography and soil as shown in maps (Figs 12, 13) and profiles (Figs 6, 8, 9). Ground vegetation is often most luxuriant at the dune/slope junction where moisture supplies are reliable but not excessive. The tallest trees usually occur on the mid to lower slopes in response to less exposure and better moisture status. An analogous situation occurs on French Island near Freeman's Point, where a narrow zone of wet sclerophyll shrubs (*Olearia argophylla, Rapanea howittiana*) appear beneath taller *E. obliqua* trees.

The communities are:

1. SAND DUNE COMPLEX consisting of:

(a) Foredune grassland of *Spinifex hirsutus, Agropyron junceum, Ammophila arenaria* and *Cakile maritima*.

(b) Hind dune complex of graminoids (*Scirpus nodosus, Lagurus ovatus, Stipa compactus*) together with *Acaena anserinifolia* and scattered bracken. Small bushes of *Banksia integrifolia* are establishing in areas of this zone, either by seed or by root suckers. This situation appears to be successional and is a similar pattern to previous descriptions (Bird 1976).

2. FERNLAND of bracken — (*Pteridium exculentum*) at the base of the main slope. This is often tangled with *Clematis aristata*, associated with or without an understorey of maidenhair fern (*Adiantum aethiopicum*). In many sites, vigorous patches of blackberry (*Rubus ulmifolia*) have overcome the bracken stands.

3. WOODLAND of *Banksia integrifolia* on two types of site; on the sands and mixed clay soils at the bluff/dune junction and on the hind dune associated with dune plants such as *Rhagodia baccata* . On some of the basalt slopes, especially the lower slopes, it is associated with an understorey of tussock grass (*Poa labilliardieri*) and various forbs. It seems that these latter sites are similar to those occupied by eucalypts. Some *Banksia* communities bear evidence of old eucalypt stumps and fallen trees. Possibly, the eucalypt component requires fire for adequate perpetuation whereas *Banksia integrifolia* may continue to regenerate vegetatively.

4. WOODLAND of *Acacia melanoxylon* in association with *Cyathea australis* and *Clematis aristata* on slumped sites. This community has a low, scattered tree canopy but the ferny, herbaceous stratum — consisting of *Adiantum aethiopicum, Pteridium esculentum, Poa labillardieri, Geranium potentilloides* and *Galium parisiense* — is luxuriant (Fig. 4a). Areas of damp clay-rubble associated with the tree ferns are almost invariably colonized by the moss, *Fissidens asplenifolius*. The percentage frequency of species in this community is illustrated in Table 1.

5. OPEN FOREST of *Eucalyptus viminalis — E. obliqua* on the slopes. This is a predominantly grassy community with an understorey of *Poa labillardieri* and forbs. On the gentler slopes *E. radiata* and *E. ovata* also occur. *Banksia integrifolia* is a common understorey or

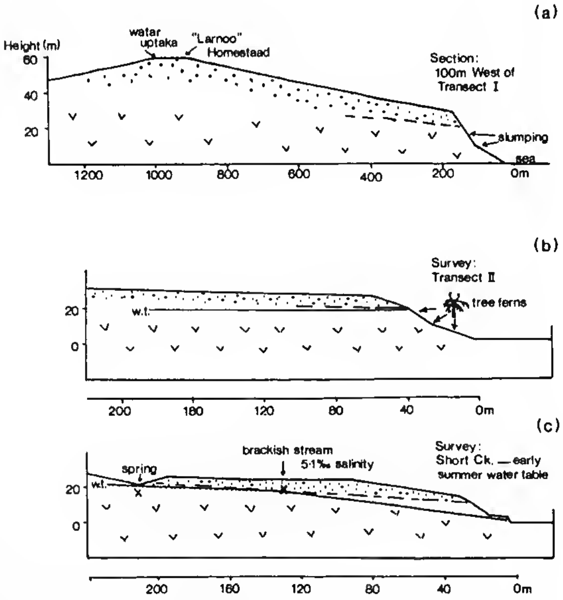


Fig. 11 — Land profiles in the Coles' Beach area in relation to Tertiary sand and sandy clay cappings (stippled), the limit of which is shown by a dashed line. The depth of the ground water table along Short Creek was determined by survey offsets from the transect lines.

a. Section 100 m west of Transect I. (Source: Contour Map, 10,000/4, 6, 1973). Vertical exaggeration × 5.

b. Survey of Transect II.

c. Survey of Short Creek.

Slumping areas occurred on the bluff slopes of each of the three transects. The extensive slumping on (b) is associated with a definite perched water table.

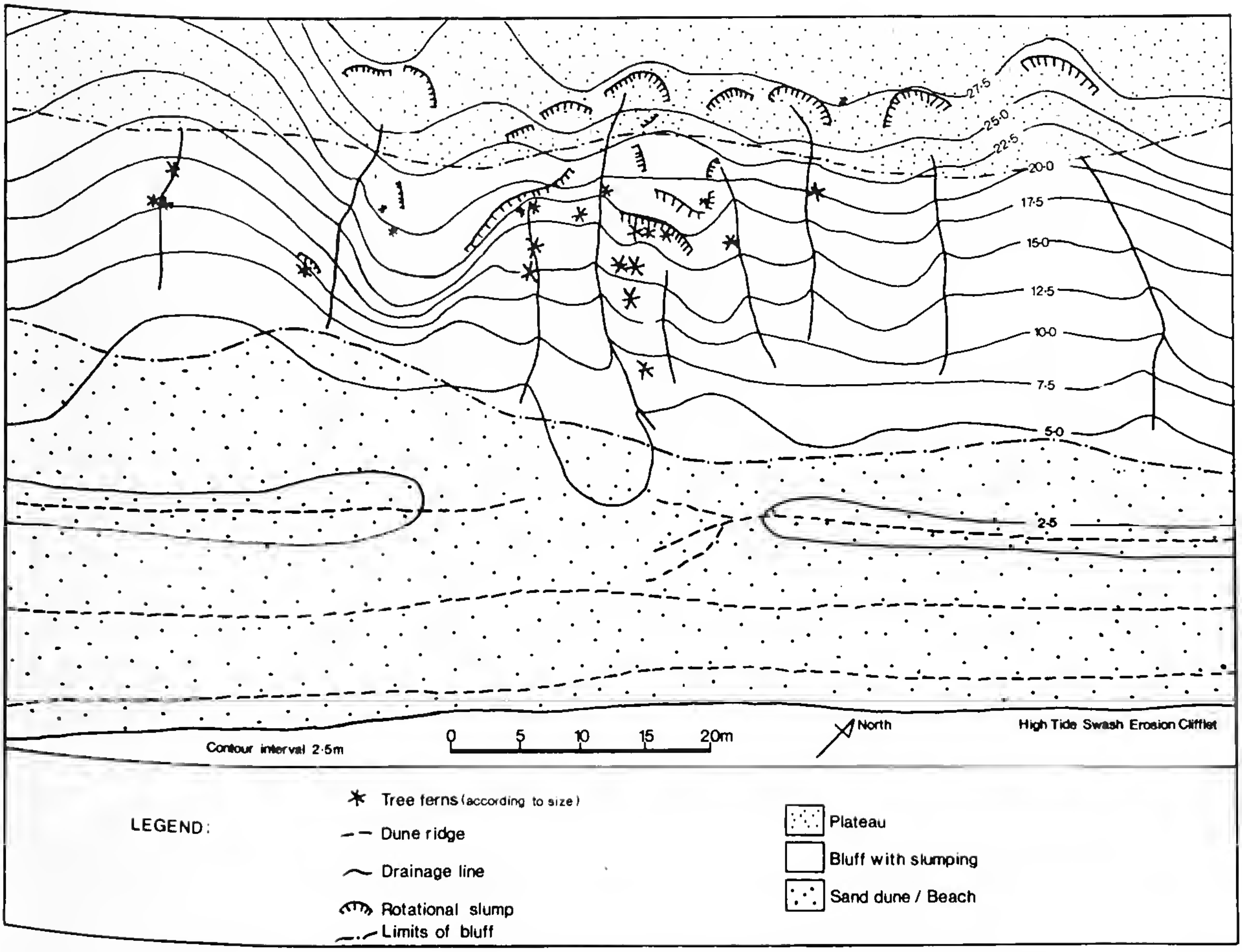


Fig. 12—Landform map of the Coles' Beach site showing the distribution of tree ferns.

codominant species and is associated with *Helichrysum dendroideum* and *Bursaria spinosa*. Large-crowned *C. australis* sometimes occur on terraced grassy slopes in this community and are visible from the beach (Fig. 4b). Establishment of *Pittosporum undulatum* into these slope communities is very common, as it is over much of Mornington Peninsula, where both seed sources and bird vectors are present. The mature development of this species will undoubtedly greatly modify these communities—as will the invasion of blackberry thickets.

6. Low Grassy Woodland complex of shrubs and scattered low trees of *Casuarina stricta* and *Banksia integrifolia*. In addition, the highly disturbed cliffed site, to the north of the main study area, also supports stunted, prostrate *Acacia melanoxylon*, scattered bushes of *Rhagodia baccata* and tussocks of both *Lomandra longifolia* and *Poa labillardieri*.

7. Mixed Plateau Open-forest of *E. obliqua*, *E. radiata*, *E. viminalis* and *E. ovata*. The frequencies of these species change locally, probably in response to seasonal waterlogging conditions. These dominants are associated with *Danthonia racemosa*, *Poa sieberiana*, *Xanthorrhoea minor* and *Leptospermum juniperinum*. The understorey has been modified to some extent by cattle grazing.

STATUS OF DEVELOPMENT OF *Cyathea australis*

The majority of tree ferns on the west coast of Western Port have trunk heights less than 1.5 m and crown diameters of about 4 m. However, at Shoreham and Somers, occasional large specimens reach heights of 2.9 and 3.2 m respectively. The frequency histograms of tree fern heights at Coles' Beach, Shoreham and Somers are compared in Fig. 14. It is clear that the Shoreham stand is bimodally distributed whilst that at Coles' Beach has only one major peak of trunk heights. The coincidence of population frequency peaks at the two sites may mean that establishment has been synchronised by similar events. The reduced frequency peaks of taller classes at Shoreham (and to some extent, Somers), suggest that there have been additional earlier phases of establishment.

Cyathea australis at Coles' Beach is actively regenerating, since 41% of plants are sessile, with crown 0.3 to 3.0 m in diameter. Young plants are found where

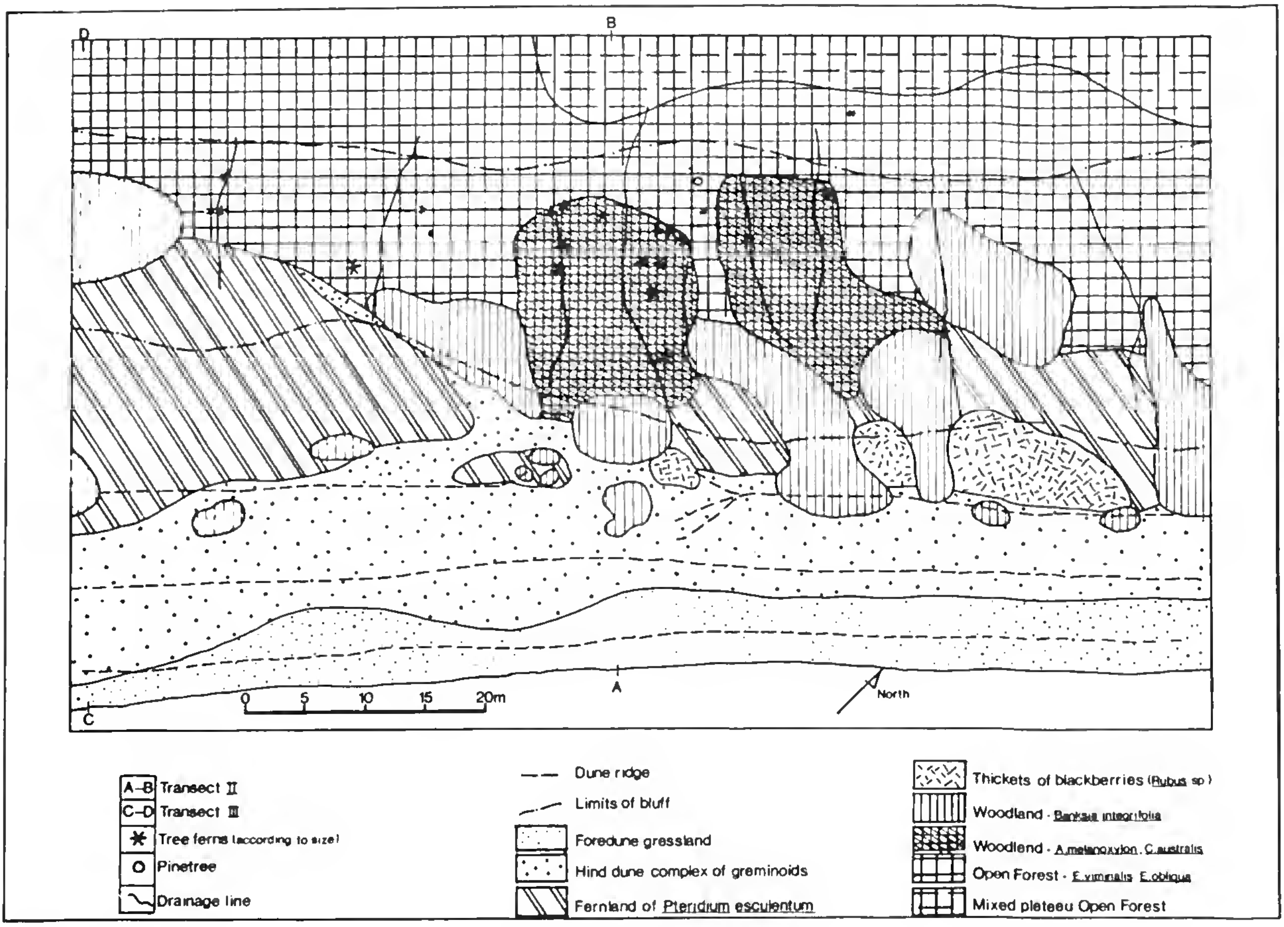


Fig. 13 — Map of the main structural vegetation units at Coles' Beach.

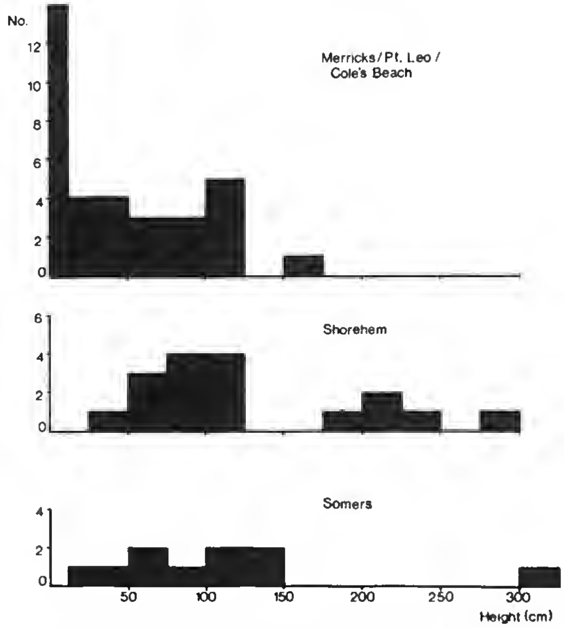


Fig. 14 — Frequency histogram of tree fern heights at the three major tree fern localities — Shoreham, Coles' Beach and Somers.

the ground stratum of bracken, maidenhair fern, grasses, forbs and *Clematis* vines is incomplete. At Shoreham, regeneration is absent beneath dense blackberries — the few small plants occurring only where this weed is still sparse. At Somers, the situation is similar, and regeneration occurs only where the dense wreaths of the introduced *Asparagus asparagoides* are patchy. It is expected that regeneration of the tree fern at Coles' Beach will eventually be curtailed by blackberry growth. However, the regeneration of the tree fern on moist clay surfaces is rapid, since at Shoreham, fernlings appeared in late 1978 — within six months of a track being graded through a tree fern site that had been cleared of dense blackberries.

From general ecological observations, the mature tree fern appears to be intolerant of prolonged drought and excessive insolation. The development and survival of the prothallus is likely to be dependent on the maintenance of moist and locally humid microclimates. These conditions are frequently satisfied by moist clay soil on slopes where obliterating litter cannot accumulate. At Coles' Beach, 50% of all tree ferns occur in seepage areas or erosion furrows in and between clay slumps; the remainder occur on open slopes where bare soil has been exposed by terracettes, hillwash or wombat

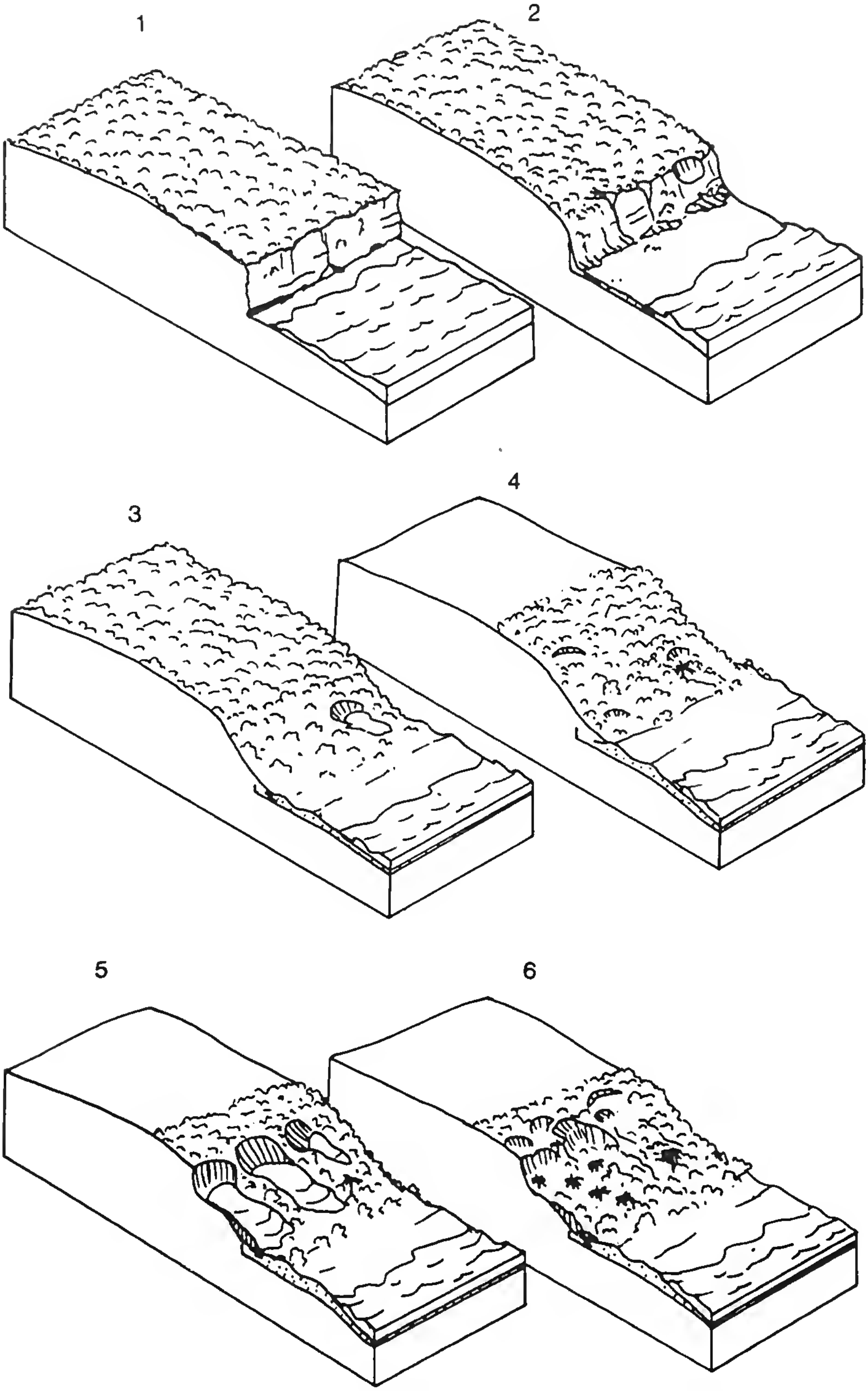


Fig. 15 — Block diagrams depicting the possible sequence of development of the tree fern habitat at Coles' Beach:

1. Cliff kept active by marine erosion.
2-3. With the build up of protective dunes, sub-areal processes denude cliffs to bluffs.
4. Hinterland cleared of forest causing a rise in water table levels.
5-6. Slumping activity increases, creating suitably moist habitats for the establishment and survival of *Cyathea australis*.

burrowing. A few in the latter sites have succumbed to drought. The ages of slumps providing conditions for tree fern establishment are not generally known. Since the biology of this species is incompletely known, the age structure of the stands can only be surmised.

Examination of five of the larger tree ferns at the Coles' Beach site in November 1979 revealed that an average of 14 fronds had been produced in the current spring season. The number of older, green and decadent fronds average 17. The length of stem subtending the older fronds averaged 11 cm. If allowance is made for a few fronds being older than one year, the annual stem growth could be about 10 cm, or the equivalent of two spirals of frond insertions.

Some corroboration of these results was obtained by measuring the growth of tree ferns beyond the char-line of the 1968 fires in Ferntree Gully National Park. The average increment of six trunks of *C. australis*, 2.5 to 4.9 m tall, was 11.3 cm per year. Thus for enriched post-fire conditions in a wet sclerophyll environment at an altitude of 200 m the annual growth rate was 10.5 cm. On the basis of these estimates the minimum age of the trunks of the Coles' Beach ferns may be only 5 to 13 years.

The period from spore germination to trunk development is more difficult to estimate. Observations are limited to the development of a transplanted rosette of *C. australis* 30 cm in diameter, in a Surrey Hills garden (Melbourne) over 20 years. A trunk, 33 cm high, developed after seven years and an extrapolation of subsequent height growth measurements (5.5 cm/yr. to zero) indicated that the juvenile rosette period was likely to be about four years. A similar time to develop to the rosette stage seems reasonable in view of glasshouse observations of prothallial and fernling stages. The age of the larger, mature tree ferns at Coles' Beach could therefore be between 12 and 20 years old. The largest specimen at Shoreham may be 35 to 40 years old, whilst that at Somers may be at least 50 to 55 years old, since growth rate is likely to diminish with increasing age.

Tree ferns may have arrived on the coastal bluffs by chance spore dispersal from the fern gullies of the Red Hill district, 10 to 15 km up-wind to the west and north west of this coastline. At the Shoreham bluffs, they are known to have been present for the last 62 years (1918-1980) (M. Wainwright pers. comm., 1980), although on the lower, weedy stretches of nearby permanent creeks (Stony Ck. and East Ck.) they appear to be absent.

At the French Island site, a cliff slump was estimated to have occurred 14 years ago, judging from the maximum number of whorls of branches on vigorously invading *Pinus pinaster* saplings. The oldest tree fern on this slump is 50 cm high and is estimated to be 9 years old. It is growing in a moist habitat, and although saltburnt, is protected locally from the prevailing SW winds by a projecting clifflet. It would appear that *Cyathea australis* is readily able to colonise such habitats when they become available, although at the French Island site, the persistence of the ferns is in jeopardy due to impending marine erosion of both the slump and the projecting clifflet.

The impression gained from this initial study is that the colonization of tree ferns on most bluff sites has been a relatively recent phenomenon. The steles of tree ferns are resistant to decay for many years. No remanants of large ferns have been found. The mature tree fern is resistant to all but the most intense fires (Jarrett & Petrie 1929). Since none of the tree ferns at Coles' Beach show evidence of charring on their lower trunks, they are certainly younger than the last fire in 1941 (Lorraine Coles pers. comm.).

CONCLUSIONS

An hypothesis which may account for the habitat complex and the general youth of the tree fern population at the Coles' Beach site concerns the rise of water table following general land clearance on the gentle hinterland slopes. If this has happened, then clays of the mid-slopes of the vegetated bluff, which may have been saturated by ground water only in very exceptional decades or centuries, have now been much more frequently under its influence. Instability may have been triggered by flood rains, such as occurred in 1952 and 1956, and have continued with variable activity until the present day. A summary of the possible generalised sequence of development of the unusual tree fern habit on the west coast of Western Port is shown in Fig. 15.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the help offered by the following people: Miss Lorraine Coles and Mrs M. Wainwright, who provided valuable information on local history; Mrs Betty Duncan for use of *Cyathea* distribution maps of Victoria; Drs E. C. F. Bird, P. G. Ladd and Pauline Ladiges and Messrs R. Lakey and P. McCumber for discussions and critical assessments of the manuscript; Messrs D. G. Moore and R. Eager for help with the field work.

REFERENCES

Bird, E. C. F., 1976. *Coasts.* 2nd Edition. A.N.U. Press, Canberra.

Bird, E. C. F., 1977. Cliffs and bluffs and the Victorian coast. *Victorian Nat.* 94: 4-9.

Bird, E. C. F., 1979. Victorian coastal geomorphology. *Proc. R. Soc. Vict.* 92: 19-35.

Evans, R. S. & Joyce, E. B.,1974. Landslides in Victoria, Australia. *Victorian Nat.* 91: 240-245.

Hills, E. S., 1976. *Physiography of Victoria.* Whitcombe & Tombs, London.

Jarrett, E. S. & Petrie, A. H. K., 1929. The vegetation of the Blacks' Spur Region. A study in the ecology of some Australian mountain *Eucalyptus* forests. II. Pyric succession. *J. Ecol.* 17: 249-281.

Leeper, G. W., 1957. *Introduction to soil science.* 3rd Edition. Melbourne University Press, Melbourne.

Selby, M. J., 1970. *Slopes and slope processes.* Waikato Branch of the New Zealand Geographical Society (Inc.) Publication No. 1. 59 pp.

Shapiro, M. A., 1975. *Westernport Bay Environmental Study* 1973/74. Ministry for Conservation, Victoria.

Spencer-Jones, D., Marsden, M. A. H., Barton, G. M. & Carrillo-Rivera, J. J., 1975. Geology of the Westernport Sunkland. *Proc. R. Soc. Vict.*, 87: 43-68.

COASTAL ARCHAEOLOGY IN VICTORIA
PART 2: ADAPTATION TECHNOLOGY & VOLCANISM

By P. J. F. Coutts

Victoria Archaeological Survey
Victoria Avenue, Albert Park 3206

INTRODUCTION

In Part 1 of this paper the morphology of coastal archaeological sites in Victoria was described. Much as it is desirable to place coastal sites in a rigorous cultural framework, the present state of knowledge of coastal archaeology in Victoria does not permit this. Instead we can do little more than review some of the more interesting aspects of coastal archaeology. Topical issues that could be discussed are: the relationship through time between resources orientated and generalised economic strategies; the relationship between the level of stone technology, coastal economies and productivity; the importance of fishing in local economies; the relative importance of sandy beach and estuarine habitats and their degree of exposure to ocean swell; changes in coastline and marine habitats induced by fluctuations in sea level; and changes in sea water temperatures and their effect on abundance and variety of marine fauna.

In this paper problems relating to the technology of flint, interpreting various archaeological sites, and man's need to adapt to a changing coastal environment are discussed. Adaptations of particular interest are those arising from natural processes (e.g. rises in sea level and volcanism) or from the actions of man himself (e.g. fire).

CHANGES IN COASTAL VEGETATION

In evaluating the economic potential of coastal areas at any prehistoric time the resources of the sea and the immediate hinterland must be assessed in concert. Vegetation is a key factor as it largely determines the range of animal and vegetable foods available. Changes in vegetation patterns almost certainly precipitated adaptation. It is likely that coastal vegetation has changed during the past 30 000 years, as sea-level rose and fell. Analyses of pollen from south-eastern South Australia, from Wilsons Promontory and from Lake Keilambete suggest that fluctuations in climate during the past 10 000 years have not been severe enough to modify the main floral associations to any great extent (Dodson 1974a, 1974b, Dodson & Wilson 1975, Hope 1974, Yezdani 1970).

However, in Gippsland, using pollen data that span the last 7000 years Hooley, Southern and Kershaw (1980) demonstrated a dramatic shift from *Casuarina* to *Eucalyptus* woodland about 3000 years before the present (BP) and a further decline in *Casuarina* about 200 BP. Both periods of change are associated with peaks in charcoal debris in soil profiles, which suggests that the changes were fire initiated, and probably by man. The major vegetation change 3000 BP must have affected coastal Aboriginal economy in that area.

Aboriginals periodically set fire to coastal vegetation along other parts of the Victorian coastline during the Late Prehistoric period, but the antiquity of this practice is not known (e.g. Port Phillip—observations by Knopwood (Nicholls 1977: 35, 37, 39)). Thus patterns of coastal vegetation have varied from time to time and resulting changes in Aboriginal economy can be expected in archaeological records.

COASTLINE CHANGES

Changes in the coastline induced changes in coastal ecology, which in turn affected Aboriginal settlement patterns (Lampert & Hughes 1974), and possibly social and economic patterns, and material culture. During the past 20 000 years the Victorian coastline has receded (Fig. 1) as the sea-level rose after the last glacial period. The coastline stabilised about 6000 BP, which is the oldest dating for most archaeological sites along the present coastline. However, in several coastal areas, Cape Nelson, Cape Woolamai, the southern tip of Wilsons Promontory, Point Hicks and Gabo Island, where the inshore submarine profiles are steep, sites having archaeological records older than 6000 BP may be found. Indeed if the interstadial high of *circa* 35 000 BP reached minus 10 m then these areas may still have the only examples of littoral exploitation dating from those periods.

Port Phillip probably began to fill about 9000 BP and its comparatively flat floor would have precluded extensive occupation anywhere as sea-level rose. Thus most middens around Port Phillip are likely to post-date 6000 BP. Western Port began to fill around 8000 BP when the western margins were inundated. The islands in Western Port would not have been formed until the sea-level was very close to its present height about 6000 BP. Evidence of slightly older littoral exploitation may also be found on the western fringes of the two largest islands in Western Port and on the mainland between Flinders and Hastings. The only other area that may have archaeological littoral sites pre-dating 6000 BP is the coastal strip along the eastern edge of Cape Otway, where the underwater terrain is steeper than in most other coastal areas. Even there the sites are unlikely to be much more than 500-1000 years older than those in other coastal areas in Victoria.

If the sea-level *circa* 6000 BP (see Gill & Hopley 1972, Thom, Hails & Martin 1969, Thom, Hails, Martin & Phipps 1972) was 2-3 m higher than at present, the man-made littoral deposits in the relatively flat zones of Western Port, Corner Inlet and the Gippsland Lakes would have been inundated and covered by sediments. Aboriginal sites formed then would be further inland than the present shoreline.

As the sea rose to its present level, areas rich in food resources were created (Bowdler 1977: 213). Such areas include Western Port, Port Phillip, Mallacoota Inlet and the Gippsland Lakes. However, it is not clear yet whether the prehistoric inhabitants living in these areas had the required technologies to exploit the resources effectively (Lampert & Hughes 1974).

One of the most important events affecting coastal ecology and therefore human settlement was the inundation of the land bridge joining Tasmania and mainland Australia. Unfortunately the impact of these changes on Aboriginal communities, occupying the Victorian coastline has not yet been documented archaeologically.

Much of the present Victorian coastline is eroding today and there is increasing evidence that many sites less than 500 years old that are or were situated in the vicinity of the foredunes or on low cliff tops, are being eroded away or have disappeared already. Other periods of active erosion may have occurred over the past few thousand years, initiated by minor fluctuations in sea-level. So far there is only one published instance of a changing coastal geomorphology affecting prehistoric human settlement in Victoria (Coutts 1967, Hope & Coutts 1971). On the west coast of Yanakie Isthmus, Wilsons Promontory, there are two dune systems associated with two series of sites 'A' and 'B' (Coutts 1970, 1981). Because 'A' series middens are exposed in the eroded cliffs along the beach they must have once extended further out onto the beach and consequently, when these sites were occupied the coastline must have been further seaward than it is today.

'A' series sites are found on the summits of Pleistocene dunes which run almost at right angles to the present coastline. Peat deposits which outcrop on the beach between these dunes can be linked stratigraphically with soils containing the 'A' series middens. Radiocarbon dating of the latter indicate that they were formed about 3000-6500 years ago and a single date (6010 ± 110 BP) from the peat deposit confirms the stratigraphic relationships (Coutts 1967). The peat contains freshwater gastropods and was probably landlocked at one time, presumably by a foredune further to the west. Results of analyses of the midden materials indicate that nearly all the shellfish in the 'A' series sites were collected from rock platforms; others were from estuaries and sandy beaches. The present coastline fronting the dunes is sandy beach, almost totally devoid of intertidal rock platforms.

Some evidence from the later 'B' series dunes (dating from 3000 BP) suggests that Aboriginal economy may have diversified towards the end of the prehistoric period and that the preferences also changed for the stone materials used. Whilst the change in the methods of collecting shellfish may be seen as an adaptive response to a changing coastal environment, the changes in material culture seem to have been widespread throughout Victoria (Coutts & Witter 1977, Hope & Coutts 1971) and cannot be explained in this way.

FLINT AND COASTAL RESOURCES USAGE

Large quantities of flint are found in many Victorian coastal archaeological sites. It derives from Gambier limestone (Gill 1957) and has been washed in from offshore, often buoyed by kelp (Fig. 2, Boutakoff 1963, Hossfeld 1966, Mitchell 1949). Gill (1957) suggested that Aboriginals obtained flint from caves, sink holes and re-emerged Pleistocene strand lines along the coast near the South Australian/Victorian border. Although similar flint can be obtained from inland areas of south and north-eastern South Australia (Wright 1971) and from isolated localities in western Victoria (Hossfeld 1966, P. Kenley pers. comm.) it is considered unlikely that the flint nodules found along the Victorian coast came from any of these sources.

The following observations are pertinent to the distribution of flint on the Victorian coast and its use by Aboriginals:

(1) Flint occurs in coastal archaeological sites and on beaches between Wilsons Promontory and the South Australian border, increasing in frequency from east to west.

(2) Flint implements are rarely found in archaeological sites east of Wilsons Promontory.

(3) Flint was used by Victorian Aboriginals at Wilsons Promontory around 5000 BP (Coutts 1970) and at Thunder Point near Warrnambool, around 4300 BP (Coutts 1978). In western Victoria, so called Gambieran implements made from flint have been found in unstratified context (Mitchell 1949). The flint is thought to derive from local outcrops rather than from coastal beaches (Clark 1979). In South Australia none of the implements from Devon Downs or Fromm's Landing (sites less than 5000 years old and little more than 200 km from the coast) were made from flint (Hale & Tindale 1930, Mulvaney 1960, Mulvaney, Lawson & Twidale 1964), but a few fragments of dark blue-grey flint have been excavated at Roonka, a site which dates from about 7000 BP (Pretty 1977). In the central Western District of Victoria, flint has been found in sites which date to less than 3000 BP. No flint artefacts have been found at Keilor, Green Gully or Cloggs Cave (Flood 1974, Mulvaney 1970, Wright 1970), sites which have a much greater antiquity than those mentioned above, and which are no more than 30 km from the present coastline.

However, it should be remembered that 15 000 years ago, the coastline was some hundreds of kilometres further south, and the prospects for collecting flint from beach sources and conveying it to these sites are unknown.

(4) Flint and quartz are the two most common types of stone materials found in recent coastal ar-

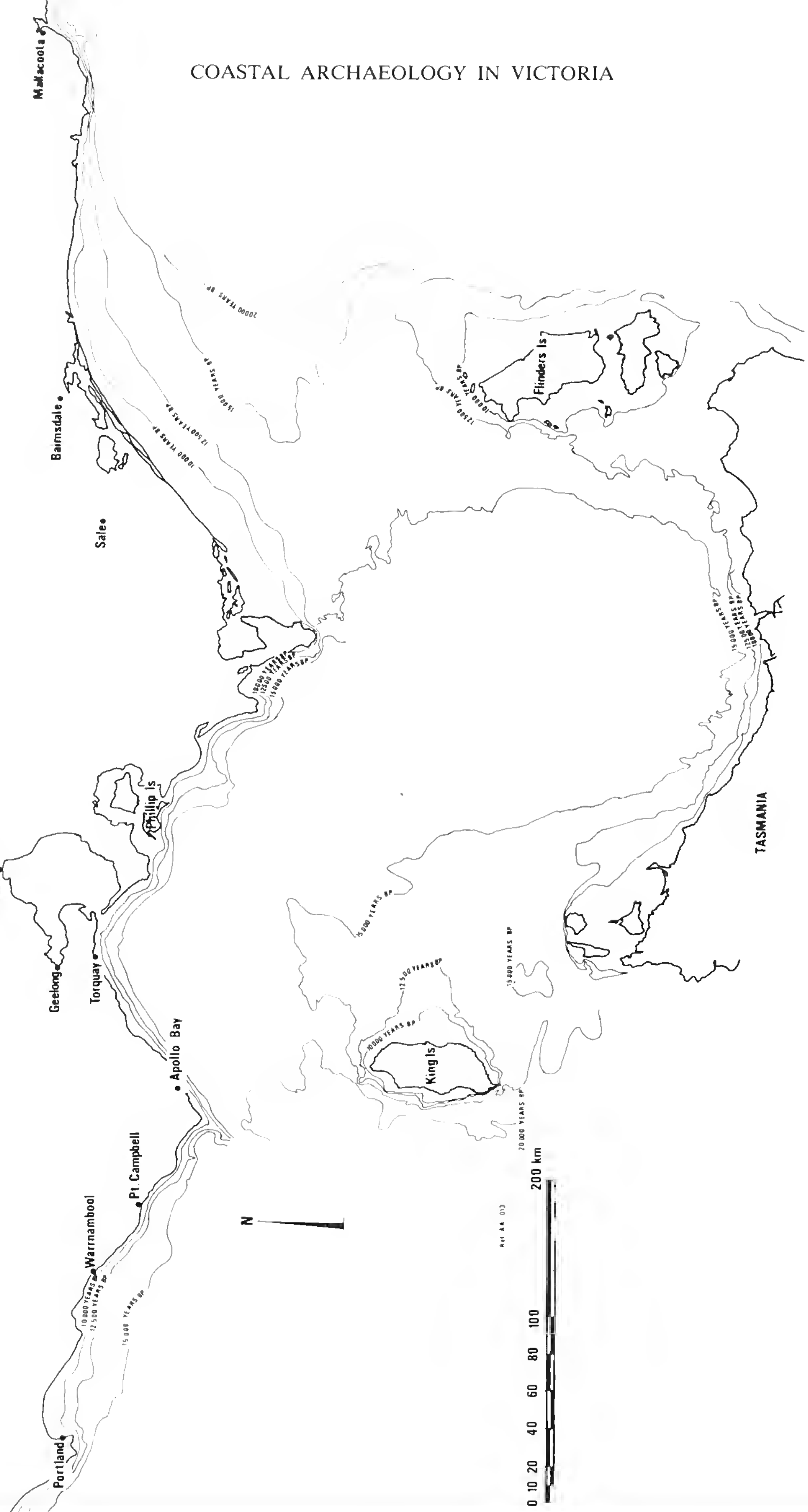


Fig. 1 – Approximate shoreline positions in Bass Strait during the post-glacial sea-level rise.

chaeological sites and in general, retouch is rare, there is little deliberate shaping of the flakes, and blade manufacture is minimal (Coutts 1970). At earlier sites a wide variety of implements were made from flint including most types of backed blade, bifacial choppers, and scrapers (Campbell & Noone 1941-43, Mitchell 1949).

(5) Inland, flint artefacts are found at Penola in South Australia; Willaura, Glen Thompson, Murtoa, Condah Swamp, Dooen Swamp, Inverleigh, Lake Bolac and at sites in the Grampians in western Victoria (Campbell & Walsh 1952, Coutts & Lorblanchet 1981, Mitchell 1949).

(6) On the shingle beaches at Port Macdonald in South Australia are large quantities of black rather brittle flint. Grey flints are often the most common components (being used extensively for backed blades) of flint assemblages on the Victorian coastline. Mulvaney (1962), in discussing his basically unretouched flint and bone assemblages from Glen Aire has noted that finely produced stone implements appear to be absent from late Victorian assemblages and he suggests that 'the basic industrial materials of recent Victorian prehistory were of organic origin', as opposed to stone.

Finely produced implements, such as backed blades, were no longer being made in any quantity at the end of the prehistoric period (Coutts 1981). However this does not necessarily mean that Aboriginals at any other time in prehistory were any less dependent on organic materials. As Mulvaney (1962) observed, 'these materials could not be expected to survive for archaeological discovery'; and it is this fact that makes it difficult to argue either way. The presence of certain classes of stone tools in more ancient Victorian sites, suggests that organic materials were being worked with them. There has also been a long tradition of working with bone in Victoria. At least one bone implement similar to those which were made several thousand years later at Glen Aire, has been found at Cloggs Cave in eastern Victoria (Flood 1974). It is not certain that a lack of retouch on tools—such as at Glen Aire—or the absence of finely worked implements, means that there was a reduction in the degree of stone tool use. The crux of the problem is an inability to recognise when a flake (retouched or otherwise) has been used.

No attempt will be made to resolve this dilemma here. However, a working hypothesis is proposed to explain why finely worked tools were abandoned in some parts of Victoria. It is based on premises of increasing population pressure and changing availability of raw materials, in particular, flint. Rising sea-level following the last glaciation, caused erosion of the Tertiary limestone outcrops, now below water, carrying quantities of flint nodules onto the shorelines of south-eastern South Australia and western Victoria where it was collected and used by Aboriginals.

It is not known how long it might take for the flint to find its way onto the beaches of Victoria in sufficient quantities to be regularly exploited. By 14 000 BP (Jennings 1971) the Bassian depression had been inundated, though Tasmania and mainland Australia were still connected by a land bridge through Wilsons Promontory and Flinders Island and the shoreline was within several kilometres of its present position.

Between 14 000 and 6000 BP the coastline stabilised. By at least 5000 BP flint had been washed up onto the beaches of Wilsons Promontory and was used by Aboriginals. If the frequency with which it was used at the Promontory is any indication of its local availability, it was not common 5000 years ago. However, 4000 years later it was a dominant material at coastal archaeological sites. During the late Pleistocene period it might be assumed that population levels in Victoria, as elsewhere in Australia, were increasing (Birdsell 1977) and that tribal and linguistic boundaries were continually adapting to changing environments and in response to changing population pressures. This period might be regarded as one of experimentation when Aboriginals were still discovering suitable outcrops for stone tool manufacture. It appears that they concentrated on exploiting sources of quartz, silcretes and quartzites, and to a much lesser degree, various other types of chert. After the close of the Pleistocene period, the Aboriginal population tended to increase or possibly stabilise, and pressure on stone resources would have increased. Moreover it is likely that the most visible and desirable sources of stone gradually became the property of small groups of Aboriginals.

At the end of the prehistoric period for example (about 1840 in Victoria) seven out of 35 Victorian tribes (Tindale 1974) had control of major 'flint catchment areas' along the coast. Five out of the seven tribes shared the Kulinic group of languages and distribution of flint implements tends to fall within the boundaries of the Drual sub-group of languages (Fig. 2, Oates & Oates 1970). Trade and exchange networks existed in the central Western District at the end of the prehistoric period and these could have sponsored the trading of flint between coastal and inland areas (Lourandos 1977, McBryde 1977, Mulvaney 1976).

Following Hayden's thesis (1977), there could have been a period of rationalisation as the value of some types of stone material increased. This period peaked after the introduction of a blade technology and the production of finely made implements such as backed blades. Since blade production can be inherently wasteful of materials, economy was achieved by utilising waste products to make utilitarian implements (Watson 1968). In South Australia and south-west Victoria the blade technology was applied to flint which became available about the time of the peak of the period. However sources of chert, jasper and other fine grained materials became less accessible to many Aboriginals and available sources of these materials probably diminished. As a result a much more utilitarian approach to the use of stone was adopted inland, leading to the demise of finely made tools, essentially because their

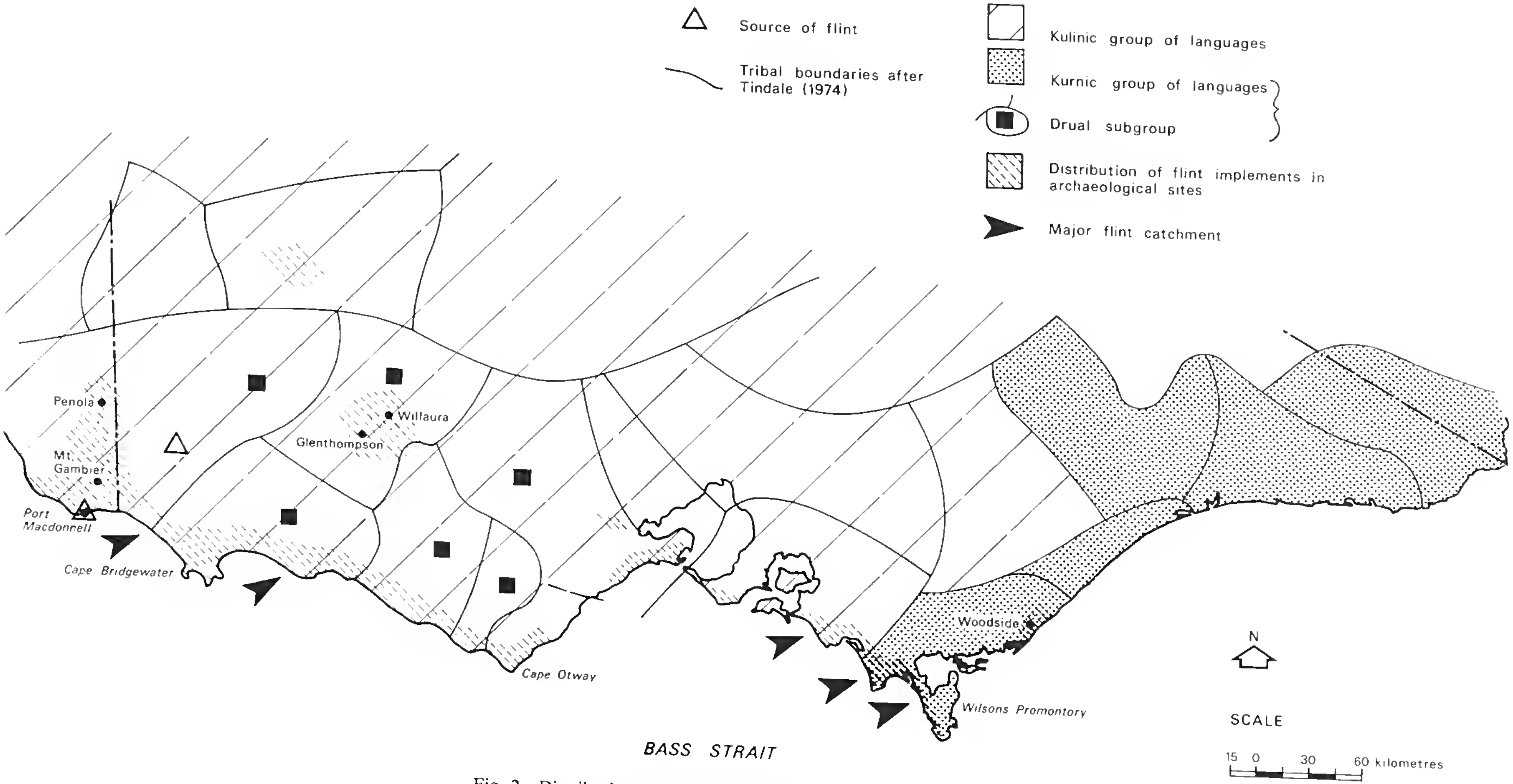


Fig. 2 – Distribution of flint and flint implements in Victoria.

manufacture was uneconomic and wasteful of stone resources. This trend spread to the coast where abundant flint materials were available and a 'throw away' technology developed.

These changes would not have happened everywhere simultaneously, but would have depended upon such factors as the availability of raw materials and the strength of local traditions pertaining to the manufacture of stone tools.

To test this theory and its variations more data are required on flint implements from coastal and inland sites, on the sources of flint, and on ways of assessing 'stone economy'.

VOLCANISM AND COASTAL ADAPTATION

Tower Hill, situated near the coast at Koroit in western Victoria, erupted during the Holocene period and had a pronounced effect on local physiography. The explosive eruption covered the landscape with ash which varied in thickness (Gill 1947, 1967). Moreover, the concommitant intense heat and bushfires would have killed off and burnt back the vegetation in the surrounding areas, and would have had dramatic effects on local wildlife. Consequently the eruption of this volcano probably precipitated a disjunction in social and economic patterns of Aboriginal groups. Ideally a range of archaeological materials need to be located above, below and within the ejectamenta so that cultural adaptations can be monitored.

DATE OF THE TOWER HILL ERUPTION

The Tower Hill eruption and deposition of tuff is presumed to have been a rapid event on the basis of the type of volcanism involved (Gill 1967) and the whole event may have taken place in something less than 50 years. Such a time span is not normally measureable in the archaeological record, though the effects of the eruption are manifested in all subsequent local records in the guise of tuff enriched sediments. If the date of the eruption can be established, the Tower Hill tuffs can be used as a chronological marker for the Warnambool district.

Gill (1953, 1955, 1967, 1972) has several dates from archaeological and geological deposits above, below and within the ejectamenta and the author has several from archaeological deposits above them (Coutts 1981). These dates need to be scrutinised carefully.

The date from Bushfield (Gill 1967), said to come from an archaeological horizon below the tuff (Coutts 1981: Table 7), can be excluded because it was obtained 'from the CO_2 fraction, and the provenance of the mineralisation is uncertain' (Gill 1967: 358). However, Gill (1978) considers that the dates of 6500 ± 200 BP (Gill 1967) obtained from marine shells from the Merri canal, and 6570 ± 115 BP (E. D. Gill pers. comm.) and 5850 ± 320 BP (Gill 1967) from marine shells of the Pertobe Coquina, which overlies the tuff, are reliable. A date of 8700 BP (E. D. Gill pers. comm.) has been obtained from a laminated mammillary calcrete at Dennington which is presumed to be the same age as the calcrete underlying the tuff at Thunder and Pickering Points.

Two suites of dates are available for midden deposits which clearly postdate the eruption: one from middens found within soil horizons associated with mobile dune systems at Armstrong Bay and the other from middens overlying the tuffs at Thunder Point.

The earliest C^{14} date for Armstrong Bay is 5680 BP (Campbell 1967) and is similar to Gill's earliest date of 5120 BP (Gill 1967). However our investigations (Coutts 1977, 1978) and those of Campbell (1967) failed to locate tuffs (which outcrop on the beach) underneath the dunes and the middens at the eastern end of Armstrong Bay. Gill (1953, 1955, 1967, 1971) on the other hand has found the tuff under the dunes on the western side of the Bay, near Gormans Lane, but this is well away from where the archaeological work has been conducted. Thus the relationships between the dunes, the middens and the tuff remain unclear in the eastern area, although Gill is certainly correct in concluding that the tuff is older than the dunes. A radiocarbon date from archaeological deposits a little above stratified tuff deposits at Thunder Point is 4130 ± 200 BP (Coutts 1977), and it can safely be assumed that the Tower Hill volcano erupted some time before this.

Some disagreement between Gill and the author persists over the interpretation of a date obtained from shells from Pickering Point. In 1972, Gill claimed to have found shells 'within the Tower Hill tuff which dated to 7300 ± 150 BP' (Gill 1972). The photographic record (Gill 1972), Gill's brief description of the site from which the C^{14} sample was taken, the results of the later textural analysis of the sediments plus archaeological excavations at Pickering Point to determine the stratigraphic context of the archaeological debris, suggest that what was dated were shells from dispersed archaeological debris recemented into tuff rich sediments sometime after the eruption. Hence the significance of the 7300 ± 150 BP date in the context of dating the Tower Hill eruption is unclear.

More recently Mortlock (1977) has attempted to date the Tower Hill ejectamenta directly by thermoluminescence dating; but as this results in the scoria predating the tuff, which is inconsistent with the geological evidence, these dates must be regarded as unreliable.

On evidence available at present, the Tower Hill volcano erupted between about 6600 and 8700 BP.

EVIDENCE FOR CULTURAL CHANGES

There are no reliable archaeological data from the period before the eruption of Tower Hill (Coutts 1976). For the post-eruption period, there are copious data from surface collections and from excavations at Thunder Point and Armstrong Bay.

Unfortunately stratigraphic and cultural evidence from Armstrong Bay is confused. Investigations by Gill have suggested that there are at least two soil horizons associated with the post-eruption coastal dune system and which are connected with Aboriginal occupation.

Gill (1955) dated occupational debris, which included large numbers of bone points from the latest of the two soils as 1750 ± 20 BP. More recently he reported that the bone industry was associated with the older soil horizon (Gill 1967). In contrast Kenyon (1912) and Mahony (1912) claimed that the bone points at Armstrong Bay came from the surface (confirmed later by Mitchell 1958), and Mahony went so far as to say that no Aboriginal material could be found in the oldest horizons of the deeper blowouts. Campbell (1967) concluded that there has been one period of soil development at Armstrong Bay. However his evidence is confusing because he obtained very different radiocarbon dates, 5680 BP and 1280 BP for two different exposures of this soil.

More recent archaeological work in this area (author), has revealed the presence of one soil horizon at the western end of the beach. A single radiocarbon date of 2450 BP for the upper part of the soil places it in the middle of the present sequence of radiocarbon dates for this area (Coutts 1981: Table 1). At the eastern end of the beach there is evidence for at least two closely spaced soils containing archaeological materials, within the beach face of the leading dune system, and dating from 570 ± 80 BP to 610 ± 110 BP and 2685 ± 110 to 2925 ± 95 BP respectively.

Judged on the dates alone, Aboriginals were exploiting the coastal resources at Armstrong Bay some 2000 years after the eruption. They camped intermittently in the vegetated areas of the dunes for the next 5000 years, and it is probable that throughout the history of the dune system at Armstrong Bay there may have been continuous soil development, punctuated by periods of dune stability and destabilisation during which parts of the vegetated landscape and the archaeological deposits were buried under loose sand.

A 3000 year old midden deposit in the leading edge of the present foredune suggests the coastline at that time was further seaward. Today these middens are approximately 3 m above high water mark and are covered by more than 6 m of sand.

A key feature of the Armstrong Bay site is the variety of faunal remains found in them. Gill (1967) and Campbell (1967) have suggested that the middens in the older soil horizons contain shellfish from both rock platforms and sandy beaches. Archaeological work in this area suggests that for a period of 2500 years shellfish collecting was confined to rock platforms with almost no evidence of exploitation of sandy beach animals. Today, the Armstrong Bay coastline is a sandy beach. Thus, if the ecology of predominant shellfish taxa found in middens reflects the type of coastline in the vicinity, it seems likely that the Armstrong Bay coastline has undergone a number of changes in physiography since the volcano erupted.

The same cannot be said of the middens at Thunder Point, which are on the tail of the volcanic ash shower and in a different physiographic situation. From 4300 BP until 800 BP there is no evidence of any significant shift in shellfish collecting strategies, although there is evidence that the coastline itself in the vicinity of Warrnambool has undergone significant changes over this period. Clearly one or more of the occupation phases at Armstrong Bay was associated with the manufacture of bone points, spatulates etc., (Coutts *et al.* 1976), and from at least 3000 BP Aboriginals utilised coastal flint, making a variety of tools including backed blades. They hunted a wide range of terrestrial animals but evidence of fishing is minimal. At Thunder Point, there is barely any material culture evidence as the site was associated almost exclusively with shellfish gathering.

CONCLUDING REMARKS

In these two papers discussion has been limited to aspects of coastal archaeology in Victoria. It is apparent that there are many varieties of coastal middens and that their interpretation has and will prove to be difficult. Indeed coastal archaeology in Victoria is still in its infancy. The need for intensive, long term regional and local studies cannot be over-stressed. Some of the most interesting areas will be adjacent to Port Phillip, Western Port, Tower Hill, the Gippsland Lakes, and Mallacoota Inlet.

ACKNOWLEDGEMENTS

My sincere thanks to Edmund Gill for his advice and for reading and commenting on this manuscript during its preparation. I would also like to thank Mr P. Kenny (Mines Department) and Ms A. McConnell (VAS) for comments on the geological aspects of this manuscript.

REFERENCES

The references listed below include only those which have not already been cited in Coutts 1981.

BIRDSELL, J. B., 1977. The recalibration of a paradigm for the first peopling of greater Australia. In *Sunda and Sahul: Prehistoric studies in south-east Asia, Melanesia and Australia*, J. Allen, J. Golson & R. Jones, eds, Academic Press, London, 113-167.

BOUTAKOFF, N., 1963. The geology and geomorphology of the Portland area, *Mem. geol. surv. Vic.* 22.

BOWDLER, S., 1977. The coastal colonisation of Australia. In *Sunda and Sahul: Prehistoric studies in south-east Asia, Melanesia and Australia*, J. Allen, J. Golson & R. Jones, eds, Academic Press, London, 205-246.

CAMPBELL, T. D. & NOONE, H. V. V., 1941-43. South Australia microlithic stone implements. *Rec. S. Aust. Mus.* 7: 281-307.

CAMPBELL, T. D. & WALSH, G. C., 1952. Aboriginal implements from campsites in the south of South Australia and Victoria. *Mankind* 4: 339-342.

CLARK, D. J., 1979. The Gambieran stone tool industry. B.A. Hons Thesis, Latrobe University (unpubl.).

COUTTS, P. J. F., 1967. Coastal dunes and field archaeology in south-east Australia. *APAO* 2: 28-34.

COUTTS, P. J. F., 1976. The prehistory of Victoria: a review. *Rec. Vict. Archaeol. Surv.* 2.

COUTTS, P. J. F., 1981. Coastal Archaeology in Victoria, Part 1: The morphology of coastal archaeological sites. *Proc. R. Soc. Vict.* 92: 67-80.

COUTTS, P. J. F., & LORBLANCHET, M., 1981. Archaeology and rock art in the Grampians, Victoria, Australia. *V.A.S. Rept.* (unpubl.)

Dodson, J. R., 1974a. Vegetation and climatic history near Lake Keilambete, western Victoria. *Aust. J. Bot.* 22: 709-717.

Dodson, J. R., 1974b. Vegetation history and water fluctuations at Lake Leake, south-eastern South Australia 1, 10 000 BP to present. *Aust. J. Bot.* 22: 719-741.

Dodson, J. R. & Wilson, I. B., 1975. Past and present vegetation of Marshes Swamp in south-eastern South Australia. *Aust. J. Bot.* 23: 123-150.

Gill, E. D., 1947. An hypothesis relative to the age of some western district volcanoes. *Proc. R. Soc. Vict.* 60: 189-194.

Gill, E. D., 1953. Geological evidence in western Victoria relative to the antiquity of the Australian Aborigines. *Mem. nat. mus. Vict.* 18: 25-92.

Gill, E. D., 1957. The Australian Aborigines and fossils. *Victorian Nat.* 74: 93-97.

Gill, E. D., 1971. Applications of radiocarbon dating in Victoria, Australia. *Proc. R. Soc. Vict.* 84: 71-88.

Gill, E. D., 1975. Calcrete hardpans and rhizomorphs in western Victoria, Australia. *Pacific Geol.* 9: 1-16.

Gill, E. D., 1978. Radiocarbon dating of the volcanoes of western Victoria, Australia. *Victorian Nat.* 95: 152-158.

Gill, E. D. & Hopley, D., 1972. Holocene sea-levels in eastern Australia. *Mar. Geol.* 12: 223-242.

Hale, H. M. & *Tindale, N. B.*, 1930. Notes on some human remains in the lower Murray Valley, South Australia. *Rec. S. Aust. Mus.* 4: 145-218.

Hayden, B., 1977. Sticks and stones and ground-edge axes: the upper Palaeolithic in south-east Asia. In *Sunda and Sahul: Prehistoric studies in south-east Asia, Melanesia and Australia*, J. Allen, J. Golson & R. Jones, eds, Academic Press, London, 73-112.

Hooley, A. D., Southern, W. & Kershaw, A. P., 1980. Holocene vegetation and environments of Sperm Whale Head, Victoria, Australia, *J. Biogeog.* 7: 349-362.

Hope, G. S. & Coutts, P. J. F., 1971. Past and present Aboriginal food resources at Wilsons Promontory, Victoria. *Mankind* 8: 104-114.

Hope, G. S. & Coutts, P. J. F., 1971. Past and present Aboriginal food resources at Wilsons Promontory, Victoria. *Mankind* 8: 104-114.

Hossfeld, P. S., 1966. Materials used in Australian Aboriginal stone implements. In *Aboriginal man in south and central Australia*, B. C. Cotton, ed., Government Printer, Adelaide, 163-168.

Jennings, J. N., 1971. Sea-level changes and land links. In *Aboriginal man and environment in Australia*, D. J. Mulvaney & Golson, eds, A.N.U. Press, Canberra, 1-13.

Kenyon, A. S., 1912. Camping places of the Aborigines of south-east Australia. *Vict. Hist. Mag.* 2: 97-110.

Lourandos, H., 1977. Aboriginal spatial organisation and population: south-western Victoria reconsidered. *APAO* 12: 202-225.

McBryde, I., 1977. Wil-im-ee Moor-ring: or, where do axes come from? *Mankind* 11: 354-382.

Mitchell, S. R., 1949. *Stone-age craftsmen.* Tait Book Co., Melbourne.

Mortlock, A. J., 1977. Progress in thermoluminescence dating. *Mem. Vict. Archaeol. Surv.* 1: 10-17.

Mulvaney, D. J., 1960. Archaeological excavations at Fromms Landing on the lower Murray River, S.A. *Proc. R. Soc. Vict.* 72: 53-85.

Mulvaney, D. J., 1970. Green Gully revisited: the later excavations. *Mem. natn. Mus. Vict.* 30: 15-78.

Mulvaney, D. J., 1975. *The Prehistory of Australia.* Penguin Books, Melbourne.

Mulvaney, D. J., 1976. The chain of connection: the material evidence. In *Tribes and boundaries in Australia,* N. Peterson ed., AIAS, Canberra, 72-94.

Mulvaney, D. J., Lawson, G. H. & Twidale, C. R., 1964. Archaeological excavations of rock shelter 6, Fromms Landing, S.A. *Proc. R. Soc. Vict.* 77: 479-516

Nicholls, M., ed., 1977. *The diary of the Reverend Robert Knopwood 1803-1838.* Tasmanian Historical Research Association, Launceston.

Oates, W. J. & Oates, L. F., 1970. *A revised linguistic survey of Australia.* Australian Aboriginal Studies No. 33, AIAS, Canberra.

Pretty, G. L., 1977. The cultural chronology of the Roonka Flat: a preliminary consideration. In *Stone tools as cultural markers*, R. V. S. Wright, ed., Prehistory and material culture series No. 12, AIAS, Canberra, 288-331.

Thom, B. G., Hails, J. R. & Martin, A. R. H., 1969. Radiocarbon evidence against higher post-glacial sea-levels in eastern Australia. *Mar. Geol.* 7: 161-168.

Thom, B. G., Hails, J. R., Martin, A. R. H. & Phipps, C. V. G., 1972. Post-glacial sea-levels in eastern Australia — a reply. *Mar. Geol.* 12: 223-242.

Tindale, N. B., 1957. Culture succession in south-eastern Australia from Late Pleistocene to the present. *Rec. S. Aust. Mus.* 13: 1-49.

Tindale, N. B., 1974. *Aboriginal tribes of Australia.* ANU Press, Canberra.

Watson, W., 1968. *Flint implements.* British Museum, London.

Wright, R. V. S., 1970. Flaked stone material from GGW-1. *Mem. natn. Mus. Vict.* 30: 79-92.

Wright, R. V. S., ed., 1971. *Archaeology of the Gallus Site, Koonalda Cave.* Australian Aboriginal Studies No. 26, AIAS, Canberra.

Yezdani, G. H., 1970. A study of the Quaternary vegetation history in the volcanic lakes region of western Victoria. Ph.D. Thesis, Monash University.

PAST AND PRESENT DISTRIBUTIONS AND TRANSLOCATIONS OF MACQUARIE PERCH *Macquaria australasica* (PISCES: PERCICHTHYIDAE), WITH PARTICULAR REFERENCE TO VICTORIA

By P. L. Cadwallader

Fisheries and Wildlife Division, Ministry for Conservation, Snobs Creek Freshwater Fisheries Research Station and Hatchery, Private Bag 20, Alexandra, Victoria 3714

Abstract: Details of past and present distributions and translocations of Macquarie perch in Victoria are presented. Prior to 1970 the species was recorded at 52 localities within its natural geographical range, in the Murray-Darling River system. Since 1970 it has been recorded at only 20 of these localities. Of the waters which are outside its natural range and into which it has been released, Macquarie perch has been taken in only three since 1970 and in only one with any regularity. In most waters, both within and outside its natural range, only relict populations remain. Siltation has probably been the main cause of the decline in range and abundance of the species in Victoria, but several other factors, including the construction of dams and weirs, interaction with introduced fish, overfishing, "river improvement" and local pollution, have probably all contributed to its demise. Data on the distribution of Macquarie perch outside Victoria are summarised.

INTRODUCTION

Past and present distribution patterns of Australian native freshwater fish are poorly documented. In addition, transfers of fish from one catchment to another often went unrecorded, thereby causing confusion for taxonomists who now try to elucidate the relationships between the various stocks of a species. However, there are more records for distributions of commercial or sporting fish than for many of the smaller species. In this paper, I have summarised data on past and present (post 1970) distributions and translocations of Macquarie perch, *Macquaria australasica* Cuvier and Valenciennes (Pisces: Percichthyidae), a native freshwater sport fish whose survival is now seriously threatened (Llewellyn & MacDonald 1980). Although I include some data on the distribution of the species outside Victoria, most of the information presented relates to the status of Macquarie perch in Victoria. Such information is a necessary prerequisite in any attempt to determine the factors responsible for the decline or elimination of Macquarie perch from specific areas and also as a basis for planning the release of hatchery-produced fish in the future.

METHODS

Information on the distribution of Macquarie perch was obtained from the following published works: Stead (1913), McKeown (1934), Butcher (1946), Whitley (1964), Roughley (1966), Lake (1967, 1971, 1978), Wharton (1968, 1973), Anon. (1973, 1974), Scott *et al.* (1974), Tunbridge & Rogan (1976), Cadwallader (1977, 1979), Cadwallader & Rogan (1977), Hungerford (1977), Wedlick (1977), Bishop & Bell (1978), Bishop & Tilzey (1978), Tunbridge (1978), Cadwallader & Eden (1979), Pratt (1979), and Llewellyn & MacDonald (1980), and from the records of the Victorian Piscatorial Council (V.P.C.), the Ballarat Fish Acclimatisation Society and the Fisheries and Wildlife Division of the Ministry for Conservation. The last source included the unpublished results of several fish surveys and an old manuscript entitled "Particulars of stocking streams with Murray perch, English perch and English tench, etc." covering the period 1909-1955. Information was also received in response to a circular distributed to angling clubs and to Fisheries and Wildlife officers throughout Victoria, and from general contact and correspondence with anglers in particular areas.

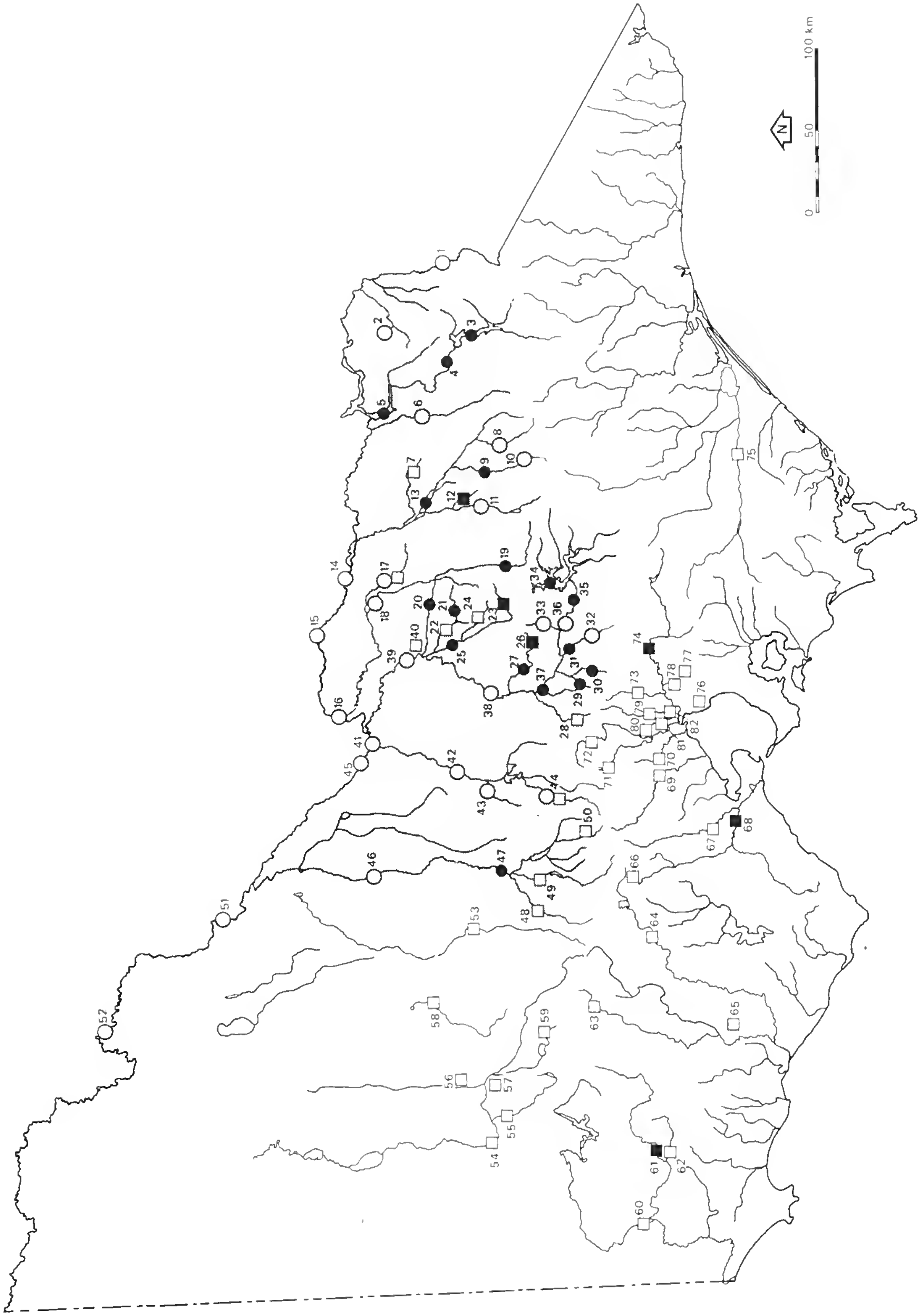
In addition, many Victorian waters known to have contained Macquarie perch in the past were surveyed by the author between 1975 and 1980, and by other Fisheries and Wildlife Division staff during routine survey work, particularly in relation to management of the trout fishery.

RESULTS

Distribution of Macquarie Perch in Victoria

The past and present distributions of Macquarie perch in Victoria are shown in Fig. 1. The natural geographical range of the species is confined to the Murray-Darling River system, north of the Great Divide, and this range is now much less than in the past (cf. open circles and solid circles in Fig. 1). There have been many recorded translocations of Macquarie perch both within and outside this natural range (Table 1) and the present status (post 1970) of Macquarie perch in the waters into which they have been introduced is indicated in Fig. 1 (cf. open squares and solid squares). In addition, there have been several transfers of Macquarie perch from natural waters to farm dams within the same catchment; details of these transfers are not included in this paper.

Several of the earliest records of translocations refer to "Murray perch", which probably included Macquarie perch as well as golden perch *Macquaria ambigua* (Richardson) and perhaps also silver perch *Bidyanus bidyanus* (Mitchell), although the last species was usually distinguished by the term "grunter". The terms "Murray bream" and "Goulburn bream" also occur in the early


0
50
100 km
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82

records; "bream" is the common name for Macquarie perch in some areas, but in other areas may also have applied to silver perch. Some of the early records of translocations of "Murray perch" are qualified by the term "of the Macquarie variety" (e.g. Table 1: the 1910 releases into the Yarra River) and several early records (from 1913 onwards) for the Yarra River refer to "Macquarie perch" being caught by anglers after earlier releases of "Murray perch". In the records of a series of translocations of "Macquarie perch" taken from the Goulburn Weir in 1922 (see Table 1), the consignments were reported to include small proportions of golden perch (about 5%) and silver perch (about 2.5%). Thus, although the species composition of the earliest translocations of "Murray perch" is in doubt, Macquarie perch probably formed the bulk of the fish, particularly of those fish taken in the Goulburn River catchment (from the Goulburn River itself, the Goulburn Weir or Broken River) from where many later batches of "Macquarie perch" were taken.

Fig. 1—Past and present distributions of Macquarie perch in Victoria. The grey shaded area indicates the presumed past distribution of Macquarie perch; ●, natural population still (post 1970) present; ○, natural population no longer present; ■, population derived from introduced fish, still present; □, introduced but no longer present. Key to locality numbers: 1, River Murray (Tom Groggin); 2, Berringamah Creek; 3, Dartmouth Dam and inflowing waters; 4, Mitta Mitta River; 5, Lake Hume; 6, Kiewa River; 7, Lake Sambell; 8, Buckland River; 9, Lake Buffalo; 10, Buffalo River; 11, King River; 12, Meadow Creek; 13, Ovens River; 14, River Murray (Burramine); 15, River Murray (Tocumwal); 16, River Murray (Barmah); 17, Boosey Creek; 18, Broken Creek; 19, Lake Nillahcootie; 20, Broken River; 21, Stony Creek; 22, Honeysuckle Creek; 23, Seven Creeks (upper reaches); 24, Faithfuls Creek; 25, Seven Creeks (lower reaches); 26, Hughes Creek (upper reaches); 27, Hughes Creek (lower reaches); 28, Sunday Creek; 29, Strath Creek; 30, King Parrot Creek; 31, Yea River; 32, Murrindindi River; 33, Home Creek; 34, Lake Eildon and inflowing rivers; 35, Goulburn River (Thornton); 36, Goulburn River (Cathkin); 37, Goulburn River (Seymour-Kerrisdale); 38, Goulburn River (Tabilk-Goulburn Weir); 39, Goulburn River (Shepparton); 40, Lake Victoria; 41, River Murray (Echuca); 42, Campaspe River; 43, Axe Creek; 44, Coliban River; 45, River Murray (Torrumbarry); 46, Loddon River; 47, Laanecoorie Reservoir; 48, Bet Bet Creek; 49, Deep Creek (=Tullaroop Creek); 50, Lake Daylesford; 51, River Murray (Swan Hill); 52, River Murray (Euston); 53, Avoca River; 54, Wimmera River; 55, Burnt Creek; 56, Marma Lake; 57, Taylors Lake; 58, Richardson River; 59, Mokepilly Creek; 60, Glenelg River; 61, Wannon River; 62, Grange Burn; 63, Hopkins River; 64, Mt. Emu Creek; 65, dam at Mortlake; 66, Lake Wendouree; 67, Moorabool River; 68, Barwon River; 69, Werribee River; 70, Kororoit Creek; 71, Middle Gully Creek; 72, Deep Creek; 73, Plenty River; 74, Yarra River; 75, La Trobe River; 76, dam at Cheltenham; 77, dam at Bayswater; 78, dam at Ringwood; 79, Edwardes Lake, Preston; 80, dam at Greenvale; 81, Coburg Lake; 82, Fish Hatchery at Studley Park.

DISTRIBUTION OF MACQUARIE PERCH OUTSIDE VICTORIA

Whitley (1964) mentioned that Macquarie perch occurred in the upper reaches of the Murray-Darling River system in southern Queensland, New South Wales, Victoria and South Australia and some eastern streams of New South Wales. However, there are no corroborative reports of Macquarie perch occurring in southern Queensland, and the occurrence of Macquarie perch in South Australia is based on one doubtful record from the Murray River (Scott *et al.* 1974). Reports of their occurrence in the River Murray upstream of the South Australian border have been incorporated into the distribution data for Victoria. Macquarie perch have also been recorded from the Edwards (or Kyalite) River; Wakool River; Wyangala Reservoir on the Lachlan River and in the Lachlan and Abercrombie Rivers upstream of the Reservoir. In the Murrumbidgee River catchment, they have been taken at Narrandera, Wagga Wagga and just below Burrinjuck Dam on the Murrumbidgee River itself; in Burrinjuck Dam and the Yass and Goodradigbee Rivers that enter it; near Tantangara Dam in the headwaters of the Murrumbidgee River; in the Cotter River system and the Cotter Reservoir; in Googong Reservoir and the Queanbeyan River that flows into it, and in the lower reaches of the Umeralla River. Macquarie perch have also been recorded in several coastal rivers and their tributaries in New South Wales, including the Hunter River; Gross River and Nepean River (Hawkesbury River catchment); Kangaroo River, Mongarlowe River, Northangara Creek and Tallowa Dam Impoundment (Shoalhaven River catchment); Clyde River; and Warrnambool River (Tuross River catchment); and in several Sydney water supply dams such as the Avon Reservoir.

Stead (1913) mentioned that the Macquarie perch occurring in the Shoalhaven, Hawkesbury and Hunter Rivers and "probably a number of others farther north" were of a smaller variety than those occurring in the Murray-Darling system. At present, the Macquarie perch in these coastal rivers are generally thought to have been introduced (by either Aboriginal or European man) from stocks occurring west of the Great Dividing Range, in the Murray-Darling River system, but there are no records of Macquarie perch having been transferred to these rivers (Bishop & Tilzey 1978). This is in contrast to the detailed description given by Stead (1913) of the transfer in 1912 of 414 Macquarie perch, ranging in length from 76 mm to 229 mm, from the upper reaches of the Murrumbidgee River near Cooma to the Snowy River near Dalgety.

According to Bishop & Tilzey (1978) the numbers of Macquarie perch in the Murray-Darling system in New South Wales appear to have been drastically reduced during the last 20 years, as also have the numbers of Macquarie perch in the Mongarlowe River. Pratt (1979) reports a similar decline in the numbers of Macquarie perch in the Canberra region, where the Macquarie perch populations are now small and localised.

TABLE 1
KNOWN TRANSLOCATIONS OF MACQUARIE PERCH IN VICTORIA
See text for further details and discussion of the terms "Murray perch" and "bream", etc.

Release locality				Source locality		
Name of water	Ref. No. (see Fig. 1)	Catchment	Date	Name of water	Ref. No. (see Fig. 1)	Catchment
A. *Translocations within the natural geographical range of Macquarie perch*						
Bet Bet Creek	48	Loddon River	1930	Goulburn Weir	38	Goulburn River
Boosey Creek	17	Broken Creek	1917	Not recorded	—	—
			1962	Broken River	20	Goulburn River
Coliban River	44	Campaspe River	1936	Broken River	20	Goulburn River
			1962	Broken River	20	Goulburn River
Lake Daylesford	50	Loddon River	1931	Goulburn Weir	38	Goulburn River
Deep Creek (= Tullaroop Creek)	49	Loddon River	1930	Goulburn Weir	38	Goulburn River
Faithfuls Creek	24	Goulburn River	1922	Stony Creek	21	Goulburn River
Honeysuckle Creek	22	Goulburn River	1937	Broken River	20	Goulburn River
Hughes Creek (upper reaches)	26	Goulburn River	1922	Goulburn Weir	38	Goulburn River
			1980	Dartmouth Dam	3	Mitta Mitta Rive
Meadow Creek	12	Ovens River	1973	Seven Creeks	23	Goulburn River
Lake Sambell	7	Ovens River	1928	Ovens River	13	Ovens River
Seven Creeks (upper reaches)	23	Goulburn River	1921	Goulburn River	36	Goulburn River
			1921	Seven Creeks (lower reaches)	25	Goulburn River
			1922	Goulburn River	36	Goulburn River
Sunday Creek	28	Goulburn River	1917	not recorded	—	—
Lake Victoria	40	Goulburn River	1937	not recorded	—	—
			1937	Broken River	20	Goulburn River
B. *Translocations to outside the natural geographical range of Macquarie perch*						
Avoca River	53	Avoca River	1927	Goulburn Weir	38	Goulburn River
Barwon River	68	Barwon River	1931	Lake Eildon	34	Goulburn River
			1935	Broken River	20	Goulburn River
			1938	not recorded	—	—
Burnt Creek	55	Wimmera River	1920	not recorded	—	—
Deep Creek	72	Maribyrnong River	1917	not recorded	—	—
Glenelg River	60	Glenelg River	1930	Goulburn Weir	38	Goulburn River
Grange Burn	62	Glenelg River	1922	Goulburn Weir	38	Goulburn River
			1926	Goulburn Weir	38	Goulburn River
Hopkins River	63	Hopkins River	1913	not recorded	—	—
Kororoit Creek	70	Kororoit Creek	1912	not recorded	—	—
La Trobe River	75	La Trobe River	1927	Goulburn Weir	38	Goulburn River
Marma Lake	56	Wimmera River	1922	Goulburn Weir	38	Goulburn River
Middle Gully Creek (= Riddells Creek)	71	Maribyrnong River	1926	Goulburn Weir	38	Goulburn River
Mokepilly Creek	59	Wimmera River	1913	not recorded	—	—
Moorabool River	67	Barwon River	1935	Broken River	20	Goulburn River
Mortlake, dam	65	Hopkins River	1920	not recorded	—	—
Mt. Emu Creek	64	Hopkins River	1920	not recorded	—	—
			1922	Goulburn Weir	38	Goulburn River
			1926	Goulburn Weir	38	Goulburn River
Plenty River	73	Yarra River	1912	not recorded	—	—
Richardson River	58	Wimmera River	1910	Goulburn Weir	38	Goulburn River
Taylors Lake	57	Wimmera River	1933	Wakool River	NSW	Murray River
			1935	not recorded	—	—
Wannon River	61	Glenelg River	1917	not recorded	—	—
			1920	not recorded	—	—
			1922	Goulburn Weir	38	Goulburn River

TABLE 1 (*Continued*)

Remarks
19 Nov.; 200 Macquarie perch released in Deep and Bet Bet Creeks at Maryborough.
200 Murray perch released in Boosey Creek at Tungamah.
50-100 small Macquarie perch released.
400 Macquarie perch netted near Nalinga on the Broken River released in the Coliban River downstream of Malmsbury Reservoir.
Macquarie perch taken in order to stock the Coliban and Campaspe arms of Lake Eppalock. Considered to be insufficient fish for a releas the wild, so the fish were stocked in farm dams in the Coliban-Campaspe catchment.
29 Jan.; 146 Macquarie perch released.
19 Nov.; 200 Macquarie perch released in Deep and Bet Bet Creeks at Maryborough.
300 small Macquarie perch released in the upper reaches of Faithfuls Creek.
Feb.; 200 Macquarie perch, average length 150 mm, released.
"18 tins" of cod, bream and golden perch taken to the Ruffy area and released in local waters.
6 Feb.; 32 Macquarie perch, TL range 215-390 mm and weight range 100-600 g, released in upper reaches of Hughes Creek.
15 Nov.; 28 Macquarie perch, 115-230 mm long, from the upper reaches of the Seven Creeks system released.
50 Macquarie perch, 150-400 mm long, released.
45 Macquarie perch taken at Cathkin on the Goulburn River released near Strathbogie above the Gooram Falls in the upper reaches of the S Creeks system.
About 50 small cod and Macquarie perch were taken in the Seven Creeks system below the Gooram Falls and released upstream Strathbogie.
167 Macquarie perch taken at Cathkin on the Goulburn River released near Strathbogie in the upper reaches of the Seven Creeks syste
Jan.; 200 Murray perch released in Sunday Creek at Broadford.
Oct.; 20 Macquarie perch released in Lake Victoria, Shepparton.
Nov.; 33 Macquarie perch released.
8 Nov.; 128 Macquarie perch released. 16 Nov.; 250 Macquarie perch released.
14 May; 80 Macquarie perch released in the Barwon River at Princes Bridge near Geelong.
April; 930 perch fry, lengths 60-215 mm, released in the Barwon and Moorabool Rivers.
April; 808 Macquarie perch released.
Dec.; 200 Murray perch, average length 150 mm, released in Burnt Creek near Horsham.
Jan.; 200 Murray perch released in Deep Creek at Romsey.
20 Nov.; 210 Macquarie perch released in Glenelg River at Casterton.
Feb.; 200 Macquarie perch, weight range 60-680 g, released in Wannon River and Grange Burn near Hamilton.
Nov.; 200 Murray perch released in Wannon River and Grange Burn near Hamilton.
Dec.; 100 Murray perch released in Hopkins River at Ararat.
50 Murray perch released in Kororoit Creek, Melbourne.
9-12 Nov.; 1072 Macquarie perch released in La Trobe River at Traralgon.
Feb.; 230 Macquarie perch, weight range 60-680 g, released in Marma Lake, Murtoa.
Nov.; 300 Murray perch released in Middle Gully Creek and Reservoir, Macedon.
Dec., 100 Murray perch released in Mokepilly Creek at Stawell.
April; 930 perch fry, lengths 60-215 mm, released in the Barwon and Moorabool Rivers.
Dec.; 100 Murray perch, average length 150 mm, released in dam at Mortlake.
Dec.; 200 Murray perch, average length 150 mm, released in Emu Creek (sic), Skipton.
Feb.; 320 Macquarie perch, from 60 to 680 g, released in Emu Creek (sic), Skipton.
Nov.; 200 Murray perch released in Emu Creek (sic), Skipton.
100 Murray perch released in Plenty River, south Yan Yean.
Nov.-Dec.; 454 Murray perch released in Richardson River at Donald; length and weight ranges of 18 tagged fish; 115-200 mm, 30-13
April; 88 cod and perch released.
April; 50 cod and perch, lengths 250-460 mm, released.
Jan.; 500 Murray perch released in Wannon River near Hamilton.
Dec.; 400 Murray perch, average length 150 mm, released in Wannon River, 200 at Coleraine and 200 at Hamilton.
Feb.; 375 Macquarie perch, from 60 to 680 g, released in Wannon River at Coleraine, and a further 200 of the same size range release Wannon River and Grange Burn, Hamilton.

TABLE 1 (*Continued*)

Release locality				Source locality		
Name of water	Ref. No. (see Fig. 1)	Catchment	Date	Name of water	Ref. No. (See Fig. 1)	Catchment
			1926	Goulburn Weir	38	Goulburn River
			1927	Goulburn Weir	38	Goulburn River
Lake Wendouree	66	Barwon River	1910	Goulburn Weir	38	Goulburn River
Werribee River	69	Werribee River	1920	not recorded	—	—
			1922	Goulburn Weir	38	Goulburn River
			1926	Goulburn Weir	38	Goulburn River
			1930	Goulburn River	38	Goulburn River
Wimmera River	54	Wimmera River	1910	Goulburn Weir	38	Goulburn River
			1920	not recorded	—	—
(?)			1922	Goulburn Weir	38	Goulburn River
			1926	Goulburn Weir	38	Goulburn River
			1938	Murray River	?	Murray River
			1948	Kyalite River	NSW	Murray River
			1949	Broken River	20	Goulburn River
			1950	Broken River	20	Goulburn River
Yarra River	74	Yarra River	1907/8	Goulburn River	38	Goulburn River
			1909	Goulburn Weir	38	Goulburn River
			1910	Goulburn Weir	38	Goulburn River
			1911	not recorded	—	—
			1912	not recorded	—	—
			1914	not recorded	—	—
			1915	not recorded	—	—
			1917	not recorded	—	—
			1920	not recorded	—	—
			1926	Goulburn Weir	38	Goulburn River
			1927	Goulburn Weir	38	Goulburn River
			1930	Goulburn River	38	Goulburn River
			1931	Goulburn River	38	Goulburn River
			1932	Goulburn River	38	Goulburn River
			1933	Goulburn River	37	Goulburn River
			1934	Goulburn River	?	Goulburn River
			1938	Broken River	20	Goulburn River
			1943	Broken River	20	Goulburn River
Miscellaneous lakes and ponds in or near Melbourne						
dam, Cheltenham	76	sea	1915	not recorded	—	—
dam, Greenvale	80	Yarra River	1915	not recorded	—	—
dam, Ringwood	78	Yarra R. or Dandenong Ck.	1920	not recorded	—	—
Edwardes Lake, Preston	79	Yarra River	1922	Goulburn Weir	38	Goulburn River
dam, Bayswater	77	Dandenong Creek	1922	Goulburn Weir	38	Goulburn River
Coburg Lake	81	Yarra River	1922	Goulburn Weir	38	Goulburn River
fish hatchery, Studley Park	82	Yarra River	1922	Goulburn Weir	38	Goulburn River
			1927	Goulburn Weir	38	Goulburn River

DISCUSSION

In their natural geographical range in Victoria, Macquarie perch have, during the last decade, been recorded at only 20 of the 52 localities where they had previously been recorded. Of these 20 localities, three (Meadow Creek and the upper reaches of both Hughes and Seven Creeks) are waters into which they were introduced from elsewhere within their natural range. Of the waters outside their natural range which have been stocked, only in three (Wannon, Barwon and Yarra Rivers) have Macquarie perch been taken since 1970, and only in the Yarra with any regularity. In most waters, both within and outside the natural range, only relict populations remain, with recent surveys recording only a few fish, in most cases often only single individuals, and anglers' reports similarly referring to the capture of only a few or single individuals. At present the largest population of Macquarie perch in Victoria is in the newly-formed Lake Dartmouth on the Mitta Mitta River. In the Goulburn River catchment there are several isolated populations,

TABLE 1 (*Continued*)

Remarks
Nov.; 200 Murray perch released in Grange Burn and Wannon River at Hamilton.
21 Nov.; 264 Macquarie perch released in Wannon River at Hamilton.
Nov.-Dec.; 494 Murray perch released in Lake Wendouree, Ballarat; length and weight ranges of 26 tagged fish: 100-220 mm, 14-140 g
400 Murray perch, average length 150 mm, released in Melton Weir on Werribee River.
Feb.; 1575 Macquarie perch, from 60 to 680 g, released in Melton Weir on Werribee River.
Nov.; 110 Murray perch released in Melton Reservoir on Werribee River.
19 April; 120 Macquarie perch taken at Tabilk released in Werribee River below the Exford Weir.
Nov.-Dec.; 250 Murray perch released in Wimmera River at Horsham
Dec.; 300 Murray perch, average length 150 mm, released in Wimmera River at Horsham.
Feb.; 450 Macquarie perch, from 60 to 680 g, released near Horsham (no waters mentioned).
Nov.; 350 Murray perch released in Wimmera River at Horsham.
April; 38 cod and Macquarie perch released in Wimmera River.
60 Macquarie perch and Murray cod released in Wimmera River.
July; 158 Macquarie perch released in Wimmera River at Eversley.
April; 156 Macquarie perch released in Wimmera River at Eversley.
500 Murray bream and perch from Tabilk released in Yarra River between Abbotsford and Heidelberg to supplement fish which had previo been introduced there.
Oct.-Nov.; 975 perch and bream released between Studley Park and Heidelberg; length and weight ranges of 48 tagged fish: 135-215 60-185 g.
Nov.-Dec.; 4431 Murray perch ("of the Macquarie variety"—V.P.C. records) released above Dights Falls (3100 fish), at Swan Street Bridge (and at Fairfield (575); length and weight ranges of 97 tagged fish: 100-255 mm, 14-215 g.
9-13 Nov.; 1000 Murray perch released above Dights Falls (400 fish), at Swan Street Bridge (400) and at Johnston Street (200).
1700 Murray perch released at Johnston Street.
Nov.; 100 Murray perch released at Fairfield.
Nov.-Dec.; 4325 Murray perch released at Studley Park.
Jan.; 4100 Murray perch released at Richmond.
Dec.; 2200 Murray perch, average length 150 mm, released at Swan Street Bridge (500 fish) and Studley Park (1700).
Nov.; 290 Murray perch released at Fairfield.
Macquarie perch released above falls (Dights ?): 500 on 14-15 Nov., 150 on 17 Nov. and 382 on 24 Nov.
April; 345 Macquarie perch, about 150 mm long, taken at Tabilk released in Yarra River between Dights Falls and Alphington.
12 March; 16 Macquarie perch taken at Tabilk released in Yarra River.
18 March; 54 Macquarie perch taken at Tabilk released at Heidelberg.
20 March; 24 Macquarie perch, 100-240 mm long, taken at Kerrisdale released at Fairfield.
14 Macquarie perch released near Burke Road Bridge.
208 Macquarie perch released at Warrandyte.
40 cod and perch released at Warrandyte.
Nov.-Dec.; 7 Murray perch and 2 grunters released.
Nov.-Dec.; 5 Murray perch and 2 grunters released.
Dec.; 200 Murray perch, average length 150 mm, released.
Feb.; 80 Macquarie perch, from 60 to 680 g, released.
Feb.; 50 Macquarie perch, from 60 to 680 g, released.
Feb.; 50 Macquarie perch, from 60 to 680 g, released.
15 Feb.; 20 Macquarie perch, from 450 to 910 g, placed in ponds at the hatchery.
"11 cans" of Macquarie perch sent to hatchery.

but only at one or two localities, Hughes Creek and the upper reaches of the Seven Creeks system, can the populations be considered viable. The population in the upper reaches of the Seven Creeks system was derived from fish liberated in the area in 1921-22 and has persisted, whereas the natural population of Macquarie perch in the lower reaches has been almost eliminated probably as a result of siltation (Cadwallader 1979).

Siltation has probably been the most important factor in the decline of Macquarie perch in Victoria (Cadwallader 1978). Although they may thrive in artificial impoundments, Macquarie perch naturally are riverine fish and are normally found in deep holes, but require shallow water flowing over a gravel-pebble-boulder substrate for spawning (Wharton 1968, Cadwallader & Rogan 1977). Silt, by filling the deep holes, destroys Macquarie perch habitat and, by settling on the river bed, provides conditions unfavourable for the demersal eggs of Macquarie perch. It also affects the composition of the benthic fauna which forms the main component of the diet of Macquarie perch (Cadwallader & Eden 1979). Significantly, most of today's riverine populations of Macquarie perch are in the upper reaches of catchments where siltation loads are not heavy and where there are still deep holes interspersed with shallow riffles.

The construction of dams and weirs for hydro-electric, irrigation and water conservation schemes has also played a role in the decline of Macquarie perch. Dams prevent Macquarie perch from moving upstream (see Appendix 3 in Cadwallader 1977). Moreover, since no dam in Victoria (including those on the River Murray adjoining Victoria) is fitted with multi-level water offtakes, water released downstream is taken from near the base of the water column and is too cold (e.g. 9°C from Lake Eildon) to induce spawning of Macquarie perch, which require a temperature threshold of 16.5°C for spawning during late spring-early summer (Wharton 1968, Cadwallader & Rogan 1977).

Interaction (including competition and predation) with introduced fish is another factor to be considered in the decline of Macquarie perch. For example, although the evidence is circumstantial, the European perch *Perca fluviatilis* (Linnaeus) has been implicated in the decline of Macquarie perch in Lake Eildon (Cadwallader & Rogan 1977). Various other factors, such as overfishing, "river improvement" and pollution (particularly that arising from spraying crops along river banks), have also probably contributed to the decline of Macquarie perch in some areas, but, again, no studies have been undertaken to examine the role of these factors in the decline of Macquarie perch.

ACKNOWLEDGEMENTS

I am grateful to the many people who provided data on the distribution of Macquarie perch. In particular, I thank Fisheries and Wildlife officers Pat Sheridan, Jack Rhodes and Jim Crozier for comments on the distribution of Macquarie perch in their areas of operation, and Charles Barnham (Fisheries and Wildlife Division) who unearthed the archival material on early translocations of Macquarie perch. I also thank Ray Donald who took part in most of the Macquarie perch surveys, Darwin Evans for his comments on the manuscript, and Keith Bishop (N.S.W. State Fisheries) for providing unpublished data on the distribution of Macquarie perch in New South Wales and for his comments on the manuscript.

BIBLIOGRAPHY

Anon., 1973. Native fish in the Campaspe and Coliban Rivers. *Fish Wildl. Div., Vic., Freshwat. Fish. Newsl.* 5: 18-19.

Anon., 1974. Endangered native fish. *Fish. Wildl. Div., Vic., Freshwat. Fish. Newsl.* 7: 9-15.

Bishop, K. A. & Bell, J. D., 1978. Observations on the fish fauna below Tallowa Dam (Shoalhaven River, New South Wales) during river flow stoppages. *Aust. J. mar. Freshwat. Res.* 29: 543-549.

Bishop, K. A. & Tilzey, R. D. J., 1978. *Welcome Reef Project Environmental Study—Aquatic Life.* Metropol. Wat. Sewerage and Drainage Bd., Sydney, 110 pp.

Butcher, A. D., 1946. *The Freshwater Fish of Victoria and Their Food.* Fish. Game Dept., Vic., 64 pp.

Cadwallader, P. L., 1977. J. O. Langtry's 1949-50 Murray River investigations. *Fish. Wildl. Pap., Vic.* 13, 70 pp.

Cadwallader, P. L., 1978. Some causes of the decline in range and abundance of native fish in the Murray-Darling River system. *Proc. R. Soc. Vict.* 90: 211-224.

Cadwallader, P. L., 1979. Distribution of native and introduced fish in the Seven Creeks River system, Victoria. *Aust. J. Ecol.* 4: 361-385.

Cadwallader, P. L., & Eden, A. K., 1979. Observations on the food of Macquarie perch, *Macquaria australasica* (Pisces: Percichthyidae), in Victoria. *Aust. J. mar. Freshwat. Res.* 30: 401-409.

Cadwallader, P. L., & Rogan, P. L., 1977. The Macquarie perch, *Macquaria australasica* (Pisces: Percichthyidae), of Lake Eildon, Victoria. *Aust. J. Ecol.* 2: 409-418.

Hungerford, R. (Ed.), 1977. *Complete Book of Australian Fishing.* Rigby, Adelaide. 1043 pp.

Lake, J. S., 1967. *Freshwater Fish of the Murray-Darling River System.* N.S.W. State Fish. Res. Bull. 7: 48 pp.

Lake, J. S., 1971. *Freshwater Fishes and Rivers of Australia.* Nelson, Melbourne. 61 pp.

Lake, J. S., 1978. *Australian Freshwater Fishes.* Nelson, Melbourne. 160 pp.

Llewellyn, L. C. & Macdonald, M. C., 1980. Australian freshwater basses and cods. In *Freshwater Fishes of South-eastern Australia*, R. M. McDowall, ed., Reed. Sydney, 142-149.

McKeown, K. C., 1934. Notes on the food of trout and Macquarie perch in Australia. *Rec. Aust. Mus.* 19: 141-152.

Pratt, B., 1979. *The Canberra Fisherman.* ANU Press, Canberra. 120 pp.

Roughley, T. C., 1966. *Fish and Fisheries of Australia.* Angus and Robertson, Sydney. 328 pp.

Scott, T. D., Glover, C. J. M. & Southcott, R. V., 1974. *The Marine and Freshwater Fishes of South Australia* (2nd Edition). Government Printer, South Australia. 392 pp.

Stead, D. G., 1913. An account of some experiments in the acclimatisation of two species of Australian freshwater perch. *Rept. Aust. Assoc. Adv. Sci.* 14(D): 279-288.

Tunbridge, B. R., 1978. A survey of the fish populations in the Mitta Mitta River and tributaries before the construction of Dartmouth Dam. In *Dartmouth Dam Project: Report on Environmental Studies.* S.R.W.S.C., Victoria.

Tunbridge, B. R. & Rogan, P. L., 1976. *A guide to the inland angling waters of Victoria.* Government Printer, Victoria. 149 pp.

Wedlick, L., 1977. *How to catch Redfin and other Australian Perch.* Wedneil, Melbourne. 80 pp.

Wharton, J. C. F., 1968. Spawning areas of the Macquarie perch *Macquaria australasica* above the Eildon Lake (Victoria). *Aust. Soc. Limnol. Newsl.* 6(1): 11-13.

Wharton, J. C. F., 1973. Spawning induction, artificial fertilization and pond culture of the Macquarie perch (*Macquaria australasica* (Cuvier 1830)). *Aust. Soc. Limnol. Bull.* 5: 43-65.

Whitley, G. P., 1964. *Native Freshwater Fishes of Australia.* Jacaranda, Brisbane. 127 pp.

THREE COROPHIOIDS (CRUSTACEA: AMPHIPODA) FROM WESTERN PORT, VICTORIA

By J. L. Barnard* and Margaret M. Drummond†

*Smithsonian Institution, Washington, D.C. 20560, USA
†National Museum of Victoria, 285-321 Russell Street, Melbourne, Victoria 3000

Abstract: Species in three genera of the superfamily Corophioidea are described for the first time in modern context. *Baracuma alquirta* gen. et sp. nov. (Ischyroceridae) lies close to the traditional *Cerapus* of the literature, a cosmopolitan genus of diverse form. A new species of the cosmopolitan *Laetmatophilus*, *L. dabberi*, (Podoceridae) is fitted into a world key. The unusual *Leipsuropus parasiticus* (Podoceridae) is redescribed.

New material of three corophioid Amphipoda from Victoria permits detailed descriptions of a new genus *Baracuma* (Ischyroceridae), a new species of *Laetmatophilus* (Podoceridae) and the unusual *Leipsuropus parasiticus* (Podoceridae). *Baracuma* is close to *Cerapus* and *Runanga* Barnard 1961. A key to the species of *Laetmatophilus* is provided to distinguish this new species within the genus. *Leipsuropus* is one of the most unusual gammaridean amphipods known because of the selective loss of uropod 2; generally, in an evolutionary cycle, gammaridean amphipods lose uropod 3 first and then uropod 2 but in *Leipsuropus* a small uropod 3 is retained.

The study was initiated and the major part of it carried out at the Marine Studies Group of the Ministry for Conservation in Victoria during J. L. Barnard's visit to Australia in 1976. Materials came from the two major benthic Surveys of Western Port: Crib Point Benthic Survey, 1964-5 (CPBS) and the Westernport Bay Environmental Study, 1973-4 (WPBES). The Australian Museum, by courtesy of Dr J. K. Lowry, Curator of Crustacea, loaned specimens from the Old Collection for use in the *Leipsuropus parasiticus* study, and made available type material for examination. Details of the Western Port Surveys have been published previously by Barnard and Drummond (1978) and much of the literature on Australian amphipods can be traced by consulting the same reference.

LEGENDS

Capital letters and numbers on the figures denote parts, as follows:
A, antenna; B, body or carcass; C, coxa; D, dactyl; E, epistome, left view; F, accessory flagellum; G, gnathopod; H, head; I, inner plate of maxilliped; J, ramus; K, variable, see legend; L, lower lip = labium; M, mandible; N, molar; O, palp; P, pereopod; Q, pleopod; R, uropod; S, maxilliped; T, telson; U, upper lip = labrum; V, brood plate; W, pleon; X, maxilla; Y, gill; Z, gland.

The figures each contain illustrations from a master specimen listed first in the caption of each figure and no lower case letters are placed on these figures; subsidiary specimens on each figure are denoted by lower case letters as specified in the caption for each figure.

SYSTEMATICS

Superfamily COROPHIOIDEA

Family ISCHYROCERIDAE

Three kinds of *Cerapus*—like genera are now recognizable. The first of these to be described as distinct from *Cerapus* was *Runanga* Barnard (1961) which differed markedly in many characters. Later, McCain (1969) described a second species, *Runanga waiora* which lessened the distance between the old concept of *Cerapus* and the more distant *Runanga*. To some extent our new genus also lessens this distance, but examination of species of so-called *Cerapus*, of which *C. tubularis* Say is the type-species, reveals generic distinctions.

Genus **Baracuma** gen. nov.

Diagnosis: Thorn-like appearance of rostrum weak. Article 1 of antenna 1 untoothed, articles 2 and 3 elongate, longer than article 1, primary flagellum much longer than any peduncular article, accessory flagellum absent. Antenna 2 slender, slightly longer than antenna 1, flagellum of male as long as article 5 of peduncle. Mandibular palp with 3 normal articles. Inner plate of maxilla 1 with one large seta. First 3 and last 2 coxae short, not touching serially; pereonite 2 in neither sex differentially elongate in comparison to pereonite 1; male coxa 1 much shorter than segment 1; coxa 5 of both sexes longer than pereonite 5, coxa 5 in female almost asetose and folding to meet partner ventrally; only female pereonite 5 much longer than pereonite 1. Gnathopod 1 normally subchelate. Gnathopod 2 in female simple though article 6 slightly inflated, article 2 not heavily setose anteriorly; gnathopod 2 in male very large, essentially carpochelate, these two teeth of carpus gaping. Article 3 of pereopod 4 elongate. Pleopod 3 with 2 rami. Uropod 3 with one small ramus. Uropod 2 with one vestigial, mostly fused ramus bearing 2 hooks. Telson narrow, cleft halfway, apices armed with rows of studs. Male with ventral keel.

Type Species: *Baracuma alquirta* gen. et sp. nov.

Relationship: In the absence of the type specimen of *Cerapus tubularis* Say 1817, and of an unequivocal diagnosis of the genus, comparison of *Baracuma* with

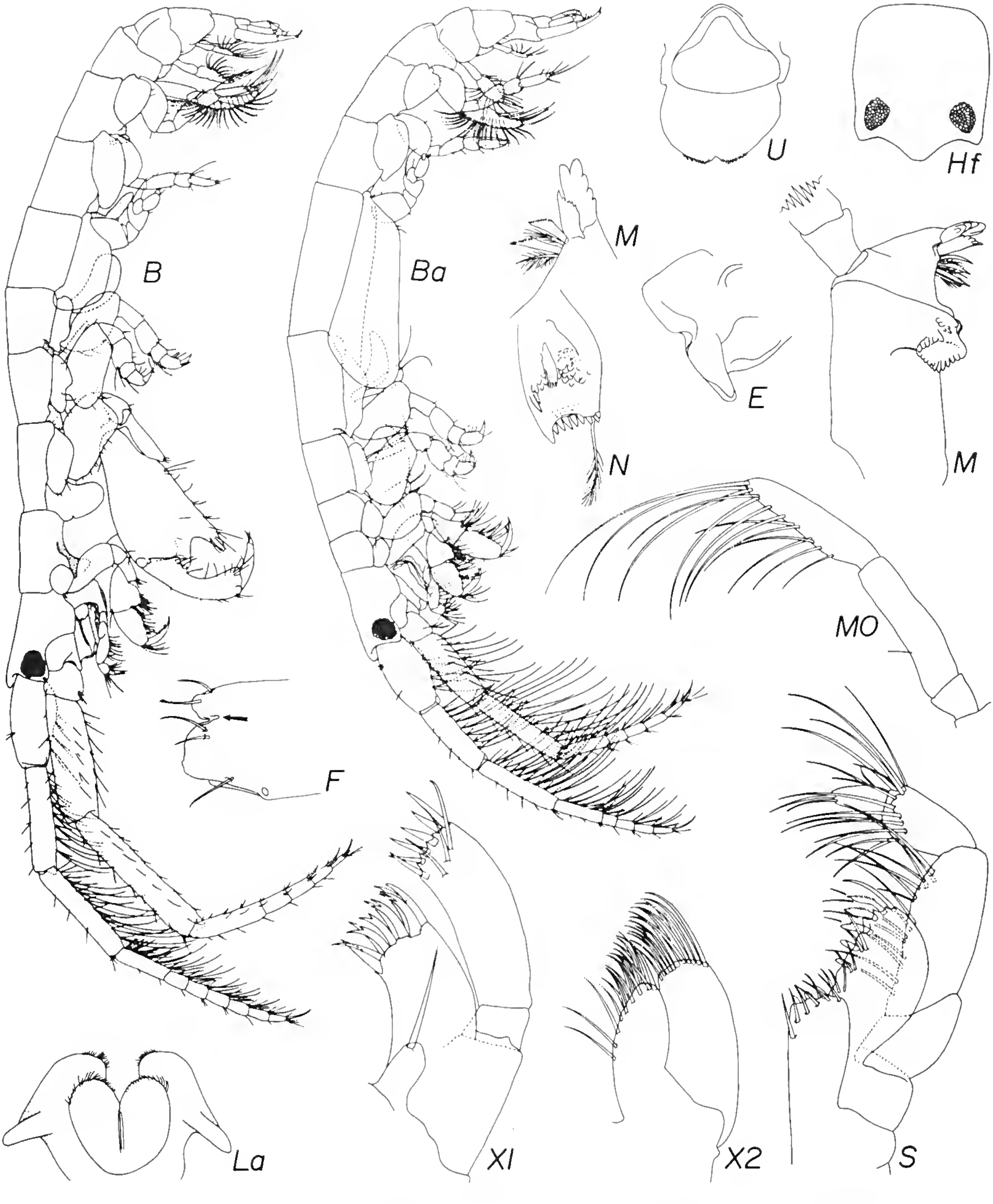


Fig. 1—*Baracuma alquirta* new species, holotype male "b" 3.92 mm; a = female "a" 3.56 mm; f = female "f" 3.40 mm.

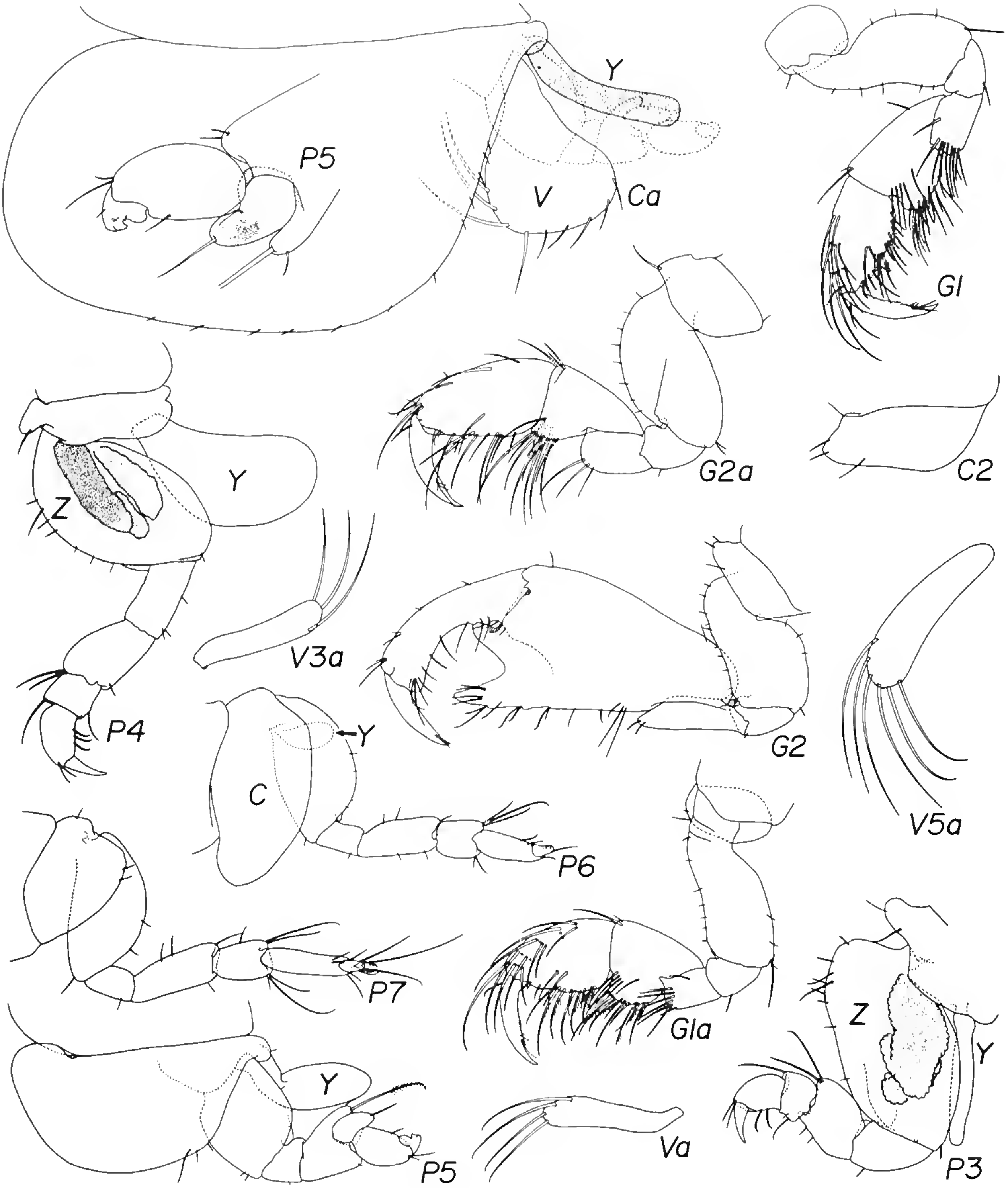


Fig. 2—*Baracuma alquirta* new species, holotype male "b" 3.92 mm; a = female "a" 3.56 mm.

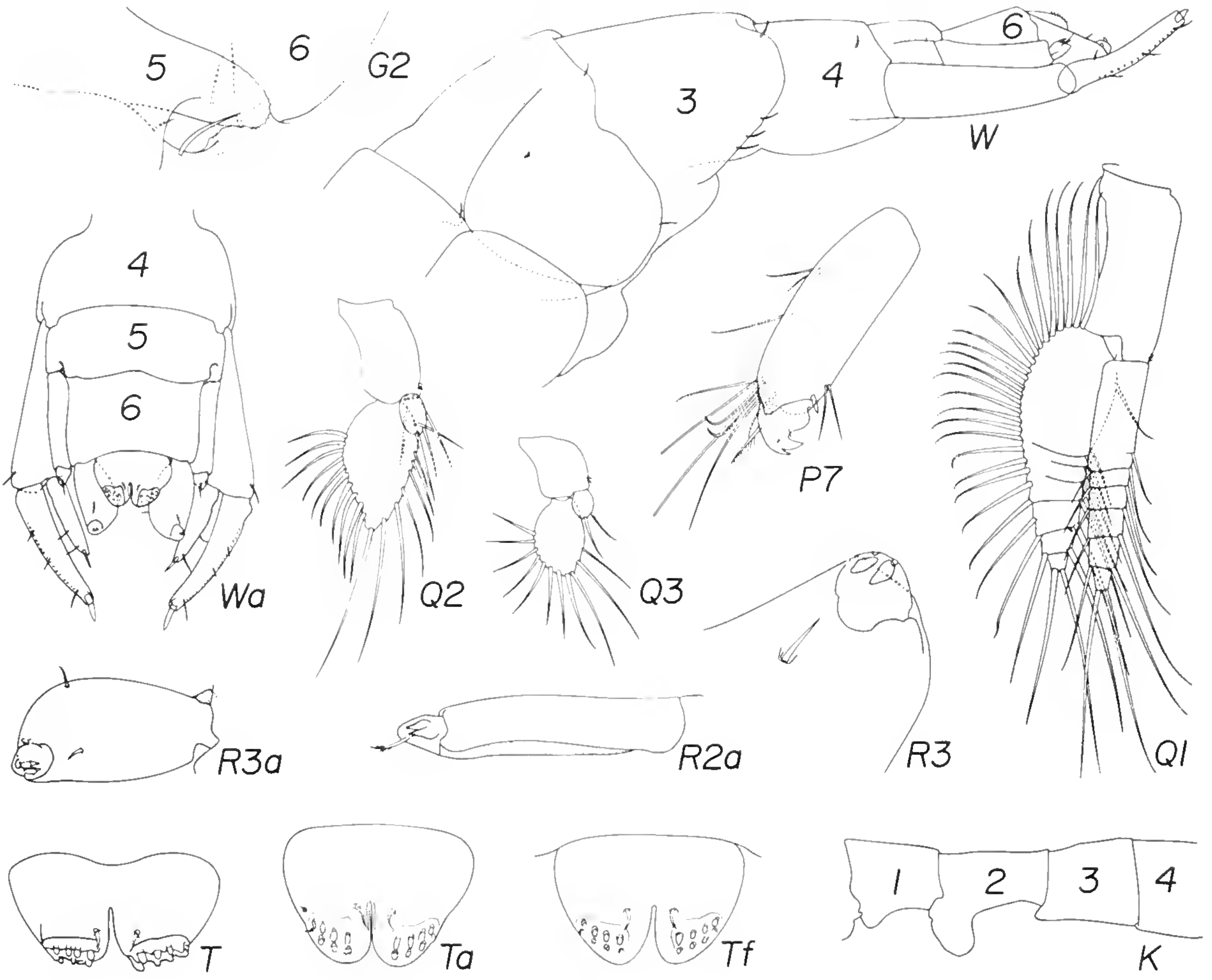


Fig. 3—*Baracuma alquirta* new species, holotype male "b" 3.92 mm; a = female "a" 3.56 mm; f = female "f" 3.40 mm; K = lateral thoracic sternites.

C. tubularis must be made from re-description of the species by S. I. Smith (1880), Stebbing (1906) and the illustrations of the female by Bousfield (1973). Whether Smith and Bousfield were even dealing with the same species seems uncertain in view of, for example, the difference in the telson, as illustrated, and in the relative lengths of the pereonites as described or figured by the two.

Smith found only 3 pairs of gills and 3 pairs of brood plates, but classic *Cerapus tubularis* specimens in Smithsonian collections have formulas identical with *Baracuma*. In a very detailed description, Smith did not mention either a ventral keel on the male nor an exceptionally elongate female coxa 5 with folding capability. Both are very noticeable features.

The genus differs from *C. tubularis* as conceived of from Bousfield's illustrations of the female, and from examination of specimens at the Smithsonian Institution, in the irregular form of coxae 1-4, the elongate coxa 5 of both sexes, the apically narrowed poorly cleft telson, and the male ventral keel. *Baracuma* differs from the classic *C. crassicornis* (Bate), as described and figured by Sars (1895), additionally, in the absence of a dorsal tooth on article 1 of antenna 1, and in the shorter, thicker second and third peduncular articles.

Baracuma differs from *Runanga* in the absence of an accessory flagellum, the longer coxa 5 and its folding capability in the female, the poor development of setae on female coxa 5, the lack of long dense setae on the anterior margin of article 2 of female gnathopod 2, and the narrow telson.

Runanga waiora McCain 1969 bears a scale-like accessory flagellum, has a broad telson, and does not have the special characteristics of female coxa 5 found in *Baracuma*.

Baracuma appears to be fairly close to the Australian species of *Cerapus*, but again, the narrow telson, the shape of female coxa 5, and the male ventral keel are strong distinctions. Australian species of *Cerapus* differ from the Northern Hemisphere concept of the genus in the lack of dorsal teeth on article 1 of antenna 1, the elongate articles 2 and 3 of antenna 1, the lack of sexual distinction on pereonite 1 and its coxa, and in the elongate article 3 of pereopod 4.

The narrow telson distinguishes *Baracuma* from all other *Cerapus*-like taxa. This telsonic form has the appearance of being most primitive in the group; but other adaptations, such as elongation of body segments and coxa 5, appear to be advanced characters.

Baracuma alquirta gen. et sp. nov.

Figs 1-3

DESCRIPTION OF THE MALE: Head as long as pereonite 5, the longest pereonite; pereonites 3 and 4 shortest. Rostrum short, blunt, broadly tapered. Eyes darkly pigmented. Peduncular articles of antenna 1 subequal in length, first article broad, dorsoventrally expanded, lacking distodorsal cusp; articles 1 and 2 long and rectangular; flagellum much longer than peduncular article 3, 7-articulate, first article nearly as long as combined length of next two; locus of accessory flagellum (near 2 setae) marked only by invagination attached to tangent reflecting internal ridge probably representing vestigial accessory flagellum. Peduncle of antenna 2 rather stouter than that of antenna 1, article 5 longer than article 4; flagellum subequal to or longer than article 5 of peduncle; first article longer than combined lengths of second and third.

Mandibular incisors with 6 teeth; left lacinia mobilis broad, right rather narrower, both toothed; left mandible with 3 rakers, right with 2; each molar with scaled flake, articles 2 and 3 of palp slender, subequal in length, only article 3 with setae.

Lower lip with inner lobes and short, splayed mandibular processes.

Inner plate of maxilla 1 small, with one long stout apical seta; outer plate with 11 spines; right and left palps alike with about 6 apical spine-setae and 3 subapical setae. Both plates of maxilla 2 apically setose, inner with a few widely-spread apico-medial and medial setae. Inner plate of maxilliped truncate, with 3 stout apical teeth and a crescent of apical setae; outer lobe spined, and with a few medial setae; article 2 of palp medially setose; article 3 with subapical spray of long setae; article 4 stout, blunt, tipped with 3 setae.

Coxae 1-4 very shallow, different from each other and irregular in shape. Coxa 1 very small, rounded, set on extreme anteroventral angle of pereonite 1; coxa 2 shorter than pereonite 2, attached well towards posterior margin of its pereonite, resultant gap between coxae 1 and 2 revealing distinctively enlarged part of ventral keel. Coxa 5 longer than pereonite 5, bulged anterodorsally to overlap coxa 4, and with vestigial posterodorsal lobe extending beyond posterior margin of pereonite. Coxa 6 larger than coxa 7, both irregular in shape. Coxal gills present on pereonites 3-6, largest and inflated on pereonite 4; strap-shaped on pereonites 3 and 5; very small on pereonite 6.

Gnathopod 1 subchelate, articles 5 and 6 subequal. Gnathopod 2 carpochelate, outer tooth on article 5 straight in line with posterior margin, deep sinus between outer and inner teeth; article 6 narrow, less than half as wide as article 5.

Article 2 of pereopod 3 broader than that of pereopod 4, bulging anteroproximally; article 3 of pereopod 4 longer than articles 4, 5 or 6. Pereopod 5 shorter and stouter than pereopods 6 or 7, articles 4, 5 and 6 inflated, articles 4 and 6 almost surrounding article 5; dactyl stout, recurved. Pereopods 6 and 7 similar, pereopod 7 slightly the longer, dactyls of both with broad, bulging base and two-toothed apex.

Epimera posteroventrally rounded; epimeron 3 with several short ventral setae.

Pleopods decreasing in size; pleopod 1 with 2 long setose rami, inner longer, outer broader; outer rami of pleopods 2 and 3 leaf-shaped, setose; inner rami of both very small, ovate.

Peduncle of uropod 1 reaching beyond the apex of urosomite 3; outer ramus longer than inner, with short lateral setae and apical spine. Uropod 2 with one very short ramus tipped with a seta. Peduncle of uropod 3 inflated; ramus vestigial, fused, with 2 apical and 2 accessory hooks.

Telson nearly 80% as long as wide, cleft about 50%, narrowing to rounded apices each with 2 sets of apical studs.

DESCRIPTION OF FEMALE: Antennae shorter than those of male, peduncle of antenna 2 relatively more slender; flagella of both antennae 5-articulate. Pereonite 5 much longer than in the male, longer than any other pereonite, though pereonite 4 also elongate; pereonites 1 and 2 shortest. Coxae 1-4 shallow, of different shapes; coxa 4 longer than 1, 2 or 3; coxa 5 enormously elongate, longer than pereonite 5, much longer than deep, almost asetose and folding to meet partner of opposite side in midventral line.

Hand of gnathopod 1 better developed than in male.

Brood plates present on pereonites 2-5; that on pereonite 5 large and distally expanded; others short and slender.

Pleopod 2 and epimera like male "b", but epimeron 3 with only 2 ventral setae. Pleopod 3 with only one seta on inner ramus, 10 on outer.

Ventral keel absent except for protruding support for maxillipede on sternite 1. Female otherwise resembling male.

Only domiciliary tube found in collection about 8 mm long, very dark, blackish-green in colour, round in section, broader at one end, smoothly and evenly constructed, containing female.

ILLUSTRATIONS: Maxilla 1 enlarged more than maxilla 2. Unfolded coxa 5 of female drawn to same enlargement as coxa 5 of male by overlaying respective fifth pereopods; brood plates of coxae 3 and 4 enlarged to this same degree. Gnathopod 1 and pereopods 3-7 at same magnification. Apex of pereopod 6 like that shown for pereopod 7. Male telson unflattened.

HOLOTYPE: NMV J1256, male "b" 3.92 mm.
TYPE LOCALITY: CPBS 41N/1, Australia, Victoria, Western Port. 24 Steptember 1973, 12.8m, fine gravel and sand with mud.
PARATYPES: Type-locality, female "A" 3.56mm, J1266, CPBS 32N/367, female "f" 3.40 mm, J1267; CPBS 12N, 1975, male, female in domiciliary tube, J1287.
MATERIAL: CPBS, 40 samples from 15 stations (92 specimens); WPBES, 7 samples from 5 stations (15 specimens).
DISTRIBUTION: Australia, Victoria, Western Port, 5-18.3 m, sand, gravelly sand, muddy sand, coarse sand and shell, coarse sand and mud.

Family PODOCERIDAE

Genus **Laetmatophilus** Bruzelius

Key to the species of *Laetmatophilus*

1. Head with one or more distinct dorsal teeth 2
   Head lacking distinct teeth 5
2. Pereonites transversely rugose but lacking multiple transverse teeth dorsally .... *L. tuberculatus*
   Pereonites with multiple transverse teeth dorsally 3
3. All pereonites with teeth on midline .... *L. hala*
   Some pereonites with teeth set sagitally in pairs on either side of midline 4
4. Anteroventral corner of head with sharp tooth, at least 5 pereonites and pleonites with 4 or more teeth each .... *L. hystrix*
   Anteroventral corner of head quadrate, only one pereonite or pleonite with more than 2 dorsal teeth .... *L. armata*
5. Outer ramus of uropod 1 much less than half as long as inner ramus (dactyl of male gnathopod 2 not overlapping palm) .... *L. dabberi*
   Outer ramus of uropod 1 more than half as long as inner ramus 6
6. Hand of gnathopod 1 very slender (incl. *L.* sp. Sivaprakasam 1970) 7
   Hand of gnathopod 1 stout 8
7. Dactyl of male gnathopod 1 fitting palm .... *L. durbanensis*
   Dactyl of male gnathopod 1 overlapping palm .... *L. leptocheir*
8. Palm of male gnathopod 2 with 2 teeth .... *L. purus*
   Palm of male gnathopod 2 with 3 teeth .... *L. tridens*

Laetmatophilus dabberi sp. nov.

Figs 4, 5

DIAGNOSIS: Head lacking dorsal teeth, anteroventral corner with small cusp, cephalic lobe with cusp, anteroventral corner of first antennal podium with small cusp. Pereonite 1 with 2 low transverse humps, pereonite 2 with one similar hump, pereonite 3 to pleonite 2 with dorsal hump or carina on midline, pleonite 3 weakly humped; pleonites laterally with plaques, especially in female; pereonites 5-7 coalesced. Coxae 2-4 with ventral points. Articles 2 and 3 of gnathopod 2 with sharp anteroventral cusp(s), articles 3-4 with sharp posterodistal cusp; dactyls of gnathopods 1-2 fitting palm; male gnathopod 2 palm with 3 teeth, 2 of these near defining corner sharp, third tooth flat and representing most of palm; female gnathopod 2 with strongly convex simple palm. Outer ramus of uropod 1 much less than half as long as inner ramus.

DESCRIPTION: See illustrations. Specimens mostly with missing appendages, only pereopods 4 and 6 of adult pereopods 3-7 recovered and illustrated; right and left gnathopod 2 of male "b" of different sizes (illustrated); young male gnathopod 2 like female. Gills thin, borne on coxae 2-7 in female, 2-6 on male; brood plates very broad and setose, borne on coxae 2-4. Peduncles of pleopods longer than wide, each with 2 coupling hooks, no other major setae, rami subequal, article 1 elongate, counts of articles on pleopods 1-3, outer and inner, of male "h" = 3-4, 5-5 and 5-5.

ILLUSTRATIONS: Detached antenna 2 of male "m" drawn to same enlargement as body of male "h". Medial texture on dactyl of gnathopod 1 with basal limit marked on Figure 5 G1h by dashed line, then enlarged in Figure 5 DG1h.

HOLOTYPE: NMV J1279 male "b" 3.64 mm.
TYPE LOCALITY: WPBES 1746/2, Western Port, 25 November 1974, 24 m, gravelly coarse sand, Victoria, Australia.
PARATYPES: Type locality, female "a" 3.14 mm J1280, juvenile "c" 1.91 mm J1282, male "m" 2.21 mm J1281, male "p" 2.60 mm J1283; WPBES 1747/3, female "f" 3.20 mm J1284, male "g" 3.34 mm J1285, male "h" 2.80 mm J1286.

RELATIONSHIP: The short outer ramus of uropod 1 coupled with lack of multiple teeth on body segments and unextended dactyl of gnathopod 1 distinguish this species from any others known. *Laetmatophilus hystrix* and *L. hala* from Australia and Hawaii respectively, have multiple teeth on body segments. The species in couplets 7 and 8, from Africa or the Indian Ocean, all have a much longer outer ramus of uropod 1 than does *L. dabberi*, those of couplet 7 also having a thin hand on gnathopod 1. Both *L. purus* and *L. tridens* have a male gnathopod 2 like *Podocerus* with the dactyl and palm occupying the full posterior margin of the hand.

MATERIAL: WPBES, 2 samples from 2 stations (9).
DISTRIBUTION: Australia, Victoria, Western Port, sand.

Genus **Leipsuropus** Stebbing 1899

Leipsuropus Stebbing 1899, p. 241; 1906, p. 698.
TYPE SPECIES: *Cyrtophium parasiticum* Haswell (monotypy). Unique.
DIAGNOSIS: Accessory flagellum vestigial; antenna 1 shorter than antenna 2; some coxae touching each other or weakly overlapping; pereonites 6-7 amalgamated; urosome with 3 segments, uropod 1 well developed, uropod 2 absent, uropod 3 forming small setose leaf lacking rami.
REMARKS: Barnard (1969) did not accept Haswell's and Stebbing's observations on the absence of uropod 2 but

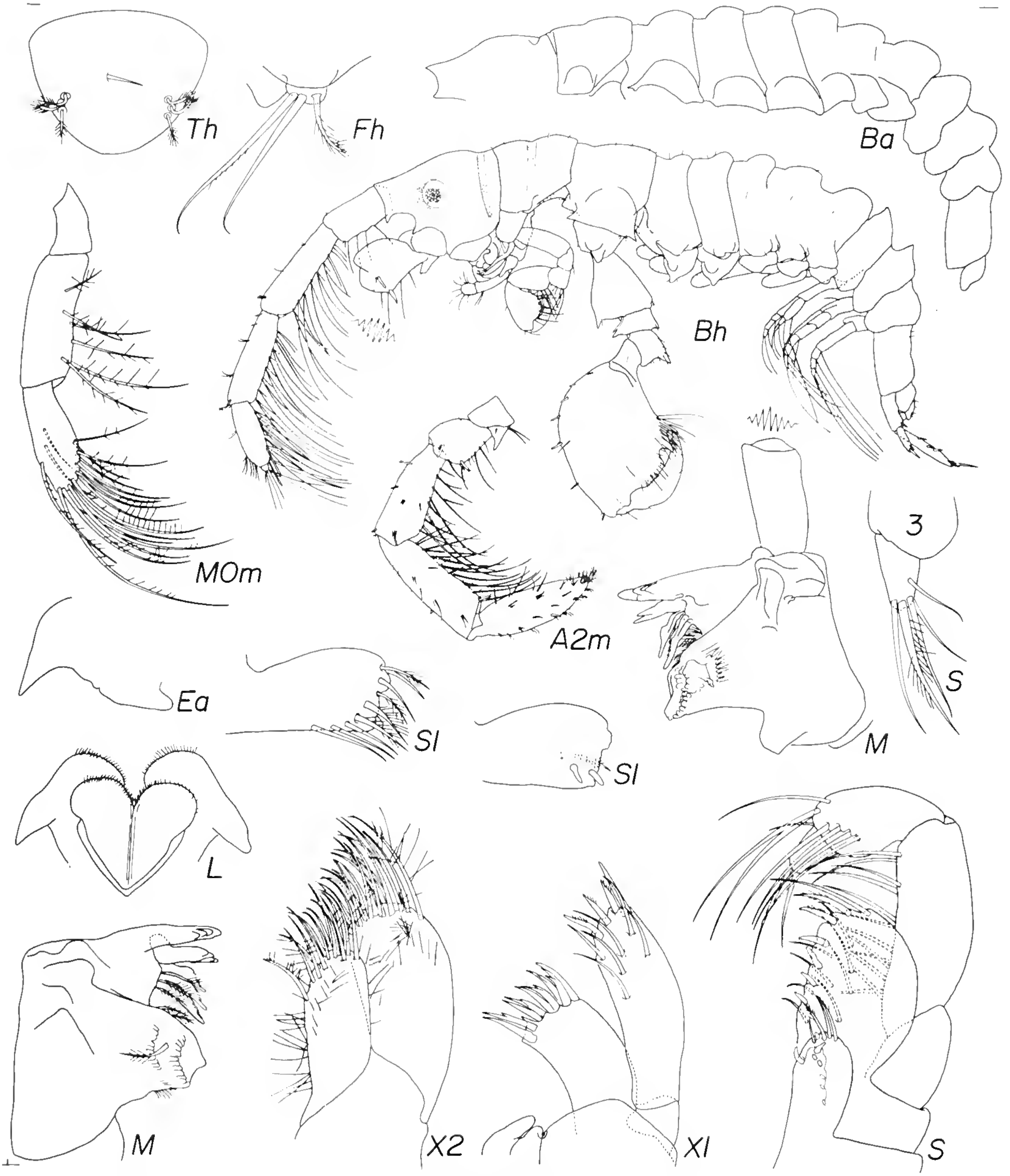


Fig. 4—*Laetmatophilus dabberi* new species, holotype male "b" 3.64 mm; a = female "a" 3.14 nm; h = male "h" 2.80 mm; m = male "m" 2.21 mm.

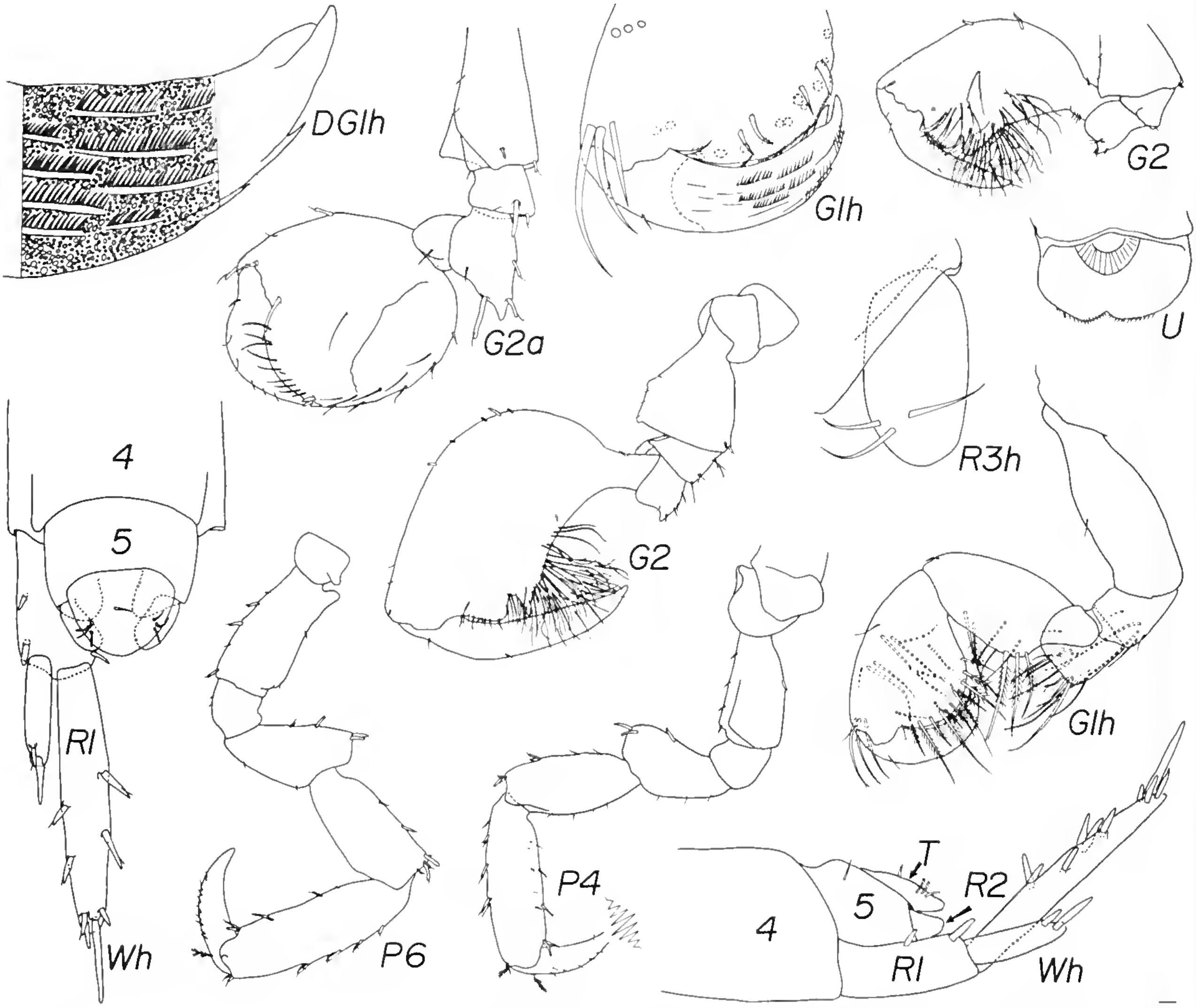


Fig. 5—*Laetmatophilus dabberi* new species, holotype male "b" 3.64 mm; a = female "a" 3.14 mm; h = male "h" 2.80 mm.

they were indeed correct as shown in the illustrations for the type-species presented below. The diagnosis is revised to show the presence of a vestigial accessory flagellum and the fusion of pereonites 6-7.

Leipsuropus parasiticus (Haswell 1879)

Figs 6, 7

Cyrtophium parasiticum Haswell 1879, p. 274; 1882, p. 271; 1885, p. 108, pl. 17 figs 1-7.
Leipsuropus parasiticus Stebbing 1906, p. 699; 1910, p. 650.

Description: Rostrum small, thin, blunt; ocular lobes forming lateral nacelles, apex of head broad in lateral view, forming weak cavity for reception of antenna 1. Article 2 of antenna 1 about twice as long as article 1, scarcely longer than article 3, primary flagellum composed of 4 articles together shorter than 3, first article elongate, accessory flagellum vestigial, antenna 1 strongly setose ventrally. Antenna 2 much larger than antenna 1, article 5 of peduncle almost 1.4 times as long as article 4, these two articles moderately setose ventrally, flagellum about as long as article 4 of peduncle, composed of one elongate article tipped with 2 vestigial articles.

Epistome with large anterior tooth, upper lip incised ventrally. Right mandibular incisor with 5 teeth, left with 4, right lacinia mobilis with 3 or 4 teeth, left with 4, right rakers 2, left 3, right molarial seta elongate, left short; palp article 3 short, clavate, heavily setose. Mandibular lobes of lower lip thin. Inner plate of maxilla 1 obsolescent, asetose, outer plate with 8 spines, right and left palps similar. Inner plate of maxilla 2 lacking submarginal setae. Palp article 4 of maxilliped short, stubby, with 2 apical rows of setae.

Coxae poorly setose; coxa 1 broadly produced anterodistally, boot-shaped; ventral margins of coxae 2-4 sinuate, coxae 2 and 3 rounded-quadrate, coxa 4

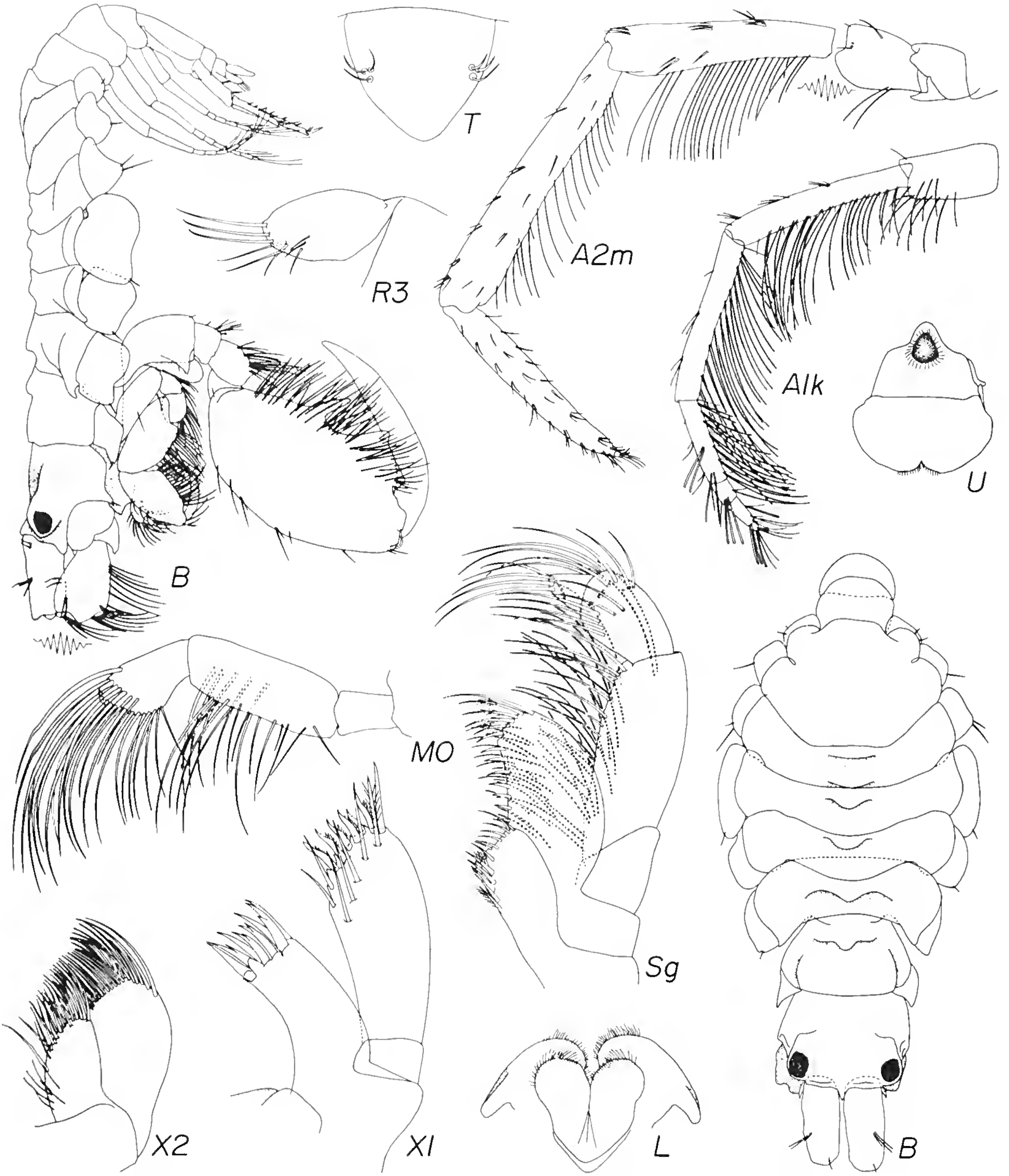


Fig. 6 – *Leipsuropus parasiticus* (Haswell), male "d" 2.95 mm; g = female "g" 3.32 mm; k = female "k" 2.85 mm; m = male "m" 4.41 mm.

broader than tall; female coxae 2-4 anteroposteriorly elongate, much broader than tall, sinuate, coxa 3 larger than coxa 2, coxa 4 very large.

Gnathopod 1 of both sexes similar, article 2 not cuspidate. Gnathopod 2 of male enlarged, article 2 with sharp apicolateral cusp, apicomedial lobe blunt and enlarged, articles 4 and 5 with posterior conical projection, article 5 almost obsolescent; hand large, longer than broad, palm carved into giant proximal defining tooth separated by large sinus from sinuate, irregularly scalloped distal marginal blade, entire palm and posterior margin of hand moderately setose, dactyl long, and in terminal males, strongly overreaching palm; female gnathopod 2 very small, appearing almost as if regenerant or stunted, articles 2, 4 and 5 unornamented, hand of simple gammarid type with almost transverse and simple palm and weak defining tooth, dactyl scarcely overreaching palm.

Articles 5-7 poorly setose on pereopods 3 and 4, more strongly on pereopods 5, 6 and 7.

Pereonites with transverse dorsal rugae, weaker in female than in male, pereonites 6 and 7 fused together; pereonites 2-3 and 4-5 with especially well developed anterior or posterior projections above coxae. Pleonites dorsally untoothed; epimera naked.

Uropod 1 well developed and spinose, outer ramus shorter than inner; uropod 2 absent; uropod 3 forming small setose leaf, lacking rami and hidden beneath telson. Telson broad, short, linguiform, each side with triad of dorsal penicillate setules.

Male "t", Port Jackson: Hand of gnathopod 2 five percent narrower than in figured male (measuring anterior margin to base of proximal tooth), main palmar projection and proximal narrow tooth much shorter than in figured male; hand thus appearing to be much narrower than in fully developed Victorian male but actual width scarcely distinct and most of narrowness owing to poorly developed sculpturing.

Observations: Most specimens lacking all or parts of antenna 2 and pereopods 5-7, often lacking pereopods 3-4, illustrated pereopods picked from different specimens, best specimen juvenile male "p" with pereopods 6 and 7 observed, article 5 of pereopod 5 stouter than that illustrated for male "n"; antenna 1 of male "m" as shown for female "k".

Intersexes: Intersexes were found at five Western Port stations:

(1) CPBS 32S/1, J1257: One individual (out of 13 in sample) with very large, asetose brood plates and typically female coxae 2-4 in addition to well developed penes. Gnathopod 2, though smaller than normal for a male of the size, larger than the normal female hand, with 2 proximal teeth and 2 sinuses, with the finger fitting into the most proximal sinus.

(2) CPBS 32S/367: One specimen (out of two) closely resembling the above. (In the Ministry for Conservation Marine Studies Division Collection.)

(3) CPBS 33N/3, J1276: One specimen, resembling the two above, but with only one palmar sinus.

(4) CPBS 35N/2, J1277: One specimen with half-grown, asetose brood plates and typical female coxa 4, well developed penes and broad, inflated gnathopod 2, bearing one proximal tooth and with one sinus.

(5) CPBS 61N/1, J1278: One specimen with large, asetose brood plates, female coxae 2-4 and well developed penes; but gnathopod 2 hand closer to male type, with fairly oblique palm.

Illustrations: Antenna 2 drawn to same magnification as antenna 1; spination obscured by agglutinates, probably not complete; female gnathopod 2 drawn as right sided attached to left coxa; female gnathopods 1-2, pereopod 3 and coxa 4 equally magnified.

Types: AM "G. 5388, *Cyrtophium parasiticum* Hasw., Port Jackson, *Type*, Old Coll 3 sp.", later added to card "3-4 fms 1879 P.T.O. 320.1"; 3 specimens mounted on white plate with gum in alcohol; one female and one male removed Nov 4 1976; female corresponds with illustrations herein; male gnathopod 2 satisfactory but urosome too occluded with deposit to determine identity; both specimens replaced in 2 tiny vials with white plate carrying third specimen. Special techniques will be required to remove occlusions from male to prepare as lectotype.

Other Material: Male "t" 3.40 mm, AM P3426, *Cyrtophium parasiticum* and 13 specs. Port Jackson Old Coll (= narrow-handed form).

Voucher Material: CPBS 32S/1, male "d" 2.95 mm J 1270, female "g" 3.32 mm J1269, female "k" 2.85 mm, J1268; WPBES 1746/2, young male "p" 2.55 mm, J1272, female "q", J1271; WPBES 1747/2, male "m" 4.41 mm, J1273, male "n" 4.35 mm, J1274.

Material: CPBS, 11 samples from 6 stations (26 specimens); WPBES, 3 samples from 3 stations (17 specimens); AM P3426, 1 sample (14 specimens).

Distribution: Australia, Western Port, Victoria, and Port Jackson, New South Wales, 12-24 m, sand, muddy sand, and muddy sand and gravel.

ACKNOWLEDGEMENTS

In an earlier paper (Barnard & Drummond 1978) acknowledgement of the help from many individuals and organizations during the Westernport Bay Survey was expressed and is reiterated here. In connection with the present study special acknowledgement is made to Dr Alistair Gilmour, Officer-in-Charge of the Marine Studies Group in 1976, and to Danuta Karpow, for technical assistance.

At the Smithsonian Institution thanks are due to Carolyn Cox and Irene F. Jewett who prepared the sketches for press, and to Elizabeth B. Harrison and Janice Clarke for technical assistance. The authors are deeply indebted to Dr Dillon S. Ripley, Secretary of the Smithsonian Institution, who made it possible for J. L. Barnard to come to Australia; and that author extends his personal thanks to members of the Marine Studies Group, and in particular to Dr Alistair Gilmour and Dr Jerry D. Kudenov, for many kindnesses during his visit.

This publication is No. 324 in the Ministry for Conservation, Victoria, Environmental Studies Series.

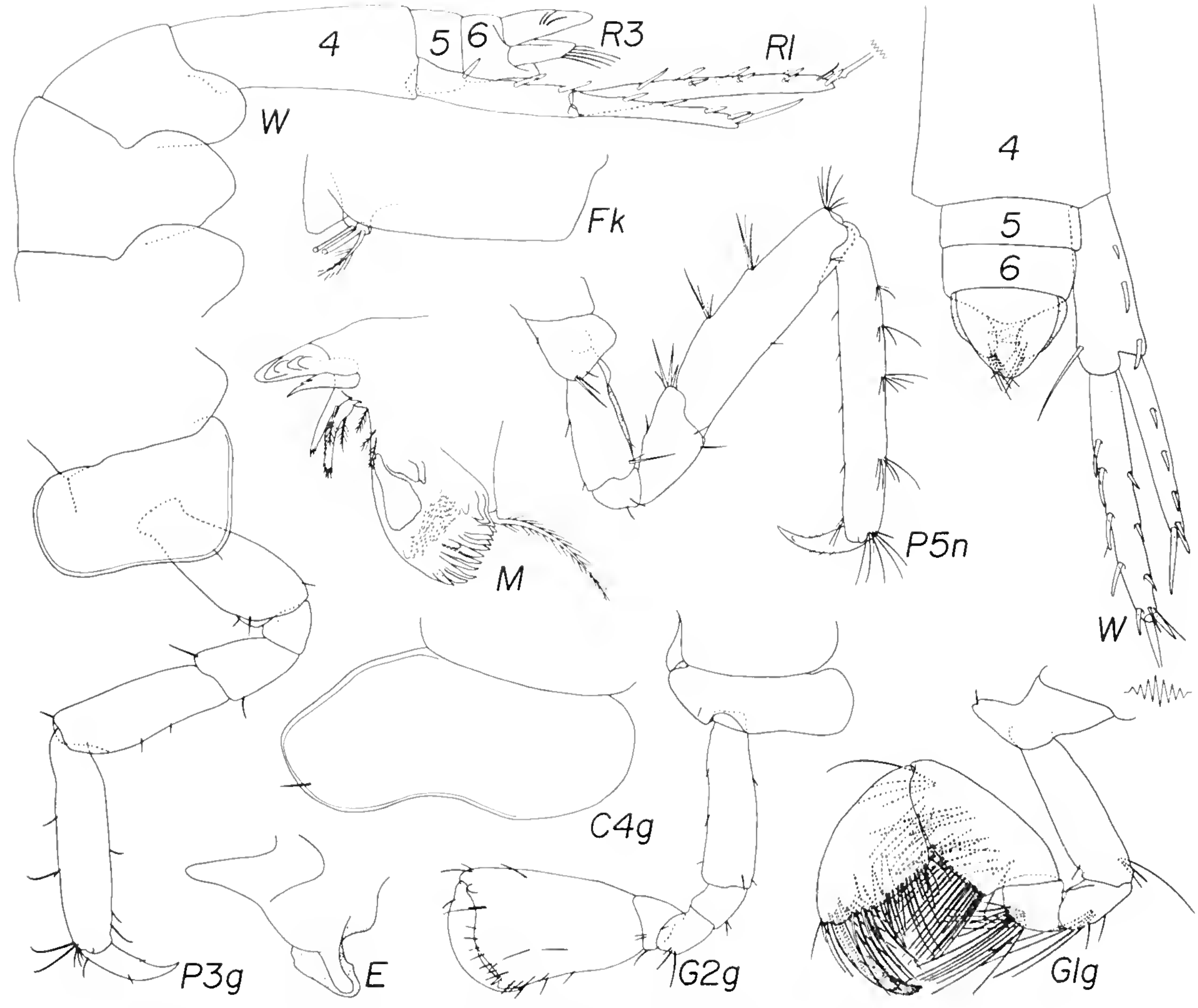


Fig. 7—*Leipsuropus parasiticus* (Haswell) male "d" 2.95 mm; g = female "g" 3.32 mm; k = female "k" 2.85 mm; n = male "n" 4.35 mm.

REFERENCES

Barnard, J. L., 1961. Gammaridean Amphipoda from depths of 400 to 6000 metres. *Galathea Rept.* 5: 23-128.

Barnard, J. L. & Drummond, M. M., 1978. Gammaridean Amphipoda of Australia, Part III: The Phoxocephalidae, *Smithsonian Contr. Zool.* 245: 1-551.

Bousfield, E. L., 1973. *Shallow-water Gammaridean Amphipoda of New England.* Cornell University Press, Ithaca.

Haswell, W. A., 1879. On Australian Amphipoda. *Proc. Linn. Soc. N.S.W.* 4: 245-279.

Haswell, W. A., 1882. *Catalogue of the Australian stalk-and-sessile-eyed Crustacea.* Aust. Mus. Sydney (plus addenda et corrigenda).

Haswell, W. A., 1885. Notes on the Australian Amphipoda. *Proc. Linn. Soc. N.S.W.* 10: 95-114.

McCain, J. C., 1969. A new species of deep sea amphipod (Gammaridea) belonging to the genus *Runanga. N. Z. J. mar. freshw.* Res. 3: 17-19.

Sars, G. O., 1895. *An account of the Crustacea of Norway with short descriptions and figures of all the species.* 1, A1b. Cammermeyers Forlag, Christiania.

Say, T., 1817. On a new genus of Crustacea and the species on which it was established. *J. Acad. nat. Sci. Philad.* 1: 49-52.

Sivaprakasam, T. E., 1970. A new species and a new record of Amphipoda from the Madras coast. *J. mar. biol. Ass. India* 10: 274-282.

Smith, S. I. 1880. On the Amphipodus genera, *Cerapus, Unciola,* and *Lepidactylis,* described by Thomas Say. *Trans. Conn. Acad. Arts Sci.* 4: 268-277.

Stebbing, T. R. R., 1899. On the true *Podocerus* and some new genera of amphipods. *Ann. Mag. nat. Hist.* ser 7, 3: 237-241.

Stebbing, T. R. R., 1906. Amphipoda 1. Gammaridea. *Das Tierreich* 21.

Stebbing, T. R. R., 1910. Crustacea. Part 5. Amphipoda. Sci. Res. Trawling Exped. H.M.C.S. "Thetis". *Mem. Aust. Mus.* 4: 565-658.

OSTRACODA FROM AUSTRALIAN INLAND WATERS—NOTES ON TAXONOMY AND ECOLOGY

By P. De Deckker

Zoology Department, University of Adelaide, Adelaide, S.A.
(Present address: Department of Biogeography and Geomorphology, Research School of Pacific Studies,
Australian National University, Canberra, A.C.T. 2601)

Abstract: One new ostracod genus, *Ampullacypris*, and ten new species of ostracods are described: *Candonocypris incosta, Cypricercus salinus, C. unicornis, Heterocypris vatia, Ilyodromus amplicolis, I. candonites, I. dikrus, Kapcypridopsis asymmetra, Limnocythere dorsosicula, L. milta.* Three other species are re-described, namely *Candonocypris novaezelandiae* (Baird 1843), *Cypretta baylyi* McKenzie 1966 and *Ampullacypris oblongata* (Sars 1896); 2 cosmopolitan species *Eucypris virens* (Jurine 1820) and *Sarscypridopsis aculeata* (Costa 1847) are recorded for the first time in Australia.

Ecological notes for these species as well as for *Limnocythere mowbrayensis* Chapman 1914 are presented.

INTRODUCTION

Knowledge of the taxonomy and ecology of ostracods from Australian inland waters is poor compared to that of other microcrustaceans, although ostracods are quite common in a variety of habitats. This paper presents new data on non-marine ostracods for use in future ecological studies and for studies of Quaternary material. Since ostracod shells are readily fossilized these data may be useful in palaeolimnological studies (see De Deckker 1981b).

Material for this study is deposited in the Department of Crustacea, National Museum of Victoria under the registry numbers: J1134-J1162. The following abbreviations are used in the text: C = carapace, H = height, L = length, LV = left valve, RV = right valve.

SYSTEMATICS

Subclass Ostracoda Latreille 1806
Order Podocopida Müller 1894
Superfamily Cytheracea Baird 1850
Family Limnocytheridae Klie 1938
Subfamily Limnocytherinae Klie 1938

Genus **Limnocythere** Brady 1867

Type Species: *Limnocythere inopinata* (Baird 1843).

Limnocythere dorsosicula n. sp.

Figs 1, 2a-j

Diagnosis: Member of *Limnocythere* with three to six small posterodorsal spines on the right valve; two small dorsal bosses separated by a main depression in the middle and never higher than the hinge in lateral view. Outline of hemipenis as in Fig. 1H.

Description: carapace (External)—Rectangular, faintly reticulated, and pitted to smooth; three main depressions on each valve: one in the centre where a vertical column of four muscle scars is often visible, another just above and a third in front just below the hinge line; greatest height at about one quarter to one fifth of length from anterior; greatest width at about 0.6 of length from anterior; right valve with three to six small spines along its edge posterodorsally; in dorsal view, anterior narrow and pointed; two small dorsal bosses, separated by the main depression in the middle, smooth, never higher than the hinge line in lateral profile. Sexual dimorphism pronounced—length:height ratio of valves greater in males.

(Internal)—Hinge with a broad tooth in right valve and a matching depression in the left one at both ends; inner lamella broadest anteriorly and peripheral selvage faint; radial pore canals numerous and straight from which many hairs protrude at a distance from the outer lamella anteriorly.

anatomy (Antennula)—(Fig. 1A) Six-segmented; length: width ratio of the last five segments: 2:1, 1:1, 1:1.3, 2:1, 4.2:1, longest distal seta bifid at about mid-length.

(Antenna)—(Fig. 1B) Two pectinate distal claws and another thinner and barren; distal segment small and squarish.

(Mandible)—(Fig. 1D) Mandibular coxale with seven teeth; palp with distal segment very small and squarish and with three thin setae; distal seta on penultimate segment thicker than the other three and pectinate.

(Maxillula)—(Fig. 1C) Distal palp elongate with three setae; 3rd lobe with three others, two of which are biramous.

(Maxilla)—(Fig. 1F) Short and stocky; no setae on 1st segment.

(Thoracopoda I)—(Fig. 1G) Longer than maxilla; distal end of 1st segment with two unequal setae; one at proximal end; another at mid-length.

(Thoracopoda II)—(Fig. 1E, J) Longer than thoracopoda I with distal claw almost twice its length and three times that of the maxilla claw; in female, setae pectinate but barren in male where the distal seta on the 2nd segment has a bifid tip.

(Hemipenis)—For outline see Fig. 1H.

(Genitalia)—For outline see Fig. 1I.

(Furca)—(Fig. 1H, I) One small and barren setae near the reproductive organs.

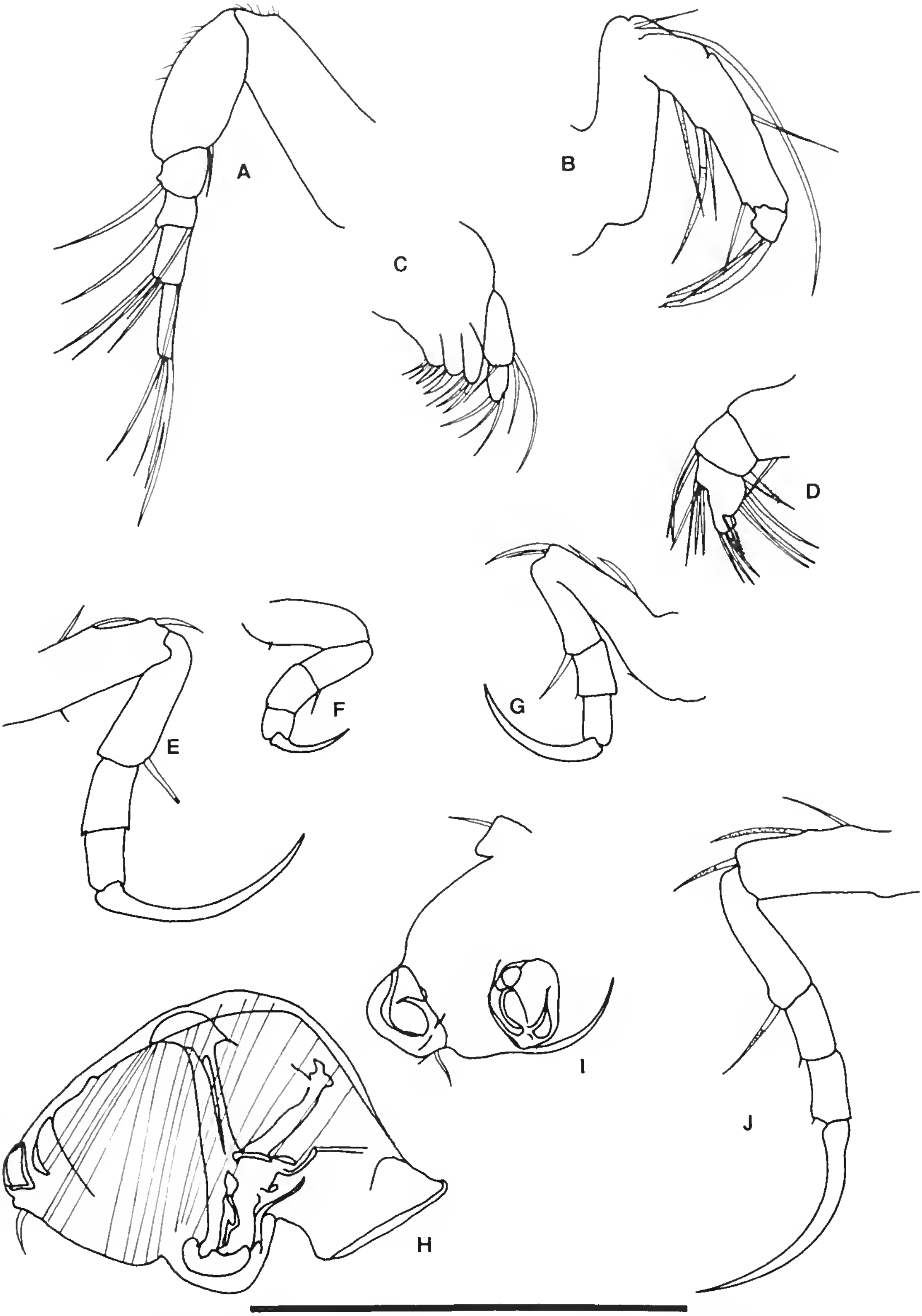


Fig. 1—*Limnocythere dorsosicula* n. sp. Lake Terangpom, Vic. A, B, E-H are drawn from the holotype adult male and C, D, I, J from the paratype female. Scale = 100μ. A, antennula. B, antennnna. C, maxillula—palp and lobes. D, mandible—palp. E, thoracopoda II. F, maxilla. G, thoracopoda I. H, hemipenis. I, genitalia. J, thoracopoda II.

COLOUR OF SHELL Light brown to transparent.

SIZE:

		L	H		L	H
holotype adult male	LV	410μ	230μ	RV	410μ	230μ
paratype adult female	LV	450μ	230μ	RV	450μ	230μ

TYPE LOCALITY: Lake Terangpom, west of Lake Corangamite, western Victoria.

DERIVATION OF NAME: From Latin *dorsum* (= black) and *sicula* (= small spine) for the diagnostic posterodorsal spines on the right valve.

ECOLOGY AND DISTRIBUTION: Only two collections of this species are known to me, one from Lake Terangpom in water of 2.03°/oo salinity and the other from South Nerrin Nerrin Lagoon in water of 1.96°/oo salinity, both in western Victoria. At first glance, it appears that this species is indicative of freshwater (<3°/oo) despite the fact that some species of *Limnocythere* live in saline waters (see *L. milta* n. sp. below and De Deckker 1981c). However, *L. dorsosicula* which has been recovered in many samples of a core from Lake George (see De Deckker 1981b), is found in some of these samples co-occurring with other ostracod species indicative of either fresh water or water of salinity <10°/oo.

REMARKS: *L. dorsosicula* is easily distinguishable from *L. notodonta* Vavra 1906 from west Java since the latter species has a maximum of four posterodorsal spines on the right valve. The anterior of the shell of the former species is narrow and pointed whereas in the latter species, the shell is much broader and rounded at both extremities. *L. dorsosicula* differs from *L. mowbrayensis* Chapman 1914 as the latter has broad alae, which are rounder or pointed and curved backward at about mid-height near the centre of the shell. Dorsal spines have also been noticed on one fossil juvenile specimen of *L. mowbrayensis* from Pillie Lake, S. A. (De Deckker 1981b), whereas this feature appears common on specimens from Pulbeena Swamp illustrated by Brehm (1939) for *L. percivali* (later synonymized to *L. mowbrayensis* by Hornibrook (1955) and Deevey (1955)). Hornibrook (1955), however, did not mention any spines on his specimens from the same locality. In addition, *L. mowbrayensis* is characterized by a dorsal boss at mid-length which extends above the hinge line when seen in lateral view. *L. stationis* Vavra 1891, which inhabits European waters, also possesses posterodorsal spines but only on the left valve.

Limnocythere milta n. sp.

Figs 2k-r, 3

DIAGNOSIS: Member of *Limnocythere* with faintly reticulated valve; with a vertical depression above the central muscle scars separating a small smooth boss anteriorly from the broad posterior; depression above and in front of the boss; row of fine denticles along the posteroventral margin of left valve. Maxilla and thoracopodae I and II with three long, pectinate setae on the inside of the 1st segment.

DESCRIPTION: CARAPACE (External)—Subrectangular and finely reticulated all over except for the anterior boss above and in front of the central muscle field and along the anterodorsal margin; this boss is separated from the posterior of the shell by a vertical groove just above the central muscle field; there is a depression adjacent to the boss dorsally which gives it a bilobate appearance in dorsal view; greatest height at about one quarter to one third of length from the anterior; mouth region concave and at about mid-length; dorsum gently curved; in dorsal view shell narrow, anterior pinched and pointed; greatest width at about 0.66 of length from the anterior; left valve slightly longer than right one posteriorly; shell compressed posteroventrally where the inner lamella is broad.

(Internal)—Inner lamella broad anteriorly in both valves and of almost similar width posteroventrally: posteriorly at mid-height and above, selvage absent; numerous straight radial pore canals from which many hairs protrude anteriorly at a distance from the outer margin; central muscle field with a vertical row of four scars; two narrow horizontal ones in the middle separated by two circular to oval ones; one antennal scar in front of the row at the level of the top scar and an additional scar above the vertical row of four; all these scars are met by depressions on the outside of the shell. Four to six minute spines along the margin of the left valve posteroventrally; hinge with broad tooth at both ends in the right valve with matching socket in the left valve; the posterior tooth is the largest.

ANATOMY (Antennula)—(Fig. 3A) Six-segmented; length width ratio of last five segments: 2:1, 1.2:1, 1:2, 1:1, 5:1; longest seta bifid at ⅓ from its base.

(Antenna)—(Fig. 3B) Three barren distal claws; distal segment almost rectangular.

(Mandible)—(Fig. 3C, D) Mandibular coxale with seven teeth, the inner two acicular; palp with distal segment almost squarish; at the distal end of the 1st segment, thick seta (α bristle?) stout, pointed and pilose; on 2nd segment there are four setae, two long ones and two pectinate and shorter (one is a β bristle?); distal end of third segment with one long and barren seta and another half its length and pectinate (γ bristle?); three unequal setae on distal end of last segment.

(Maxillula)—(Fig. 3E) Epipod with 14 long and one small plumose Strahlen plus a shorter barren one; palp two-segmented with distal segment rectangular; for chaetotaxy see Fig. 3E.

(Maxilla)—(Fig. 3F) Distal claw stout and curved; three thick and pectinate setae on inner side of 1st segment and a longer pectinate one near its base outside.

(Thoracopoda I)—(Fig. 3G) Similar to maxilla but larger.

(Thoracopoda II)—(Fig. 3H) Similar to thoracopoda I but larger and with no basal seta on the outside of the 1st segment.

(Genitalia)—Weakly chitinized (see Fig. 3I).

(Furca)—(Fig. 3I) Single barren seta.

(End of body) (Fig. 3J) With tuft of hairs and one biramous short seta.

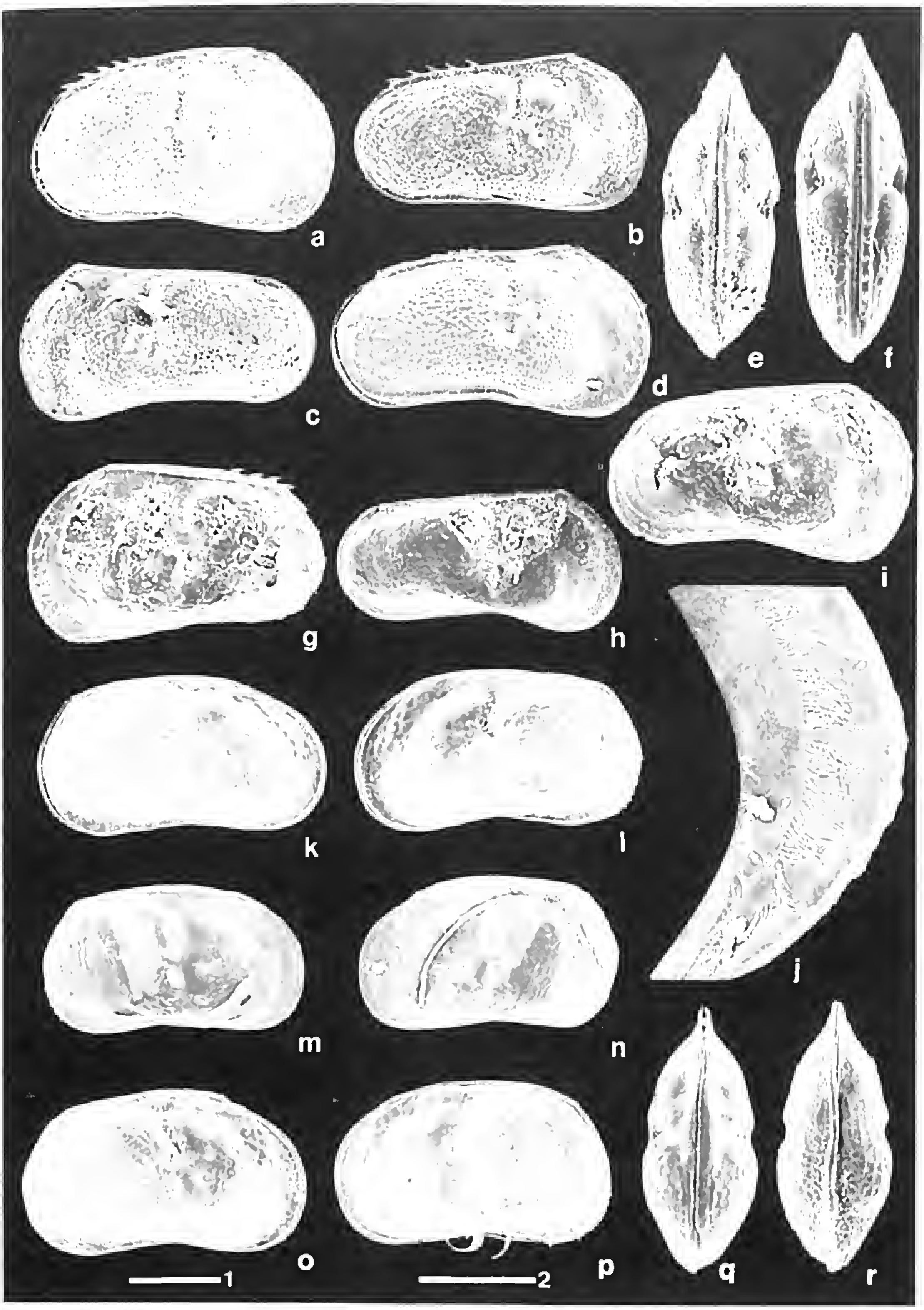


Fig. 2 – a-j, *Limnocythere dorsosicula* n.sp. Lake Terangpom, Vic. a, e, g, i, j female paratypes; b-d, f male paratypes; h male holotype. a, C showing RV. b, RV external. c, LV external. d, C showing RV. e, C dorsal. f, C dorsal. g, RV internal. h, LV internal. i, LV internal. j, anterior detail of i. k-r, *Limnocythere milta* n. sp. Small lake N.W. of Lake Werowrap, Vic. k, l, o-r female paratypes; m, n female holotype. k, C showing RV. l, LV external. m, LV internal. n, RV internal. o, RV external. p, C showing LV. q, C dorsal. r, C ventral. (Scales: 1 = 200μ for a-i, = 35μ for j; 2 = 200μ for k-r.)

Fig. 3—*Limnocythere milta* n. sp. Small lake NW of Lake Werowrap, Vic. Drawn from holotype adult female. Scale = 100μ. A, antennula. B, antenna. C, mandible—palp. D, mandible—coxale. E, maxillula. F, maxilla. G, thoracopoda I. H, thoracopoda II. I, genitalia. J, end of body.

COLOUR OF SHELL: Yellow to light brown.

SIZE:		L	H		L	H
Holotype adult female	LV	545μ	310μ	RV	540μ	310μ

TYPE LOCALITY: Small lake north-west of Lake Werowrap, Red Rock area, near Colac, western Victoria (38°15′23″S, 143°29′35″E).
DERIVATION OF NAME: From Greek *miltos* meaning red earth for the Red Rock area.
ECOLOGY AND DISTRIBUTION: *L. milta* is known only from the type locality where salinity was 15.42‰ and pH 9.5. This lake is known to dry up occasionally. No males have yet been found.
REMARKS: *L. milta* differs from *L. aspera* Henry 1923, as the latter does not possess the typical posteroventral spines along the margin of the left valve.

Limnocythere mowbrayensis Chapman 1914

1914 *Limnicythere mowbrayensis* Chapman p. 60.
1955 *Limnicythere sicula*; Hornibrook p. 268.
1955 *Limnicythere mowbrayensis*; Hornibrook, p. 268.
1978 *Limnocythere mowbrayensis*; McKenzie, p. 181.
1980 *Limnocythere* sp., De Deckker & Geddes, p. 691.
1981 *Limnocythere mowbrayensis*; De Deckker, p. 37.

DIAGNOSIS: Member of *Limnocythere* with almost straight dorsum and deeply concave ventrum; two large dorsal bosses, which, in lateral view, extend above the hinge line, are separated by a vertical groove which is situated above a vertical row of four muscle scars; in front of the row, there is a broad lateral process which, on most occasions, is pointed and curved backwards.
DISCUSSION: *L. mowbrayensis* has recently been redescribed by De Deckker (1981a). *Limnocythere* sp., briefly described by De Deckker and Geddes (1980) from an ephemeral salt lake near the Coorong Lagoon, is here considered to be *L. mowbrayensis* as it is almost identical to the specimens of *L. sicula* described by Chapman (1919), later synonymized by Hornibrook (1955) to *L. mowbrayensis*, as it has poorly developed lateral processes.
ECOLOGY AND DISTRIBUTION: *L. mowbrayensis* cannot swim: it is usually found crawling among filamentous algae. It is a fresh water species which can tolerate slightly saline waters up to 6‰. This upper record refers to the *Limnocythere* sp. of De Deckker and Geddes (1980) mentioned above, and is not surprising as some other *Limnocythere* species can inhabit saline waters (e.g. *L. milta*; see De Deckker 1981c).

L. mowbrayensis has also been recorded at 2.8‰ in Fresh Dip Lake, near Robe, S. A. Apart from the ephemeral locality near the Coorong Lagoon where *L. mowbrayensis* was collected only once, all other localities are permanent; this species has never been found in temporary pools.

L. mowbrayensis has been recorded from southern Australia (even Kangaroo Island) and as fossil from north-western Tasmania (from where it was originally described) and New Zealand.

Superfamily CYPRIDACEA Baird 1845
Family CYPRIDIDAE Baird 1845
Subfamily HERPETOCYPRIDINAE Kaufmann 1900

Genus **Candonocypris** Sars 1896

TYPE SPECIES: *Cypris candonioides* King 1855 (= *Candonocypris novaezelandiae* (Baird 1843).
DIAGNOSIS: Adult with smooth elongated shell and with broad inner lamellae anteriorly; selvage prominent and raised posteroventrally in the right valve. Two jointed sensory seta on the 2nd segment of the antennula. Thoracopoda II with two setae at mid-length on the last segment.
REMARKS: The opinion held by Sars (1894) that the well defined selvage placed far away from the edge of the right valve anteriorly was a diagnostic feature of *Candonocypris* species is no longer valid as this feature is not present in *C. incosta* which, on other features of the shell and anatomy, is considered here to be a true *Candonocypris*.

Two Australian species are included in *Candonocypris* namely, *C. incosta* n. sp. and *C. novaezelandiae* (Baird 1843). *Herpetocypris caledonica* Méhes 1939, from New Caledonia, definitely represents a *Candonocypris* species since he illustrated the distal segment of thoracopoda II with two setae at mid-length. No type material could be examined, as it has not been deposited in the Natural History Museum in Basle, Switzerland contrary to Méhes' (1939) indication. (C. Stocker pers. comm. 26 Jan. 1981).

Candonocypris incosta n. sp.

Figs 4, 5

1914 *Candona lutea*; Chapman, p. 59, fig. 6.
1971b *Ilyodromas* cf. *smaragdinus*; McKenzie, p. 396.
1977 *Ilyodromus* cf. *smaragdinus*; Danielopol & McKenzie, p. 309.

DIAGNOSIS: Member of *Candonocypris* with peripheral selvage anteriorly in both valves and broad and near the outer margin in the posterior of the right valve.
DESCRIPTION: CARAPACE (External) — Smooth and elongated, ellipsoid shell with dorsum arched and with ventrum flat except in front of the middle where it is slightly concave. Both ends of the valves tapering but posterior more pointed. Greatest height at about mid-length. Shell narrow in dorsal view. Obvious overlap of the left valve antero- and posterodorsally.

(Internal) — Inner lamellae similar in both valves anteriorly and approximately twice as broad anteriorly compared to the posterior area. Selvage peripheral anteriorly and only prominent posteroventrally in the right valve. This selvage is met by a depression in the left valve where the selvage is peripheral.
ANATOMY: The species fully described by McKenzie (1971b) as *Ilyodromus* cf. *smaragdinus* from New Guinea is here synonymized to *C. incosta*. Its diagnostic anatomical features are the short third segment of the antennula with a length width ratio of about 1.6:1 (Fig. 5A), strongly arched palps on the male maxilla (Fig. 5I,

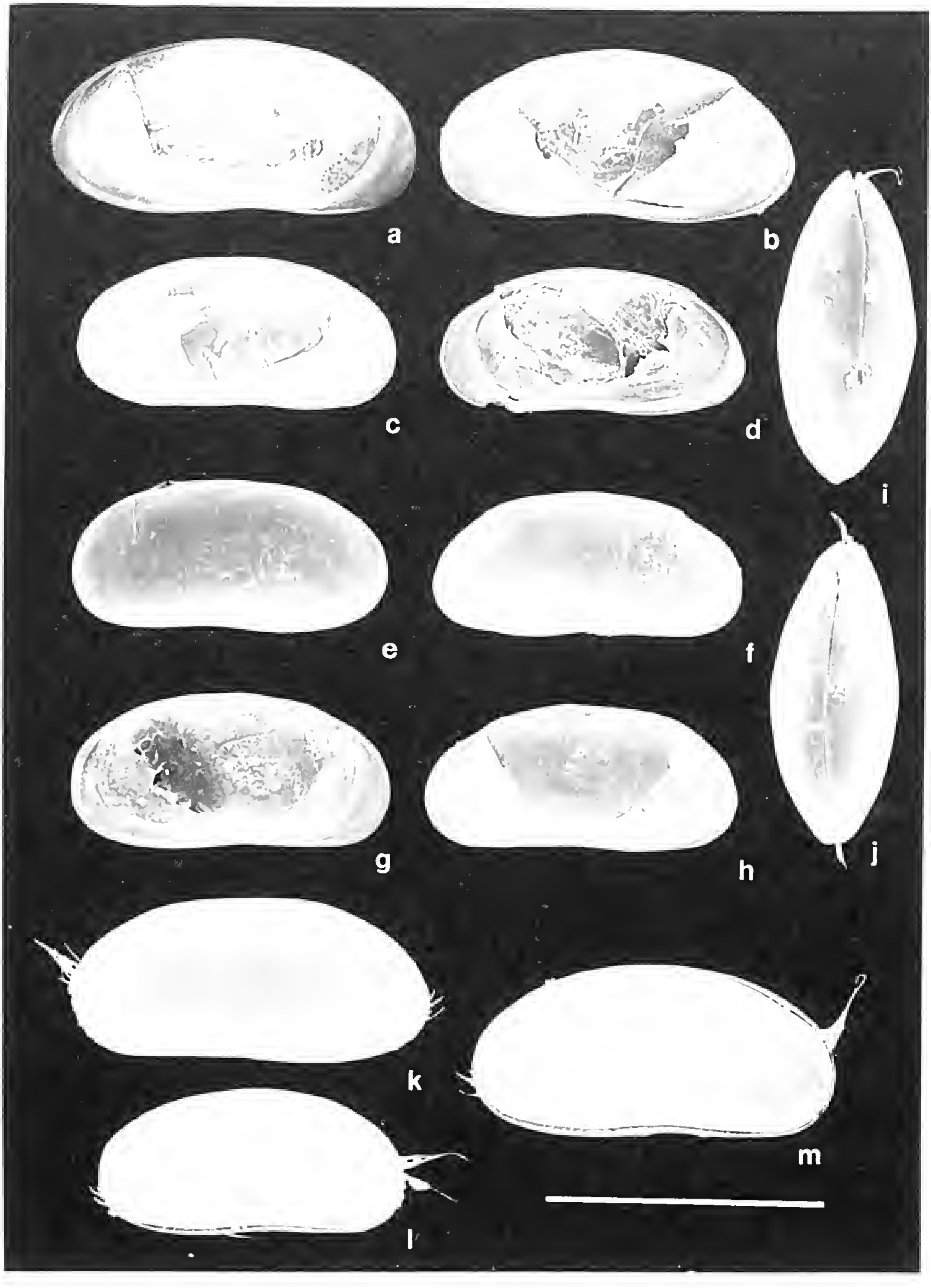


Fig. 4—*Candoncypris incosta* n. sp. Spring at base of limework quarry at Pulbeena Swamp, Tas. Scale = 1 000 μ. a, b, i, k, m female paratypes; c, d male holotype; e-h, j-l male paratypes. a, LV internal. b, RV internal. c, LV internal. d, RV internal. e, RV external. f, RV external. g, LV internal. h, RV internal. i, C dorsal. j, C dorsal. k, C showing LV. l, C showing RV. m, C showing RV.

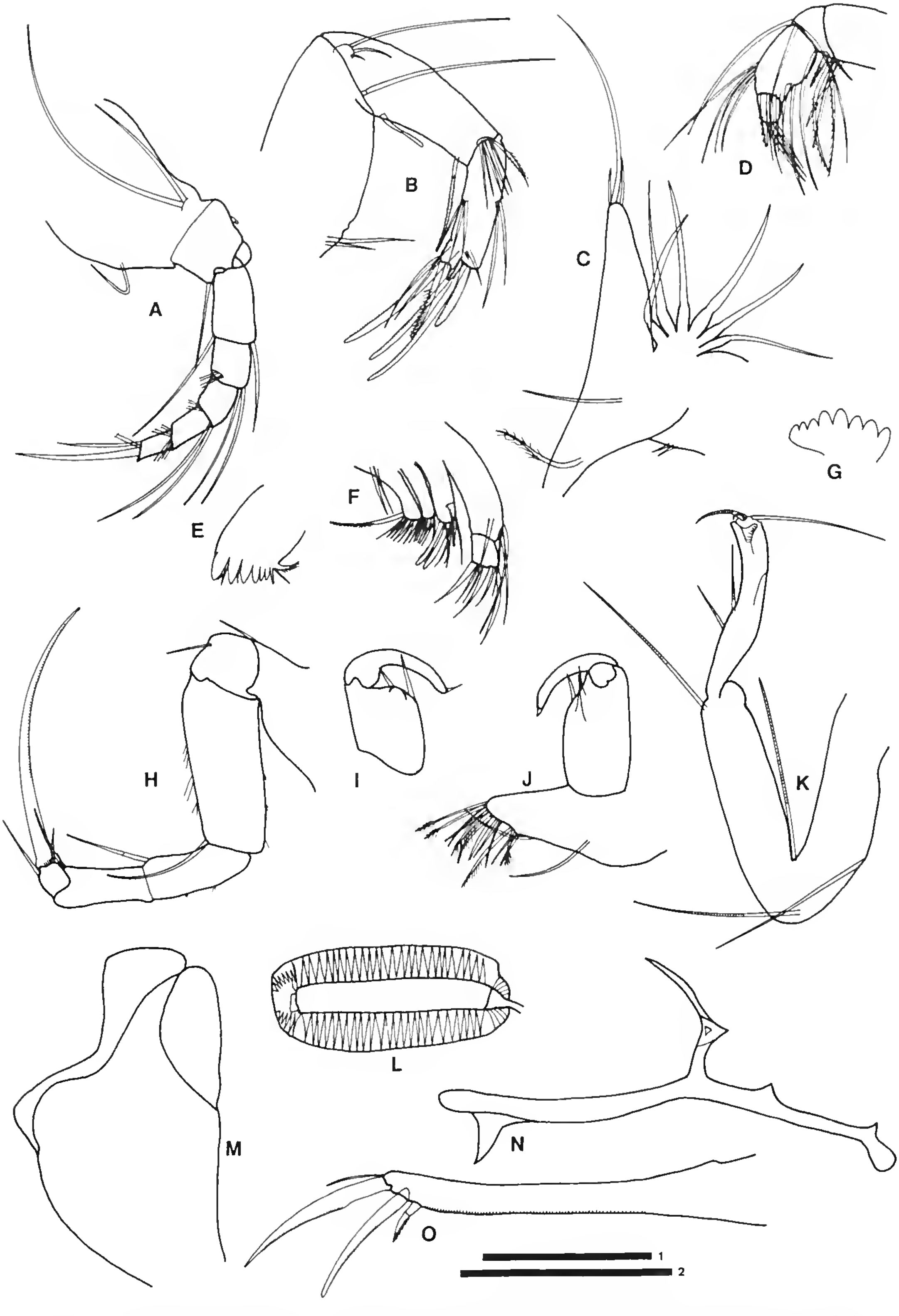


Fig. 5—*Candonocypris incosta* n. sp. Spring at base of limework quarry at Pulbeena Swamp, Tas. C, F, K are drawn from a paratype adult male, the remainder from the holotype adult male. Scales: 1 = 100μ for A-F, H-O; 2 = 50μ for G. A, antennula. B, antenna. C, maxilla. D, mandible—palp. E, mandible—coxale. F, maxillula—palp and lobes. G, rake-like organ. H, thoracopoda I. I, maxilla—endopodite. J, maxilla. K, thoracopoda II. L, Zenker organ. M, hemipenis. N, furcal attachment. O, furca.

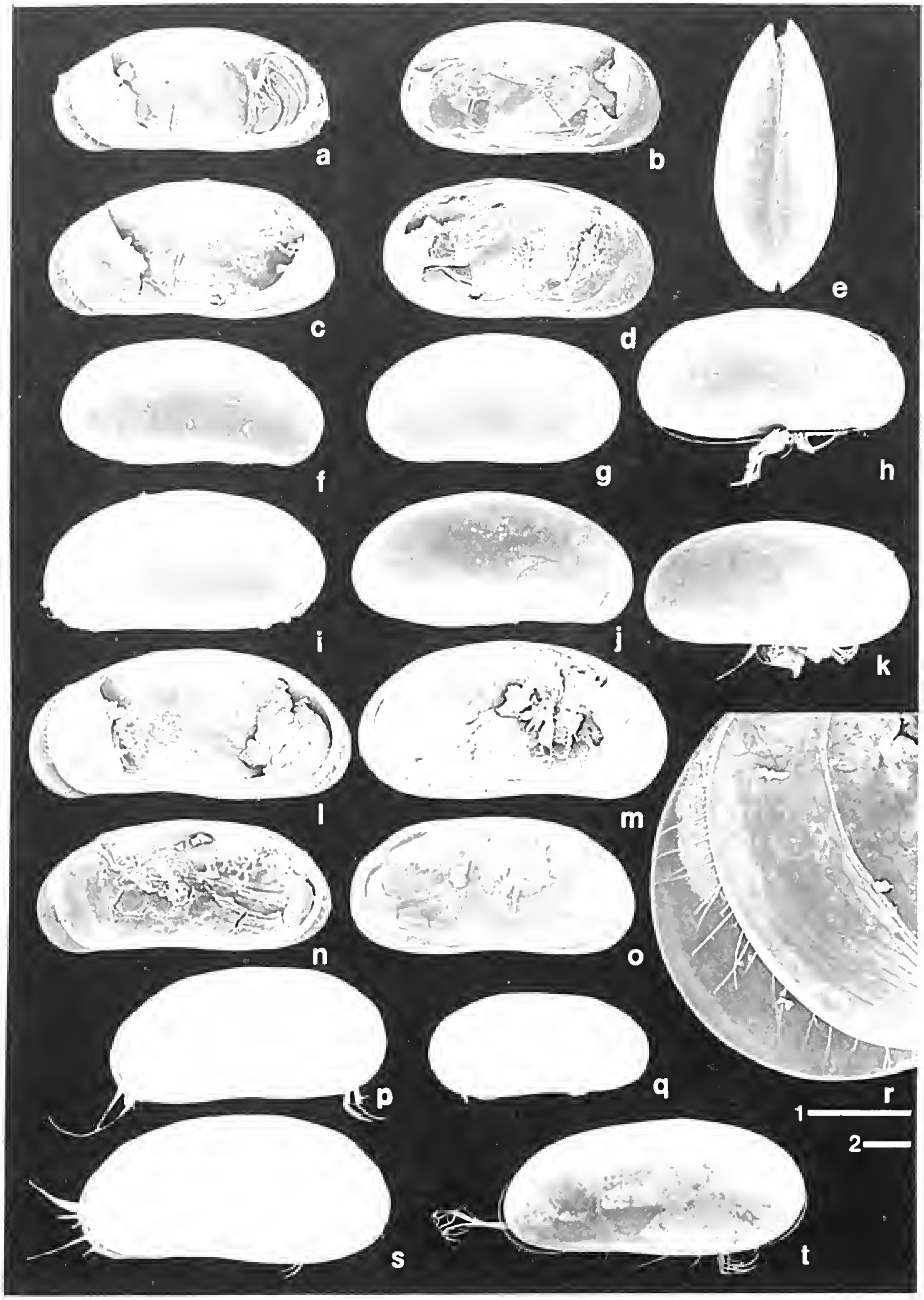


Fig. 6 -- *Candonocypris novaezelandiae* (Baird 1843). a-d, Kangaroo Creek Reservoir, Adelaide, S.A. e-k, t, Milbrook Reservoir, Adelaide, S.A. l-s, Small farm dam near Gilmandyke Creek, S. of Bathurst, N.S.W. Scales: 1 = 500μ for a-l, s, t; 2 = 50μ for r. a, b, f-h, k: adult male; c-e, i, j, l, m, s, t adult female; n-p, r juvenile female; q juvenile. a, RV internal. b, LV internal. c, RV internal. d, LV internal. e, C dorsal. f, RV external. g, LV external. h, C showing RV and hemipenis. i, LV external. k, C showing LV and hemipenis. l, RV internal. m, LV internal. n, RV internal. o, LV internal. p, C showing LV. q, C showing LV. r, RV internal, anterior detail of n. s, C showing LV. t, C showing LV.

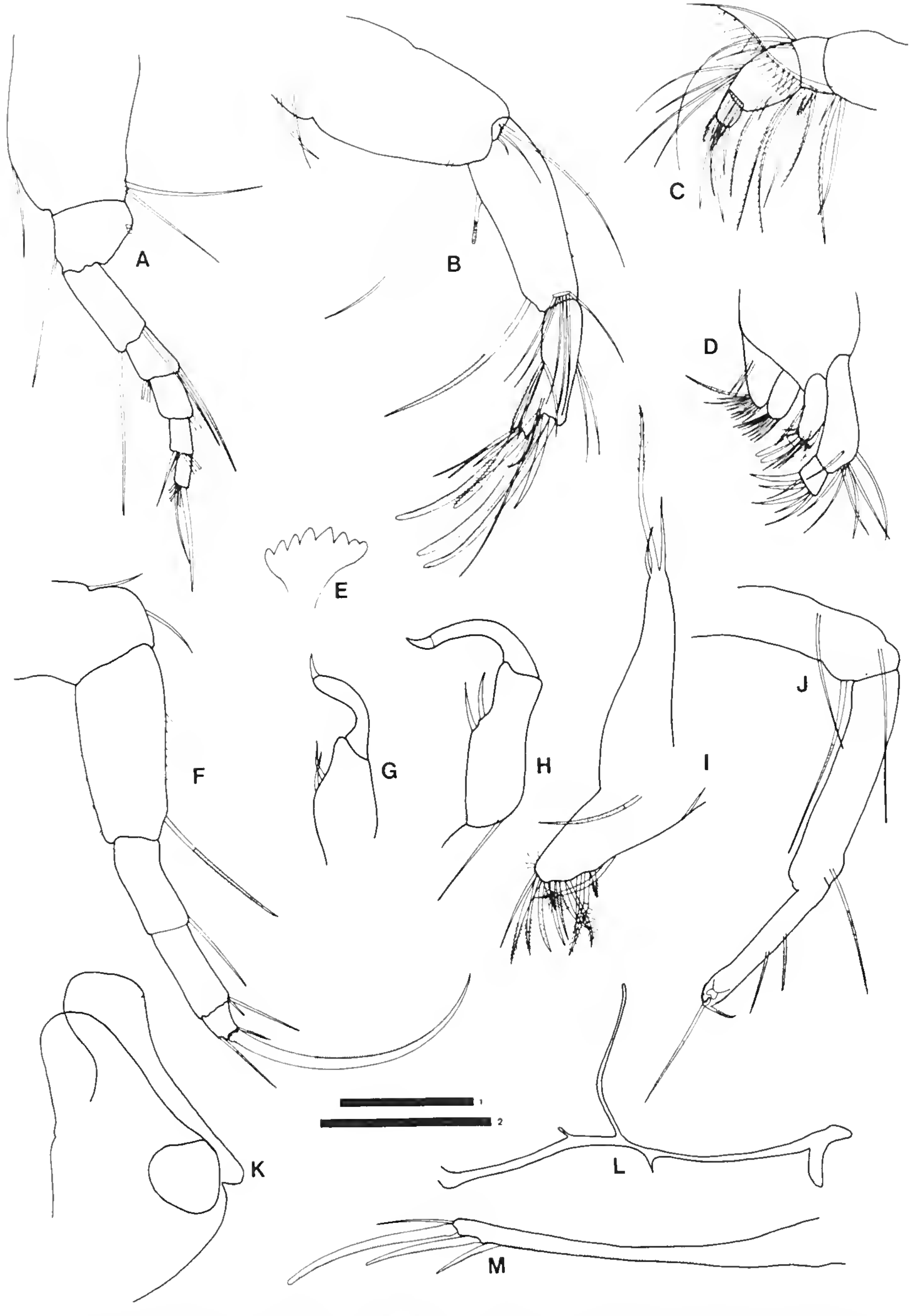


Fig. 7 — *Candonocypris novaezelandiae* (Baird 1843). Kangaroo Creek Reservoir, Adelaide, S.A. I, J, drawn from adult female remainder from adult male. Scales: 1 = 100μ for A-D, F-M; 2 = 50μ for E. A, antennula. B, antenna. C, mandible — palp. D, maxillula — palp and lobes. E, rake-like organ. F, thoracopoda I. G, maxilla — endopodite. H, maxilla — endopodite. I, maxilla. J, thoracopoda II. K, hemipenis. L, furcal attachment. M, furca.

J), outer extremity of copulatory sheath at mid-length forming a broad hump with right angle (Fig. 5M), and furca with almost equal claws (Fig. 5O).
Colour of Shell: White to transparent.

Size:		L	H		L	H
holotype adult male	LV	1 220μ	600μ	RV	1 160μ	560μ
paratype adult female	LV	1 410μ	700μ	RV	1 390μ	660μ

Type Locality: Spring at base of limework quarry at Pulbeena Swamp in north-western Tasmania.
Derivation of Name: From Latin *in* (= without) and *costa* (= ridge) for the absence of prominent selvage in the right valve anteriorly in comparison with *C. novaezelandiae*.
Ecology and Distribution: This species has been collected from the type locality only once; it was found crawling on and within the topmost centimetre of sediment in freshwater. It is also recorded from Lake Peunde, near Mt. Wilhelm (about 3 750 m), Bismarck Range in New Guinea (McKenzie 1971b). A few specimens of *C. incosta* (labelled *Candona lutea*) are present in Chapman's (1914) slide of fossil specimens from Mowbray Swamp in north-western Tasmania. This species has since been re-collected at that site (De Deckker 1981b).
Remarks: This species differs from *C. novaezelandiae* because of the absence of a prominent selvage at a distance from the edge of the shell in the right valve. This prominent selvage was originally thought to be characteristic of *Candonocypris* species but this is not the case. *C. incosta* has to be included in *Candonocypris* as it shares many other shell and anatomical features with the type species *C. novaezelandiae*. Both species, for example, possess the prominent selvage posteroventrally in the right valve. In the type lot thoracopoda II possesses the two typical setae at mid-length on the last segment (Fig. 5K). This feature is also found on specimens of *Ilyodromus* cf. *smaragdinus* described by McKenzie (1971b). As this feature is not found in *Ilyodromus* (verified from type material of *Ilyodromus smaragdinus*, held in the Oslo Museum), this alone justifies the transfer to *Candonocypris* of McKenzie's specimens. These are now synonymized to *C. incosta* as they have identical shell features and anatomies. Additionally, the outline of the hemipenis and the very short two-jointed sensory seta on the second segment of the antennula (in *Ilyodromus* species it is very long and three-segmented) in *C. incosta* and *C. novaezelandiae*, further justify the grouping of these two species under the same genus.

The only feature different in McKenzie's specimens is the broader extension of the copulatory sheath over the lateral lobe. This difference is not considered to be important. Comparison with the New Guinea material kept in the British Museum and the species described here indicates that all other details of the hemipenis are the same.

Candonocypris novaezelandiae (Baird 1843)

Figs 6, 7

1843 *Cypris Novae Zelandiae* Baird, p. 268.
1855 *Cypris candonioides* King, p. 66.
1855 *Cypris sydneia* King, p. 65
1889 *Herpetocypris stanleyana*; Sars, p. 35.
1894 *Candonocypris assimilis* Sars, p. 36.
1894 *Candonocypris candonoides*; Sars, p. 35.
1919 *Candonocypris assimilis*; Chapman, p. 28.
1955 *Candonocypris assimilis*; Hornibrook, p. 271.
1956 *Candonocypris candonoides;* Hornibrook *in* Gill & Banks, p. 19.
1969 *Candonocypris assimilis*; Hussainy, p. 305.
1971 *Candonocypris novaezelandiae*; Eagar, p. 55.
1975 *Candonocypris assimilis*; Okubo, p. 157.
1976 *Candonocypris novaezealandiae*; Chapman & Lewis, p. 95.
1976 *Candonocypris assimilis*; Chapman & Lewis, p. 95.

Diagnosis: Member of *Candonocypris* with prominent selvage in right valve usually half way between the outer and inner margins and following the curvature of the shell; posteroventrally in the right valve and near the inner margin, selvage is prominent.
Description: carapace (External) — Smooth shell like a flattened ellipsoid with dorsal area slightly arched; overlap of left valve over right one ventrally and to a lesser extent dorsally at both extremities of the hinge area; right valve larger and like a flatter ellipsoid compared to left one.
(Internal) — Broad selvage all around and placed at a distance from the anterior edge of the right valve; in the left valve, it is faint and peripheral; in both valves, inner lamella twice as broad anteriorly; posteriorly in the right valve, the selvage is prominent, especially posteroventrally where it is near the inner margin: this area is met by a depression in the left valve where the selvage is faint.
anatomy: Characterized by a long third segment of the antennula with a length to width ratio of 2.2:1 (Fig. 7A); male maxillar palps differently arched (Fig. 7G, H); outer extremity of copulatory sheath at mid-length forming a narrow but prominent hump (Fig. 7K); furca with unequal claws (Fig. 7M).
Colour of Shell: Green to beige brown.

Size Range:	L	H
adult male	1 400-1 500μ	700-800μ
adult female	1 650-1 800μ	750-850μ

Note: LV narrower but taller than RV in both sexes.
Ecology and Distribution: This freshwater species is usually found in farm dams and eutrophic waters, even sewerage lagoons. It is commonly found in high numbers crawling in among decaying vegetal matter and black organic muds, especially near lake shores. Hussainy (1969) was the first to describe the male of *C. assimilis* (synonymized here to *C. novaezelandiae*) from Lake Purrumbete. Males have since been found in a number of permanent waterbodies (e.g. Milbrook and Kangaroo Creek Reservoirs) but not in ephemeral waters or small waterbodies such as farm dams.

Adults of *C. novaezelandiae* are a benthic species and have never been seen to swim. Juveniles, on the other hand, are good swimmers, having natatory setae of their antennae much longer than in adults.

Remarks: Examination of the type material of *C. novaezelandiae* (empty valves only) kept in the British Museum confirmed the suggestion of Eagar (1971) that this species is synonymous with *C. candonioides*. Additionally, since in many collections taken in ephemeral waters, morphs representing both *C. candonioides* and *C. assimilis*, as illustrated by Sars (1894, Plate V.1 and 2), are found together, it is suggested here that they represent the same species: *C. candonioiodes* synonymized to *C. novaezelandiae*. For example, forms of *C. assimilis* as illustrated in Fig. 6 n-p from a small farm dam near Gilmandyke Creek, south of Bathurst in New South Wales are considered to be young specimens of *C. novaezelandiae* found in the same collection and illustrated in Fig. 6 l, m, s. There are no morphological differences in anatomy except that appendages of *C. novaezelandiae* are bigger. In the latter, the colour of the shell is green with yellow to brown diagonal bands caused by the ovarics, whereas shells of *C. assimilis* morphs are beige brown in colour with similar bands for the ovaries (Sars 1894).

The latter morph is smaller and has a slightly arched dorsum (the greatest height is at the middle) whereas the *C. novaezelandiae* morph is larger, more arched dorsally (greatest height at about 0.66 of length from the anterior) and with the right valve much larger than the left anteriorly and posteriorly. This synonymy is further confirmed by the fact that the anatomy of male specimens described by Hussainy (1969) from Lake Purrumbete in Victoria for *C. assimilis* is identical to that of male specimens of *C. novaezelandiae* found in Milbrook Reservoir in South Australia. The presence of well formed ovaries in juveniles in some ostracod species is not uncommon in the family Cyprididae and this would therefore explain why previous authors have considered *C. assimilis* morphs to represent the last molt stage of the species.

From the original illustration and short description of *Cypris sydneia* King 1855, it appears that King's species represents the *C. assimilis* morph because of the outline and colour of the shell, limited ability to swim, and the habit of crawling on mud.

C. novaezelandiae is found in New Zealand (Sars 1894, Chapman 1963, Chapman & Lewis 1976), Australia (Sars 1894, 1896a, Henry 1923) and Japan (Okubo 1975). Originally Sars (1894) stated that this species was also present in South Africa as he had raised it in his aquaria from samples of dried mud collected at Knysna, Cape of Good Hope, but later (Sars 1924) suggested that this had been caused by contamination by Australian material in his aquaria.

Genus **Ilyodromus** Sars 1894

Type Species: *Candona stanleyana* King 1855.

Diagnosis: See Danielopol & McKenzie (1977, p. 305).

Remarks: The genus *Ilyodromus* has recently been redescribed by Danielopol and McKenzie (1977) who provided a diagnosis for *I. stanleyanus* and redescription of *I. varrovillius* (King 1855) from New Zealand specimens. Both species were originally described from Australia. These authors also discussed all the other *Ilyodromus* species and their geographical distribution.

Ilyodromus amplicolis n. sp.

Figs 8, 9 l-r

Diagnosis: Member of *Ilyodromus* with striated shell; anterior and posterior ends broadly rounded; a slight concavity in front of the hinge anterodorsally; inner lamellae broad anteriorly and posteriorly; lateral lobe of hemipenis broad and rectangular in shape; maxilla palps of male similar to each other.

Description: carapace (External)—Weakly calcified; elongated ellipsoid with joint striations all over; dorsum straight along the hinge line and slightly concave anterior to it; dorsally behind the hinge line it is flat and inclined; anterior and posterior broadly rounded but the latter is narrower; ventrum almost flat except in the middle of the mouth region where it is concave; greatest height at 0.33 of length from the anterior, left valve slightly larger.

(Internal)—Inner lamella very broad and similar in both valves; anteriorly, the width of the inner lamella is one-third of the length of the shell; there it is slightly broader and it extends all around the shell except in the hinge area dorsally; selvage faint and peripheral in both valves.

anatomy (Antennula)—(Fig. 8A) Seven-segmented; length width ratio of the last six segments: 1.2:1, 1.6:1, 1.2:1, 1.6:1, 2:1, 2:1; natatory setae as long as last five segments; 3-segmented sensory organ on second segment with distal end pointed.

(Antenna)—(Fig. 8B) Natatory setae short: two longest ones shorter than the penultimate segment and two minute ones reaching the proximal end of the same segment.

(Mandible)—(Fig. 8I) Mandibular coxale with seven teeth; palps with α bristle short, barren and slim, β bristle stout, pointed and densely pilose, γ bristle thick, slightly longer than the last segment and pilose in the distal half.

(Rake-like organ)—(Fig. 8C, D) Seven to nine teeth with an additional bifid one on the inner side.

(Maxillula)—(Fig. 8E) Distal palp trapezoid and two smooth Zahnborsten on third lobe.

(Maxilla)—Sexually dimorphic; in male (Fig. 8 G, H) palps strongly and similarly arched and one slightly narrer in the proximal 0.33 of its length; in female (Fig. 8F) three plumose setae, the middle one being twice the length of the other two which are equal; in both sexes, epipod with five long and a shorter plumose Strahlen; for chaetotaxy of protopod, see Fig. 8L.

(Thoracopoda I)—(Fig. 8J) Third segment well divided; inner distal seta of second segment shorter than half the length of the 3rd segment and outer seta on distal segment 0.2 of the length of the claw.

(Thoracopoda II)—(Fig. 8N) Three-segmented with large distal pincers; distal setae unequal: shorter one

Fig. 8—*Ilyodromus amplicolis* n. sp. Granite rock pool on top of Boyagin Rock, between Brookton and Pingelly, W.A. A, B, D, E, G-J, L-N drawn from paratype adult male; remainder from holotype adult female. Scales: 1 = 100μ for A, B, E-N; 2 = 50μ for C, D. A, antennula. B, antenna. C, rake-like organ. D, rake-like organ. E, maxillula—palp and lobes. F, maxilla—endopodite. G, maxilla—endopodite. H, maxilla—endopodite. I, mandible—palp. J. thoracopoda I. K, furca. L, maxilla—protopodite. M, hemipenis. N, thoracopoda II.

hook-shaped and about 0.33 of the length of the other.

(Hemipenis)—(Fig. 8M) Lateral lobe broad and rectangular; inner lobe broad, subrectangular but about 0.8 of the width of the lateral lobe and almost same length; near the base of the lateral lobe on the inside, small knob-like protuberance.

(Zenker organ)—More than 30 rosettes.

(Furca)—(Fig. 8K) Claws almost equal with pectinate and thick posterior seta half the length of the posterior claw and 0.66 longer than the pectinate and narrow anterior seta.

(Furcal attachment)—Median branch long, divided distally and with a broad, but short, spike at right angle near its proximal end ventrally.

Colour of Shell: White to transparent ventrally and bluish green dorsally.

Size:		L	H		L	H
holotype adult female	LV	2 000μ	920μ	RV	2 020μ	960μ
paratype adult male	LV	1 540μ	720μ	RV	1 550μ	—

Type Locality: Granite rock pool on top of Boyagin Rock, between Brookton and Pingelly, W.A.

Derivation of Name: From Latin *amplus* (= large) and *colis (* = penis) for the unusually large penis.

Ecology and Distribution: This species has been collected in the following localities: granite rock pools in Sullivan Rocks, 11 km south of Gleneagle, W.A. (or 63 km south of Perth on Albany Highway); roadside ditch north of Scadden, W.A. (56 km north of Esperance on road to Norseman). *I. amplicolis* appears to be restricted to fresh, temporary pools.

Remarks: *I amplicolis* differs from *I. varrovillius* (King 1855) and *I. stanleyanus* (King 1855), which have similar shell outlines, by the absence of long natatory setae on its antennae (in specimens of these two species examined in Sars' collection, the natatory setae extend past the tip of the antennal claws). No males have been found in the latter two species.

Ilyodromus candonites n. sp.

Figs 9a-k, 10

Diagnosis: *Ilyodromus* with subrectangular shell in lateral view, with posterior broadly rounded and anterior tapering; valves faintly striated; inner lamella anteriorly almost three times the width of the posterior in both valves; faint selvage peripheral in the right valve and broader, 0.33 of width from the outer margin on the in ner lamella posteriorly and ventrally; natatory setae of antenna atrophied; maxilla palps in male similar, hook-shaped and angular; lateral lobe of hemipenis digitate and broadest distally.

Description: CARAPACE (External)—Subrectangular in lateral outline with posterior broadly rounded and almost forming a right angle with the dorsum which is almost flat; anterior tapering but rounded and anterodosal area inclined; ventrum almost flat except in the mouth region which is slighly concave 0.4 of length from the anterior; surface of shell faintly striated with two generations of striae (Fig. 9k; in dorsal view, like a flattened ellipsoid with both ends pointed; simple normal pore canals scattered with broad rim.

(Internal)—Inner lamella anteriorly almost three times the width of the posterior in both valves; selvage peripheral and faint in the right valve and broader and 0.33 from the outer margin on the inner lamella posteriorly and ventrally; anteriorly the inner lamella is faintly reticulated like all *Ilyodromus* species.

ANATOMY (Antennula)—(Fig. 10A) Seven-segmented: length width ratio of last six segments: 2:3, 1.8:1, 1.2:1, 1.4:1, 1.8:1, 1.3:1; sensory organ on second segment 3-segmented and short; natatory setae as long as all segments together.

(Antenna)—(Fig. 10B) Three claws on penultimate segment and a fourth one on the distal one; natatory setae extremely short except for the outer one which is as long as half the length of the penultimate segment.

(Mandible)—(Fig. 10G) Mandibular coxale with seven teeth; palp 3-segmented and with α bristle stylet-like, β bristle stout, pointed and densely pilose, γ bristle slightly longer than distal segment, stout and densely pilose in the distal two thirds; epipod with five long plumose Strahlen plus a shorter one at mid-length and a smaller barren seta near its base.

(Rake-like organ)—Seven to nine teeth plus a bifid one on the inner side of each rake.

(Maxillula)—(Fig. 10C) Distal part short and trapezoidal; third lobe with two smooth Zahnborsten; epipod plate with 22 Strahlen.

(Maxilla)—Sexually dimorphic: in male (Fig. 10D, E) palps similar, narrow, angular and hook-shaped; in female (Fig. 10F) three plumose setae with middle one twice the length of the other two which are of almost equal length; for chaetotaxy of protopod, see Fig. 10F.

(Thoracopoda I)—(Fig. 10I) 3rd segment divided; distal seta of 2nd segment as long as half of the length of the 3rd segment; outer seta on 4th segment 0.25 of the length of the distal claw.

(Thoracopoda II)—(Fig. 10K) Three-segmented; distal setae unequal with shorter one curved and about 0.33 of the length of the other; distal pincers small.

(Hemipenis)—(Fig. 10H) Lateral lobe digitate with distal end broadest; inner lobe bilobate distally and curved inward.

(Zenker organ)—With about 27 rosettes.

(Furca)—(Fig. 10J) Both claws of almost equal length; posterior seta thick; pectinate and half the length of the posterior claw; slim anterior seta barren and about half length of the other seta.

(Furcal attachment)—median branch long, divided distally and with a broad, short and curved spike at right angle near its proximal end ventrally.

Colour of Shell: Green.

Size:		L	H		L	H
holotype adult male	LV	1 140μ	600μ	RV	1 140μ	600μ

Type Locality: Small granite rock pool at summit of Mt. Chudalup, near Northcliffe, W.A.

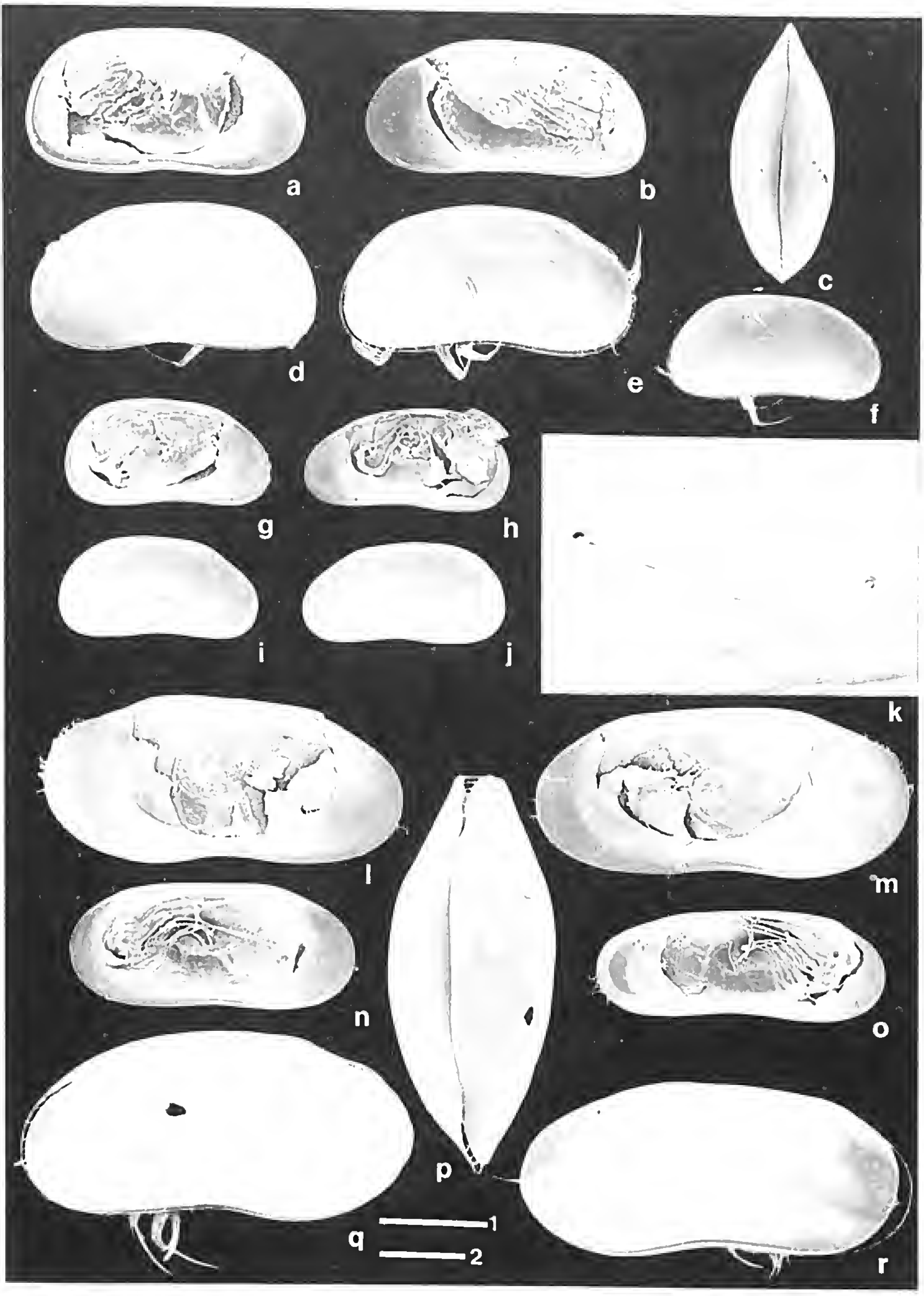


Fig. 9 – a-k *Ilyodromus candonites* n. sp. a-e, k Small granite rock pool on Muirillup Rock, near Northcliffe, W. A. f-j Small granite rock pool at summit of Mt Chudalup, near Northcliffe, W.A. Scales: $1 = 500\mu$ for a-j; $2 = 10\mu$ for k. a-e, k females; f, i-j male paratypes; g, h male holotype. a, LV internal. b, RV internal. c, C dorsal. d, C showing LV. e, C showing RV. f, C showing RV. g, LV internal. h, RV internal. i, RV external. j, LV external. k, C showing LV, detail of d. l-r, *Ilyodromus amplicolis* n. sp. Granite rock pool on top of Boyagin Rock, between Brookton and Pingelly, W.A. Scale: $1 = 500\mu$ l, m holotype female; n, o paratype male; p, r paratype female. l, RV internal. m, LV internal. n, LV internal. o, RV internal, specimen distorted. p, C dorsal. q, C showing RV, same specimen as p. r, C showing LV, specimen distorted.

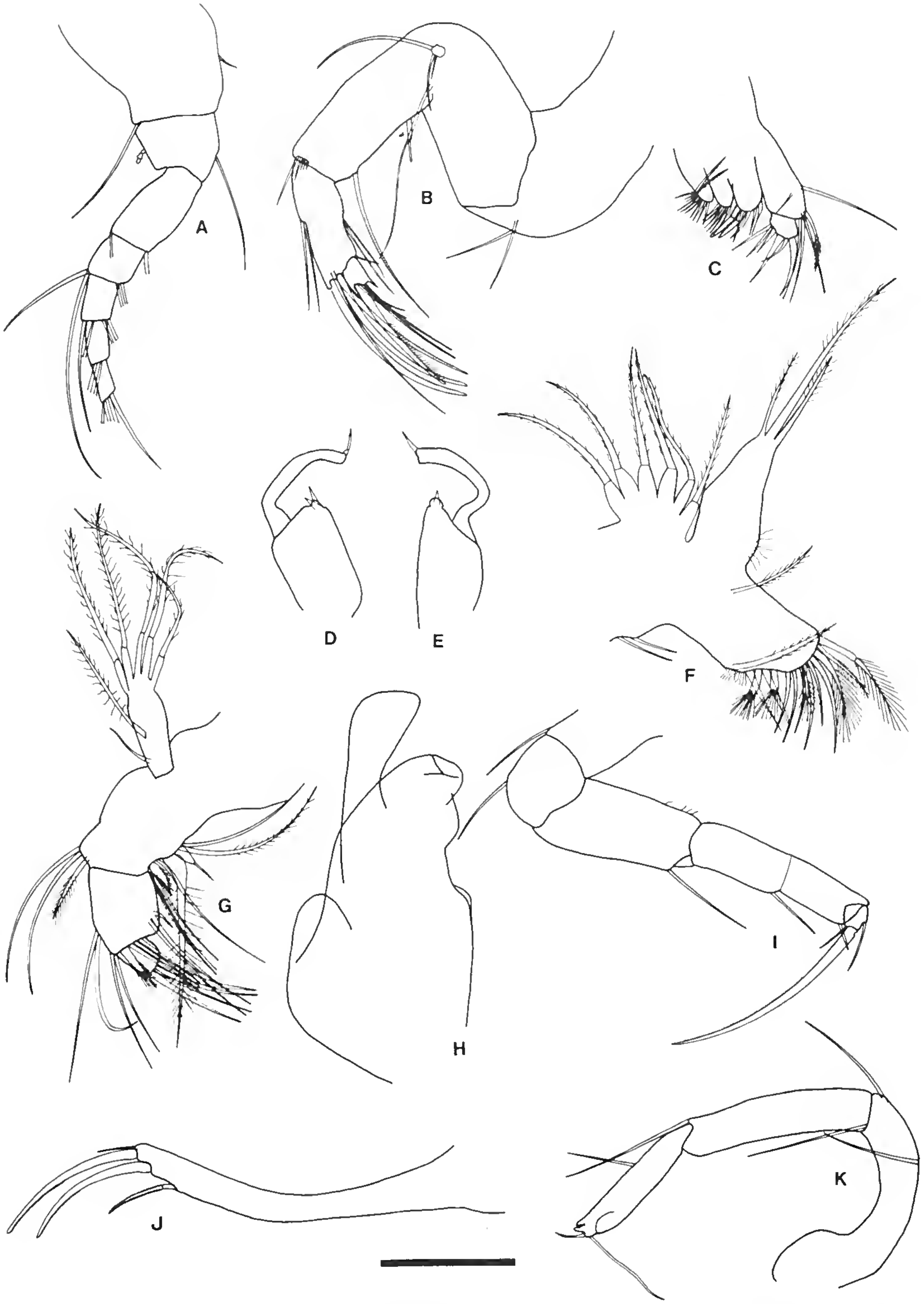


Fig. 10 — *Ilyodromus candonites* n. sp. Granite rock pool on top of Boyagin Rock, between Brookton and Pingelly, W.A. A-E, H-K drawn from holotype adult male, F, G from paratype adult female. Scale: = 100μ. A, antennula. B, antenna. C, maxillula — palp and lobes. D, maxilla — endopodite. E, maxilla — endopodite. F, maxilla. G, mandible — palp. H, hemipenis. I, thoracopoda I. J, furca. K, thoracopoda II.

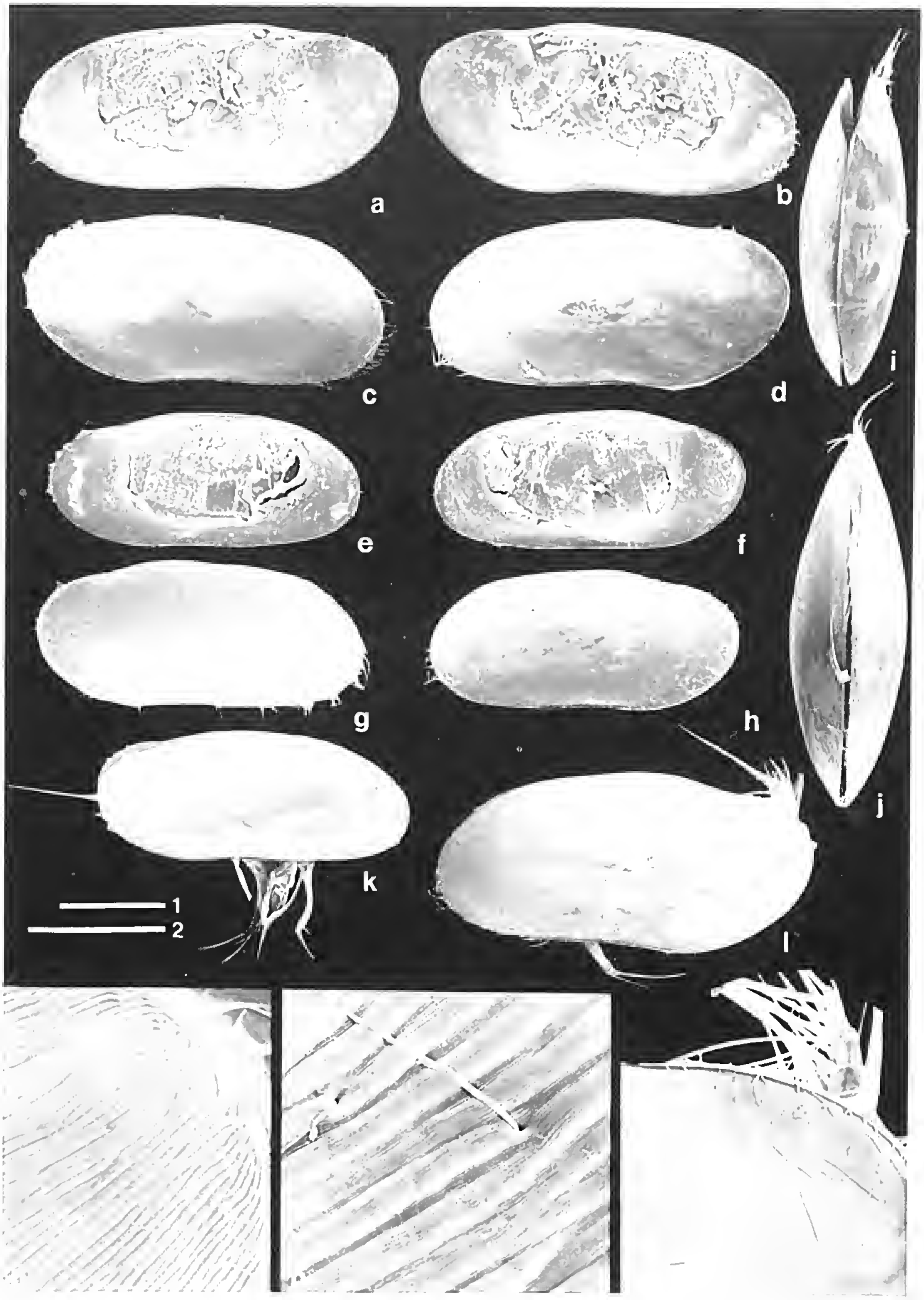


Fig. 11 – *Ilyodromus dikrus* n. sp. Dam at Wasley Well, near Nallan, W.A. Scales: 1 = 500μ for a-l; 2 = 100μ for m, = 20μ for n, = 200μ for o. a-d, j, l, o female paratypes; e, f, i-k male paratypes; g, h, m, n male holotype. a, LV internal. b, RV internal. c, LV external. d, RV external. e, RV internal. f, LV internal. g, LV external. h, RV external. i, C dorsal. j, C ventral. k, C showing LV, penis and some appendages. l, C showing RV. m, LV external, posterior detail of g. n, LV external, detail of g. o, C showing RV, anterior detail of l.

Fig. 12—*Ilyodromus dikrus* n. sp. Dam at Wasley Well, near Nallan, W.A. A, B, D, E, G, H, K, L, N drawn from holotype adult male, the remainder from paratype adult female. Scale: 1 = 100μ. A, antennula. B, antenna. C, maxillula—palp and lobes. D, thoracopoda I. E, hemipenis. F, maxilla. G, maxilla—right endopodite. H, maxilla—left endopodite. I, mandible—palp. J, mandible—coxale. K, Zenker organ. L, thoracopoda II. M, furcal attachment. N, furca.

Derivation of Name: From the genus *Candona* plus the Greek suffix—*ites* (=like) as the lateral profile of this species is reminiscent of many species of *Candona*.

Ecology and Distribution: This species has only been collected in Western Australia. It occurs in many temporary granite pools near Northcliffe—at and near summit of Mt. Chudalup, and on and near Muirillup Rock. The size of *I. candonites* is variable: the length of adult specimens can vary between 1 100μ and 1 400μ.

Remarks: *Ilyodromus candonites* differs from *I. viridulus* specimens examined in Sars' collection on the following important details: the natatory setae of the antenna almost reach the tip of the claws in the latter species, and its shell is more elongated: it is faintly concave dorsally in front of the hinge (*I. candonites* is flat) and the selvage is near the inner margin posteriorly in the left valve and is broader posteriorly in the right valve. The greatest extension of the shell posteriorly in *I. viridulus* is at mid-height whereas it is near the ventrum in *I. candonites*. The latter species differs from type specimens of *I. substriatus* Sars 1894 and *I. obtusus* Sars 1894 from Sars' collection (which have short natatory setae on the antenna extending to the middle of the penultimate segment), on the following features of the shell: *I substriatus* has a broad selvage posteriorly in the right valve which is met by a depression in the left valve where the selvage is faint and along the periphery of the inner margin; in *I. obtusus* the selvage is faint and along the outer margin in both valves. No males are known for Sars' species.

Ilyodromus dikrus n. sp.

Figs 11, 12

Diagnosis: Member of *Ilyodromus* like an inclined parallelogram with rounded ends in lateral view; obvious depression anterior to the hinge dorsally; with the greatest extension of the shell anteriorly 0.4 from the dorsum plane; inner lamella broad throughout in both valves; male maxilla palps asymmetrical, the narrower one being more arched; outer seta of 4th segment thoracopoda more than half the length of the distal claw; hemipenis with digitate lateral lobe and inner lobe like an elongated rectangle reaching almost the tip of the lateral lobe.

Description: carapace (External)—Inclined parallelogram with rounded ends in lateral view, with obvious depression anterior to the hinge dorsally; shell with longitudinal striations of two generations (Fig. 11n) all over except in the anterior area near the margin; simple type normal pores; greatest extension of the shell anteriorly at 0.4 from dorsum plane and 0.6 posteriorly; ventrum concave just before mid-length. In dorsal view extremely narrow and with both ends pointed.

(Internal)—Inner lamella similar in both valves and of similar width anteriorly and posteriorly: it is broadest anteriorly where the valve extends the furthest, and narrowest in the mouth region above the concavity.

anatomy. (Antennula)—(Fig. 12A) Seven-segmented: length width ratio of last six segments: 1:1, 1.8:1, 1:1, 1.3:1, 1.7:1, 2.5:1; natatory setae as long as last six segments, sensory organ on second segment elongate.

(Antenna)—(Fig. 12B) Three distal claws on the penultimate segment with a shorter one on the distal segment; natatory setae extending much further than the tip of the claws.

(Mandible)—(Fig. 12I, J) Mandibular coxale with seven teeth; palp with α bristle stylet-like, β bristle stout and densely pilose, γ bristle broad, almost twice the length of the distal segment and pilose in the distal half; epipod plate with four pilose Strahlen.

(Rake-like organ)—Seven to nine teeth, plus one bifid tooth on inner side of each rake.

(Maxillula)—(Fig. 12C) Distal segment of palp trapezoidal and third lobe with two smooth Zahnborsten; epipod with about 18 plumose Strahlen.

(Maxilla)—Sexually dimorphic: male (Fig. 12G, H) palps asymmetrical with the narrower more strongly arched; the other is broadest at mid-length; female (Fig. 12F) palp with three short plumose setae, the middle one almost twice the length of the other two which are of similar length; for chaetotaxy of protopod see Fig. 12F.

(Thoracopoda I)—(Fig 12D) Seta at mid-length on outer side of fourth segment thick and more than half the length of the distal claw; proximal seta on first segment 0.33 of the length of the distal one.

(Thoracopoda II)—(Fig. 12L) Three-segmented; distal pincers small and distal setae unequal: longest seta 1.6 times the length of the shorter and slightly curved one.

(Hemipenis)—(Fig. 12E) Lateral lobe digitate and inner lobe like an elongated rectangle reaching almost the tip of the lateral lobe; the broad tip of the inner lobe is covered with small hooks.

(Zenker organ)—(Fig. 12K) Elongate, with 25 rosettes.

(Furca)—(Fig. 12N) Claws almost equal; posterior seta slim, pectinate, twice the length of the other barren seta and 0.66 of the length of the posterior claw.

(Furcal attachment)—(Fig. 12M) Median branch thick, bifurcate distally and with broad spike at right angle near its base.

Colour of Shell: White.

Size:		L	H		L	H
holotype adult male	LV	1 270μ	560μ	RV	1 270μ	560μ
paratype adult female	LV	1 470μ	660μ	RV	1 470μ	660μ

Type Locality: Dam at Wasley Well, near Nallan, 21 km NNE of Cue, W.A. (27°16′54″S, 118°09′06″E).

Derivation of Name: From Greek *dikros* (=forked) for the forked appearance of the distal end of the thoracopoda I which has a long outer seta on the last segment.

Ecology: this species has only been collected once from the type locality: water was fresh and turbid.

Remarks: Although this species appears at first glance to resemble the elongated *I. varrovillius* (King 1855), it is easily separated from the latter by its long seta on the

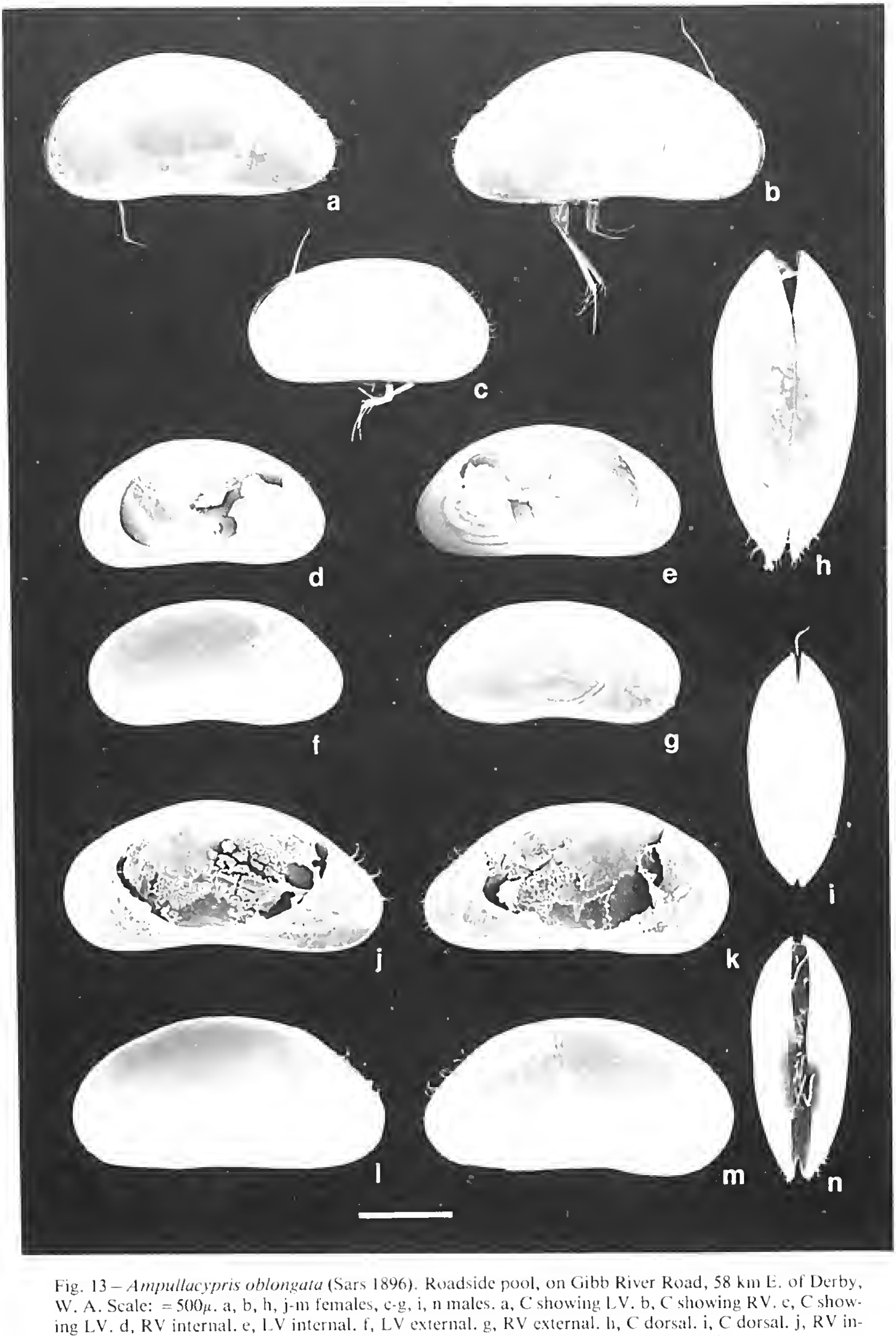


Fig. 13 – *Ampullacypris oblongata* (Sars 1896). Roadside pool, on Gibb River Road, 58 km E. of Derby, W. A. Scale: = 500μ. a, b, h, j-m females, c-g, i, n males. a, C showing LV. b, C showing RV. c, C showing LV. d, RV internal. e, LV internal. f, LV external. g, RV external. h, C dorsal. i, C dorsal. j, RV internal. k, LV internal. l, LV external. m, RV external. n, C ventral.

last segment of the thoracopoda I and by its inclined parallelogram outline in lateral view. *I. varrovillius* in Sars' collection has short natatory setae on the antenna.

Ilyodromus williamsi (McKenzie 1966)

1966 *Isocypris williamsi* McKenzie, p. 266.

REMARKS: The transfer of this species to *Ilyodromus* is suggested here because this species possesses many typical anatomical features of that genus. These are: 3-segmented sensory organ on the 2nd segment of the antennula; slim stylet-like α bristle; stout, pointed and densely pilose β bristle; thick, stout γ bristle which is pilose in its distal half; trapezoid palp and smooth Zahnborsten on maxillula; presence of two setae on 1st segment of thoracopoda I; thick and pectinate posterior seta on furca and furcal attachment with stout spike forming a right angle with the median branch near its base. All these were seen on the holotype.

Although *I. williamsi* has a smooth shell (when examined under a binocular microscope), contrary to most *Ilyodromus* species, it is still included in that genus for the reasons given above. It is worth noting, however, that striations on the shell of many *Ilyodromus* specimens, all belonging to the one species and collected together, can vary; on some specimens of *I. viridulus*, for example, striations are only visible anteriorly and posteriorly, on others the shell is smooth, and others the shell is finely striated.

McKenzie (1971a) has already pointed out that *I. williamsi* was not an *Isocypris sensu stricto* on shell characters alone. This species in fact is closely related to *I. dikrus* as they both have a similar shell outline but *I. williamsi* has a faint selvage at a distance from the outer lamella anteriorly in the left valve and has a very short outer seta on the distal segment of the thoracopoda I.

I. williamsi is only known from the type locality, about 16 km west of Inverway, N.T.

Genus **Ampullacypris** n. gen.

TYPE SPECIES: *Ampullacypris oblongata* (Sars 1896).

DIAGNOSIS: Smooth ellipsoidal shell with normal pore canals and flattened when viewed dorsally; inner lamella broad anteriorly and posteriorly in both valves; central muscle field consisting of a row of three in front and two behind plus a hollow inclusion above and in front of the upper adductor scar; two mandibular scars in front and below the adductor scars; two toothed Zahnborsten and rectangular palp on maxillula; mandibular palp with α bristle smooth and slim, β bristle longer (but not stout) and densely pilose, γ bristle longer than last segment, stout and pilose on its distal half; maxilla palps on male asymmetrical; 1st segment of thoracopoda I with one long seta, furcal shaft smooth and posterior seta on furca thick and pectinate; furcal attachment with median branch long and no distal ornament plus dorsal branch forming narrow elongated loop.

DERIVATION OF NAME: from Latin *ampulla* meaning flask (as the type species has been described from specimens originally grown in an aquarium by G. O. Sars) and the generic name *Cypris*.

REMARKS: *Ampullacypris* n. gen. is closely related to *Psychrodromus* Danielopol & McKenzie 1977 and *Ilyodromus* Sars 1894. It differs from these two genera on the following important anatomical feature: the distal end of the furcal attachment does not have a wedge shaped spike and the dorsal branch forms a loop. *Ampullacypris* differs from *Psychrodromus* by possessing a smooth furcal shaft and from *Ilyodromus* by its two-toothed Zahnborsten and a rectangular palp on the maxillula. The α, β, and γ bristles on the maxilla of *Ampullacypris* are like those of *Psychrodromus* as is the two-segmented, short sensory organ on the 2nd segment of the antennula.

Ampullacypris oblongata (Sars 1896)

Figs 13, 14

1896 *Cypris oblongata* Sars, p. 29.
1901 ? *Amphicypris oblongata*; Sars, p. 18.
1923 *Amphicypris oblongata*; Henry, p. 268.

DIAGNOSIS: Smooth ellipsoidal shell with posterior narrower than anterior and ventral area almost flat; in dorsal view, shell narrow and greatest width at about a third from the anterior. Inner lamella broad anteriorly and posteriorly in both valves. Lateral lobe of hemipenis crescent-shaped; Zenker organ with 42 rosettes.

DESCRIPTION: CARAPACE (External)—smooth ellipsoidal shell with posterior narrower than anterior and ventral area almost flat except in the mouth area in the middle where it is faintly concave. Valves similar with left one slightly longer and overlapping the other slightly ventrally. In dorsal view, shell narrow and greatest height at about a third from the anterior. Shell hirsute posteriorly.

(Internal)—Inner lamella broad anteriorly and posteriorly in both valves and selvage faint and peripheral except in the right valve ventrally; thin flange along the periphery of the right valve. Marginal pore canals common, short and straight. Central muscle field consisting of a row of 3 scars in front with the central one the smallest; two scars are situated behind the front row and are at the level of the two lower scars; two mandibular scars in front and below the adductor scars and a hollow inclusion above and in front of the upper adductor scar.

ANATOMY: (Antennula)—(Fig. 14B) Seven-segmented, length width ratio of the last six segments: 1:1, 2.2:1, 5:3, 8.5:5, 7:4, 3:1; 2nd segment with two segmented, short sensory organ.

(Antenna)—(Fig. 14C) Natatory setae reaching the tip of the claws; 3 claws of equal length on penultimate segment and reaching the tip of the other claw on the last segment.

(Mandible)—(Fig. 14A, G) Palp with α bristle smooth and slim, β bristle longer (but not stout) and densely pilose, γ bristle longer than last segment, stout and pilose on its distal half.

(Rake-like organ)—(Fig. 14D) Seven teeth plus one inner bifid tooth.

Maxillula)—(Fig. 14F) Distal palp rectangular and two toothed Zahnborsten on the third lobe.

Fig. 14—*Ampullacypris oblongata* (Sars 1896). Roadside pool, Gibb River Road, 58 km E. of Derby, W.A. A-D, G-N drawn from adult male, E, F, O from adult female. Scales: 1 = 100μ for A-C, E-O; 2 = 50μ for D. A, mandible—coxale. B, antennula. C, antenna. D, rake-like organ. E, maxilla—endopodite. F, maxillula—palp and lobes. G, mandible—palp. H, thoracopoda I. I, maxilla—left endopodite. K. right maxilla. L, thoracopoda II. M, Zenker organ. N, hemipenis. O, furca. P, furcal attachment.

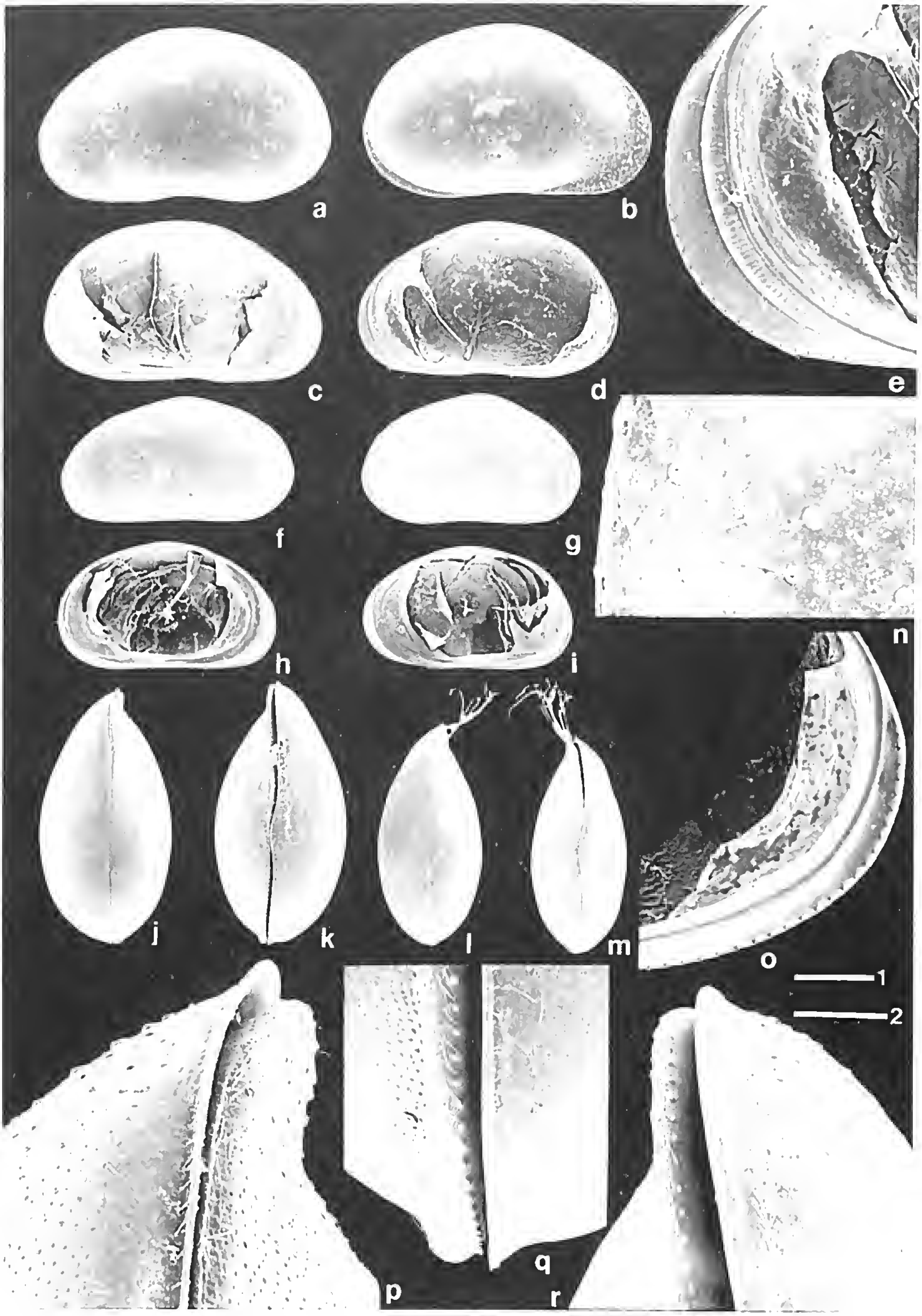


Fig. 15—*Heterocypris vatia* n. sp. Hexham Swamp, Newcastle, N.S.W. Scales: 1 = 500μ for a-d, f-m, = 200μ for e, o, = 40μ for n; 2 = 100μ for p-r. a-e, j, l, o, p female paratypes; f, g, k, m, n, q, r male paratypes; h-i male holotype. a, LV external. b, RV external. c, LV internal. d, RV internal. e, RV internal, anterior detail of d. f, LV external. g, RV external. h, LV internal. i, RV internal. j, C dorsal. k, C ventral. l, C dorsal. m, C ventral. n, RV external, anterior detail of g. o, RV internal, posterior detail of d. p, C dorsal, anterior detail of j. q, C ventral, posterior detail of k. r, C ventral, anterior detail of k.

(Maxilla)—Sexually dimorphic: male (Fig. 14I, J) palps asymmetrical: right one broad and triangular with outer side forming a rounded right angle and with two long bristles near the base of the palp; other smaller, narrower and more arched plus, at the base of the palp, with two shorter and also smooth bristles. Female (Fig. 14E) palp with three unequal plumose setae, the middle one being longer than the other two together.

(Thoracopoda I)—(Fig. 14H) Proximal end of 1st segment with a long seta only; penultimate segment divided; seta at the inner distal end of the last 3 segments and at the division of the penultimate segment; last segment with an outer seta, as long as inner one, near the distal end.

(Thoracopoda II)—(Fig. 14K) 3-segmented; distal seta of second segment longer than half the length of the third segment; distal setae unequal with shorter one curved and about one-third the length of the other straight one; distal pincers small.

(Hemipenis)—(Fig. 14M) Broadly ellipsoidal in shape with lateral lobe crescent-shaped.

(Zenker organ)—(Fig. 14L) Narrow long and with 42 rosettes.

(Furca)—(Fig. 14N) Distal claws unequal; posterior seta pectinate, much thicker and longer than anterior one and half the length of the posterior claw.

(Furcal attachment)—(Fig. 14 O) Median branch long and slightly curved with dorsal branch like a narrow, elongate loop normal to the median branch and forming an obtuse angle with the straight ventral branch.

Colour of Shell: Beige brown.

Size:

			L	H
From Sars' (1896)	female:	carapace	1 900μ	800μ
	male :	carapace	1 600μ	—
Specimens examined here:				
	adult female :	carapace	1 840μ	880μ
	adult male :	carapace	1 520μ	760μ

Ecology and Distribution: This species was raised by Sars (1869b) from a dry sample of sand collected 64 km east of Roebuck Bay in W.A. In Sars' collection, there are a number of samples of *A. oblongata* for which the given locality is central Australia and others for which females and one male, all undissected and preserved in a hardened polyvinyl alcohol slide (Oslo Museum—Sars' collection No. 11 600) are syntypes. The male is designated here as lectotype. In addition, the vial containing about 10 specimens of *A. oblongata* in the "old spirit collection of Sars" held in the Oslo Museum, under the number of 53.3/2 are also syntypes. The specimens described here have been collected in a roadside pool on the Gibb River road, 58 km east of Derby, W.A. The specimens labelled "*Eucypris*" cf. *oblongata* (Sars, 1896) by McKenzie (1966) do not belong to the species described here as one of the specimens studies by him has peripheral tubercles on the right valve.

Subfamily Cyprinotinae Bronstein 1947

Genus **Heterocypris** Claus 1892

Type Species: *Heterocypris incongruens* (Ramdohr 1808).

Heterocypris vatia n. sp.

Figs 15, 16

Diagnosis: Member of *Heterocypris* with anterior edge of right valve bent outward; lateral lobe of hemipenis boot-shaped with "sole" of the boot convex; inner lobe of hemipenis with scattered minute hooks.

Description: carapace (External)—Bean-shaped in lateral view with dorsum curved; greatest height at 0.4 to 0.5 from the anterior; posterior slightly more broadly arched than anterior; ventral area nearly flat except in the mouth region which is faintly concave; in dorsal view like a flattened ellipsoid with both ends pointed; anteriorly the extremity is bent slightly clockwise; anteriorly and posteroventrally the right valve bends outward along the edge; the left valve bends inward to meet the right valve all along its periphery except ventrally where it overlaps the other; shell pseudopunctate with numerous rounded wart-like tubercles on the anterior of the shell; a hair protrudes from each tubercle.

(Internal)—Right valve faintly tuberculate all along its periphery except dorsally; inner lamella broadest anteriorly in both valves; in right valve, selvage broad following the curvature of the shell halfway between the outer and inner margins anteriorly, whereas it is near the inner margin posteroventrally; the inner lamella between the outer margin and the selvage is convex anteriorly and posteroventrally; in left valve, selvage faint and peripheral and presence of narrow flange all along; radial pore canals numerous and straight.

anatomy (Antennula)—(Fig. 16A) Seven-segmented; length width ratio of the last six segments: 1:1, 2.25:1, 1.5:1, 1.5:1, 1.7:1, 2.5:1; small, rod-shaped, sensory organ at mid-length on the second segment; natatory setae slightly longer than all segments together.

(Antenna)—(Fig. 16C) Sexually dimorphic: in female the claw attached to the small 3rd segment is narrower and smaller.

(Mandible)—(Fig. 16E, F) Mandibular coxale with seven teeth (Fig. 16F); inner tooth longer than the previous two and pointed and near its base two setae, one of which is pilose; endopod (Fig. 16E) with α bristle short and narrow, β bristle of same length, wrinkled and covered with a few short hairs, γ bristle longer than last segment, stout and thickly pilose externally in its distal half; epipod with five plumose Strahlen plus a shorter one half way and a short, stout and pilose seta at its base.

(Rake-like organ)—With seven teeth and inner one bifid.

(Maxillula)—(Fig. 16D) Endopod with about 17 plumose Strahlen; length width ratio of palps: 3:1, 2:1; third lobe with two toothed Zahnborsten and near their base presence of a short and thick tufted bristle.

(Maxilla)—Sexually dimorphic: male palps strongly asymmetrical (Fig. 16I, J) with left one narrower and strongly arched; female palp with three plumose setae,

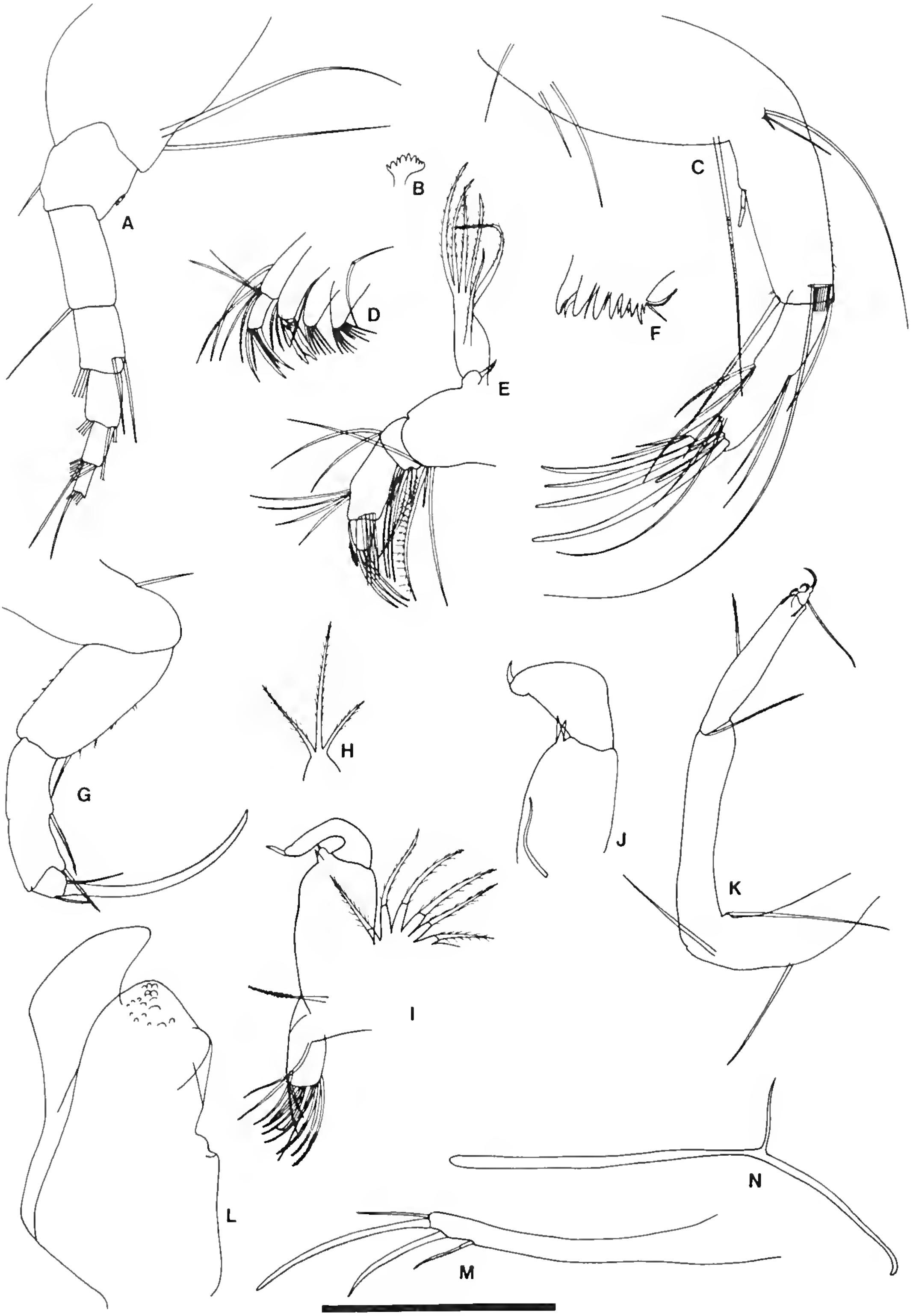


Fig. 16—*Heterocypris vatia* n. sp. Hexham Swamp, Newcastle, N.S.W. A-E, G, I-M drawn from holotype adult male, remainder from paratype adult female. Scale: = 200μ. A, antennula. B, rake-like organ. C, antenna. D, maxillula—palp and lobes. E, mandible—palp. F, mandible—coxale. G, thoracopoda I. H, maxilla—endopodite. I, left maxilla. J, maxilla—right endopodite. K, thoracopoda II. L, hemipenis. M, furca. N, furcal attachment.

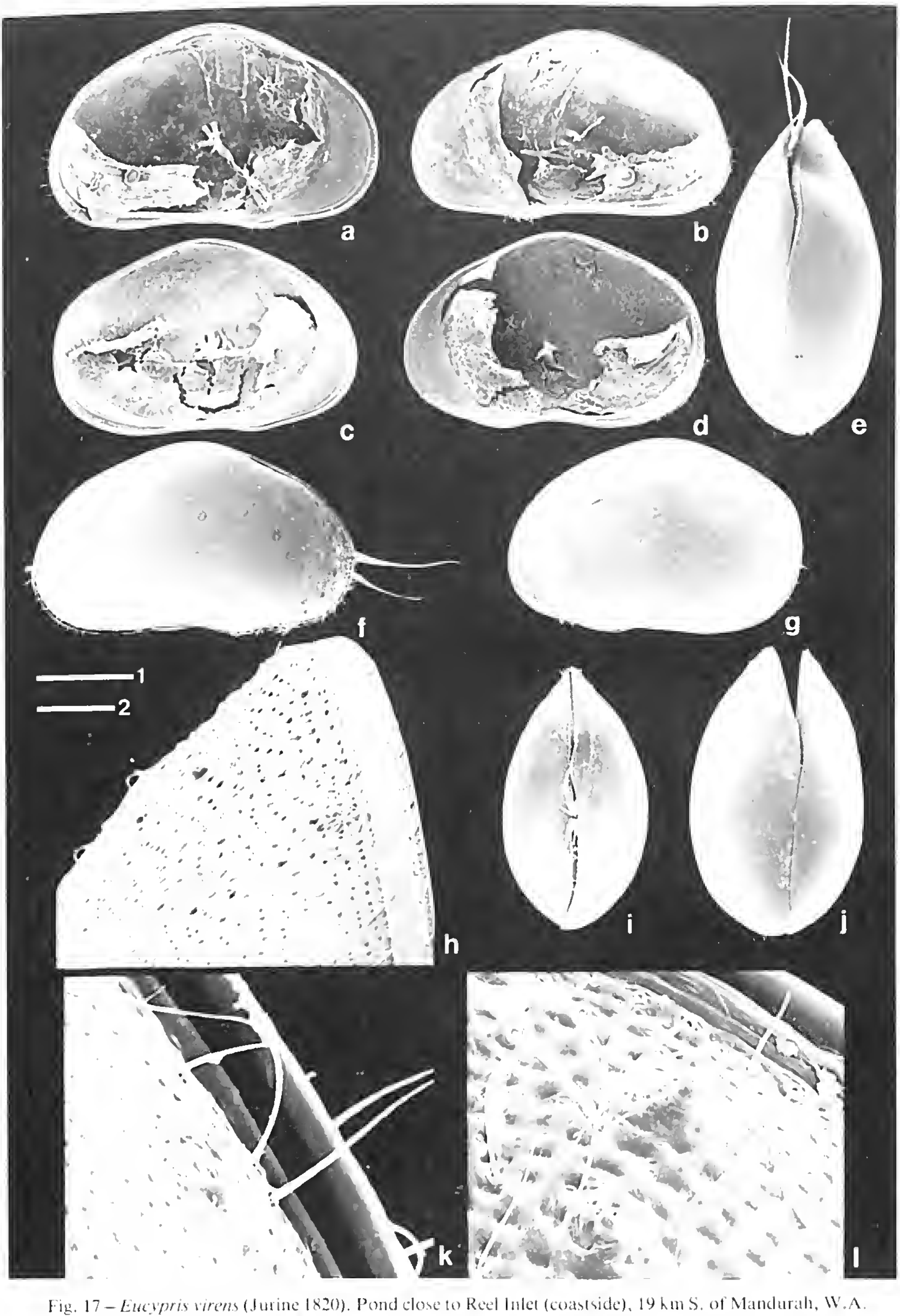


Fig. 17 – *Eucypris virens* (Jurine 1820). Pond close to Reel Inlet (coastside), 19 km S. of Mandurah, W.A. Scales: 1 = 500μ for a-g, i-j; 2 = 40μ for h, = 20μ for k, = 30μ for l. All females. a, LV internal. b, RV internal. c, LV internal. d, RV internal. e, C dorsal. f, C showing RV. g, C showing LV. h, C dorsal, anterior LV detail of j. i, C ventral. j, C dorsal. k, C showing RV, posterior detail of f. l, C showing RV, anterior detail of f.

the two outside ones being of similar length; for chaetotaxy, see Fig. 16I.

(Thoracopoda I)—(Fig. 16G) Penultimate segment weakly divided and distal claw 1.2 times the length of the last two segments together.

(Thoracopoda II)—(Fig. 16K) Distal setae on last segment unequal: the longer one four times the length of the other which is hook-shaped.

(Hemipenis)—(Fig. 16L) Outer lateral lobe boot-shaped with "sole" part of the boot convex and "heel" part slightly angular and forming an obtuse angle; inner lobe broadly rectangular and covered with numerous short hooks.

(Zenker organ)—Both ends rounded with 48 rosettes.

(Furca)—(Fig. 16M) Setae almost equal with posterior one finely pectinate; claws unequal; anterior one 1.6 times the length of the other.

(Furcal attachment)—(Fig. 16N) Median branch straight with short dorsal branch normal to it; ventral branch curved and 2.5 times the length of the dorsal one.

(Eye)—Cups of nauplius eye fused; brown in colour.

Colour of Shell: Translucent pale brown.

Size:		L	H		L	H
holotype adult male	LV	1 700μ	1 000μ	RV	1 710μ	1 000μ
paratype adult female	LV	2 400μ	1 400μ	RV	2 340μ	1 360μ

Type Locality: Hexham Swamp, behind the University campus at Newcastle, New South Wales.

Derivation of Name: From Latin *vatius* meaning bent outward for the diagnostic feature of the right valve.

Ecology and Distribution: This species has only been collected once; water at the type locality is known to be fresh.

Remarks: It was thought that this species belonged to *H. leana* (Sars 1896) because of its large size. The female specimens described by Sars (1896a) were 2.70 mm long and came from Hay, N.S.W. However, after examination of Sars' collections in the Oslo Museum, it became obvious that none of the male specimens labelled *H. leana* by Sars have the same outline of the lateral lobe as the specimens from Hexham Swamp; all Sars' specimens have a small and pointed protuberance in the "heel" part, the boot-shaped lateral lobe of the hemipenis. This feature is not seen in *H. vatia.* However, no specimen from Hay was found in Sars' collection; only specimens which are labelled as "Victoria" A or C are found. Therefore, designation of a lectotype will prove to be difficult. However, a 2.4 mm long male specimen collected from Goulburn Billabong, Alexandra, Vic. by R. Shiel corresponds to Sars' description of *H. leana* and possesses the pointed "heel" on the lateral lobe of the hemipenis. This substantiates the separation of the two taxa into different species which have a large shell but different anatomy. *H. vatia* differs from all other *Heterocypris* species recently reviewed in Victor and Fernando (1980).

Subfamily Eucypridinae Bronstein 1947

Genus **Eucypris** Vavra 1891

Type Species: *Eucypris virens* (Jurine 1820)

Eucypris virens (Jurine 1820)

Figs 17, 18

1820 *Monoculus virens* Jurine, p. 171.
1900 *Eucypris virens*; Daday, p. 143.

Diagnosis: Subrectangular shell with dorsum arched and greatest height in the middle; length height ratio of carapace: 1.45 to 1.65; shell convex ventrally just in front of the slightly concave mouth region; in dorsal view oval in shape with anterior more pointed than posterior; wart-like protuberances (Fig. 17h, k, l) near the outer margin anteriorly best seen in dorsal view. Colour of shell: pale green.

Remarks: *E. virens* is a cosmopolitan species well known outside Australia; description of the shell and anatomy is therefore unnecessary but illustrations are provided in Figs 17, 18. This species has already been recorded from New Zealand (Barclay 1968, Chapman & Lewis 1976). In Australia, it is a common inhabitant of temporary pools and is usually found in fresh waters but has been recorded in slightly saline water; the highest salinity record for *E. virens* is 4.4‰ in a Western Australian locality (Geddes *et al.* 1981). So far *E. virens* has been collected in southern Australia (W.A., S.A., Vic.).

Variations in the outline of *E. virens* have been commonly noted, even on specimens collected in the same locality. These variations are illustrated in Fig. 17. They are best seen in lateral view and correspond to variations in shell outline already noted by Müller (1900) who designated the following variations: *E. virens* var. *acuminata* which has a more elongated shell (see Fig. 17a, b, f) and *E. virens* var. *obtusa* which has a more compressed shell and more broadly curved outline posteriorly (see Fig. 17 e, d, g). These variations may be ecologically significant but remain as yet unexplained.

It is likely that *Eucypris pratensis* Eagar 1970, recorded only from three localities near Wellington in New Zealand (Eagar 1970), is also a variant of *Eucypris virens.*

Eucypris virens in Australia is a parthenogenic species although both sexes have been recorded in other parts of the world (North Africa (Gauthier 1928); pond in the delta of the River Don, USSR—material received from Dr. E. I. Shornikov).

Subfamily Cypricercinae McKenzie 1971

Genus **Cypricercus** Sars 1895

Type Species: *Cypricercus cuneatus* Sars 1895.

Cypricercus salinus n. sp.

Figs 19 a-l, 20

Diagnosis: Smooth, triangular shell, elongated ellipsoid

Fig. 18 — *Eucypris virens* (Jurine 1820). Pond very close to Reel Inlet (coastside), 19 km S. of Mandurah, W.A. Scale: I = 100μ. Drawn from adult female. A, antennula. B, antenna. C, thoracopoda I. D, maxilla — protopodite. E, maxillula — palp and lobes. F, maxilla — endopodite. G, mandible — palp. H, furca. I, furcal attachment. J, thoracopoda II.

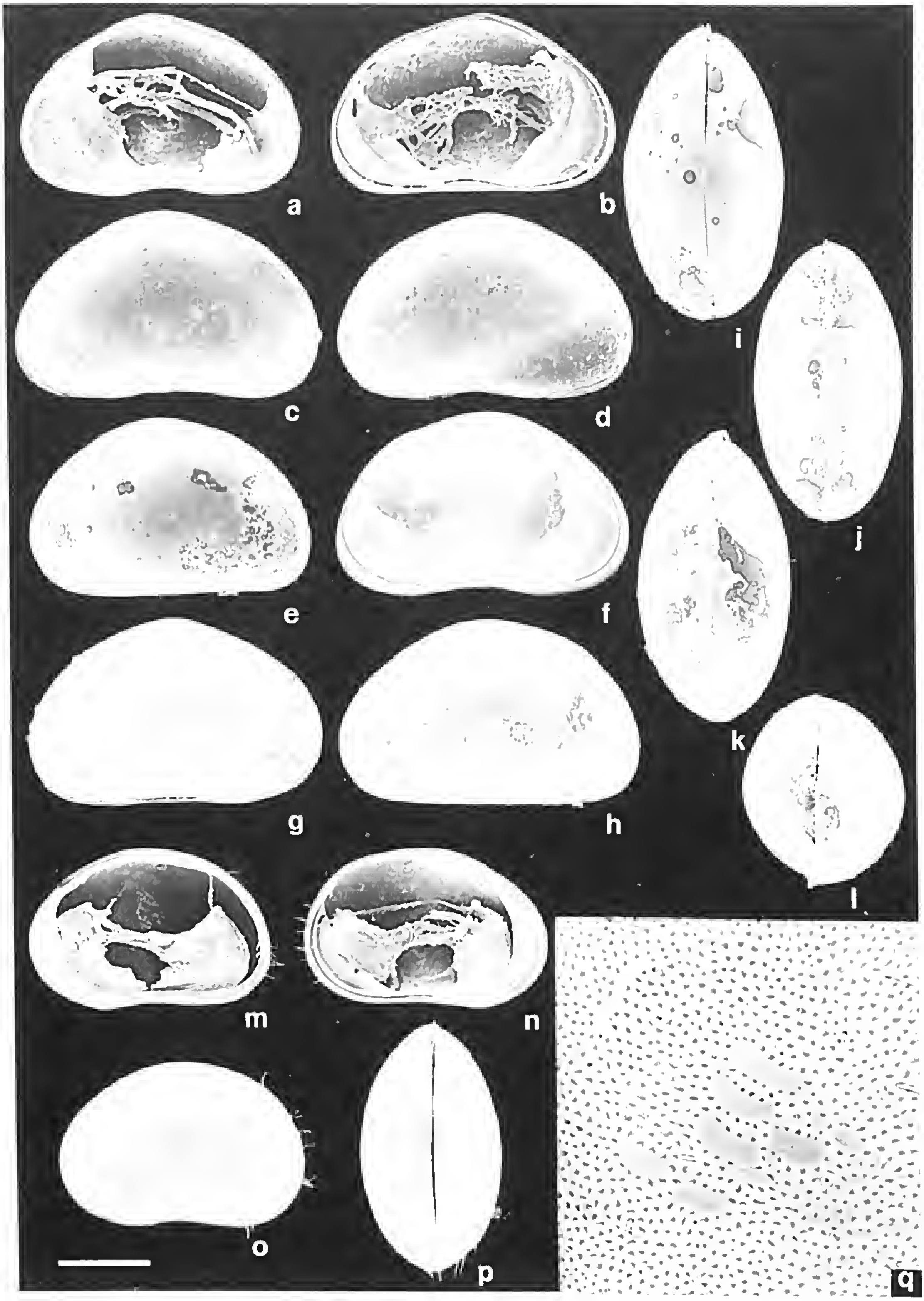


Fig. 19 – a-l, *Cypricercus salinus* n. sp. Small lake N. of Lake Terangpom, Vic. Scale: $=200\mu$. a, b male holotype; c-e, i, j male paratypes; f-h, k, l female paratypes. a, RV internal. b, LV internal. c, LV external. d, RV external. e, C showing LV. f, LV internal. g, RV external. h, LV external. i, C dorsal. j, C ventral. k, C dorsal. l, C anterior. m-q, *Cypretta baylyi* McKenzie 1966. Granite rock pool on top of Boyagin Rock, between Brookton and Pingelly, W.A. Scale: $=200\mu$ for m-p, $=40\mu$ for q. m, n male; o-q unknown sex. m, RV internal. n, LV internal. o, LV external. p, C dorsal. q, LV external, detail of o (central muscle scar area).

in dorsal view; distal end of lateral lobe of hemipenis broader than its base.

DESCRIPTION: CARAPACE (External)—Triangular in lateral view with greatest height at about middle; anterior and posterior ends broadly rounded; anterodorsal area almost straight whereas posterodorsally it is slightly arched; ventral area almost flat except in the mouth region in the middle where it is concave. Left valve slightly larger anteriorly and overlapping ventrally, especially in the mouth region. In dorsal view, like a flattened ellipsoid.

(Internal)—Inner lamella twice as broad anteriorly in both valves compared to posteroventral area; selvage near the rounded outer margin in right valve anteriorly, and at about 0.33 of the width of the inner lamella from the outer margin posteroventrally; in left valve, selvage bordering the rounded outer margin antero- and posteroventrally and separated from it by a broad groove all along; ventrally it is distant from the outer margin.

ANATOMY (Antennula)—(Fig. 20A) Length width ratio of the last six segments: 1:1.4, 1.7:1, 1.2:1, 1.2:1, 1:6.5, 2.7:1; natatory setae slightly longer than all segments together.

(Antenna)—(Fig. 20B) Natatory setae much longer than the last three segments and claws together; four terminal claws in both sexes.

(Mandible)—(Fig. 20C) Endopod with α and γ bristles long, narrow and smooth; β bristle short, stout and pilose; mandibular coxale with seven teeth: inner one slightly longer than the two adjacent.

(Rake-like organ)—Seven teeth plus one bifid on the inner side of each rake.

(Maxillula)—(Fig. 20E) third palp with two smooth Zahnborsten; length width ratio of palps 4.5:1, 2.5:1.

(Maxilla)—Sexually dimorphic: in male (Fig. 20 H, I) distal palps unequal with the narrow one strongly arched and forming a right angle; female (Fig. 20 D) endopod with three unequal setae. For chaetotaxy of epipod, see Fig. 20 D, H.

(Thoracopoda I)—(Fig. 20F) Third segment divided at mid-length where an inner seta as long as the distal half of the third segment and the fourth one together occurs.

(Thoracopoda II)—(Fig. 20L) Distal setae unequal with small one hook-shaped; seta at mid-length of the last segment shorter than hook-shaped distal seta; small distal pincers present.

(Hemipenis)—(Fig. 20G, K) Outline of copulatory sheath triangular with greatest length on inner side; lateral lobe arched inward and distal end broader than its base.

(Zenker organ)—(Fig. 20M) Elongate with 13 broad rosettes.

(Furca)—(Fig. 20J) Anterior claw 1.6 times longer than posterior one; anterior seta slightly longer than posterior one.

(Furcal attachment)—(Fig. 20N) Ventral branch almost as long as median one and hook-shaped distally; dorsal branch short with a spike at each end on the distal side to form an almost closed eyelet which is typical of the genus as illustated for the type species *C. cuneatus* by McKenzie (1977). (In the latter species, the eyelet is closed).

(Eye)—Cups of nauplius eye fused; dark brown in colour.

COLOUR OF SHELL: Pale Green.

SIZE:		L	H		L	H
holotype adult male	LV	600μ	380μ	RV	580μ	360μ
paratype adult female	LV	640μ	390μ	RV	620μ	370μ

TYPE LOCALITY: Small lake (38°06′06″S, 143°18′47″E) north of Lake Terangpom, west of Lake Corangamite, western Victoria.

DERIVATION OF NAME: From Latin *salinus* meaning saline as this species has been collected in many slightly saline waters.

ECOLOGY AND DISTRIBUTION: *C. salinus* has been collected from lakes in the vicinity of Colac and Camperdown, Victoria (e.g. Lakes Martin, Koreetnung, Kariah, Wingeel, Terangpom). The salinity range of the species is: 0.34-12.3°/oo. Salinity of the water at the type locality was 4.9°/oo.

Cypricercus unicornis n. sp.

Figs 21, 22

DIAGNOSIS: Pseudopunctate, ellipsoid shell with asymmetrical valves: left valve longer especially posteriorly where it often tapers to a broad and rounded spike; no spike in the right valve; lateral lobe of hemipenis digitate and straight.

DESCRIPTION: CARAPACE (External)—Ellipsoid in lateral view with greatest height at about middle in the right valve; surface of shell deeply pseudopunctate except dorsally and ventrally. Anterior broadly rounded, ventrum almost flat and posterior tapered. Valves asymmetrical: left valve, which overlaps the right one all around, has protuberance posteriorly which extends slightly outward. The extension of this protuberance is variable: in some specimens, it is almost non-existent. In dorsal view, like a flattened ellipsoid except in the posterior area of the left valve where the protuberance occurs. Normal pore canals of two types; some simple and others simple with a broad rim.

(Internal)—Inner lamella twice as broad anteriorly compared to posterior; selvage faint and peripheral in the right valve whereas it is broad and follows the periphery of the left valve where it is separated from the rounded outer margin only by a narrow but deep groove. The posterior protuberance in the left valve is hollow. Radial pore canals numerous, narrow and straight.

ANATOMY (Antennula)—(Fig. 22A) Length width ratio of the last six segments: 1:1, 2.6:1, 1.6:1, 2:1, 2.3:1, 4:1; natatory setae slightly longer than all segments together.

(Antenna)—(Fig. 22B) Four terminal claws in both sexes: the claw attached to the small distal segment is

Fig. 20—*Cypricercus salinus* n. sp. Small lake N. of Lake Terangpom, Vic. A-C, F-N drawn from holotype adult male, D, E from paratype adult female. Scale: = 100μ. A, antennula. B, antenna. C, mandible. D, maxilla. E, maxillula—palp and lobes. F, thoracopoda I. G, hemipenis. H, left maxilla. I, maxilla—right endopodite. J, furca. K, hemipenis. L, thoracopoda II. M, Zenker organ. N, fureal attachment.

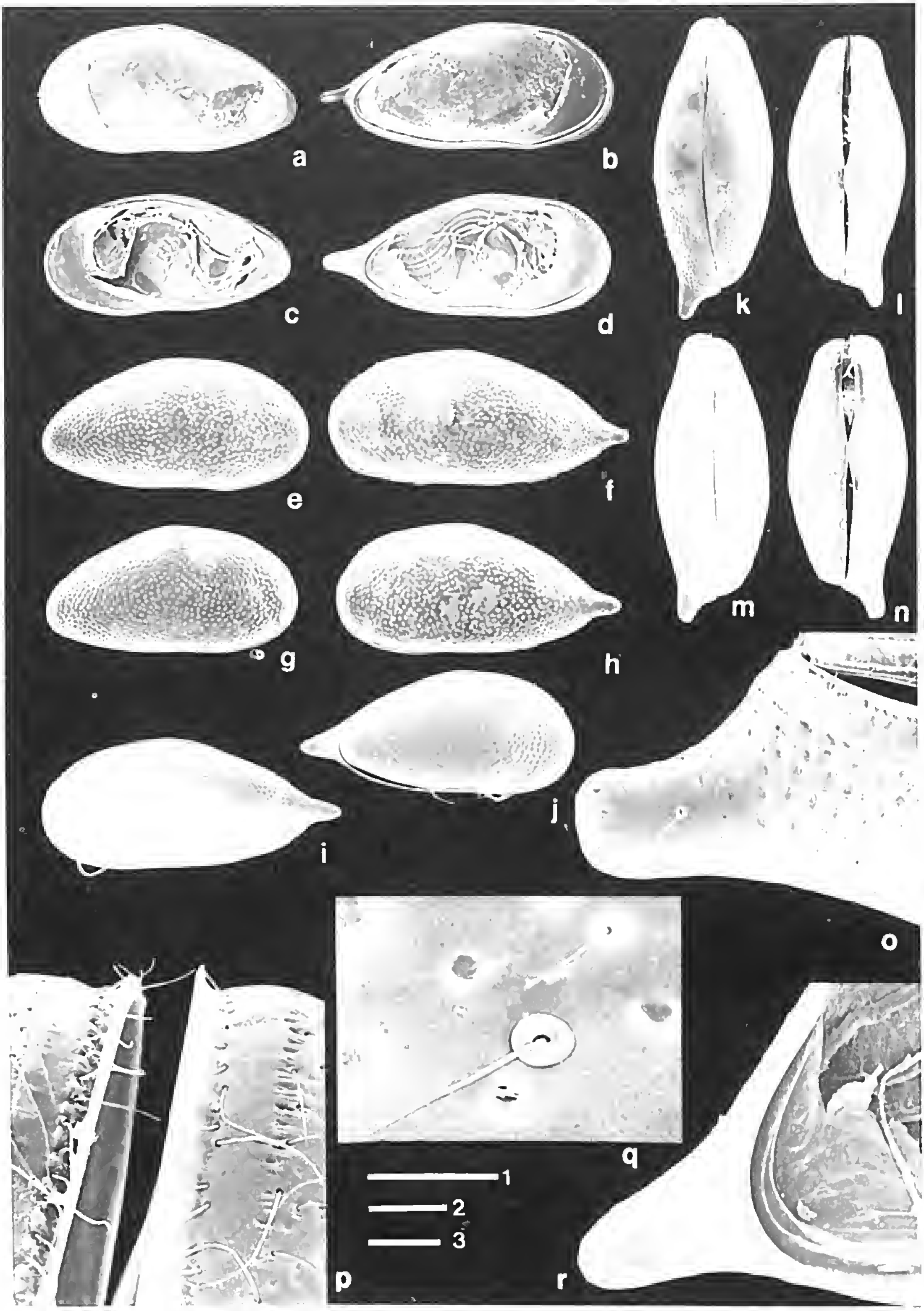


Fig. 21 – *Cypricercus unicornis* n. sp. Granite pool, Newmann's Rocks, 140 km E. of Norseman, W. A. Scales: 1 = 500μ for a-n; 2 = 40μ for o, = 20μ for p, = 60μ for r; 3 = 10μ for q. a, b, e, f, j-l, p female paratypes; c, d, r male holotype; g-i, m-o, q male paratypes. a, RV internal. b, LV internal. c, RV internal. d, LV internal. e, RV external. f, LV external. g, RV external. h, LV external. i, C showing LV. j, C showing RV. k, C dorsal. l, C ventral. m, C dorsal. n, C ventral. o, C ventral, posterior detail of n. p, C ventral, anterior detail of l. q, RV external, detail of g. r, LV internal, posterior detail of d.

Fig. 22—*Cypricercus unicornis* n. sp. Granite pool, Newmann's Rocks, 140 km E. of Norseman, W.A. A-G, I-M drawn from holotype adult male, H, N from paratype adult female. Scale: = 100μ. A, antennula. B, antenna. C, mandible—palp. D, maxillula—palp and lobes. E, thoracopoda I. F, maxilla—left endopodite. G, right maxilla. H, maxilla—endopodite. I, hemipenis. J, hemipenis. K, thoracopoda II. L, furca. M, Zenker organ. N, furcal attachment.

strongly pectinate in male; natatory setae extend further than the tip of the claws.

(Mandible)—(Fig. 22C) As for *C. salinus.*

(Rake-like organ) As for *C. salinus.*

(Maxillula)—(Fig. 22D) Third palp with two toothed Zahnborsten; length width ratio of palps 5:1, 3:1.

(Maxilla)—Sexually dimorphic: in male (Figs. 22F, G) distal palps unequal with the narrow one strongly arched whereas the other is narrow at mid-length and only slightly curved; female (Fig. 22H) endopod palp with three unequal setae. For chaetotaxy see Fig. 22G.

(Thoracopoda I)—(Fig. 22E) Third segment divided at mid-length with an inner seta slightly longer than half of the third segment.

(Thoracopoda II)—(Fig. 22K) Distal setae unequal with longest seta twice the length of the other; seta at mid-length on last segment almost reaching the tip of the terminal pincers and the distal seta on the penultimate segment slightly longer than half of the last segment.

(Hemipenis)—(Fig. 22I, J) Outline of copulatory sheath triangular with greatest length on inner side; lateral lobe digital and straight with distal end rounded.

(Zenker organ)—(Fig. 22M) Elongated with 17 broad rosettes.

(Furca)—(Fig. 22L) Length of anterior claw over posterior one 1.7; setae small and almost equal; furcal shaft extremely long: 2.5 times the length of the anterior claw.

(Furcal attachment)—(Fig. 22N) Median branch broad and about three times the length of the ventral branch; dorsal branch curved inward and with a basal eyelet.

(Eye)—Cups of nauplius eye fused; brown in colour.

Colour of Shell: Green to pale green.

Size:		L	H		L	H
holotype adult male	LV	880μ	400μ	RV	780μ	380μ
paratype adult female	LV	870μ	400μ	RV	790μ	370μ

Type Locality: Granite pool, Newmann's Rocks, 140 km east of Norseman, W.A.

Derivation of Name: From Latin *unus* (=one) and *cornu* (=horn) for the protuberance on the posterior of the left valve.

Ecology and Distribution: This freshwater species has been found in three widely separated localities in Australia: Newmann's Rocks in W.A. (=type locality), swamp at Booligal, N.S.W., and roadside pool, 13 km east of Rocky River, Kangaroo Island, S.A.

Remarks: The extension of the posterior protuberance on the left valve is variable: in some valves from the type locality, the protuberance was restricted to a slight lengthening of the left valve over the right one.

Subfamily Cyprettinae Hartmann 1963

Genus **Cypretta** Vavra 1895

Type Species: *Cypridopsis (Cypretta) tenuicaudata* Vavra 1895.

Cypretta baylyi McKenzie 1966

Figs 19 m-q, 23, 24

1966 *Cypretta baylyi* McKenzie, p. 273.

Diagnosis: *Cypretta* with pitted to reticulated shell and ventral margin in front of the concave mouth region, 0.33 from the anterior, forming a strongly convex lump in both valves. Anterior to this lump, the shell margin is flattened.

Description: The original description of *C. baylyi* by McKenzie (1966) is sufficient, and does not warrant additional description here except for the diagnostic features of the male anatomy since McKenzie (1966) only dealt with female specimens.

(Maxilla)—(Fig. 24F, G) Male palps broadly arched but of different width.

(Hemipenis)—For outline see Fig. 24J; lateral lobe broad and tongue-like.

(Zenker organ)—(Fig. 24K) One end funnel-shaped, with 11 rosettes.

Colour of Shell: Green to dark green.

Remarks: In one male specimen, two inner distal setae, instead of one, were seen on the second segment of the thoracopoda I. The surface of the shell of *C. baylyi* is known to vary extensively from finely punctate, as in Fig. 19q, to regularly reticulate, as in Fig. 23L. The finely punctated specimens are usually smaller, narrower in dorsal view and the convex lump anterior to the mouth region is less pronounced.

Ecology and Distribution: *C. baylyi* is a freshwater species and a very common inhabitant of temporary pools in Western Australia (collections from Dr. I. A. E. Bayly and personal ones). It was originally described from near Inverway in the Northern Territory, and has not been recorded in eastern Australia. A brief review of all *Cypretta* species is provided by Sohn and Kornicker (1973).

On one occasion numerous specimens of *C. baylyi* were found crawling on soft mud in a granite pool below 2 cm of water. This is presumably the typical mode of locomotion for this species which is devoid of long natatory setae on the antennae, an unusual feature for *Cypretta* species which are commonly good swimmers.

Subfamily Cypridopsinae Kaufmann 1900

Kapcypridopsis McKenzie 1977

Type Species: *Kapcypridopsis barnardi* McKenzie 1977

Kapcypridopsis asymmetra n. sp.

Figs 25, 26

Diagnosis: *Kapcypridopsis* with valves asymmetrical posteriorly: right valve with posterodorsal hump extending well beyond the smoothly curved left valve; lateral lobe of hemipenis digitate and with a concave and blunt distal end.

Description: carapace (External)—Pseudopunctate, subrectangular in lateral view with dorsum gently arched and ventrum almost flat except in the mouth region where it is slightly concave; right valve larger than left

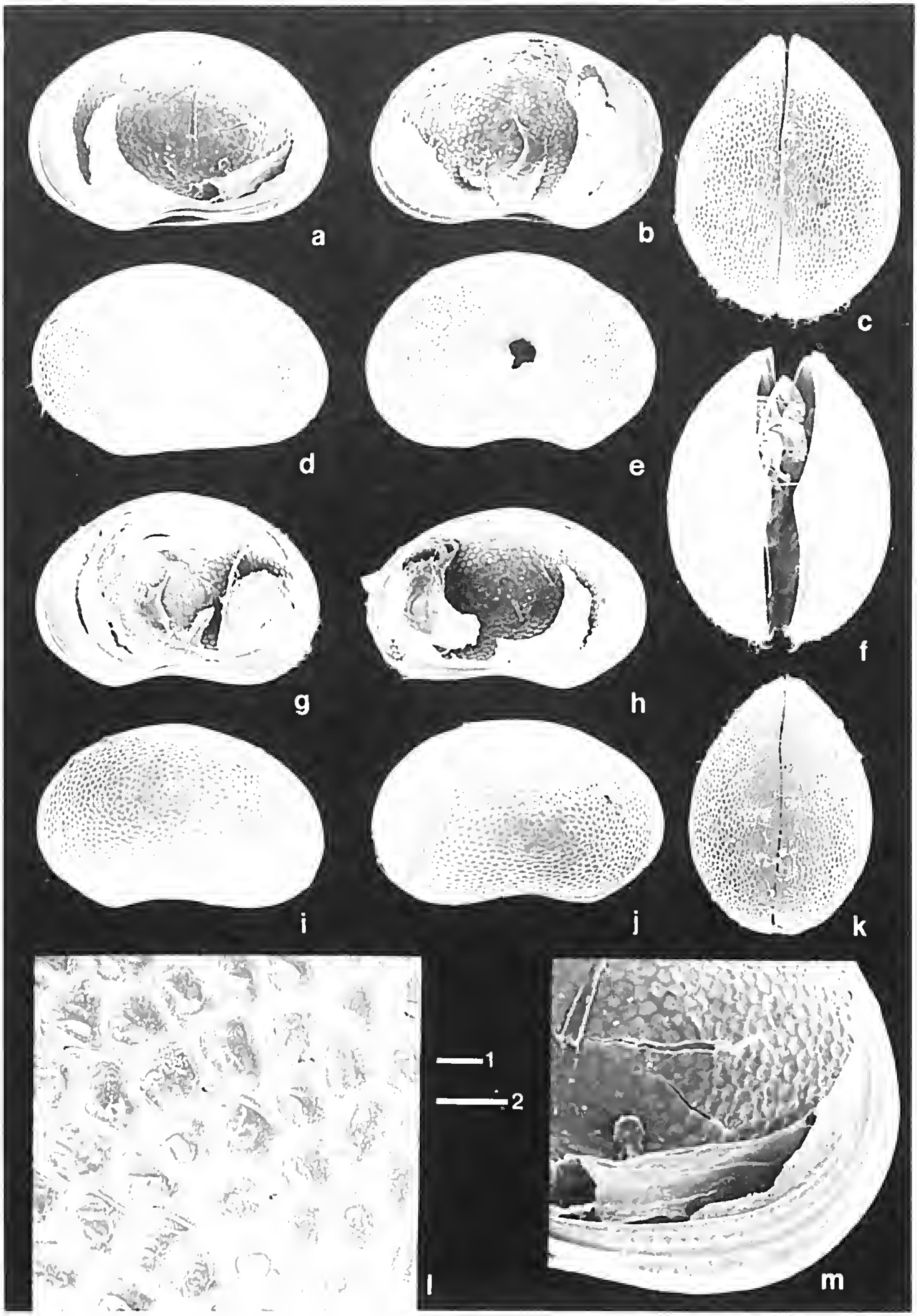


Fig. 23 – *Cypretta baylyi* McKenzie 1966. Granite pool on top of Boyagin Rock, between Brookton and Pingelly, W.A. Scales: 1 = 100μ for a-k, = 10μ for l; 2 = 50μ for m. a-f, l, m females; g, h males. a, RV internal. b, LV internal. c, C dorsal. d, LV external. e, RV external. f, C ventral. g, RV internal. h, LV internal. i, LV external. j, RV external. k, C dorsal. l, C dorsal, detail of c. m, RV internal, posterior detail of a.

Fig. 24—*Cypretta baylyi* McKenzie 1966. Granite rock pool on top of Boyagin Rock, between Brookton and Pingelly, W.A. A, B, D-K drawn from adult male; L, M from adult female. Scale: = 100μ. A, antennula. B, antenna. C, maxillula—palp and lobes. D, mandible—palp. E, thoracopoda II. F, maxilla—left endopodite. G, right maxilla. H, maxilla—endopodite. I, thoracopoda I. J, hemipenis. K, Zenker organ. L, furca. M, furcal attachment.

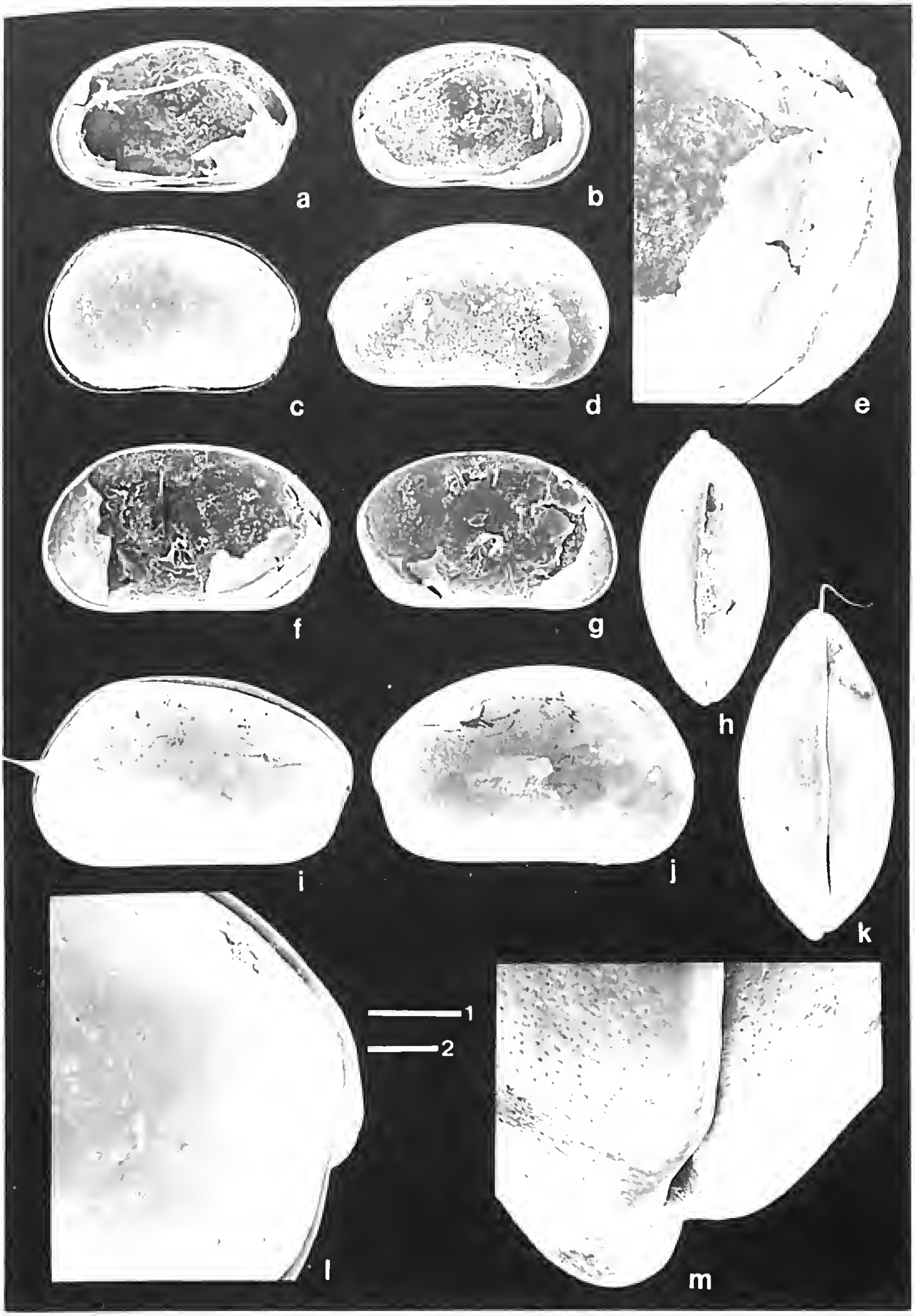


Fig. 25 – *Kapcypridopsis asymmetra* n. sp. Natural granite rock pool near Frenchman's Bay Road, Albany, at turn off to the Blow Holes, W.A. Scales: 1 = 200μ for a-d, f-k; 2 = 50μ for e, l, = 20μ for m. a-d, h, l male paratypes; e-g, i-k, m female paratypes. a, RV internal. b, LV internal. c, C showing LV. d, RV external. e, RV internal, posterior detail of f. f, RV internal. g, LV internal. h, C dorsal. i, C showing LV. j, C showing RV. k, C ventral. l, C showing LV, posterior detail of c. m, C ventral, posterior detail of k.

Fig. 26—*Kapcypridoposis asymmetra* n. sp. Natural granite rock pool near Frenchman's Bay Road, Albany, at turn off to the Blow Holes, W.A. A-F, H, J, K drawn from holotype adult male, remainder from paratype adult male. Scale: = 100μ. A, antennula. B, antenna. C, mandible—palp. D, thoracopoda I. E, right maxilla. F, maxilla—left endopodite. G, maxillula—palp and lobes. H, thoracopoda II. I, furca. J, hemipenis. K, Zenker organ. L, maxilla—endopodite.

one and overlapping it slightly all around; posterodorsally, however, the right valve possesses a hump which extends well beyond the edge of the left valve in that area, which is also the furthest point of extension of the valve. Edge of both valves rounded all around; normal pore canals rare and scattered.

(Internal) – Inner lamella broad anteriorly and narrow posteriorly; selvage peripheral in both valves except posteroventrally in the right valve, where it borders the inner lamella which does not follow the curvature of the shell in that area; narrow groove outside and all along the selvage in both valves.

ANATOMY: (Antennula) – (Fig. 26A) Seven-segmented; length width ratio of last six segments: 1:1, 1:1, 1:1.3, 1:1, 1.3:1, 4:1; natatory setae as long as all segments together.

(Antenna) – (Fig. 26B) Four claws: three almost equal on penultimate segment and a shorter pectinate one on distal segment nearly reaching the tip of the other claws in male; in female it is barren and shorter; unequal natatory setae reduced to three and not reaching the distal end of the penultimate segment.

(Mandible) – (Fig. 26C) Mandibular palp with α bristle slim, long and barren, β bristle thick, short, pointed and densely pilose, γ bristle slim, twice the length of the distal segment and pilose in its distal third.

(Rake-like organ) – Six to seven teeth plus one inner bifid on each rake.

(Maxillula) – (Fig. 26G) Epipod with about 17 Strahlen; distal palp rectangular and third lobe with toothed Zahnborsten.

(Maxilla) – Sexually dimorphic: in male (Fig. 26 E, F) palps asymmetrical but both strongly and similarly arched; in female (Fig. 26L) middle seta faintly plumose and twice the length of the other equal setae; for chaetotaxy of protopod, see Fig. 26E.

(Thoracopoda I) – (Fig. 26D) Third segment divided; distal seta on segment and inner seta, at mid-length of the third segment where it is divided, of equal length and longer than half the third segment; inner distal seta of third segment slightly shorter than the other two mentioned above.

(Thoracopoda II) – (Fig. 26H) Distal pincers narrow but long; distal setae unequal with shorter curved one 0.4 of the length of the other straight one.

(Hemipenis) – (Fig. 26J) Lateral lobe digitate with blunt and concave end; inner lobe like a broad and pointed hump reaching half the length of the outer lobe; copulatory sheath like a narrow tongue near the outer lobe and almost completely covered by it.

(Zenker organ) – (Fig. 26K) Both ends rounded and with 12 rosettes.

(Furca) – (Fig. 26I) Weakly chitinized, whip-like and with a short seta near its base.

(Furcal attachment) – Thin and bifurcate distally.

COLOUR OF SHELL: Dark green to almost black, except in the eye region where it is reddish brown.

SIZE:		L	H		L	H
holotype adult male	LV	580μ	340μ	RV	590μ	360μ
paratype adult female	LV	640μ	400μ	RV	680μ	410μ

TYPE LOCALITY: Natural granite rock pool near Frenchman's Bay Road, Albany, at turn off to The Blow Holes, W.A.

DERIVATION OF NAME: From Greek *a-* (= not) and *symmetros* (= symmetrical) for the asymmetrical valves posterodorsally.

ECOLOGY AND DISTRIBUTION: This species has only been collected twice, in the same year, at the type locality in 2.5 cm of water; it is not found in nearby artificial holes dug in granite.

REMARKS: Differences between the type species from the Cape Province in South Africa and *S. asymmetra* are the posterodorsally asymmetrical valves (in the latter), the broad inner lamella (in the former), the number of reduced natatory setae on the antenna, the number of teeth on the rake-like organ, and the outline of the hemipenis. These are considered to be specific differences only.

Genus **Sarscypridopsis** McKenzie 1977

TYPE SPECIES: *Sarscypridopsis gregaria* (Sars 1896).

Sarscypridopsis aculeata (Costa 1847)

Figs 27, 28

1847 *Cypris aculeata* Costa, p. 11.
1867 *Cypridopsis aculeata*; Brady, p. 117
1900 *Cypridopsis aculeata*; Müller, p. 85.
1968 *Cypridopsis obstinata* Barclay, p. 75.
1977 *Sarscypridopsis aculeata*; McKenzie, p. 49.

DIAGNOSIS: Member of *Sarscypridopsis* with subtriangular shell in lateral profile; with dorsum straight along the hinge line and forming an obtuse angle with the almost straight posterodorsal area; surface of shell pitted and with or without spines; shallow depression above the hingeline as both valves are higher than the hinge line; ventral overlap of right valve over left.

DESCRIPTION: This cosmopolitan species has been described fully on numerous occasions (Müller 1900, Sars 1928, illustrated Swain 1976). It is not further described here but it is illustrated as the first Australian record.

ECOLOGY AND DISTRIBUTION: *Sarscypridopsis aculeata* is a cosmopolitan species, commonly found in temporary pools. It has been collected in pools in WA, SA, and Victoria. The salinity range for the species is freshwater to 11.2°/₀₀ with one additional record at 21.3°/₀₀. This record is much higher than in European waters where the upper salinity is 1.95°/₀₀ (see De Deckker 1981c). This might be the result of an acclimatization to Australian conditions where water in temporary pools is commonly saline.

REMARKS: *S. aculeata* is definitely not a *Cypridopsis* since its right valve overlaps the left one ventrally – this is the opposite in *Cypridopsis*. The difference is also reflected in the male anatomy where the right prehensile palp of the maxilla is larger than the left in *Cypridopsis*, the opposite of *Sarcypridopsis* and *Plesiocypridopsis*

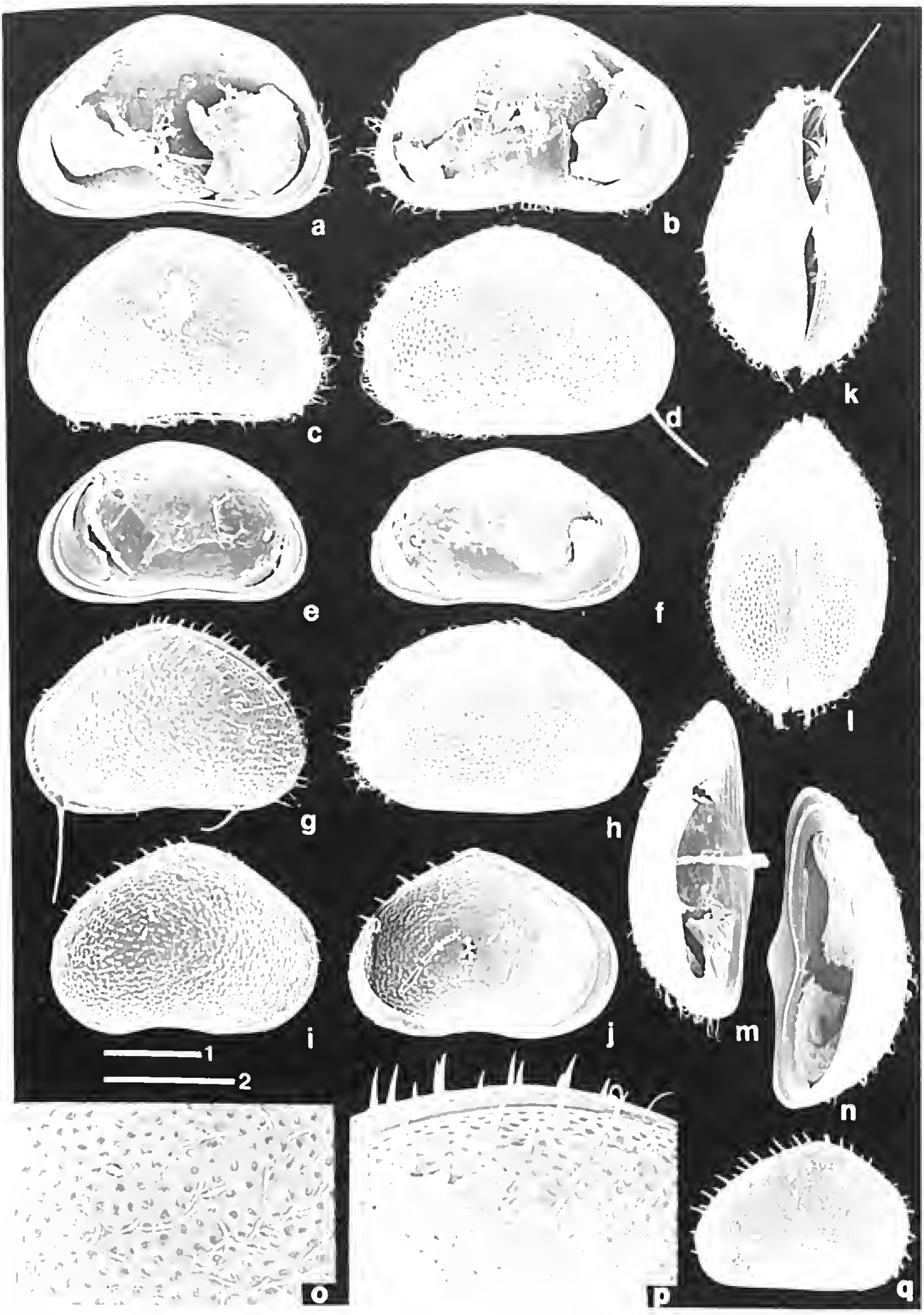


Fig. 27 – *Sarscypridopsis aculeata* (Costa 1847). a-d, h, k-n, o, pond very close to Reel Inlet (coastside), 19 km S. of Mandurah, W.A. e, f, shallow lake near south-western Highway, 15 km N. of Horney or immediately S. of Yarloop, W.A. g, i, j, q Lake Sadie, E. end of Wilson Inlet, near Denmark, W. A. Scales: 1 = 250μ for a-n, q; 2 = 100μ for o, p. a-h, k-p females; i-j, q juveniles. a, RV internal. b, LV internal. c, C showing LV. d, C showing RV. e, RV internal. f, LV internal. g, C showing LV. h, C showing RV. i, RV external. j, LV internal. k, C ventral. l, C dorsal. m, LV dorsal. n, RV dorsal. o, C showing RV, detail of h. p, C showing LV, dorsal detail of g. q, C showing RV.

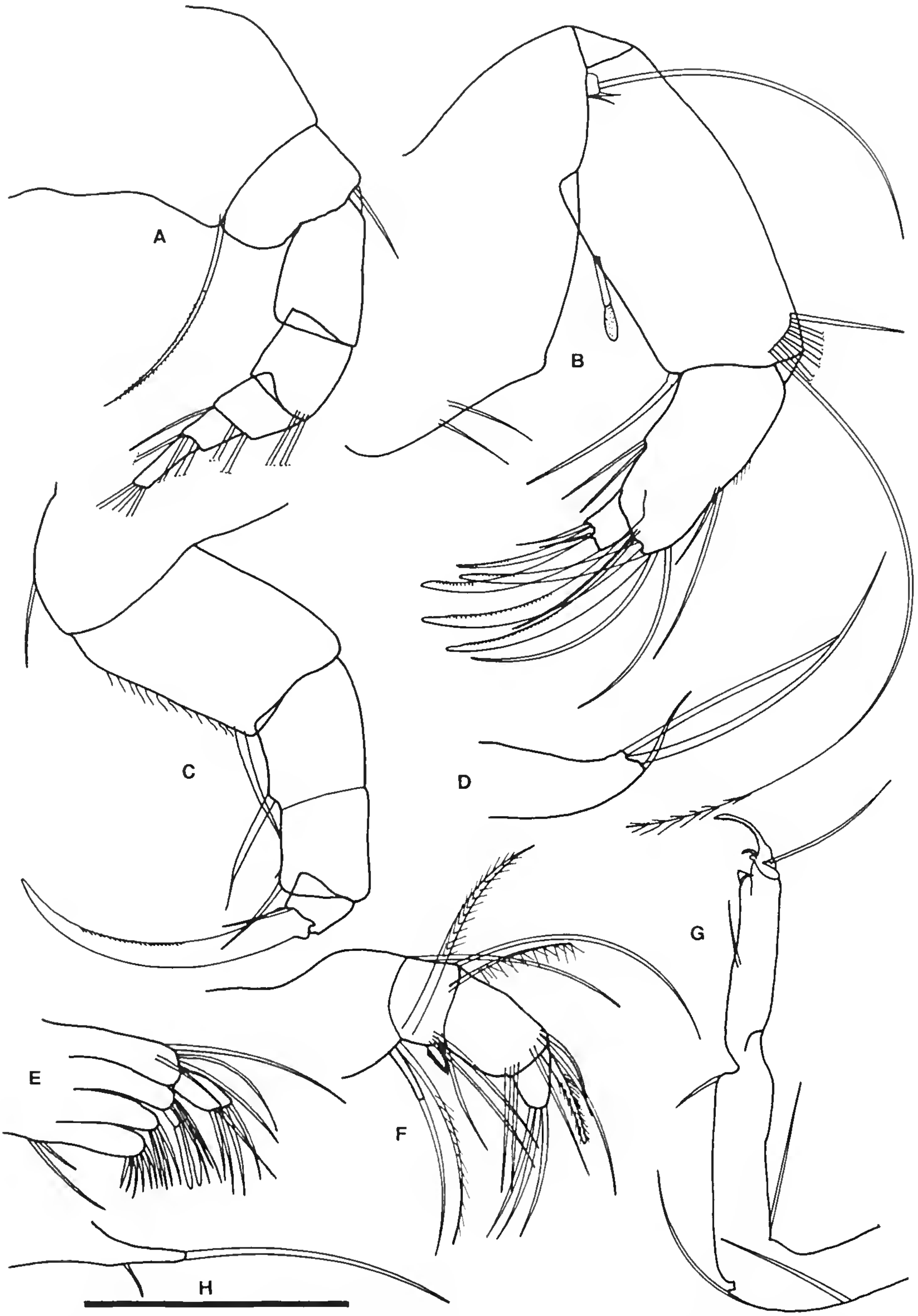


Fig. 28—*Sarscypridopsis aculeata* (Costa 1847). Pond very close to Reel Inlet (coastside), 19 km S. of Mandurah, W.A. Drawn from an adult female. Scale: = 100μ. A, antennula. B, antenna. C, thoracopoda I. D, maxilla—endopodite. E, maxillula—palp and lobes. F, mandible—palp. G, thoracopoda I. H, furca.

Rome 1965. Unfortunately, no males of *S. aculeata* have yet been found to confirm the transfer of this species to *Sarscypridopsis.*

S. aculeata has a green to dark green shell and often many large pseudopores. In addition, between these pseudospores, either hairs or small spines, are present (see Fig. 27o, p). These differences are presumably controlled ecologically. It appears therefore that species which are almost identical with *S. aculeata* but which are extremely spinose, as described by Sars (1924) for *Cypridopsis spinifera* Sars 1924 from South Africa, are to be synonymized with *S. aculeata.* The non-spinose species *Cypridopsis obstinata* Barclay 1968, described from New Zealand by Barclay (1968) is considered here to be synonymous with *S. aculeata* as the anatomy of the type specimen of the former has been examined and is identical with the specimen of *S. aculeata* illustrated in Fig. 28.

ACKNOWLEDGEMENTS

This paper was written during the tenure of a Commonwealth Postgraduate Research Award under the supervision of Professor W. D. Williams in the Zoology Department, University of Adelaide.

Many of the collections described here have been received from Dr I. A. E. Bayly, Mr R. Croome, Ms M. Davies, Dr B. V. Timms and Mr M. J. Tyler. I wish to thank these people as well as Dr M. Christiansen (Oslo Museum) and Dr G. Poore (National Museum of Victoria) for the loan of type specimens.

I also wish to acknowledge Mr P. G. Kempster for his prompt help in photographical matters and Miss A. Sebastyan who typed the manuscript.

REFERENCES

Barclay, M. H., 1968. Additions to the freshwater ostracod fauna of New Zealand. *N.Z. J. Mar. Freshwat. Res.* 2: 67-80.

Brehm, V., 1939. Eine neue, subfossile *Limnocythere* von Neuseeland. *Zool. Anz.* 127: 191-193.

Chapman, F., 1914. Notes on Testacea from the Pleistocene marl of Mowbray Swamp, North West Tasmania. *Mem. natn. Mus. Melb.* 5: 55-61.

Chapman, F., 1919. On an ostracod and shell marl of Pleistocene age from Boneo Swamp, West of Cape Schanck, Victoria. *Proc. R. Soc. Vict.* 32: 24-32.

Chapman, M. A., 1963. A review of the freshwater ostracods of New Zealand. *Hydrobiologia* 22: 1-40.

Chapman, M. A. & Lewis, M. H., 1978. *An introduction to the freshwater Crustacea of New Zealand.* Collins, Auckland.

Danielopol, D. L. & McKenzie, K. G., 1977. *Psychrodromus* gen. n. (Crustacea, Ostracoda), with redescription of the cypridid genera *Prionocypris* and *Ilyodromus. Zool. Scr.* 6: 301-322.

De Deckker, P., 1981a. Taxonomic notes on some Australian ostracods with description of new species *Zool. Scr.* 10: 37-55.

De Deckker, P., 1981b. Taxonomy, ecology and palaeoecology of ostracods from Australian inland waters. Unpublished Ph. D. Thesis, University of Adelaide.

De Deckker, P., 1981c. Ostracods of athalassic salt lakes: a review. In *Salt Lakes: Proceedings of an International Symposium,* W. D. Williams, ed., Junk, The Hague.

De Deckker, P. & Geddes, M. C., 1980. Seasonal fauna of ephemeral saline lakes near the Coorong Lagoon, South Australia. *Aust. J. Mar. Freshwat. Res.* 31: 677-699.

Deevey, E. S., 1955. Paleolimnology of the upper swamp deposit, Pyramid Valley. *Rec. Cant. Mus.* 6: 291-344.

Eagar, S. H., 1970. A new species of *Eucypris* (Ostracoda) from Wellington. *N.Z. J. Mar. Freshwat. Res.* 4: 195-202.

Eagar, S. H., 1971. A checklist of the Ostracoda of New Zealand. *J. R. Soc. N.Z.* 1: 53-64.

Gauthier, H., 1928. Ostracodes et cladocères de l'Afrique du Nord (2^e note). *Bull. Soc. Hist. Nat. Afr. Nord.* 19: 69-79.

Geddes, M. C., De Deckker, P., Williams, W. D., Morton, D. & Topping, M., (1981). On the chemistry and biota of some saline lakes in Western Australia. In *Salt Lakes: Proceedings of an International Symposium,* W. D. Williams, ed., Junk, The Hague.

Gill, E. D. & Banks, M. R., 1956. Cainozoic history of the Mowbray Swamp and other areas of northwestern Tasmania. *Rec. Q. Vict. Mus.* 6: 1-41.

Henry, M., 1923. A monograph of the freshwater Entomostraca of New South Wales, Part III. Ostracoda. *Proc. Linn. Soc. N.S.W.* 48: 267-286.

Hornibrook, N. de B., 1955. Ostracoda in the deposits of Pyramid Valley Swamp. *Rec. Cant. Mus.* 6: 267-278.

Hussainy, S. U., 1969. Description of the male of *Candonocypris assimilis* G. O. Sars 1894 (Cyprididae, Ostracoda). *Pap. Proc. R. Soc. Vict.* 82: 305-307.

King, R. L., 1855. On Australian Entomostracans. *Pap. Proc. Roy. Soc. Tas.* 3: 56-75.

McKenzie, K. G., 1966. *Mytilocypris,* a new ostracode genus from Tasmania. *Pap. Proc. R. Soc. Tasm.* 100: 27-30.

McKenzie, K. G., 1971a. Distribution of freshwater Ostracoda. *Bull. Centre Rech. Pau-SNPA* 5 suppl.: 179-190.

McKenzie, K. G., 1971b. Ostracoda from Lake Peunde, near Mt. Wilhelm, New Guinea. *Zool. Anz.* 186: 391-403.

McKenzie, K. G., 1977. An illustrated Key to South African continental Ostracoda. *Ann. S. Afr. Mus.* 74: 45-103.

Mehes, G., 1939. Ostracodes de la Nouvelle Calédonie. *Rev. Suisse Zool.* 46: 549-565.

Muller, G. W., 1900. Deutschlands Süsswasser-ostracoden. *Zoologica* 12: 1-112.

Okubo, I., 1975. Studies on Ostracoda in fish ponds – 1 – Two species in fish ponds on the Chiba Prefectural Freshwater Fisheries Experimental Station. *Bull. Jap. Soc. scient. Fish.* 41: 155-165.

Rome, D. R., 1969. Morphologie de l'attache de la furca chez les Cyprididae et son utilisation en systématique. In *The Taxonomy, Morphology and Ecology of Recent Ostracoda,* J. W. Neale, ed., Oliver & Boyd, Edinburgh.

Sars, G. O., 1894. Contributions to the knowledge of the freshwater Entomostraca of New Zealand as shown by artificial hatching from dried mud. *Forch. Vidensk. Selsk. Krist.* (1894) 5: 1-62.

Sars, G. O., 1896a. On some freshwater Entomostraca from the neighbourhood of Sydney, partly raised from dried mud. *Arch. Math. Naturv.* 18: 1-81.

Sars, G. O., 1896b. On some West Australian Entomostraca raised from dried sand. *Arch. Math. Naturv.* 19: 1-35.

Sars, G. O., 1924. The freshwater Entomostraca of the Cape Province (Union of South Africa) Part II. Ostracoda. *Ann. South Afr. Mus.* 20: 105-193.

Sars, G. O., 1928. *An account of the Crustacea of Norway with Short descriptions and figures of all the species. 9: Ostracoda.* Bergen Museum, Bergen.

SOHN, I. G. & KORNICKER, L. S., 1973. Morphology of *Cypretta kawatai* Sohn & Kornicker, 1972 (Crustacea, Ostracoda), with a discussion of the genus. *Smith. Contrib. Zool.* 141: 1-28.

SWAIN, F. M., 1976. Evolutionary development of cypridopsid Ostracoda. *Abh. Verh. naturwiss. Ver. Hamburg.* (NF) 18/19 (Suppl.): 103-118.

VICTOR, R. & FERNANDO, C. H., 1980. On *Herpetocypris makua* (Tressler) 1937, a freshwater ostracod (Crustacea: Ostracoda) from the Hawaiian Islands, with notes on the other species of the genus. *Can. J. Zool.* 58: 1288-1297.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF VICTORIA

Volume 93

NUMBER 2

ROYAL SOCIETY'S HALL
9 VICTORIA STREET, MELBOURNE 3000

CONTENTS OF VOLUME 93 NUMBER 2

THE BRUUN RULE—THE RELATIONSHIP OF SEA-LEVEL CHANGE TO COASTAL EROSION AND DEPOSITION

By H. Allison* and Maurice L. Schwartz†

*Institute of Earth Resources, Division of Land Resources Management, CSIRO, Private Bag, P.O., Wembley, 6014, Western Australia.
†Western Washington University, Bellingham, Washington, 98225, U.S.A.

Abstract: The Bruun Rule in shore erosion is presented systematically, starting from initial assumptions and axioms towards a rigorous mathematical treatment. Mathematical treatment is given with detail to assist geologists in full understanding of the development. Cases of beach excavation, littoral drift, artificial beach nourishment and formation of a cuspate shoreline are treated by the theory, based on the Bruun Rule.

INTRODUCTION

The concept of shore erosion due to sea-level rise expressed by Bruun (1962), later becoming widely known as the "Bruun Rule" (Schwartz 1967), belongs to the class of concepts, which are enthusiastically supported by some scientists, while immediately triggering a negative response from others.

The chronology of Bruun Rule studies (Fisher 1980a) includes laboratory and/or field observations, by Schwartz (1965, 1967), Dubois (1975, 1976, 1977a, 1977b), Hands (1976, 1977, 1980), Fisher (1977a, 1977b, 1977c, 1980b), and Rosen (1977, 1978a, 1978b, 1980); all of them strongly supporting Bruun's concepts. On the other hand, the concept was criticized by Swift (1976) as being of limited applicability. Another criticism is that by Kaplin (1973), who is skeptical about the validity of Bruun's concepts; although supportively stating simultaneously that at least some of Bruun's concepts were known by the Soviet school as early as 1946. Valuable comments on applicability of the concept are given by Gill (1979).

It appears that most of the controversy exists solely due to differences in interpretation of the Bruun Rule. The differences arise, in their turn, due to lack of rigorous mathematical formulation as well as lack of clarity in the statements of the initial assumptions of the Rule. Hence, our task in this paper is to present the Bruun Rule as a rigorous theory based on clearly stated assumptions. It is shown that the Bruun Rule has, in fact, a much wider field of application, than was previously thought. The Bruun theory can be applied for both "closed" and "open" beach systems. We start from formulation of the Bruun Rule as in Schwartz (1965, 1967).

THE BRUUN RULE AND ITS INITIAL ASSUMPTIONS

The Bruun Rule states the following (Fig. 1):

1. A rise in sea level causes erosion of the upper beach and shoreward displacement of the shore-water boundary.
2. The change in sea level corresponds to translation of the transverse beach profile while retaining its original shape.
3. The material eroded from the upper beach is equal in volume to the material deposited on the nearshore bottom.
4. The rise of the nearshore bottom is equal to the rise in sea level.
5. The relationship between sea level rise a and shoreward displacement s of the beach profile is given by the formula (Bruun 1962):

$$a = \frac{hs}{l} \tag{1}$$

where: l is the length of the transverse profile,
h is the profile height, being the sum of sea depth at the distance l from the shore and the shore elevation above the sea level.

LIMITS OF THE BRUUN RULE

As stated by Gill (1979) the rule only applies 1, where there is sufficient energy; 2, where equilibrium has been attained; 3, where there is sufficient space in the subtidal area; and 4, if there is sufficient sediment.

EXPERIMENTAL SUPPORT OF THE BRUUN RULE

The two classes of experiments, supporting the Bruun Rule, are laboratory (Schwartz 1965, 1967) and field experiments. The advantage of laboratory experiments is that the "equilibrium profile" which is practically unobservable on a beach, due to continuous variations in wave climate, can be maintained in a laboratory where the wave climate can be set constant.

Laboratory Experiments

In the first experiment (Schwartz 1965), the wave basin was 81.25 cm wide and 115 cm long with variable gradient of the bottom adjustable at 0°, 2.5°, and 4.5°. The waves generated had a period of 0.33 sec ±5%, an amplitude of 8 ± 2 mm and a wave length of 15 ± 1 cm. Water depth ranged from 5 to 10 cm, the sand used was a natural Ottawa sand, washed and sorted.

It was found that 30 mins of wave attack produced a beach profile which did not change with subsequent wave action, and this profile was assumed to be the "original profile" figuring in the Bruun statements. The water level was then raised by 10 mm, the wave

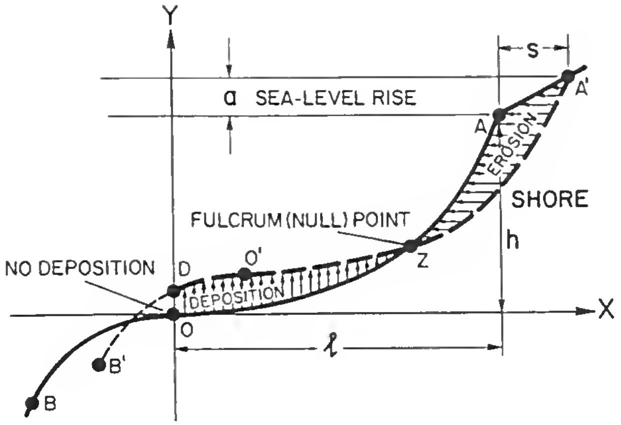


Fig. 1 – Definition sketch of the variables in the Bruun Rule. The proto-profile AOB is translated towards the shore (positive x-direction) to its new position $A'O'B'$. However, no deposition occurs at the values of $x<0$. The segment DO is assumed to be the sharp boundary between the regions. In reality there will always be a smooth transition from the point D to the curve BO. However, this is neglected in the Bruun theory.

generator was set up again and as soon as the equilibrium profile was reached water depth and depth of sediment at the outer edge of the shelf were measured.

The profile retained its original shape after water level rise and was translated towards the shore, causing the shore recession. During the experiment the slope of the bottom was varied and it is remarkable that this change did not have any significant effect on water depth or sand heights accumulated at the lower portions of the beach.

In the second laboratory experiment (Schwartz 1967) the wave tank was larger in size (100 × 232.5 cm) and the wave generator operated with variable periods. The sand was the same as in the previous experiment and water level was raised in different increments and at various rates.

Profile shapes were observed before and after water level rise and the results indicated support for statements 1, 2 and 3 of Bruun's Rule. The most important statement (4), that the increase in sand height deposition on the outer shelf equals the rise of water level (hence, maintaining the constant water depth there), was supported by the experimental results.

These experimental results support the first 4 statements of the Bruun Rule. However, formula (1) was not checked during the laboratory experiments. This was done in some of the following field experiments.

FIELD EXPERIMENTS

In 1964 an experimental program was established to study the variation of beach profiles under the variation of sea level due to neap and spring tides (Schwartz 1967, 1979). At Herring Cove Beach in the Cape Cod National Seashore (USA) during a slight breeze, small waves approaching the breaker zone were observed with 15-20 cm heights and periods of 3 sec. The direction of wave approach during the summer is predominantly from the north-west. Shore drift at this time, is consequently, toward the south. Sediment supply for this part of the Cape was provided by shore drift from the cliffs of glacial drift that form the outer coast. The nearshore bottom is characterized by a steep slope prior to grading off to a gentler slope.

At nearby Nauset Light Beach which bears 12° west of north and is exposed to the fetch of the Atlantic Ocean, small waves from the southeast approach the breaker zone on a calm day with a period of 8 secs and a height of 30 cm. Erosion of the back beach cliff of glacial drift supplies sediment that drifts northward. The nearshore bottom slopes gently to a bar 500 m offshore at low tide.

The results of profiling during low and high water levels indicate parallel translation without significant change in shape during sea-level rise. The more dynamic regime at Nauset Light Beach means greater translation.

Another field experiment, strongly supporting statement 2 of the Bruun Rule, was conducted by Dubois (1976) who measured nearshore profiles of Lake Michigan as water level seasonally rose from April to July, 1971. There were a total of 17 measurements of beach profiles during this period. The profiles presented by Dubois clearly indicate the parallel translation without significant changes in shape of profiles as water level rose.

Using the Bruun formula (1), in which the value l was taken as a distance from foreshore base to the position of breaking waves, Dubois (1977a) calculated shore recessions and compared them with the observed values for various wave conditions recorded. The agreement between the values of shore recession observed in the field and those calculated on the basis of Bruun's formula (1) was remarkable.

The above field observations were limited to only two sites and a few months in both Schwartz's and Dubois' experiments. The following field experiment by Hands (1976, 1980) was devoted to more long-term shore erosion.

Hands (1976, 1980) described the response of Lake Michigan shores to increased water level over a 9 year period at 34 sites. He used formula (1) and demonstrated good agreement with observed erosion. His most interesting result was the clear transition zone between the area of bottom erosion and no erosion. Hands was the first to point out that actual length of the bottom profile (value l in eq. (1)) is not important, because it is the value h/l, which is critical in the formula (1), and this value does not change much whether the length of a transition zone is considered or not.

Observations by Fisher (1977a, 1977b, 1980b) of Rhode Island shoreline retreat over 35 years with a scope of 113 sites take into account an advance of sea-shore boundary due to a submergence (drowning) of the shore without erosion, separating this from shore retreat due to shore erosion, to which he applies Bruun's formula

(1). The greatest contribution of Fisher is to consider the "open" system, in which not all the sediment volume eroded is deposited on the nearshore bottom. Sediment budget calculations by Fisher require knowledge of the position of the point between the beach erosion zone and the offshore deposition zone (point Z on Fig. 1) to which various names had been prescribed (inflection, fulcrum, null point).

It will be demonstrated below, however, that knowledge of position of such a point is not needed for either "closed" or "open" systems.

The longest project undertaken up to date was that of Rosen (1978b, 1980), who described the shore erosion on 146 beach units, due to sea level rise, over 100 years.

The study area consisted of 350 km of estuarine shoreline in the southern half of Chesapeake Bay. Bruun's formula (1) was applied to calculate an average over 100 years' shore recession rate and the results were compared to the measured values.

On the basis of the above laboratory and field experiments it is clear that experimental support exists for the Bruun Rule. We now have to analyze the Bruun Rule statements themselves.

ANALYTICAL DESCRIPTION OF THE BRUUN EFFECT

Statement 2 of the Bruun Rule, termed the "Bruun Effect" (Schwartz 1967), must be accompanied by statement 1, which indicates in what direction (onshore or offshore) the profile is translated during sea level rise. Considering these two statements together as separated for the time being from the other Bruun statements, we must introduce a notation $\bar{a}$ for the rise of the profile, which is not required at this stage to be equal to the sea level rise a.

The bottom profile is considered as a function $f(x,s)$ of the variable x and the parameter s.

Assume that the initial shape of the profile, before erosion occurred ($s=0$), was given by a certain arbitrary function $f_0(x)$. Then the initial condition can be written as

$$f(x,\ s)\Big|_{s=0} = f_0(x) \tag{2}$$

The translated profile, shifted by s and lifted by $\bar{a}(s)$ is given by

$$f(x,\ s) = f_0(x-s) + \bar{a}(s) \tag{3}$$

Let us assume now, that we accept Bruun formula (1), equating $a=\bar{a}$, which, when substituted into (3) gives the result:

$$f(x,a) = f_0(x - \frac{al}{h}) + a \tag{4}$$

This is the analytical form of the Bruun effect, because, when $a=0$, the function $f(x,a)$ reduces to the initial profile shape $f_0(x)$; for any given positive sea level rise a, the profile is shifted shorewards in the positive x-direction by the value al/h and raised by the value a, retaining its original shape $f_0(x)$, hence statements 1 and 2 of Bruun's theory follow from (4). (For the negative a (sea level fall), the profile moves offshore and downwards).

Let us consider now the case in a certain sense opposite to rise in sea level, namely, elevation of the beach profile by the value $b(s)$ due, for example, to artificial nourishment of a beach. Elevation of the beach profile while the absolute sea level remains still is equivalent to a fall of the relative sea level with respect to the nearshore bottom. Hence, according to Bruun's statements 1 and 2, the beach should retain its original shape, but must be translated seawards.

If, once again, the Bruun formula (1) is utilized, with the value of profile rise b substituted instead of a, a formula analogous to (4) emerges:

$$f(x,b) = f_0(x + \frac{bl}{h}) + b \tag{5}$$

When there is no beach nourishment ($b=0$), the beach profile reduces to the original profile shape $f_0(x)$.

For any positive $b>0$ (beach nourishment) the profile is shifted seawards by the value bl/h, while retaining its original shape. (For b negative due, for example, to sinking of sediments offshore, littoral drift or bottom excavation, the profile is moving shorewards, i.e. erosion occurs.)

If it happens that sea level rise a is accompanied by beach nourishment, resulting in the bottom rise b, then, combining equations (4) and (5), the resultant beach transformation can be described as:

$$f(x,a,b) = f_0[x + \frac{l}{h}(b-a)] + (b+a) \tag{6}$$

where $f_0(x)$ is the original shape of the beach.

Note that the basic equations (4), (5) and (6) were obtained solely on the basis of the first two statements of Bruun Rule.

BRUUN RULE FOR CLOSED BEACH SYSTEMS

Statement 3 of the Bruun Rule is the definition of the closed beach system, in which the volume of erosion is balanced by the volume of deposition and no exchange of beach material with the outer world exists.

It may seem obvious that for the calculation of volumes of erosion and deposition one needs to know the position of the fulcral (null) point (see Fig. 1) and this need was, in fact, expressed by Dubois (1977a) and Fisher (1980). The difficulty here is that there could be, in principle, several such fulcral points, as shown in Fig. 2. Determination of their positions requires knowledge of beach profile shape and foreknowledge of the same values which one is going to calculate on the basis of equating the volumes of erosion and accretion.

This difficulty, however, can be by-passed if one prescribes opposite signs to the volumes of erosion and accretion according to the signs of difference in ordinates between the protoprofile $f_0(x)$ and the translated profile $f(x,s)$. (Sign plus corresponds to accretion; sign minus to erosion.) Then the definite integral taken along the x-axis will be equal to zero, when volumes (area between the curves in Fig. 2) of erosion and accretion balance each other.

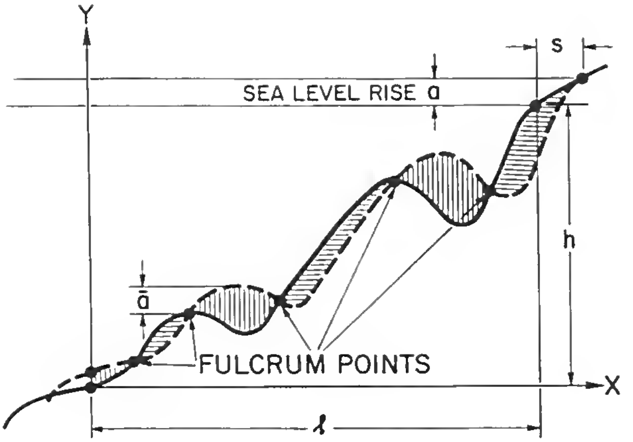


Fig. 2 – Multiple fulcrum points, corresponding to multiple areas of erosion (horizontal dashing) and deposition (vertical dashing).

The important issue here is the limits of integration. As already mentioned, the value l (offshore beach length) is supposed to have been chosen in such a way that no erosion or deposition occurs offshore beyond this length, i.e. to the left of the point $x=0$ in Fig. 2. Therefore, it is reasonable to accept point $x=0$ as the lower limit of integration. On the other hand, if the beach profile retreat is equal to value s during sea level rise, it is reasonable to take the upper limit of integration as $(l+s)$. Consequently, we conclude that Bruun's statement 3 can be equivalently written analytically (in the co-ordinate system of Figs 1, 2) as

$$I=\int_0^{l+s}[f(x,s)-f_0(x)]\,dx=0 \tag{7}$$

The first two statements of the Bruun Rule were shown in the previous paragraph to lead to the analytical expression (3) of the function $f(x,s)$, in which the rise of bottom profile as a whole was denoted $\bar{a}(s)$. According to statement 4 we now equate the rise of profile $\bar{a}(s)$ to the sea level rise $a(s)$. Hence, the function $f(x,s)$, figuring in (3) can be written

$$f(x,s)=f_0\,(x-s)+a(s) \tag{8}$$

Let us emphasize that equations (7) and (8) comprise statements 1-4 of the Bruun Rule, but the Bruun formula (1) (statement 5) is *not* used. On the contrary, we are going to demonstrate, that these four statements form the complete set of axioms, from which formula (1) can be derived. We start from several examples of profiles, having simple analytical expressions.

ANALYTICAL PROFILES

Parabolic profile

Consider the profile, described by a parabola

$$f_0\,(x)=x^2 \tag{9}$$

Let us note, that when $x=l$, the right end value of function (9) equals the profile height h (see Fig. 3), hence $h=l^2$. Substituting (9) into (8) and then into (7), one obtains

$$\int_0^{l+s}[(x+s)^2+a(s)-x^2]dx=\int_0^{l+s}[-2xs+s^2+a(s)]dx= \tag{10}$$
$$-x^2s+s^2x+xa(s)\Big|_0^{l+s}=-l^2s\;-ls^2+(l+s)a(s)=0$$

Hence

$$a(s)=\frac{l^2s+ls^2}{l+s}-\frac{hs(1+\frac{s}{l})}{l(1+\frac{s}{l})}=\frac{hs}{l} \tag{11}$$

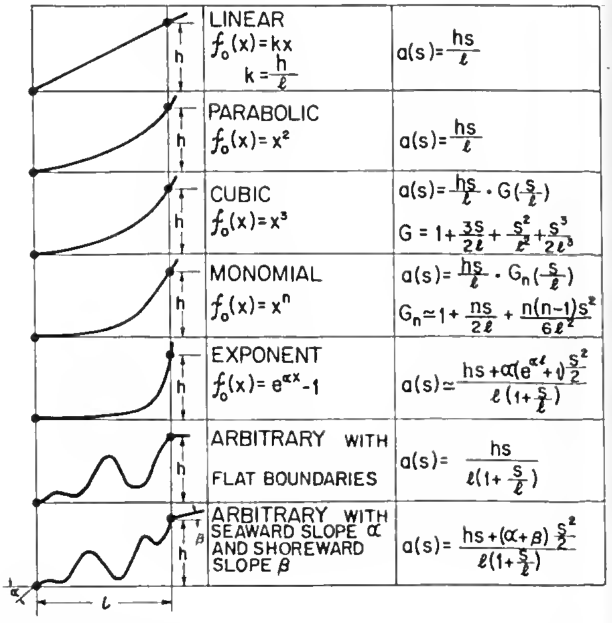
where the value l^2 was equated to h. Bruun's formula (1) emerges rigorously from equations (7) and (8) for the parabolic profile.

Now the position of the fulcrum point can be found as the point of intersection of the functions $f_0(x)$ and $f(x,s)$ by solving the equation
(notice that $a(s)=hs/l=l^2s/l=ls$)

$$x^2=(x-s)^2+a(s)=(x-s)^2+ls$$
$$0=-2xs+s^2+ls$$
$$x=\frac{s(l+s)}{2s}=\frac{l+s}{2} \tag{12}$$

The fulcrum point appears to be at the distance $(l+s)/2$ from the coordinate system origin.
Let us find the volume (area, as in Fig. 1) of accretion. This is the integral between the points $x=0$ and the fulcrum point $x=\tfrac{1}{2}(l+s)$

$$V_A=\int_0^{\frac{1}{2}(l+s)}[(x-s)^2+ls-x^2]dx=s\int_0^{\frac{1}{2}(l+s)}[(l+s)-2x]dx$$
$$=s[(l+s)x-x^2]\Big|_0^{\frac{1}{2}(l+s)}=\tfrac{1}{4}s(l+s)^2 \tag{13}$$



LINEAR	$f_0(x)=kx$ $k=\frac{h}{l}$	$a(s)=\frac{hs}{l}$
PARABOLIC	$f_0(x)=x^2$	$a(s)=\frac{hs}{l}$
CUBIC	$f_0(x)=x^3$	$a(s)=\frac{hs}{l}\cdot G(\frac{s}{l})$ $G=1+\frac{3s}{2l}+\frac{s^2}{l^2}+\frac{s^3}{2l^3}$
MONOMIAL	$f_0(x)=x^n$	$a(s)=\frac{hs}{l}\cdot G_n(\frac{s}{l})$ $G_n\simeq 1+\frac{ns}{2l}+\frac{n(n-1)s^2}{6l^2}$
EXPONENT	$f_0(x)=e^{\alpha x}-1$	$a(s)\simeq\frac{hs+\alpha(e^{\alpha l}+1)\frac{s^2}{2}}{l(1+\frac{s}{l})}$
ARBITRARY WITH FLAT BOUNDARIES		$a(s)=\frac{hs}{l(1+\frac{s}{l})}$
ARBITRARY WITH SEAWARD SLOPE α AND SHOREWARD SLOPE β		$a(s)=\frac{hs+(\alpha+\beta)\frac{s^2}{2}}{l(1+\frac{s}{l})}$

Fig. 3 – Analytical and non-analytical profiles with corresponding formula, relating sea level rise a to shore retreat s.

Analogously, the volume of erosion, i.e. between the fulcrum point $x = \frac{1}{2}(l+s)$ and the shoreward limit $x = l+s$, is equal to

$$V_E = \int_{\frac{1}{2}(l+s)}^{l+s} [(x-s)^2 + ls - x^2]dx = s[(l+s)x - x^2]_{\frac{1}{2}(l+s)}^{l+s}$$

$$= -\tfrac{1}{4}s(l+s)^2 \qquad (14)$$

From this example it is seen that volumes of erosion and accretion are equal in absolute values, as it should be according to the Bruun statement 3.

However, the actual volumes can be found *only* when the position of the fulcral point has been calculated. The impressive result obtained was that the Bruun formula is exact for the parabolic profile. We shall see now, that this is *not* necessarily correct for other profile shapes.

Cubic profile

Let $f_0(x) = x^3 \qquad (15)$

then at the right end of the profile, where $x = l$, the value $f_0(x)\big|_{x=l} = l^3 = h$, the value h being the profile height in the coördinate system of Fig. 3. Substituting (15) into (8) and then into (7), we arrive at

$$I = \int_0^{l+s}[(x-s)^3 + a(s) - x^3]dx = -x^3s + \frac{3}{2}x^2s^2 - xs^3 + xa(s)\Big|_0^{l+s}$$

$$= l^3s + \frac{3}{2}l^2s^2 + ls^3 + \frac{1}{2}s^4 - (l+s)\,a(s) = 0 \qquad (16)$$

Using the identity $l^3 = h$, it follows:

$$a(s) = \frac{hs\,(1 + \frac{3s}{2l} + \frac{s^2}{l^2} + \frac{1}{2}\frac{s^3}{l^3})}{l(1+\frac{s}{l})} = hs/l.\mathrm{G}(s/l) \qquad (17)$$

One can recognize here the right-hand side of the Bruun formula, being multiplied by the correction factor G(s/l). When the ratio s/l is small in comparison to unity, the value of the correction factor is also small. For example, when $s/l = 0.1$, the value G(s/l) = 1.05, meaning that use of Bruun formula (1) for a cubic profile results in an error of 5%. For the more realistic value $s/l = 0.01$, the factor G(s/l) equals 1.005, meaning an error of 0.5%. We show below, that for other analytical profiles the errors could be much larger.

Monomial profile

Let $f_0(x) = x^n \qquad (18)$

where $n \geq 1$. At the point $x = l$ the height of the profile is $h = l^n$. Substituting (18) into (8) and then (7), we can expand the integrand:

$$(x-s)^n + a(s) - x^n = -nx^{n-1}s + \frac{n(n-l)}{2!}x^n s^2$$

$$-\frac{n(n-1)(n-2)}{3!}x^{n-3}s^3 + \ldots (-1)^n s^n + a(s). \qquad (19)$$

Upon integration, the powers of $(l+s)$ appear, which are expanded in the series such as

$$(l+s)^n = l^n(1+\frac{s}{l})^n = l^n[1 + n.\frac{s}{l} + \frac{n(n-1)}{2}.\frac{s^2}{l^2} + \ldots]$$

$$(l+s)^{n-1} = (1+\frac{s}{l})^{n-1} = l^{n-1}[1 + (n-1)\frac{s}{l} + \frac{(n-1)(n-2)}{2}.\frac{s^2}{l^2}\ldots]$$

Preserving only the terms with the value s/l of power two and less, one obtains in the same manner as for the parabola and cubic function

$$a(s) \doteq \frac{l^n s[1 + \frac{n}{2}\cdot\frac{s}{l} + \frac{n(n-1)}{6}\frac{s^2}{l^2}]}{l(1+s/l)} = hs/l.\mathrm{G}_n(s/l) \quad (20)$$

It is seen, that for large n the value of the correction factor can also be large and departure from the Bruun formula can be significant. For example, for $n = 10$ and $s/l = 0.1$ the value $\mathrm{G}_n = 1.5$. We shall discuss these results later and consider now another class of profiles, for which departure from the Bruun formula can also be large.

Exponential profile

Let $f_0(x) = e^{\alpha x} - 1 \qquad (21)$

The profile has a zero ordinate when $x = 0$ and the height of the profile at $x = l$ is equal to $h = e^{\alpha l} - 1$. By varying the (positive) parameter a various shapes can be obtained (Fig. 3). Substituting the translated function

$$f(x,s) = e^{\alpha(x-s)} - 1 + a(s) = e^{\alpha x}e^{-\alpha s} - 1 + a(s) \qquad (22)$$

together with (21) into the integral (7) we obtain, with some simple manipulations

$$I = \int_0^{l+s}[e^{\alpha x}(e^{-\alpha s} - 1) + a(s)\,dx \qquad (23)$$

$$= \frac{1}{\alpha}(e^{-\alpha s} - 1)\,(e^{\alpha l}e^{\alpha s} - 1) + (l+s)a(s)$$

$$= \frac{1}{\alpha}[e^{\alpha l}(1 - e^{\alpha s}) + (1 - e^{-\alpha s})] + (l+s)a(s) = 0$$

As the value s is considered to be small, we employ now the familiar Taylor expansions, retaining only the terms with s in the power two and less

$$1 - e^{\alpha s} = 1 - (1 + \alpha s + \frac{\alpha^2 s^2}{2} + \ldots) \triangleq -(\alpha s + \frac{\alpha^2 s^2}{2})$$

$$1 - e^{-\alpha s} = 1 - (1 - \alpha s + \frac{\alpha^2 s^2}{2} - \ldots) \triangleq \alpha s - \frac{\alpha^2 s^2}{2} \qquad (24)$$

Substitution of (24) into (23) leads to

$$-s(e^{\alpha l} - 1) - \frac{\alpha s^2}{2}(e^{\alpha l} + 1) + (l+s)a(s) = 0$$

wherefrom, if one recalls that $(e^{\alpha l} - 1) = h$, the result emerges

$$a(s) = \frac{hs + \alpha(e^{\alpha l} + 1)s^2/2}{l(1+\frac{s}{l})} \qquad (25)$$

It is seen that for α small in comparison with unity the Bruun formula follows once again. However, for large α (see Fig. 3) the second term in the numerator may become predominant and it grows alarmingly fast with the increase of α. We again temporarily postpone the discussion of the reasons for such large errors and instead return back to the case of the linear profile, which we avoided discussing before, quite deliberately.

Linear profile

Let $f_0(x) = kx; f(x,s) = k(x-s) + a(s)$ (26)

where the slope $k = \frac{h}{l}$

The integral (7) then reduces to:

$$I = \int_0^{l+s} [k(x-s) + a(s) - kx]dx = \int_0^{l+s} [-ks + a(s)]dx$$

$$= -ks + a(s) = 0 \qquad (27)$$

Hence,

$$a(s) = ks = hs/l \qquad (28)$$

and the Bruun formula emerges, exactly. Notice, that in this particular case of linear profile (and in this case only) the integrand in (27) equals zero identically, independently of the value of x, as soon as (28) is used. If we recall the case of the parabolic profile, where to find the fulcrum point we need to equalize the integrand to zero, it becomes obvious that for a linear profile every point x is the fulcrum point; hence no erosion or accretion really occurs.

As any analytical function $f(x)$ can be expanded as a power series, it follows from equations (11), (17), (20) and (28), that Bruun formula (1) is rigorous only for generalised parabolic profile

$$f(x) = c_1x + c_2x^2 \qquad (29)$$

where the constants c_1 and c_2 are arbitrary. For higher order of profiles the Bruun formula (1) holds only as an approximation, as summarised in Fig. 3.

NON-ANALYTICAL PROFILES AND BOUNDARY CONDITIONS

One may notice that when the profile $f_0(x)$ is shifted shorewards by the value s, the portion of the profile which originally corresponded to the values $x<0$, appears at the positive part of the x-axis (see Figs 1, 2).

This means, that it is insufficient to know the profile shape $f_0(x)$ strictly within the interval $0 \leq x \leq l$; to calculate the integral (7) one needs also to know the behavior of the function $f_0(x)$ *beyond* the points 0; l, namely, in the wider interval $[-s; l+s]$.

Hence, the outer boundaries of the segment $[0;l]$ are important, and the shape of the profile at these boundaries $-s \leq x \leq 0$ and $l \leq x \leq l+s$ forms some kind of boundary condition (not to be confused with the boundary conditions for differential equations).

We are going to demonstrate now that these are precisely the boundary conditions, which determine validity or invalidity of the Bruun formula (1).

Let us consider an arbitrary function $f(x)$ with its domain of definition in the interval $[-s<x<l+s]$. (The subscript zero is dropped out here for simplicity of notation only.)

Using the general formulae (7) and (8), the integral I is as follows:

$$I = \int_0^{l+s} \{f(x-s) + a(s) - f(x)\}dx = I_1 + I_2 - I_3 \qquad (29)$$

where

$$I_1 = \int_0^{l+s} f(x-s)dx;\ I_2 = \int_0^{l+s} a(s)dx;\ I_3 = \int_0^{l+s} f(x)dx \qquad (30)$$

By a change of variables the integrals may be rewritten as:

$$I_1 = \int_0^{l+s} f(x-s)dx = \int_{-s}^{l} f(x)dx = \int_0^{l} f(x)dx + \int_{-s}^{0} f(x)dx = \qquad (31a)$$

$$= \int_0^{l} f(x)dx + \int_0^{s} f(-x)dx.$$

$$I_2 = \int_0^{l+s} a(s)dx = (l+s)a(s) \qquad (31b)$$

$$I_3 = \int_0^{l+s} f(x)dx = \int_0^{l} f(x)dx + \int_l^{l+s} f(x)dx = \int_0^{l} f(x)dx +$$

$$\int_0^{s} f(x+l)dx \qquad (31c)$$

Combining the expressions (31a, b and c) according to (29) it is seen, that the integrals $\int_0^l f(x)dx$ cancel each other and:

$$I = \int_0^{s} [f(-x) - f(x+l)]dx + (l+s)a(s) \qquad (32)$$

According to equation (7), the value I should equal zero and the rigorous expression for the relationship $a(s)$ follows:

$$a(s) = \frac{\int_0^{s} [f(x+l) - f(-x)]dx}{l+s} \qquad (33)$$

Returning back to the temporarily dropped notation $f_0(x)$, it is convenient to rewrite (33) in the following form:

$$a(s) = \frac{F(s)}{l+s};\ F(s) = \int_0^{s} [f_0(x+l) - f_0(-x)]dx \qquad (34)$$

The main advantage of (34) is that it makes clear the role of boundary conditions. It is seen from (34) that behavior of the profile $f_0(x)$ *outside* the interval $[0; l]$ contributes to the value F(s), while shape of the profile *within* this interval is of no importance at all.

To clarify this statement, consider the two classes of non-analytical profiles.

(1) Consider one class of profiles, which are *arbitrary* between the points $[0, l]$ and *horizontal* beyond these points (Fig. 3). The profile is assumed to have the height h, then

$$f_0(x+l) \equiv f_0(l) = h$$

$$f_0(-x) \equiv f_0(0) = 0 \qquad (35)$$

Calculation of the function $F(s)$ in (34) gives, after substitution of (35) in it

$$F(s) = \int_0^{s} h\,dx = hs \qquad (36)$$

Hence, for such a profile

$$a(s) = \frac{hs}{l+s} = \frac{hs}{l(1+\frac{s}{l})} \qquad (37)$$

and Bruun formula (1) follows, if the value s/l is small in comparison to unity.

(2) Consider another class of profiles, which again are *arbitrary* between the points $[0,l]$, but have extensions

beyond the terminal points as linear functions (Fig. 3)

$$f_0(x+l) = h + \beta x - \text{shoreward}$$

$$f_0(-x) = -\alpha x - \text{seaward} \tag{38}$$

The parameter α is, in fact, the seaward slope of the profile, while β is the shoreward slope.

Substitution of (38) into (34) gives

$$F(s) = \int_0^s (h + \beta x + \alpha x]dx = [hs + (\beta + \alpha)\frac{s^2}{2}] \tag{39}$$

It is seen, that the seaward slope α is accompanied in formula (39) by the corresponding shoreward slope β and *both* slopes play equal roles.

Particularly, when the slopes are horizontal, (i.e. $\alpha = \beta = 0$) formula (39) reduces to (36).

Another case of reduction to (36) occurs when $\alpha = -\beta$, i.e. seaward and shoreward slopes are of opposite signs.

An interesting case emerges when slopes $\alpha = \beta = k$, where $k = h/l$. Then it follows from (39)

$$F(s) = hs + ks^2 = hs(1 + \frac{s}{l}) \tag{40}$$

and the Bruun formula appears rigorously once again

$$a(s) = \frac{hs(1 + \frac{s}{l})}{l+s} = \frac{hs(1 + \frac{s}{l})}{l(1 + \frac{s}{l})} = hs/l \tag{41}$$

Hence, when both seaward and shoreward slopes of otherwise *arbitrary* profiles are equal to the value h/l of the profile, the Bruun formula (1) is exact.

The results obtained so far for the profiles of various shapes are depicted on Fig. 3 with the corresponding exact formula $a(s)$.

One can see from Fig. 3 that steepness of monomial and exponential profiles grows with the increase of their order and so does the error in the use of the Bruun formula (1). Hence, *the boundary conditions, rather than the shape of the profiles, are responsible for accuracy of the Bruun formula.* It is seen from (39), that the value $F(s)$ can depart from the Bruun value hs if the seaward and/or shoreward slopes are large. Reversely, one can always estimate the error, given by the Bruun formula, by means of exact formula (34).

Consequently, we may conclude that Bruun's formula (1) follows from the exact formula (34) as a very accurate approximation, providing the seaward and shoreward slopes of the profile are not too steep. In turn, formula (34) is based rigorously on equations (7) and (8), which are the mathematical formulation of the first four statements of the Bruun rule.

We show that the same Bruun statements form the basis for the theory of erosion/accretion in open beach systems.

BRUUN RULE FOR OPEN BEACH SYSTEMS

It is convenient to define an open beach system as one in which an additional volume (+V) of sediment is supplied from outside the system (for example, beach nourishment and/or littoral drift) or, alternatively, some volume of sediment (−V) is removed from the system (for example, due to excavation of the nearshore bottom and/or to littoral drift).

BEACH NOURISHMENT

Consider the case of a positive volume (+V) of sediment being supplied to the system, while the sea level a is still. This case was partly touched in section 4 where equations (3) and (4) were derived solely on the basis of the first two of Bruun's statements.

In this section we denote the horizontal profile displacement due to supply or removal of sediment as r, leaving the notation s for horizontal profile retreat solely due to sea-level rise. Correspondingly, equation (3) in the new notation is

$$f(x,r) = f_0(x+r) + b(r) \tag{42}$$

where $b(r)$ is positive, when rise of the profile occurs due to income of positive volume (+V) of sediment into a beach system and horizontal displacement r due to the same factor is taken as positive for *seaward* displacement of the profile.

The increment in volume of sediment in a beach system due to translation of the profile given by (42) can be calculated as an integral I, analogous to (29).

However, the limits of integration must be different now. As the profile is shifting seawards (positive r), part of the shifted profile will appear *left* of point $x=0$ (Fig. 4), beyond the limiting length l offshore. But our initial assumption was that a profile is undisturbed to the left of point $x=0$. Hence, the lower limit of integration should be taken as $x=0$.

On the other hand, as the profile is shifted seaward, no disturbance of the profile occurs beyond point $x=l$, which should be taken now as the upper limit of integration. Consequently, the additional volume (+V) of sediment supplied to the beach should be equal to the integral (we again temporarily drop the subscript zero in $f_0(x)$)

$$I = \int_0^l [f(x+r) + b(r) - f(x)]dx = I_1 + I_2 - I_3 = V \tag{43}$$

where

$$I_1 = \int_0^l f(x+r)dx = \int_r^{l+r} f(x)dx + \int_r^l f(x)dx + \int_l^{l+r} f(x)dx \tag{44a}$$

$$I_2 = \int_0^l b(r)dx = lb(r) \tag{44b}$$

$$I_3 = \int_0^l f(x)dx. \tag{44c}$$

Adding to I_1 eq. (44a) the self-cancelling pair of integrals

$$\int_0^r f(x)dx - \int_0^r f(x)dx \tag{45}$$

we can rewrite I_1 as

$$I_1 = \int_0^r f(x)dx + \int_r^l f(x)dx + \int_l^{l+r} f(x)dx - \int_0^r f(x)dx \tag{46}$$

where the sum of the first two integrals exactly equals I_3, thus cancelling it.

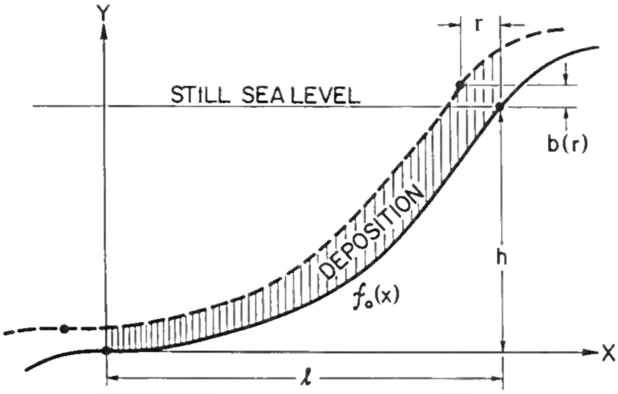


Fig. 4 – Deposition of sediments, resulting in rise of profile by the value $b(r)$ and seaward shift by the value r (r is positive seaward).

Consequently

$$1 = \int_{l}^{l+r} f(x)dx - \int_{0}^{r} f(x)dx + lb(r) = V \tag{47}$$

and the formula for $b(r)$ emerges (returning back to subscript zero)

$$b(r) = \frac{1}{l}\left(V - \int_{l}^{l+r} f_0(x)dx + \int_{0}^{r} f_0(x)dx\right) \tag{48}$$

One has to notice that the profile shape between the points $x = r$ and $x = l$ does not figure in (48) and value of the integrals is determined by the behavior of the profile shape in the neighborhood of its terminal points $x = 0$ and $x = l$. Let us assume that the profile is nearly flat around $x = 0$ and $x = l$, i.e. at the interval $[0,r]$ the function $f_0(x) = 0$ and at the shoreward end $f_0(x) = h$ at the interval $[l,\ l+r]$, then the first integral in (48) reduces to the value hr and the second to zero. Formula (49) then emerges as:

$$b(r) = (V - hr)/l \tag{49}$$

It can be shown, by analogy with the previous section, that (49) is a very good approximation of the exact result of (48) when the boundary conditions are such that the seaward and shoreward slopes are not too steep and the difference in their slope angles is small.

The expression for r follows from (49)

$$r = (V - bl)/h \tag{50}$$

On the other hand, we did have another expression for the same value r in equation (5)

$$r = \frac{bl}{h} \tag{51}$$

Combining (50) and (51), we obtain

$$r = \frac{V}{2h},\ b = \frac{V}{2l} \tag{52}$$

Consequently, equation (42), becomes dependent on the volume of sediment supplied to the beach

$$f(x, V) = f_0\left(x + \frac{V}{2h}\right) + \frac{V}{2l} \tag{53}$$

We want to emphasize, that the values r and b in (52) and formula (53) are independent of the profile shape.

If the beach loses sediment (due to excavation of the bottom, littoral drift, etc.), then the value V in (52) and (53) should be taken as negative and the beach profile shifts shorewards and downwards, because the values r and b become negative.

When beach nourishment (excavation) is accompanied by sea level rise, it follows from equations (6) and (53), that the new beach profile is described by the equation

$$f(x, a, V) = f_0\left[x + \frac{1}{h}\left(\frac{V}{2} - al\right)\right] + \frac{1}{l}\left(\frac{V}{2} + al\right), \tag{54}$$

where positive values V and a correspond to beach nourishment and rise in sea level.

Equation (54) was obtained, after all, solely on the basis of the first four Bruun Rule statements.

The previous treatment was performed for a two-dimensional cross-section of a beach, which may also be considered a slice (of unit thickness) of an actually three-dimensional beach.

BRUUN RULE FOR THREE-DIMENSIONAL BEACH SYSTEM WITH LITTORAL DRIFT

Consider the three-dimensional portion of shoreline in the coordinate system of Fig. 5 (note that the y coordinate is now directed alongshore). Any vertical plane, parallel to the plane ZOX, dissecting the shore, forms in its cross-section a two-dimensional profile, such as described in the previous sections. However, there is no need to assume that all the cross-sections have the same or similar shape. For each cross-section with a longshore coordinate y equation (54) holds; therefore independent of the shape of the particular cross-section, its seaward motion (denoted $R(y)$ from now on) and vertical uplift (denoted $\bar{a}(y)$) is equal to

$$R(y) = \frac{1}{h(y)}\left[\frac{V(y)}{2} - al(y)\right] \tag{55a}$$

$$\bar{a}(y) = a + [V(y)/2l(y)] \tag{55b}$$

where a is the rise in sea level as before and the functions $h(y)$; $l(y)$; $V(y)$ are dependent on the longshore coordinate y. Consider the equation of continuity or the volume conservation equation for longshore sediment drift (see, for example, Komar, 1976)

$$\partial V/\partial t = -\partial Q/\partial y$$

where Q is the longshore volumetric rate of sediment transport (measured, for example, in m³/day).

The physical sense of equation (56) is quite obvious: it states that the time-rate (speed) of volume of sediment removal (sign negative in 56) from a beach equals the longshore rate in change of volumetric transport along the beach. This is illustrated in Fig. 5, where both function $Q(y,t)$ and $\partial Q/\partial y$ are plotted along the longshore coordinate y for one specific type of dependancy $Q(y)$.

It is reasonable to assume further that the basic parameters $h(y)$ and $l(y)$, figuring in (55), do not change much in time due to shore erosion (accretion), and only the values, R, $\bar{a}$, a and V in (55) are variable in time.

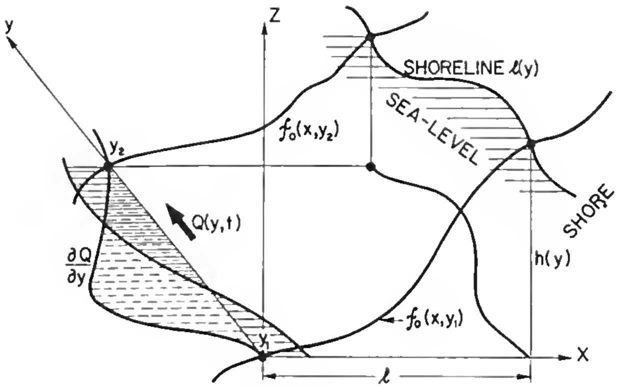


Fig. 5 – Definition sketch for longshore littoral drift. Axis y directed alongshore. Profile shapes could be different for various y, such as y_1 and y_2.

Consequently, equations (55) can be rewritten to incorporate the above assumption as

$$R(y,t) = \frac{1}{h(y)}\left[\frac{V(y,t)}{2} - a(t)l(y)\right] \tag{57a}$$

$$\bar{a}(y,t) = a(t) + \frac{V(y,t)}{2l(y)} \tag{57b}$$

Notice that sea level rise a in (57) is assumed to be dependent on time, but independent of longshore coordinate y, meaning that extremely long coastlines, where sea-level varies along the coastline, are not considered. Equations (57) give the complete steady-state solution of the problem of beach nourishment (excavation) in the presence of variations in the time sea level rise $a(t)$ for any distribution of $V(y,t)$ along the shore and in time, providing the values $h(y)$ and $l(y)$ are known.

Differentiating (57) with respect to time t one obtains

$$\partial R/\partial t = ½\partial V/\partial t - l(y)\partial a/\partial t]/h(y) \tag{58a}$$

$$\partial\bar{a}/\partial t = \partial a/\partial t + ½ l(y)\cdot\partial V/\partial t \tag{58b}$$

Substituting instead of $\partial v/\partial t$ in (58) the equal value $-\partial Q/\partial y$ from (56), it follows

$$\partial R/\partial t = -[½\cdot\partial Q/\partial y + l(y)\cdot\partial a/\partial t]/h(y) \tag{59a}$$

$$\partial\bar{a}/\partial t = \partial a/\partial t - ½ l(y)\cdot\partial Q/\partial y \tag{59b}$$

Integrating equations (59) with respect to time, one obtains the final formulae for calculation of shoreward displacement R and profile rise $\bar{a}$ as functions of longshore sediment transport Q and variations in the time of sea level rise $a(t)$

$$R(y,t) = -\frac{l}{h(y)}\left[\frac{l}{2}\int_0^t \frac{\partial Q(y,t)}{\partial y}dt + l(y)\,.\,a(t)\right] \tag{60a}$$

$$\bar{a}(y,t) = a(t) - \frac{l}{2l(y)}\int_0^t \frac{\partial Q(y,t)}{\delta y}dt \tag{60b}$$

We illustrate the use of (60) by two examples.

Example 1

Let $a(t)=0$ and $Q(y,t)=y\sin\omega t$, meaning that the sediment transport rate is linearly distributed along the shoreline and varies periodically in time.

Then

$$\partial Q(y,t)/\partial y = \sin\omega t \tag{61}$$

and from (60) one obtains by integration:

$$R(y,t) = -\frac{1}{2\omega h(y)}\cos\omega t + C \tag{62a}$$

$$\bar{a}(y,t) = -\frac{1}{2\omega l(y)}\cos\omega t + D \tag{62b}$$

where C and D are the constants to be determined from initial conditions. Assuming them as $R(y,t)=0$ and $\bar{a}(y,t)=0$ (no initial erosion – accretion) when $t=0$, it is easy to find from (62)

$$C = \frac{1}{2\omega h(y)};\ D = \frac{1}{2\omega l(y)} \tag{63}$$

hence, the seaward shore displacement and rise of the bottom are:

$$R(y,t) = \frac{1}{2\omega h(y)}(1-\cos\omega t) \tag{64a}$$

$$\bar{a}(y,t) = \frac{1}{2\omega l(y)}(1-\cos\omega t), \tag{64b}$$

meaning periodic (for example; seasonal) variation in shore erosion, *dependent* on the original longshore shape (functions $h(y)$ and $l(y)$) of the coastline.

Example 2

Let $a(t)=0$ and a tropical cyclone (hurricane) moves alongshore, causing a propagating wave-like longshore transport $Q(y,t)$ with magnitude Q_0

$$Q(y,t) = Q_0\cos(Ky+\omega t) \tag{65}$$

Then

$$\frac{\partial Q}{\partial y} = -KQ_0\sin(Ky+\omega t) \tag{66}$$

and upon substitution of (66) into (60a, b) and integration

$$R(y,t) = -\frac{KQ_0}{2\omega h(y)}\cos(Ky+\omega t) + C(y) \tag{67a}$$

$$\bar{a}(y,t) = -\frac{KQ_0}{2\omega l(y)}\cos(Ky+\omega t) + D(y) \tag{67b}$$

Here instead of constants C and D, as in the previous example, the functions $C(y)$ and $D(y)$ should be found from initial conditions. One obtains from (67) for $t=0$

$$C(y) = \frac{KQ_0}{2\omega h(y)}\cos Ky \tag{68a}$$

$$D(y) = \frac{KQ_0}{2\omega l(y)}\cos Ky \tag{68b}$$

and the final result emerges from (67) upon substitution of (68)

$$R(y,t) = \frac{K\,Q_0}{2\omega h(y)}[\cos Ky - \cos(Ky + \omega t)] \qquad (69a)$$

$$\bar{a}(y,t) = \frac{K\,Q_0}{2\omega l(y)}[\cos Ky - \cos(Ky + \omega t)] \qquad (69b)$$

Note the appearance of the time independent term cos Ky in (69), meaning that after passage of a cyclone (hurricane) an irreversible cuspate change of a coastline occurs, if the rate of sediment transport could be approximated as a propagating wave (65).

DISCUSSION

The first four statements of the Bruun Rule form a non-contradictory set of axioms, which need no other axioms for development of the theory of shore erosion; incorporating not only sea level rise, for which the statements were originally intended, but also the problems of beach nourishment, excavation and littoral drift.

The most important of all assumptions of the theory, its cornerstone, is the statement, that beach profile essentially preserves its shape during process of shore evolution, be it due to sea-level rise, wave attack, beach nourishment etc. Of course, it is recognised, that some temporal variations, perhaps caused by a sudden storm, can be superimposed on the conservative shape of beach profile, but these variations are usually short-lived and can be discarded in the first approximation.

The experimental data available support this assumption. No doubt, further experimental work is necessary.

The most important limitation of the above theory is its static nature.

This means, that the beach system is considered only in two states: initial state, before evolution started and final state, after evolution was completed. The transition process between these two states is beyond the scope of the present theory. Clearly, this shortcoming must be rectified. This is our direction for future research.

ACKNOWLEDGEMENTS

Discussions with Mr R. A. Perry and Mr E. D. Gill (both CSIRO) were most stimulating. The authors thank reviewers for their valuable comments.

REFERENCES

Allison, H., 1980. Enigma of the Bruun's formula in shore erosion. In *Proc. of the Per Bruun Symposium*, M. L. Schwartz & J. J. Fisher, eds., IGU & Western Washington University, Bellingham, 67-78.

Bruun, P., 1962. Sea level rise as a cause of shore erosion: *Am. Soc. Civil Engineers Proc., Jour. Waterways and Harbors Div.* 88: 117-130.

Bruun P., 1980. The "Bruun Rule", Discussion on boundary conditions. In *Proc. of the Per Bruun Symposium*, M. L. Schwartz & J. J. Fisher, eds., IGU & Western Washington University, Bellingham, 79-83.

Gill, E. D., 1979. Change from quartz arenite to calcarenite at Warrnambool, Victoria, Australia. *Vict. Naturalist* 96: 151-153.

Dubois, R. N., 1975. Support and refinement of the Bruun Rule on beach erosion. *J. Geol.* 83: 651-657.

Dubois, R. N., 1976. Nearshore evidence in support of the Bruun Rule on shore erosion. *J. Geol.* 84: 485-491.

Dubois, R. N., 1977a. Predicting beach erosion as a function of rising water level. *J. Geol.* 85: 470-476.

Dubois, R. N., 1977b. Nearshore evidence in support of the Bruun Rule on shore erosion, Reply. *J. Geol.* 85: 492-494.

Fisher, J. J., 1977a. Coastal erosion revealed in the U.S.S.R.: *Geotimes* 22 (9): 24-25.

Fisher, J. J., 1977b. Rate of erosion relative to sea level rise and profile of equilibrium, Rhode Island and North Carolina. *Astrcts 10th Int'l Quaternary Congress*, Birmingham, 140.

Fisher, J. J., 1977c. Relationship of shoreline erosion rates to eustatic sea level rise, Rhode Island coast. *Geol. Soc. Amer. Abstract* 9 (3): 265.

Fisher, J. J., 1980a. Holocene sea level rise, shoreline erosion and the Bruun Rule-overview. In *Proc. of the Per Bruun Symposium*, M. L. Schwartz & J. J. Fisher, eds. IGU & Western Washington University, Bellingham, 1-5.

Fisher, J. J. 1980b. Shoreline erosion, Rhode Island and North Carolina coasts – test of Bruun Rule. In *Proc. of the Per Bruun Symposium*, M. L. Schwartz & J. J. Fisher, eds., IGU & Western Washington University, Bellingham, 32-54.

Hands, E. B., 1976. Some data points on shoreline retreat attributable to coastal subsidence. *Proceedings of the Anaheim Symposium*, International Association of Hydrological Sciences, p. 629-645.

Hands, E. B., 1977. Implications of submergence for coastal engineers. In *Coastal Sediment '77 Proceedings, Fifth Symposium of the Waterways, Port, Coastal and Ocean Division of the A.S.C.E.*, p. 149-166.

Hands, E. B., 1980. Bruun's concept applied to the Great Lakes. In *Proc. of the Per Bruun Symposium*, M. L. Schwartz & J. J. Fisher, eds., IGU & Western Washington University, Bellingham, 63-66.

Kaplin, P. A., 1973. *Recent history of the coasts of the world oceans.* University of Moscow, Moscow, 265 p. (in Russian).

Komar, P. D., 1976. *Beach processes and sedimentation.* Prentice-Hall, Englewood Cliffs, N. J., 429 p.

Rosen, P. S., 1977. Nearshore evidence in support of the Bruun Rule on shore erosion: Discussion. *J. Geol.* 85: 491-492.

Rosen, P. S., 1978a. Predicting beach erosion as a function of rising water level: Discussion. *J. Geol.* 86: 763.

Rosen, P. S., 1978b. A regional test of the Bruun Rule on shoreline erosion. *Mar. Geol.* 26: m7-m16.

Rosen, P. S., 1980. An application of the Bruun Rule in the Chesapeake Bay. *Proc. of the Per Bruun Symposium*, In M. L. Schwartz & J. J. Fisher, eds., IGU & Western Washington University, Bellingham, 55-62.

Schwartz, M. L., 1965. Laboratory study of sea level rise as a cause of shore erosion. *J. Geol.* 73: 528-534.

Schwartz, M. L., 1967. The Bruun theory of sea level rise as a cause of shore erosion. *J. Geol.* 75: 76-92.

Schwartz, M. L., 1979. Case history of a coastal investigation at the Cape Cod National Seashore. In Proceedings of the First Conference on Scientific Research in the National Parks; R. M. Linn, ed., *National Park Service Transactions and Proceedings* ser. 5, 2: 757-759.

Schwartz, M. L. & Milicic, V., 1978. The Bruun Rule controversy. *Coastal Research* 5: 13-14.

SCHWARTZ, M. L. & MILICIC, V., 1980. The Bruun Rule: A historical perspective. In *Proc. of the Per Bruun Symposium*, M. L. Schwartz & J. J. Fisher, eds., IGU & Western Washington University, Bellingham, 6-12.

SWIFT, D. J., 1976. Coastal sedimentation. In *Marine sediment transport and environmental management*, Stanley, D. J. & Swift, D. J., eds., John Wiley & Sons, New York, 255-310.

A STUDY OF MT KOROROIT, VICTORIA—A SMALL VOLCANIC VENT

By W. S. Fischer* & L. Thomas

Department of Geology, University of Melbourne, Parkville, Vic. 3052

*Now at Esso Exploration Inc.

Abstract: A geological reconnaissance and gravity survey indicate that Mt Kororoit is composed mainly of scoriaceous material and began to grow in the early stage of formation of the surrounding lava sheet.

REGIONAL GEOLOGY

Mt Kororoit (also known as Mt Misery, at 37°39′S, 144°40′E) is a small conical hill about 1500 m in diameter at the base, rising about 100 m above the surrounding countryside. It is one of many flat-topped volcanic cones on the Werribee Plains, which lie on the northern and western outskirts of Melbourne. The plains consist mainly of sheets of basaltic lavas, dotted with vents, of the Pliocene to Pleistocene Newer Volcanics. The lavas lie unconformably on folded Palaeozoic (mainly geosynclinal) sediments, which protrude through the basalt in a number of places, especially to the northwest of the plains. Deposition of these sediments ceased in the Middle Devonian, and was followed by a period of granite intrusion during the Upper Devonian. Sedimentation resumed in the Cainozoic; in adjacent areas it continued during the Lower Carboniferous, Permian and Mesozoic (Vandenberg *et al.* 1973).

GEOLOGY OF MT KOROROIT

Although occasionally noted in the literature on Victorian volcanoes, we believe that Mt Kororoit has not previously been studied in any detail. A geological map of the volcano based on aerial photograph interpretation with some field work is presented in Figure 1. Basically, the hill appears to be a scoria pile elongated somewhat to the west, with a minor change of slope probably marking the edge of the scoria. Cultivation of the surrounding area has made the background difficult to define.

Shallow pits have been dug in the scoria on the northwest flank of the mountain. These expose some vesicular lava containing small feldspar phenocrysts and pieces of fresh scoria. Outcrops of unweathered rock show the scoria to consist of small irregular lapilli welded together with spatter material. Small scale flow features can often be recognised in the spatter.

Four features are prominent on the aerial photographs:

(a) The resistant capping on the summit of the mountain.
(b) Two thin ridges which trend northeast and southeast from the cap.
(c) A series of concentric arcuate structures on the northwestern side of the northeast ridge.
(d) A series of arcuate structures about 1 km northwest of the cap.

Close investigation in the field shows that the cap rock consists largely of agglomeratic material, although basalt is found in some places. Three almost concentric tiers form the cap, the upper showing consistent dips of about 40° towards the centre of the cap, while the third and lowest has a much gentler dip. Some thin layering is also present in the cap outcrop, being aligned parallel to the dip.

A large number of volcanoes in the Gisborne district show the distinct flat-topped basalt capping. It has been suggested by Edwards and Crawford (1940) that the cappings represent basaltic crater infillings later exposed by the erosion of the scoria crater walls which once confined the lava. Some of these volcanoes also show evidence of the crater having been breached, resulting in a lava flow forming what is now the gentlest slope. This is not as strongly evident at Mt Kororoit.

Another possibility is that the basalt cap is more than just a crater infilling, and is in fact the top of the former lava conduit.

Originating at the cap rock and striking radially, the highly vesicular basalt ridges have been variously described as radial dykes (Singleton 1973) and as a fine example of radial squeeze-ups (Vandenberg *et al.* 1973). These seem similar in composition to the summit capping.

Within the outcrop, one can recognise flow patterns lying sub-parallel and parallel to the dip of the outcrop. It is most noticeable where one finds thin elongate vesicles aligned in curved patterns. Often, however, the vesicles are very fine or there are no vesicles present at all.

Along the northeastern ridge, one encounters dips to the southeast of between 20° and 70°. Dips along the southeastern ridge are generally about 30° to the northeast and east. The forks of the southeastern "dyke" extend in discontinuous outcrop further than was noted from aerial photographs. Between these forks lie a number of small outcrops of basalt, many of which are linear, sub-parallel to and dipping in the same direction as the nearby ridges.

The concentric arcs of rock to the northwest of the northeast ridge are very prominent on the aerial photogaphs, but are much more difficult to recognise on the ground. At this level they are not readily

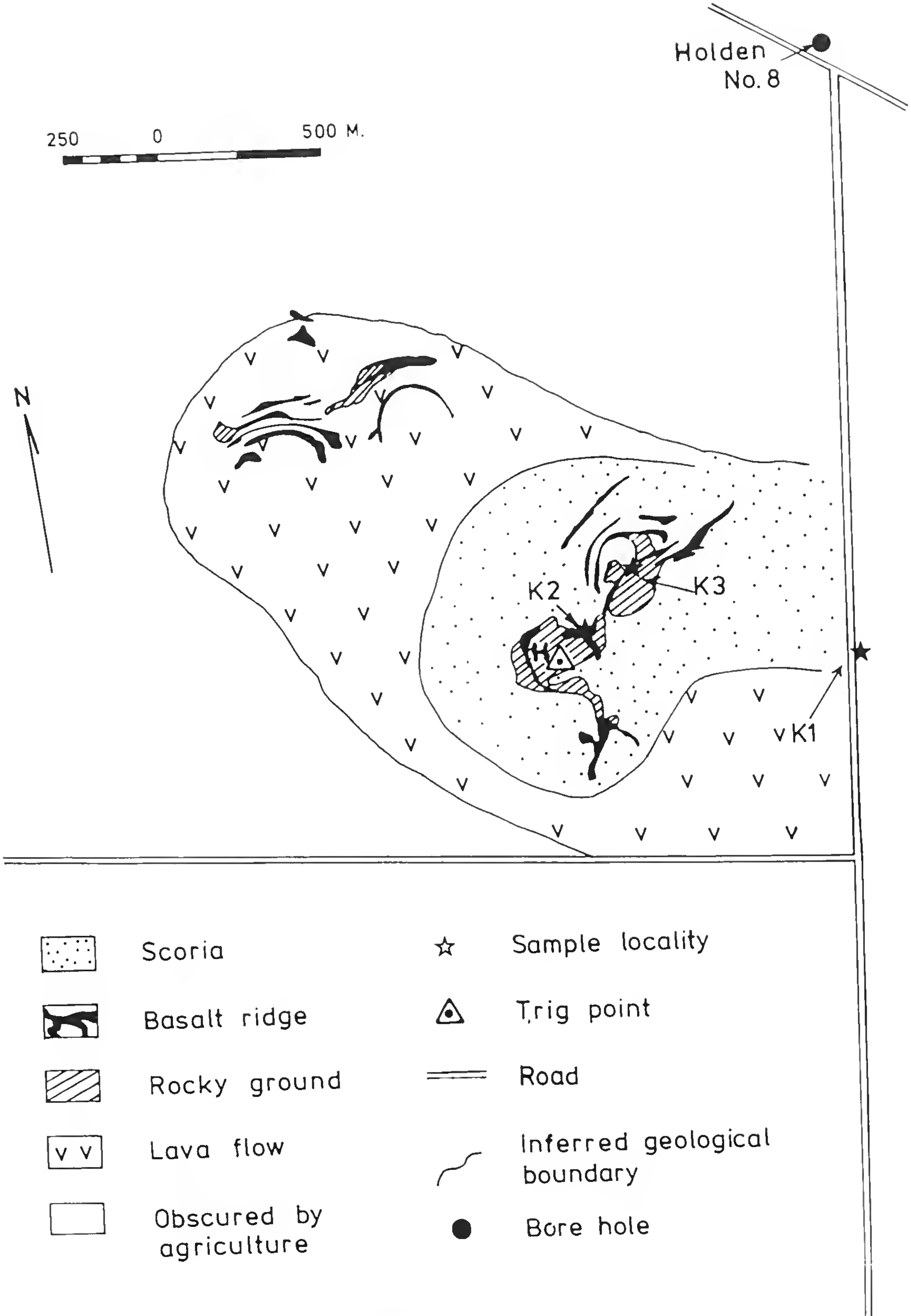


Fig. 1 – Geological Sketch Map, Mt Kororoit, Victoria.

distinguishable from other areas of rocky ground presumably weathered from the basaltic material.

The arcuate features northwest of the cap have flat tops and relatively steep fronts, and are probably either tumuli in, or lobes of, a lava flow extending in that direction.

Samples were taken of the two major rock types for density determinations, and a brief description of these is given in Table 1.

TABLE 1

BRIEF DESCRIPTION OF ROCKS USED IN DENSITY MEASUREMENT

Rock Type	Description	Locality of Samples
Scoria	Red-brown colour, fairly well consolidated, fine vesicles showing some flattening; in part made of fine lapilli aggregates; some well preserved phenocrysts.	K1, road cutting about 1 km east of the cap.
Basalt	Medium to dark brown colour; vesicular basalt; very hard; fine to coarse gradation of vesicles-elongate, aligned and compressed; occasional vesicles filled with muddy material.	K2; edge of basalt cap. K3; northeast ridge.

GRAVITY SURVEY

The gravity survey at Mt Kororoit formed part of an undergraduate field exercise. Four major traverses, running approximately north, south, east and west were laid out from the trig marker on the summit. These lines extended at least 1 km from the summit. Additional lines were also laid out on the flanks of the hill to provide additional control on the anomaly shapes on the hill slopes. The average station spacing was 60 m; the lines are shown on Fig. 2.

Two gravity meters were used; Worden No. 169, loaned by the Bureau of Mineral Resources, and Scintrex No. 255-G. Both meters were calibrated immediately before the survey. All station elevations were determined by spirit levelling. Loop closure errors in both the gravity and levelling data were adjusted numerically after gross errors had been detected and removed.

DENSITIES

Density determinations were carried out on 45 rock samples collected from three localities in the field (Fig. 1). The results are given in Table 2. Although the two classes of sample were quite distinctive in appearance, their densities were similar; in fact they appear statistically to be drawn from the same population (Student's test; $p > 0.95$). Accordingly, a weighted mean density of 1.66 g.cm^{-3} was taken as the density of the hill material for Bouguer reduction purposes.

The indirect 'density profile' method of Nettleton (1976) was also used. The density indicated by this method was about 1.6 g.cm^{-3} in good agreement with the sample results.

TABLE 2

SUMMARY OF WET BULK DENSITIES FOR THE ROCK TYPES SAMPLED

Rock Type: (Locality)	Mean Density (g.cm^{-3})	S.D.	No. of Samples
Scoria: (K1)	1.63	0.09	20
Basalt: (K2) & (K3)	1.68	0.06	25

Weighted mean density of scoria and basalt = 1.66 g.cm^{-3}
Standard Deviation (S.D.) = 0.06

DATA REDUCTION

The gravity data were corrected for latitude, elevation and Bouguer plate effects, using the scoria density value (1.66 g.cm^{-3}) and a datum plane at the approximate level of the surrounding land (150 m above sea level). Terrain corrections were determined for isolated stations, but found to be negligible.

No regional gravity gradient was observed on the major traverses, so the Bouguer gravity values were arbitrarily adjusted before display by subtracting 45.62 mGal from each value. The resulting values were then three-point smoothed before plotting (Fig. 2).

The residual gravity contour map (Fig. 2) clearly shows a negative anomaly, with a maximum amplitude of 1.8 mGal. The anomaly is hour-glass shaped, with the long axis approximately north-south and the narrowest point just where the present volcanic cap appears.

INTERPRETATION

GRAVITY DATA

The form of the gravity anomaly, together with the surface features, suggests that a shallow subsurface depression filled with less dense material exists. The shape of the anomaly may reflect the shape of the depression, or variations of the density of the fill.

The near-surface rocks near Mt Kororoit are the Newer Volcanic lava flows, and in a nearby bore (Holden No. 8, see Fig. 1) a total of 74 m of flows were encountered overlying Silurian mudstones.

The form of the gravity anomaly around the two minima can be satisfied by assuming that the source is approximately 75 m in thickness, with its surface at the level of the surrounding terrain, and with a density contrast of approximately -0.9 g.cm^{-3}. If the material filling the depression is scoria similar to that sampled, then the bulk density of the basalt flows should be about 2.56 g.cm^{-3}, which is a reasonable value for such rocks. We therefore propose that the fundamental basin shape of the anomaly is due to the presence of an island of scoria in the basalt sheet.

The 'neck' of the anomaly coincides approximately (but not exactly) with the position of the prominent surface ridges to the northeast and southeast. The amplitude of this part of the anomaly (positive, with respect to the larger anomaly) is about 0.5 mGal, which could arise from a shallow sheet of more dense material (density equal to that of the surrounding lavas) of approximately 10 m thickness buried within the cone.

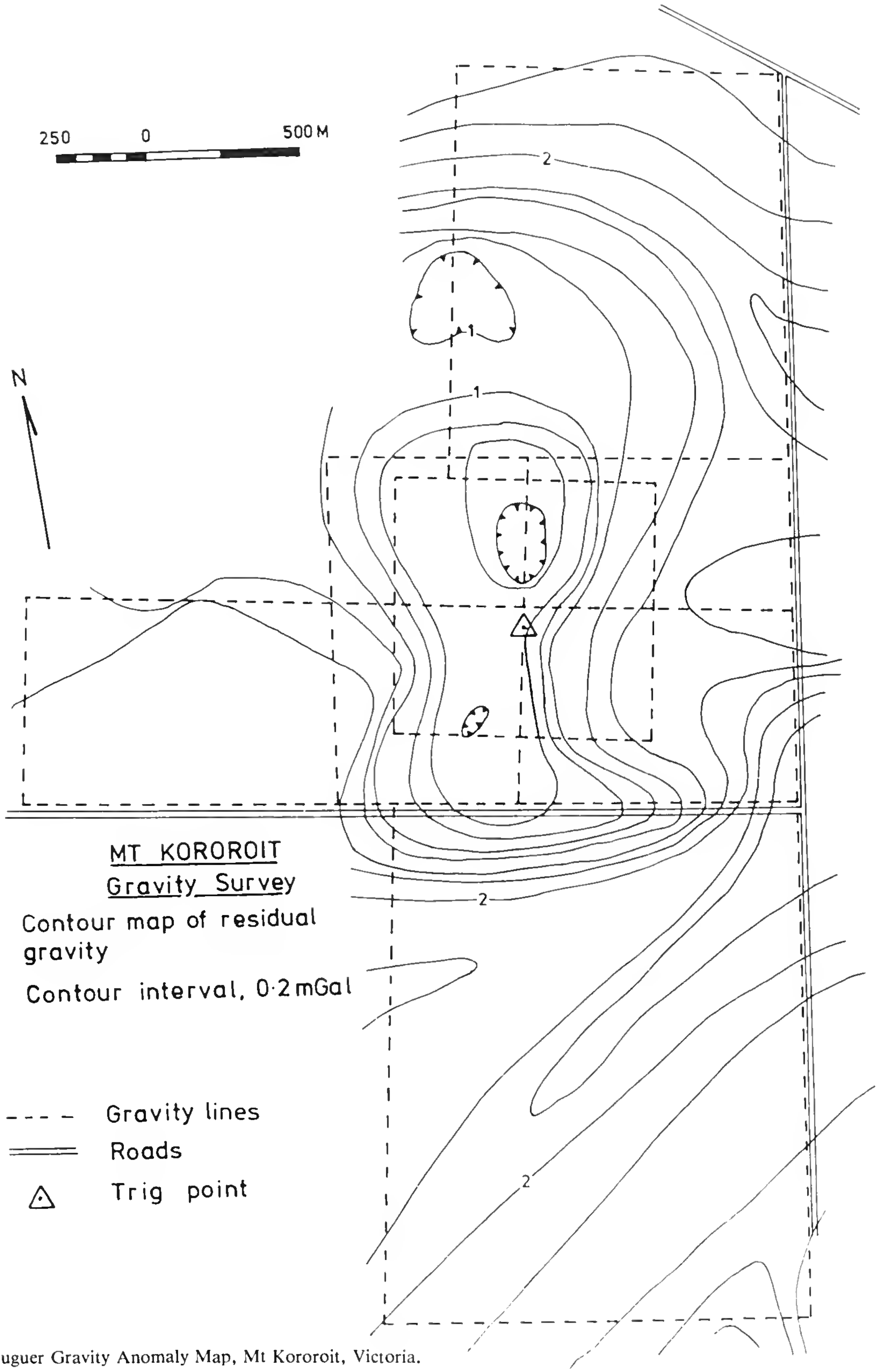


Fig. 2 — Bouguer Gravity Anomaly Map, Mt Kororoit, Victoria.

A more detailed interpretation of the gravity anomaly has been attempted, but is not very illuminating, as the details depend to a great extent on the interpreter's starting assumptions.

We modelled, for instance, a hypothetical feeder pipe below the cone as a vertical circular cylinder of radius 25 m with its top at 75 m below the datum plane. With a density contrast of $+0.4$ g.cm^{-3} such a column would give a circular gravity anomaly with a maximum value of 0.25 mGal and a half width of the order of 200 m. While such a component could be added to any model, we see no compelling evidence for a significant column of lava at the centre of the cone.

COMBINED DATA

We propose the following sequence of events to explain the field and gravity data which we have reported. Eruption at Mt Kororoit began at an early stage in the development of the surrounding lava sheet, with effusion of mainly scoriaceous material forming an island in the lava. Periods during which more fluid material was erupted were interspersed, probably adding to the flows forming the sheet around the cone, and accounting for the lobes to the northwest of the cone. Discontinuities of eruption allowed the magma to withdraw in the narrow central vent, and so produce the inward dips in the tiers of lava remaining at the top of the cone.

Near the end of activity, lava flowed from the cone towards the east over a bed of scoria. The ridges northeast and southeast of the cap represent the edges of this flow, and dip inwards toward the flow as a result of subsidence while the flow was still plastic. The dips could also result from confinement in a channel of scoria now eroded. The rocks sampled at the ridge may be more vesicular than the body of the flow and so give the lower densities observed.

The final phase of eruption began with a burst of spatter (fire fountaining) which agglomerated to form the present cap rock, and ended with an eruption of scoria which blanketed the flanks of the cone.

Gases derived from beneath the flow may have formed the arcuate structures to the north of the northeast ridge, by a blistering process. Subsidence of the flow may have been aided by the weight of the scoria erupted in the final phase and which now covers the flow.

The topography suggests that the final flow must have occurred after most of the surrounding lavas were in place; however, subsequent erosion has most probably severely modified the external shape of the cone.

SUMMARY

Observations at Mt Kororoit indicate that the cone is composed of a pile of scoria, with basalt layers interspersed, which began to form during the early stages of the formation of the surrounding lava flows. Eruption must have continued, intermittently, for much of the period during which the flows were emplaced.

ACKNOWLEDGEMENTS

We thank our colleagues (staff and students) in the Department of Geology for their assistance during various stages of this study, and the Bureau of Mineral Resources for making a gravimeter available.

REFERENCES

EDWARDS, A. B. & CRAWFORD, W., 1940. The Cainozoic volcanic rocks of the Gisborne district, Victoria. *Proc. R. Soc. Vict. 52*: 281-311.

NETTLETON, L. L., 1976. *Gravity and Magnetics in Oil Prospecting*. McGraw Hill, New York.

SINGLETON, O. P., 1973. Geology and petrology of the Macedon district. In *Regional Guide to Victorian Geology*, J. McAndrew & M. A. H. Marsden, eds., Department of Geology, University of Melbourne, 2nd Edition.

VANDENBERG, A. H. M., MARSDEN, M. A. H. & MCANDREW, J., 1973. Geology of the Melbourne district. In *Regional Guide to Victorian Geology*, J. McAndrew & M. A. H. Marsden, eds., Department of Geology, University of Melbourne, 2nd Edition.

CHAPMAN'S "MALLEE BORES" AND "SORRENTO BORE" OSTRACODA IN THE NATIONAL MUSEUM OF VICTORIA, WITH THE DESCRIPTION OF *MADDOCKSELLA* NEW GENUS

By K. G. McKenzie

Riverina College of Advanced Education, Wagga Wagga, N.S.W.

Abstract: Fifty-four Ostracoda in the collections of the National Museum of Victoria, which were named or described either by Chapman or by Chapman and Crespin in two early papers on Victorian Cainozoic Ostracoda, are reassessed and reassigned as to genus and species. The new pontocypridid genus *Maddocksella*, type species *Maddocksella tumefacta* (Chapman 1914), is described and illustrated from among these taxa.

INTRODUCTION

No Australian palaeontologist can afford to ignore the voluminous writings of Frederick Chapman on the continent's fossil faunas. From his arrival in Victoria during 1902 to his death in 1943 Chapman's output was so prodigious that it became synonymous with the development of Australian palaeontology. He undertook, virtually singlehanded, the description of all groups of fossils found in this country; his bibliography includes over a dozen papers on Ostracoda (McKenzie 1974).

Chapman had a decade of ostracode studies behind him, in the impressive company of men such as Jones and Sherborn, when he arrived in Australia. For this reason his ostracode taxonomy was never questioned. Unfortunately, with the passage of time, Chapman's generic level assignments need revision and many of his species names, especially those referring to taxa described by G. S. Brady, are now known to be incorrect. Most of the errors made by Chapman can be accounted for by the unremitting pace at which he must have worked. Sometimes, sex dimorphs or juveniles and adults of the same species are given different names. When he referred species to taxa described by G. S. Brady, which he did regularly, his only references were Brady's papers, notably Brady's "Challenger" Report (Brady 1880); to my knowledge he never rechecked Brady's type materials, most of which were then deposited at the Hancock Museum, Newcastle-upon-Tyne.

SYSTEMATIC PALAEONTOLOGY

Family Pontocyprididae Muller 1894

Genus **Maddocksella** gen. nov.

Genus A; McKenzie 1964, pp. 448-453.
Australoecia; McKenzie 1969, p. 11.
Australoecia; Maddocks 1969, pp. 49-50.
Australoecia; McKenzie 1974, pp. 158 (Text-fig. 3g), 166.
Australoecia n. subgen.; McKenzie 1979, pp. 90-94.

Etymology: For Dr R. F. Maddocks, who has several papers, including an important monograph, on pontocypridids.

Type Species: *Maddocksella tumefacta* (Chapman 1914) (Fig. 1).

Diagnosis: Argilloeciine pontocypridids characterised by an inflated and robust shell, strong left valve overlap and an adductor rosette of 5 large wedge-shaped scars.

Geological Age: Eocene to Recent.

Discussion: As pointed out by Maddocks (1969, p. 49), the right valve overlap displayed by the type species of *Australoecia* McKenzie (1967, pp. 67-8) is not matched by some different species otherwise referrable to it because these have a marked left valve overlap. Further, the new genus is characterized by an inflated and robust shell whereas the shell in *Australoecia victoriae* McKenzie 1967 is less well calcified and cigar shaped rather than inflated. These three characters sufficiently differentiate between *Maddocksella* and *Australoecia* and also between *Madocksella* and *Argilloecia* Sars, the only other genus which bears any resemblance to the new taxon. The adductor scar pattern of the new genus resembles that of *Australoecia* but is clearly different from that of *Argilloecia*.

The strong left valve overlap which characterises *Maddocksella vis à vis Australoecia* is not fortuitous nor is it confined to only one or a few species. Indeed, all the many Tertiary records belong in *Maddocksella*. On this evidence, *Maddocksella* is the ancestral taxon and *Australoecia* is a radiation from the ancestral stock which is represented in the known living fauna of southern Australia only by the type species *Australoecia victoriae*.

Other Species: These include *Maddocksella mackenziei* (Maddocks 1969). Several as yet undescribed species of *Maddocksella* are known to occur in the Tertiary of Victoria and South Australia (McKenzie 1974, 1979). Genus A sp. A of McKenzie (1964) represents yet another species which lives in Oyster Harbour, near Albany, Western Australia. Other living species are known from Sahul Shelf, off northwestern Australia (McKenzie 1974, p. 166).

Note that McKenzie (1979, p. 90) refers the deep sea taxon *Australoecia abyssophila* Maddocks 1969 to the genus *Abyssocypris* van den Bold 1974.

Ecology: *Maddocksella* appears to be restricted to coastal waters, including protected bays and estuarine harbours where it is usually found living in sublittoral, muddy silts and fine sand facies. Since empty shells are often washed onto beaches, it is unlikely that the preferred depth for this genus is much greater than 15-30 m. It

TABLE 1

GENERIC AND SPECIFIC REASSIGNMENTS OF OSTRACODA DESCRIBED IN CHAPMAN'S (1914) "MALLEE BORES" PAPER

	Chapman's Name	Reassignment	NMV Reg No
1.	*Cytherella pulchra* G. S. Brady	= *Cytherella* [non *pulchra*]	P12539
2.	*Cytherella polita* G. S. Brady	= *Cytherella* [non *polita*]	P12538
3.	*Cytherella muricultus* Chapman	= *Cytherelloidea* Alexander 1929	P12536-7
4.	*Cytherella lata* G. S. Brady	= *Cytherella* [non *lata*]	P12535
5.	*Cytherella subtruncata* Chapman	= no change	P12541
6.	*Cytherella punctata* G. S. Brady	= *Platella* Coryell & Fields 1937 [non *punctata*]	P12540
7.	*Cytherura ouyenensis* Chapman	= *Loxocythere* Hornibrook 1952	P12529
8.	*Cytheropteron postumbonatum* Chapman	= *Bythoceratina* Hornibrook 1952	P12532
9.	*Cytheropteron reticosum* Chapman	= no change	P12534
10.	*Cytheropteron batesfordiense* Chapman	= n. gen.	P12531
11.	*Cytheropteron batesfordiense aculeata* Chapman	= n. gen. [same sp. as 10]	P12530
12.	*Cytheropteron praeantarcticum* Chapman	= *Oculocytheropteron* Bate 1972	P12533
13.	*Cytheropteron rostratum* Chapman	= non *Cytheropteron*	P12553
14.	*Cythere rastromarginata* G. S. Brady	= *Cletocythereis* Swain 1963	P12518
15.	*Cythere scabrocuneata* G. S. Brady	= *Trachyleberis* Brady 1898 [male, non *scabrocuneata*]	P12520
16.	*Cythere scintillulata* G. S. Brady	= *Parakrithe* van den Bold 1946 [non *scintillulata*]	P12519
17.	*Cythere scutigera* G. S. Brady	= *Trachyleberis* [non *scutigera*]	P12521
18.	*Cythere wyvillethomsoni* G. S. Brady	= n. gen. [non *wyvillethomsoni*]	P12522
19.	*Krithe eggeri* Chapman	= *Parakrithe* [same sp. as 16]	P12523
20.	*Loxoconcha australis* G. S. Brady	= no change	P12524
21.	*Xestoleberis curta* G. S. Brady	= *Xestoleberis* [non *curta*]	P12525
22.	*Xestoleberis marginata* G. S. Brady	= *Xestoleberis* [non *marginata*]	P12526
23.	*Xestoleberis variegata* G. S. Brady	= [slide empty]	P12527
24.	*Cytherura capillifera* Chapman	= n. gen.	P12528
25.	*Cythere dictyon* G. S. Brady	= *Bradleya* Hornibrook 1952 [non *dictyon*]	P12507
26.	*Cythere flexicostata* Chapman	= n. gen.	P12508
27.	*Cythere lactea* G. S. Brady	= *Tenedocythere* Sissingh 1972 [non *lactea*?]	P12509
28.	*Cythere lepralioides* G. S. Brady	= *Cytheralison* Hornibrook 1952 [non *lepralioides*] [juv.]	P12510
29.	*Cythere lubbockiana* G. S. Brady	= ?*Keijia* Teeter 1975 [non *lubbockiana*]	P12511
30.	*Cythere militaris* G. S. Brady	= *Ponticocythereis* McKenzie 1967 [aff. *clavigera* G. S. B.]	P12512
31.	*Cythere normani* G. S. Brady	= *Quasibradleya* Benson 1972 [non *normani*]	P12513
32.	*Cythere obtusalata* G. S. Brady	= *Loxoconcha* Sars 1866 [non *obtusalata*]	P12514
33.	*Cythere ovalis* G. S. Brady	= *Cytheralison* [non *ovalis*] [adult male of 28]	P12515
34.	*Cythere parallelogramma* G. S. Brady	= n. gen. [same sp. as 26] [non *parallelogramma*]	P12516
35.	*Cythere postdeclivis* Chapman	= *Cytheralison* [adult male, same sp. as 28, 33]	P12517
36.	*Macrocypris decora* G. S. Brady	= *Tasmanocypris* McKenzie 1979 [non *decora*]	P12496
37.	*Macrocypris tumida* G. S. Brady	= *Maddocksella* [non *tumida*]	P12497
38.	*Bythocypris tumefacta* Chapman	= *Maddocksella* [same sp. as 37]	P12498
39.	*Bythocypris tumefacta* Chapman	= *Maddocksella* [same sp. as 37, 38]	P12499
40.	*Bairdia amygdaloides* G. S. Brady	= *Neonesidea* Maddocks 1969 [non *amygdaloides*]	P12500
41.	*Bairdia australis* Chapman	= *Neonesidea*	P12501
42.	*Cythere canaliculata* Reuss	= *Callistocythere* Ruggieri 1953 [non *canaliculata*]	P12502
43.	*Cythere crispata* G. S. Brady	= pectocytherid n. gen. [non *crispata*]	P12503
44.	*Cythere dasyderma* G. S. Brady	= *Cytheralison* [female, same sp. as 28, 33, 35]	P12504
45.	*Cythere demissa* G. S Brady	= *Keijia* [non *demissa*]	P12505
46.	*Cythere dictyon* G. S. Brady	= *Trachyleberis* [non *dictyon*] [female, same sp. as 15]	P12506

Notes: 1. For description of *Maddocksella* see text.
2. juv. = juvenile.

TABLE 2
GENERIC AND SPECIFIC REASSIGNMENTS OF OSTRACODA DESCRIBED IN CHAPMAN, CRESPIN AND KEBLE (1928) — THE "SORRENTO BORE" PAPER.

	Chapman's and Crespin's Name	Reassignment	NMV Reg No
1.	*Cythere sorrentae* Chapman & Crespin	= *Tenedocythere* [?] [juv.]	P14431
2.	*Cythere caudispinosa* Chapman & Crespin	= *Oertliella* Pokorny 1964 [?]	P14432
3.	*Cythere baragwanathi* Chapman & Crespin	= *Osticythere* Hartman 1980	P14433
4.	*Bythocythere keblei* Chapman & Crespin	= n. gen. [A-1 juv.]	P14434
5.	*Cytherura praemucronata* Chapman & Crespin	= *Pokornyella* Oertli 1956 s.l.	P14435
6.	*Cytherella sulcosa* Chapman & Crespin	= no change	P14436
7.	*Cytherella intermedia* Chapman & Crespin	= *Cytherelloidea*	P14437
8.	*Cytherella araneosa* Chapman & Crespin	= same sp. as 6	P14438

Note: juv. = juvenile.

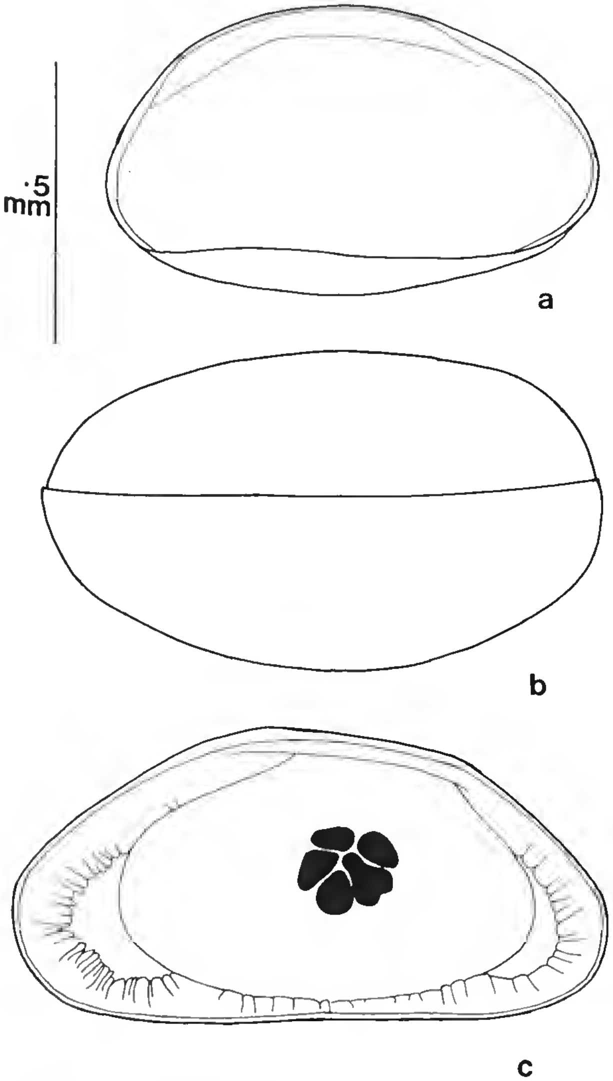


Fig. 1 — *Maddocksella tumefacta* (Chapman 1914). a, A-1 juvenile left valve, internal view (outline) NMV 12499 lectoparatype; b, adult carapace, external view NMV 12498 lectotype; c, adult right valve, internal view NMV 12497 lectoparatype. Note: normal pore canals not illustrated.

is thus a useful shallow water marine and inshore index in the Cainozoic of Australia.

ACKNOWLEDGEMENTS

I am grateful to Dr Peter Jell, Curator of Invertebrate Fossils, for access to the collections and use of facilities at the National Museum of Victoria; and to Mr A. Tynan, Hancock Museum, Newcastle-upon-Tyne, for access to G. S. Brady's types. Mrs Margaret Nichol typed the manuscript. The research is supported by ARGC Grant No. E7615127.

REFERENCES

BRADY, G. S., 1880. Report on the Ostracoda dredged by H.M.S. Challenger during the years 1873-76. *Challenger Reps, Zool.* 1 (3): 1-184. pl. 1-44.

CHAPMAN, F., 1914. Description of new and rare fossils obtained by deep boring in the Mallee. Pt. 3, Ostracoda to fishes. *Proc. R. Soc. Vict.* 27: 28-71, pl. 6-10.

CHAPMAN, F., CRESPIN, I., & KEBLE, R. A., 1928. The Sorrento Bore, Mornington Peninsula, with a description of new or little-known fossils. *Rec. geol. Surv. Vict.* 5 (1): 1-195, pl. 1-12.

MADDOCKS, R. F., 1969. Recent ostracodes of the family Pontocyprididae chiefly from the Indian Ocean. *Smithson. Contribs Zool.* 7: 1-56, figs. 1-35.

MCKENZIE, K. G., 1964. The ecologic associations of an ostracode fauna from Oyster Harbour, a marginal marine environment near Albany, Western Australia. *Pubbl. staz. zool. Napoli* 33 (suppl.): 421-461.

MCKENZIE, K. G., 1967. Recent Ostracoda from Port Phillip Bay, Victoria. *Proc. R. Soc. Vict.* 80: 61-106, figs 1-10, pl. 11-13.

MCKENZIE, K. G., 1969. Discussion. In *The Taxonomy, Morphology and Ecology of Recent Ostracoda,* J. W. Neale, ed., Oliver and Boyd. Edinburgh, 11-13.

MCKENZIE, K. G., 1974. Cenozoic Ostracoda of southeastern Australia with the description of *Hanaiceratina* new genus. *Geoscience and Man* 6: 153-182.

MCKENZIE, K. G., 1979. Appendix 2. Notes on Ostracoda from Willunga Embayment Boreholes WLG 38, WLG 40 and WLG 42. In: B. J. Cooper "Eocene to Miocene Stratigraphy of the Willunga Embayment". *S. Aust. geol. Surv., Rep. Investigations* 50: 90-101.

STUDIES ON WESTERN AUSTRALIAN PERMIAN BRACHIOPODS

2. THE FAMILY RUGOSOCHONETIDAE MUIR-WOOD 1962

By N. W. Archbold

Department of Geology, University of Melbourne, Parkville, Victoria 3052

Abstract: Representatives of the family Rugosochonetidae (Chonetidina, Brachiopoda) from the Western Australian Permian sequences are documented. The genus *Neochonetes* Muir-Wood 1962 is discussed with the establishment of the new subgenus *Neochonetes* (*Sommeria*). The following species are revised or described: *Neochonetes* (*Sommeria*) *pratti* (Davidson), *Neochonetes* (*Sommeria*) *robustus* sp. nov., *Neochonetes* (*Sommeria*) *tenuicapillatus* sp. nov., *Neochonetes* (*Sommeria*) *afanasyevae* sp. nov., *Svalbardia narelliensis* sp. nov. Additional material indicating the presence of further species of *Neochonetes* (*Sommeria*) and a species of *Chonetinella* is described.

INTRODUCTION

Brachiopods of the suborder Chonetidina are abundant in the diverse faunas of the west Australian Permian sedimentary sequences. Representatives of the Anopliidae have been documented elsewhere (Archbold 1980a). This paper concludes the investigation of members of the Rugosochonetidae, some results of which have already appeared (Archbold 1981a, 1981b). *Neochonetes* Muir-Wood, in the form of the new subgenus *Neochonetes* (*Sommeria*), is particularly abundant at certain stratigraphical levels and species of the genus are useful for intrabasinal correlations.

Neochonetes (*Sommeria*) has a disjunct or bipolar distribution. Such a distribution for Permian chonetids was anticipated by Afanas'yeva (1978) and has been demonstrated for *Tornquistia*, *Svalbardia* and *Quinquenella* (Archbold 1980a, 1981a, 1981b).

Collections

All figured and measured specimens are housed in the following institutions as indicated by the prefix to registered numbers. CPC—Commonwealth Palaeontological Collections of the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. GSWA—Geological Survey of Western Australia, Perth, Western Australia. NMVP—National Museum of Victoria, Melbourne, Victoria. UWA—Geology Department, University of Western Australia, Nedlands, W.A. SM—South Australian Museum, Adelaide, S.A.

Stratigraphy

Marine Permian sedimentary sequences occur in the Perth, Carnarvon, Canning and Bonaparte Gulf Basins (Fig. 1) with representatives of the Rugosochonetidae in each. The sequence of the Perth Basin was revised by Playford *et al.* (1976), those of the Carnarvon and Canning Basins were reviewed by Playford *et al.* (1975) with the latter revised by Yeates *et al.* (1975) and Crowe and Towner (1976), and the Permian succession of the Bonaparte Gulf Basin was revised by Dickins *et al.* (1972).

Age

The biostratigraphic scheme of Glenister & Furnish (1961) based on ammonoids is still largely followed for Western Australia with one important exception. Those authors were unable to recognise the distinction of the Kungurian stage. Dickins (1976) attempted correlation of the Western Australian Permian sequences with the International Time Scale and he indicated the Baigendzinian-Kungurian boundary at about the level of the Baker Formation of the Carnarvon Basin. Dickins (1956) and Waterhouse (1976) favoured a slightly lower position for the boundary at the base of the Baker Formation and Archbold (1981b) suggested that the boundary may be within the Nalbia Greywacke below the Baker Formation. This latter suggestion is compatible with information on ammonoids provided by Bogoslovskaya (1976) and Cockbain (1980).

Terminology

The terminology applied to the Chonetidina has been clearly defined by Muir-Wood (1962, 1965) and Sarycheva (1970).

Palaeoecology of Massed Chonetid Occurrences

Western Australian chonetids occur in two types of coquinites, those where the individuals are disarticulated and invariably worn and those where the individuals are conjoined with excellent preservation of fine external, surface ornament.

Specimens of *Svalbardia narelliensis* sp. nov. occur by the thousands in large slabs of rock from high in the Noonkanbah Formation, Canning Basin. All specimens are disarticulated, many are worn, and other fossils are restricted to one or two isolated individuals. With few exceptions all ventral valves are convex up; dorsal valves show no preferred orientation. Elias (1962, 1966) suggested: 1, that chonetids may be gregarious and when they occur in great numbers, to the virtual exclusion of other invertebrates, they indicate waters shallower than normal for articulate brachiopods; 2, that nested ventral valves possibly indicate deposition in gently agitated water, above wave base. One such valve in valve ar-

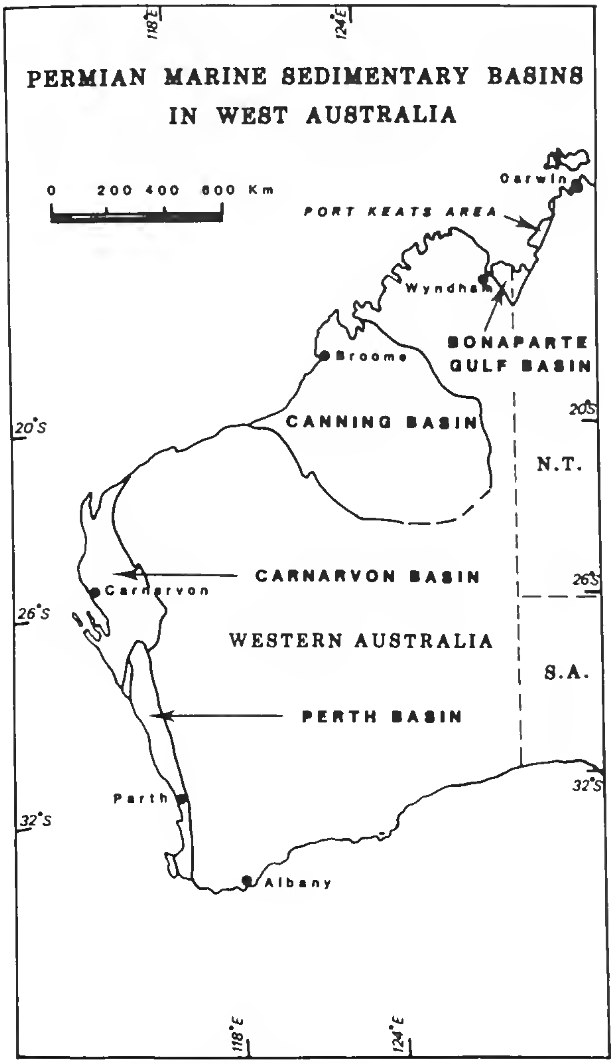


Fig. 1 – Permian sedimentary basins in west Australia.

rangement of ventral valves concave up for *Svalbardia narelliensis* sp. nov. is figured herein (Fig. 2Y). Accumulations of *Neochonetes* (*Sommeria*) *afanasyevae* sp. nov. are also of disarticulated valves in the three basins in which the species occurs. The faunas of the three formations containing the species are molluscan dominant, which, in the scheme of Thomas (1958) are shallower water assemblages than brachiopod dominant assemblages.

On the other hand, accumulations of *Neochonetes* (*Sommeria*) in the Callytharra, Madeline and Wandagee Formations are often of articulated shells suggesting deposition in water below wave base. The same is true of chonetid conquinites of *Tornquistia magna* from the Bulgadoo Shale. These formations all possess brachiopod dominated assemblages inferred to reflect deeper water (Thomas 1958).

SYSTEMATIC PALAEONTOLOGY

Suborder Chonetidina Muir-Wood 1955
Superfamily Chonetacea Bronn 1862
Family Rugosochonetidae Muir-Wood 1962
Subfamily Svalbardiinae Archbold 1981

Genus **Svalbardia** Barkhatova 1970

Type Species: *Chonetes capitolinus* Toula 1815.
Diagnosis: See Archbold (1981b, p. 3).
Discussion: *Svalbardia* has been discussed by Archbold (1981b).

Svalbardia narelliensis sp. nov.

Fig. 2

Holotype: CPC19167U, a dorsal valve.
Etymology: From Narelli Rockhole, Canning Basin, Western Australia.
Location and Occurrence: Upper Noonkanbah Formation, Canning Basin.

The following B.M.R. localities yielded several hundred specimens of *Svalbardia narelliensis* which were examined for the present investigation. Additional localities in the Canning Basin that have yielded *Svalbardia* are documented in Dickins and Jell (1974) who identified the species as a representative of *Neochonetes*. L.3., Lat. 20°08'S, Long. 127°58'E, 4.8 km west of Balgo Mission; L.101., Lat. 20°08'S, Long. 127°58'E, 4.8 km west of Balgo Mission, L.610., Lat. 20°09'S, Long. 127°56'E, 1.2 km south of Narelli Rockhole.

Measurements: The specimens measured for Table 1 are paratypes from L610 and have the registered numbers CPC 19167A to 19167Z; CPC19168A to 19168E.

Description: external. Shell length is about three-quarters maximum width which occurs about mid-length of the shell. The ventral valve is convex, usually without a sulcus, although a slight flattening or a very shallow sulcus is visible on rare specimens. The anterior commissure is not flexed. The dorsal valve is normally flat or rarely gently concave. The interareas are narrow, that of the ventral valve being striate parallel to its width. The exterior of the shell is smooth except for concentric growth lines. Worn ventral valves exhibit a surface feature of pits arranged in concentric rows formed by exposure of the taleolae. Worn dorsal valves, in which growth lines may still be visible, exhibit a pseudocapillate exterior. Hinge spines are worn on all examined specimens. However, spine base canals 1 to 1.5

Table 1

Size Ranges of Populations of *Svalbardia narelliensis* sp. nov. (mm)

Maximum Width	Hinge Width	Ventral Length	Dorsal Length	Thickness
12.4-20.5	8.6-19.0	10.9-15.7	8.9-11.6	2.7- 4.3

mm apart are clearly visible in the ventral interarea of several specimens. Where traces of spines remain they indicate the spines emerged at a low angle to the hinge. INTERNAL. the ventral median septum is over three-quarters valve length and arises under the delthyrium as a high pronounced structure. One ventral valve (CPC19167H) possesses two parallel, weakly impressed striations adjacent to the septum. Vascular trunks and muscle scars are poorly impressed. Specimen CPC19167G exhibits a pair of small adductor scars adjacent to the posterior third of the median septum. The teeth are small and sharp.

The dorsal median septum is just over two-thirds valve length and is higher and broader posteriorly. The alveolus is small but distinct and, at times, deep. The lateral septa are stout and arise anterior to the alveolus, where they are fused with the median septum to form a low platform. The sockets are deep with pronounced inner socket ridges. The brachial ridges are indistinct and their anterior recurved portions are only slightly raised in mature individuals. The cardinal process is low but distinct, externally quadrilobed, internally bilobed. The interior of the dorsal valve is finely papillose with the anterior papillae being arranged in radiating rows.

Delthyrial structures are poorly known, however, a minute pseudodeltidium is present in the apex of the delthyrium of specimen CPC19167G. None of the specimens exhibit a chilidium.

DISCUSSION: *Svalbardia narelliensis* is morphologically similar to *Svalbardia thomasi* Archbold (1981b) from the Baker Formation and Nalbia Greywacke of the Carnarvon Basin. *S. narelliensis* possesses, in mature individuals, only weakly raised anterior recurved portions of the brachial ridges. In other respects *S. narelliensis* is similar to *S. thomasi* and they are of approximately the same age. *S. narelliensis* attains a larger size than *S. thomasi*. *S. thomasi* was compared with many boreal occurrences of the genus by Archbold (1981b); the boreal species usually being larger and possessing prominently raised anterior recurved portions of the brachial ridges.

AGE: *Svalbardia* in the Nalbia Greywacke and Baker Formation (Archbold 1981b) indicates an earliest Kungurian age. *Svalbardia* occurs high in the Noonkanbah Formation, beneath the Middle Kungurian Lightjack Formation (see discussion under *Neochonetes* (*Sommeria*) *afanasyevae* sp.nov.). It therefore appears that the Noonkanbah Formation contains Baigendzinian and earliest Kungurian faunas.

TABLE 2

REPRESENTATIVE REPORTS OF SPECIES OF *Neochonetes* Muir-Wood INDICATING TIME RANGE AND GEOGRAPHICAL DISTRIBUTION OF STOCKS WITHIN THE GENUS.

1. Stock of *Neochonetes* (*Neochonetes*) *carboniferus* (Keyserling 1846)

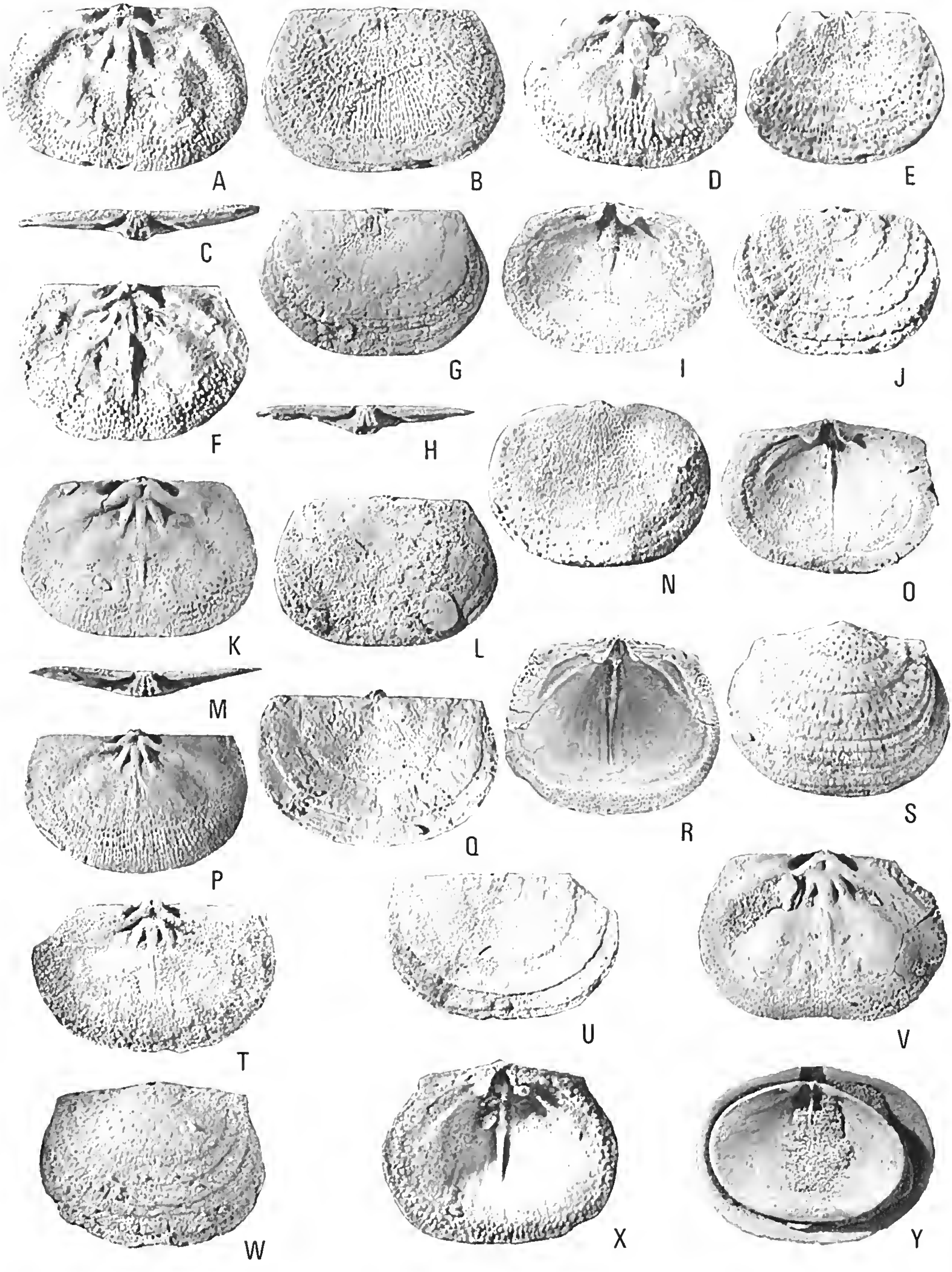
Chonetes sarcinulata var. *carbonifera* Keyserling 1846; North Urals; Late Carboniferous. *Neochonetes carboniferus* Afanas'yeva 1975b; Russian Platform; Kasimovian-Gzhelian. *Neochonetes? donetzianus* Afanas'yeva 1975b; Donetz Basin; Middle Carboniferous. *Chonetes carboniferus* Semenova 1972; Kuibyshev Region; Bashkirian. *Chonetes ex* gr. *carboniferus* Lapina 1958; Kharaulakh Mts, NE USSR; Late Carboniferous. *Neochonetes acanthophorous* Winkler-Prins 1968; Cantabrian Mts Spain; Bashkirian. *Chonetes pseudovariolatus* Loczy 1897; Kansu Province, China; Late Carboniferous. *Chonetes pseudovariolatus* Schellwien 1911; Nth Nan-Shan, China; Late Carboniferous. *Chonetes carbonifera* Chao 1928; China, widespread; Middle & Late Carboniferous. *Neochonetes puanensis* Liao 1979; Western Guizhou Province, China; Gzhelian. *Chonetes* cf. *carboniferus* Ozaki 1934; Korea; Late Carboniferous. *Neochonetes permicus* Grushenko 1975; Donetz Basin; Asselian.

2. Stock of *Neochonetes* (*Neochonetes*) *granulifer* (Owen 1852)

Chonetes granulifer Owen 1852; Iowa, U.S.A.; Pennsylvanian. *Chonetes dominus* King 1938; Texas, U.S.A.; Pennsylvanian. *Chonetes granulifer*. var. Dunbar & Condra 1932; Nebraska, U.S.A.; Pennsylvanian. *Neochonetes granulifer* Spencer 1970; Kansas, Missouri, U.S.A.; Pennsylvanian-Sakmarian. *Neochonetes granulifer* Brand 1970; England; Late Carboniferous. *Chonetes* sp. C Brand 1970; Scotland; Late Carboniferous. *Chonetes (Chonetinella) granulifer* Böger & Fiebig 1963; Germany; Stephanian. *Leptaena variolata* d'Orbigny 1842; Bolivia; Asselian-Sakmarian. *Chonetes variolatus* Thomas 1930; Peru; Asselian-Sakmarian.

3. Stock of *Neochonetes* (*Sommeria*) *pratti* (Davidson 1859)

Chonetes pratti Davidson 1859; Western Australia; Sakmarian. *Chonetes arabicus* Hudson & Sudbury 1959; Oman Peninsula; Sterlitamakian. *Neochonetes variolatus* Termier *et al.* 1974; Afghanistan; Sterlitamakian. *Neochonetes variolatus* Fantini Sestini 1965b; Karakorum; Sakmarian? *Neochonetes forbesi* Czarniecki 1969; Spitzbergen; Asselian-Sakmarian. *Chonetes variolatus* Zavodovsky & Stepanov 1971; Kolyma, USSR; Asselian. *Neochonetes tschernyschewi* Barkhatova 1970; Urals; Sakmarian. *Neochonetes fredericksi* Archbold 1979; Pechora Basin, USSR; Artinskian. *Chonetina superba* Gobbett 1964; Spitzbergen; Late Kungurian. *Chonetina?* cf. *C. superba* Brabb & Grant 1971; Alaska; Late Kungurian. *Neochonetes* sp. Bamber & Waterhouse 1971; Yukon; Late Kungurian. *Neochonetes asseretoi* Fantini Sestini 1964; Iran; Late Kungurian-Kazanian. *Chonetes wageri* Muir-Wood 1941; Himalaya; Chhidruan. *Neochonetes (Sommeria)* sp. herein; Western Australia; Chhidruan.


A
B
D
E
C
G
I
J
F
H
N
O
K
L
M
R
S
P
Q
U
V
T
W
X
Y

Subfamily Rugosochonetinae Muir-Wood 1962

Genus **Neochonetes** Muir-Wood 1962

(= *Quadranetes* Sadlick 1963)

Type Species: *Chonetes dominus* King 1938

Diagnosis: *Neochonetes* includes medium to large sized weakly to moderately concavo-convex, rugosochonetinids with finely capillate external ornament and a feebly to distinctly developed sulcus; dorsal interior with distinct alveolus, lateral septa, median septum and brachial ridges; inner socket ridges well developed and outer socket ridges may be present. Ventral valve with prominent septum, two parallel vascular trunks forming prominent ridges, and hinge spines at a low to moderate angle to hinge line.

Discussion: The long time range and large number of species undoubtedly account for the rather broad generic diagnosis. Within *Neochonetes* several groups or stocks may be recognised and generalised evolutionary trends defined.

One of the early stocks of *Neochonetes*, arising in the Bashkirian, characterised by hinge spines at a low angle (may curve to higher angle distally), a low convexity of the shell, a moderately transverse outline often with small ears, the hinge line usually being the position of maximum width, and an obsolescent sulcus, can be referred to as the group of *Neochonetes carboniferus* (Table 2).

Closely allied to the *Neochonetes carboniferus* stock is the group of *Neochonetes granulifer* (Table 2). This stock also possesses hinge spines at a low angle (one exception being the Late Mississippian *Neochonetes oklahomensis* (Snider) as redescribed by Branson (1964) which has hinge spines at 45°) a moderate to low convexity and a broad shallow sulcus, the latter usually more strongly developed than in the *Neochonetes carboniferus* stock. Younger variants of the *Neochonetes granulifer* stock are often, but not invariably, more transverse than older variants and possess hinge spines at a greater angle to the hinge. South American occurrences of the stock remain poorly understood despite attempts at the redescription of *Neochonetes variolatus* (d'Orbigny) by Koninck (1847) and Kozlowski (1914). The binomen *Chonetes variolatus* has at times been applied to members of the *Neochonetes carboniferus* stock (Gorskii & Timofeeva 1950) indicating a degree of confusion as to the nature of *Neochonetes variolatus*. The only representative of *Neochonetes* from the Late Permian of New Zealand (Waterhouse 1964, 1976), a large species with hinge spines at a low angle and a gentle broad sulcus may be a migratory descendent of the *N. granulifer* stock. Waterhouse (1964) compared the New Zealand *N. beatusi* with several species of the *N. granulifer* stock. A species in the Bowen Basin (Dear 1971) possesses a maximum width at midlength of the shell and a greater convexity of the ventral valve.

A third group within *Neochonetes* is the *Neochonetes pratti* stock here named *Neochonetes* (*Sommeria*). This stock is characterised by large size, ventral hinge spines at an angle of about 40° to 45°, often a prominent sulcus and a maximum width invariably anterior of the hinge.

Boreal species of the stock replace the older *N. carboniferus* stock in the northern Urals during the Sakmarian (Barkhatova 1964). Few boreal species are well documented, exceptions being the early Artinskian Pechora Basin species *N. fredericksi* Archbold 1979 and the Sakmarian *N. tschernyschewi* Barkhatova 1970 from the Urals.

During the Kungurian and subsequent stages, *Neochonetes* again underwent subtle changes in morphology, but stocks are not clear because of the paucity of documented species. Small species of *Neochonetes* from the Zechstein of Germany and England (Schauroth 1856, Trechmann 1944) and the Kazanian of Armenia (Sokolskaya 1965) exhibit a trend to weakly developed ornament and an obsolescent sulcus. Discussions and illustrations of the Zechstein species (Davidson 1880, Malzahn 1957 and Muir-Wood 1962) indicate that they belong to a separate stock within *Neochonetes*.

Other representatives of *Neochonetes* of Kungurian and younger age do not exhibit obsolescent ornament or an obsolescent ventral sulcus, although the species may be small in size. *Chonetes pinegensis* Kulikov (1974) from the Kazanian of northern European USSR, *Neochonetes* cf. *pinegensis* of Stepanov *et al.* from the Kazanian of the Kanin Peninsula and *Chonetes* sp. of Licharew (1913) from the late Kungurian of Kirillov are all small species with distinct ornament and ventral sulcus. The wide variety of morphologies of Kungurian and younger neochonetids probably reflects greater isolation of specific gene pools resulting from the elimination of seaways for migratory exchanges and from other environmental factors such as increase in salinity (the latter undoubtedly affecting the Zechstein stock).

Subgenus **Neochonetes (Sommeria)** subgen. nov.

Type Species: *Chonetes prattii* Davidson 1859.

Fig. 2—*Svalbardia narelliensis* sp. nov.

All specimens from the Noonkanbah Formation, Canning Basin; A-C, Holotype CPC 19167U, Dorsal valve in ventral, dorsal and posterior views. x3; D, CPC 19168B, Dorsal valve in ventral view. x3; E, CPC 19168C, Dorsal valve in ventral view. x3; F-H, CPC 19167Z, Dorsal valve in ventral, dorsal and posterior views. x3; I, CPC 19167R, Ventral valve in dorsal view. x3; J, CPC 19168 E, Dorsal valve in dorsal view. x3; K-M, CPC f19167V, Dorsal valve in ventral, dorsal and posterior views. x3; N, CPC 19168D, Dorsal valve in dorsal view. x3; O, CPC 19167B, Ventral valve in dorsal view. x2; P-Q, CPC 19167X, Dorsal valve in ventral and dorsal views. x3; R, CPC 19167H, Ventral valve in dorsal view. x2.5; S, CPC 19167G, Ventral valve in ventral view. x3; T-U, CPC 19168F, Dorsal valve in ventral and dorsal views. x3; V, CPC 19168A, Dorsal valve in ventral view. x3.25; W, CPC 19167F, Ventral valve in ventral view. x3; X, CPC 19167K, Ventral valve in dorsal view. x3.25; Y, CPC 19168G, Valve in valve arrangement, dorsal view. x3.5.

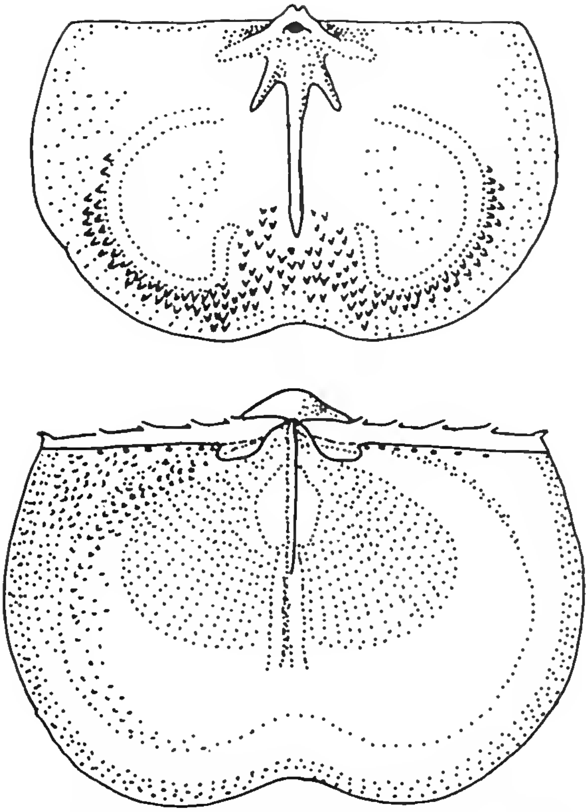


Fig. 3—The internal morphology of *Neochonetes* (*Sommeria*) *pratti* (Davidson); after Muir-Wood (1962, fig. 3, p. 13).

Etymology: Named in honour of Ferdinand von Sommer, pioneer geologist in Western Australia.

Diagnosis: Similar to *Neochonetes* (*Neochonetes*) but sulcus usually conspicuously developed, gentle fold often developed in the dorsal valve, a greater convexity of the ventral valve and hinge spines at about 40° to 45°. Maximum width of mature shells usually anterior of the hinge. Interior as for *Neochonetes* (*Neochonetes*).

Discussion. Although, as discussed above, several stocks can be identified in the genus *Neochonetes*, to give these full generic status is considered premature because the stocks do exhibit a degree of morphological overlap. The stock of *Neochonetes pratti*, outlined above, from Western Australia and the Boreal Realm is considered to belong to the new subgenus *Sommeria*. Many of the poorly known boreal species are compared with *Neochonetes* (*Sommeria*) *pratti* below. Fig. 3 shows the internal morphology of *Neochonetes* (*Sommeria*) *pratti*.

Neochonetes (Sommeria) pratti (Davidson) 1859

Figs 4, 5, 6.

1859 *Chonetes prattii* Davidson, *The Geologist* 2: 116, pl. 4, figs 9-12.

1890 large *Chonetes* Etheridge, *Annu. Rep. Dept. Mines N.S.W.* 1889: 239.

1892 *Chonetes pratti*; Newton, *Geol. Mag.* (3) 9: 468, 542, pl. 14, figs 1-12.

1893 *Chonetes pratti*; Newton, *Rep. Br. Assoc. Advmt. Sci.* 1892: 725.

1903 *Chonetes pratti*; Etheridge, *Bull. geol. Surv. W. Aust.* 10: 23.

1907 *Chonetes pratti*; Etheridge, *Bull. geol. Surv. W. Aust.* 27: 31, pl. 8, fig. 2; pl. 9, fig. 7; pl. 10, fig. 2.

1910 *Chonetes pratti*; Glauert *partim*, *Bull. geol. Surv. W. Aust.* 36: 86.

1931 *Chonetes pratti*; Hosking, *J. Proc. Roy. Soc. W. Aust.* 17: 19.

1952 *Chonetes pratti*; Guppy *et al.*, *19th Int. Geol. Cong., Alger., Sym. Gond.*, 110.

1962 *Neochonetes pratti*; Muir-Wood, *Monograph Br. Mus.* (*Nat. Hist.*) p. 13, pl. 11, figs 7-8.

Holotype: (by monotypy) BM(NH), BB 41082. A complete shell (valves separate) Figured by Davidson (1859), Newton (1892), and Muir-Wood (1962).

History of Discovery: The locality of the type specimen, from the collection of Mr. Pratt was unknown to Davidson (1859). Newton (1892, 1893) considered that the type specimen came from the Irwin River, Western Australia, after examination of specimens of a chonetid brachiopod from that locality, particularly in view of the nature of preservation of the specimens available to him. He further considered the holotype part of the Strzelecki collection but this is unlikely as Strzelecki's investigations and collections were made in eastern Australia at an earlier date.

Permian sediments were discovered by Commander J. L. Stokes between 1837 and 1843 near Port Keats (Bonaparte Gulf, Northern Territory). *Neochonetes* (*Sommeria*) *afanasyevae* sp. nov. from that locality is not close to *Chonetes pratti* and is preserved as moulds and casts, whereas the type specimen of *Chonetes pratti* is a well preserved shell. Samuel Peace Pratt (1789-1863) was an active member of the Geological Society of London and spent much time arranging the collections of the Society (Woodward 1907). As a result Pratt had access to collections from the Irwin River sent to the Society by the Gregory Brothers and von Sommer (Archbold 1981c) and hence the specimen in his collection probably comes from one of these sources.

It appears that Davidson's original specimen probably

Fig. 4—*Neochonetes* (*Sommeria*) *pratti* (Davidson).

All specimens from the Fossil Cliff Member of the Holmwood Shale, Fossil Cliff, Irwin River; A-B, GSWA F 11038, Dorsal valve in dorsal and ventral views. x1.75; C, GSWA F 11022, Ventral valve in dorsal view x2; D-E, GSWA F 11039, Dorsal valve in dorsal and ventral views. x1.75; F-G, GSWA F 11023, Ventral valve in dorsal and ventral views. x1.75; H-I, GSWA F 11027, Ventral valve views. x1.5; J-K, GSWA F 11041, Dorsal valve in ventral and dorsal views. x1.75; L-M, GSWA F 11044, Dorsal valve in dorsal and ventral views x1.75 and 1.5; N-O, GSWA F 11018, Shell in ventral and dorsal views x1.75; P, GSWA F 11031, Ventral valve in ventral view x2; Q, GSWA F 11046, Dorsal valve in ventral view x2.5; R-S, GSWA F 11043, Dorsal valve in dorsal and ventral views x 1.75; T, GSWA F 11045, Dorsal valve in ventral view x2; U, GSWA F 11030, Ventral valve in ventral view x2.

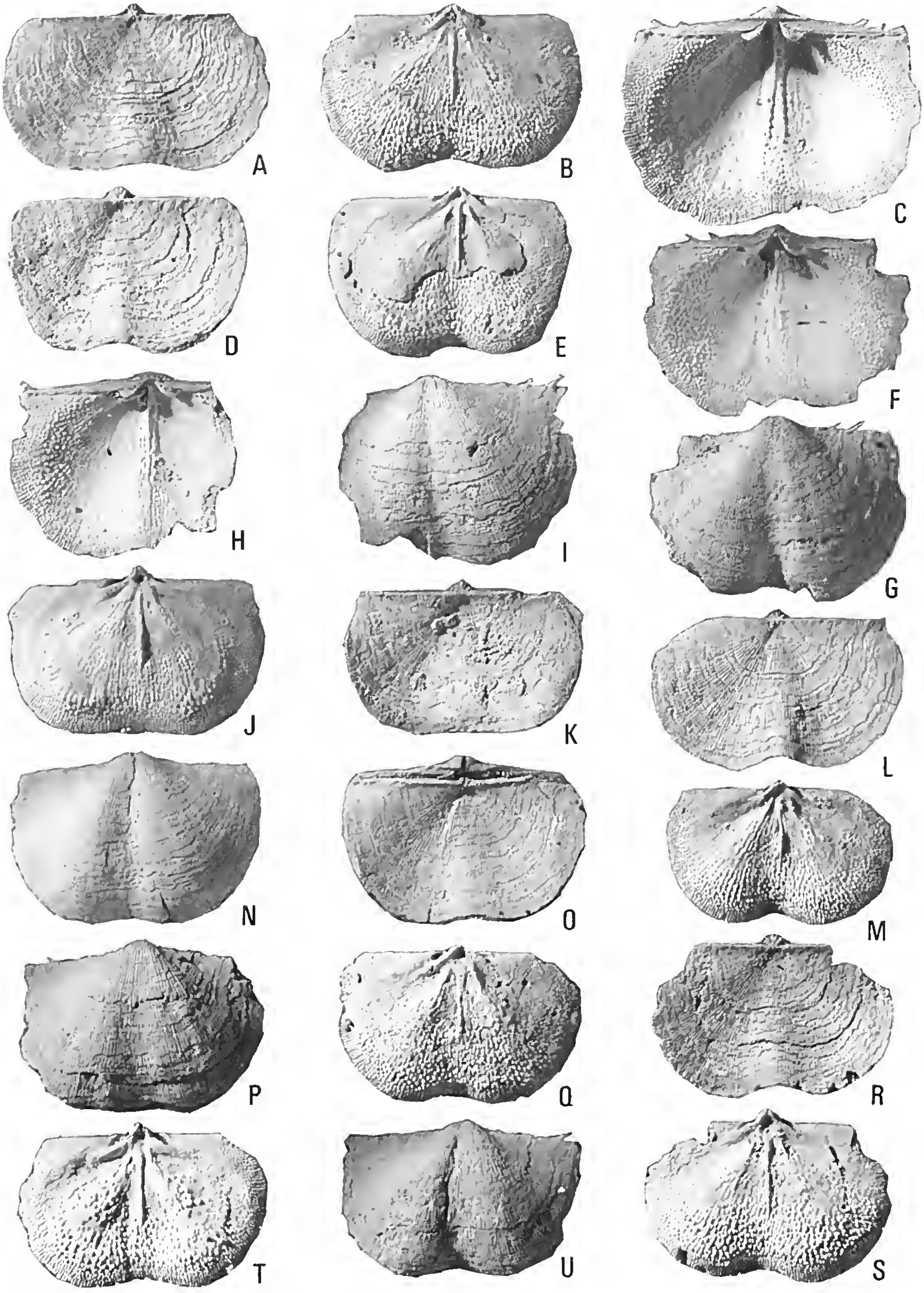

A
B
C
D
E
F
H
I
G
J
K
L
N
O
M
P
Q
R
T
U
S

TABLE 3

SIZE RANGES OF POPULATIONS OF *Neochonetes* (*Sommeria*) *pratti* (mm)

Stratigraphic Horizon	Maximum Width	Hinge Width	Ventral Length	Dorsal Length	Thickness
Fossil Cliff	18.0-29.0	13.8-24.0	11.5-21.0	11.7-19.0	4.0- 8.8
Callytharra	12.0-28.0	12.0-28.0	11.5-21.2	8.3-19.0	4.0-10.0
Jimba Jimba	30.0	24.7	20.0	17.3	7.7
Nura Nura	14.4-31.4	14.4-31.4	7.0-14.0	7.8-14.0	2.8- 4.1

came from Fossil Cliff on the Irwin River where the Fossil Cliff Member of the Holmwood Shale outcrops.

MATERIAL: Perth Basin: GSWA F 11017-11046, 4 conjoined shells, 14 ventral valves (VV) and 12 dorsal valves (DV) from Fossil Cliff, Irwin River, Fossil Cliff Member of the Holmwood Shale. Carnarvon Basin: CPC 19863-19865, 19867-19868, 3VV and 2DV from BMR locality GW74, about 1.2 km west of Callytharra Springs, near base of Callytharra Formation; CPC 19866, DV from BMR locality GW87, Lat. 25°32'S, Long. 115°30'E about 40 to 45 m above base of Callytharra Formation; GSWA F 11047A-11047I, one conjoined shell, 5VV, 4DV, from GSWA locality 30137A, Glenburgh (1920) run 7/079, pt. 1312, RMH BK6, Yard Grid 387-803, Callytharra Formation; CPC 19869, a conjoined shell, from BMR locality WO3, Lat. 25°02'75"S, Long. 114°58'E, type section of Jimba Jimba Calcarenite. Canning Basin: CPC 19880A-19880D, three conjoined shells and 1VV from BMR locality KNuA$_1$ 2.4 km south-west of Paradise Homestead (Lat. 18°02'50"S, Long. 124°31'00"E), Nura Nura Member of Poole Sandstone; CPC 19881A-19881V, three internal moulds of conjoined shells, 5 internal moulds of VV, 2 external moulds of VV, 7 external moulds of DV and 6 internal moulds of DV, from BMR locality KPA54, 23.5 km at 120° from Mt. Tuckfield in the southern part of the St. George Range, near base of Pool Sandstone.

DIAGNOSIS: Large *Neochonetes* (*Sommeria*). Ventral sulcus well developed; dorsal fold low but distinct. Exterior ornament of fine capillae, on average 4 per mm at 1 and 3 cm from umbones.

DESCRIPTION: EXTERNAL. Length of the shell is just over two-thirds the maximum width. Maximum width about mid-length of the shell, hinge width being less than maximum width. The ventral valve is strongly convex, especially in gerontic individuals. The sulcus is distinct, sometimes deep and produces a flexure on the anterior commissure of the valve. The dorsal valve is gently concave with a low median fold or flexure corresponding to the sulcus of the ventral valve. The interareas are narrow. The chilidium is small and seldom preserved; the pseudodeltidium appears to be absent. Ornament is of fine capillae which increase by either bifurcation or intercalation. Growth lines are distinct, variable and may be lamellose. Spinule bases are randomly scattered on well preserved shells. Spines along the ventral interareas are distinct with at least six on each side of the umbo of large individuals. The angle of emergence is about 40°. Spines up to 1.5 mm in length have been observed but are broken.

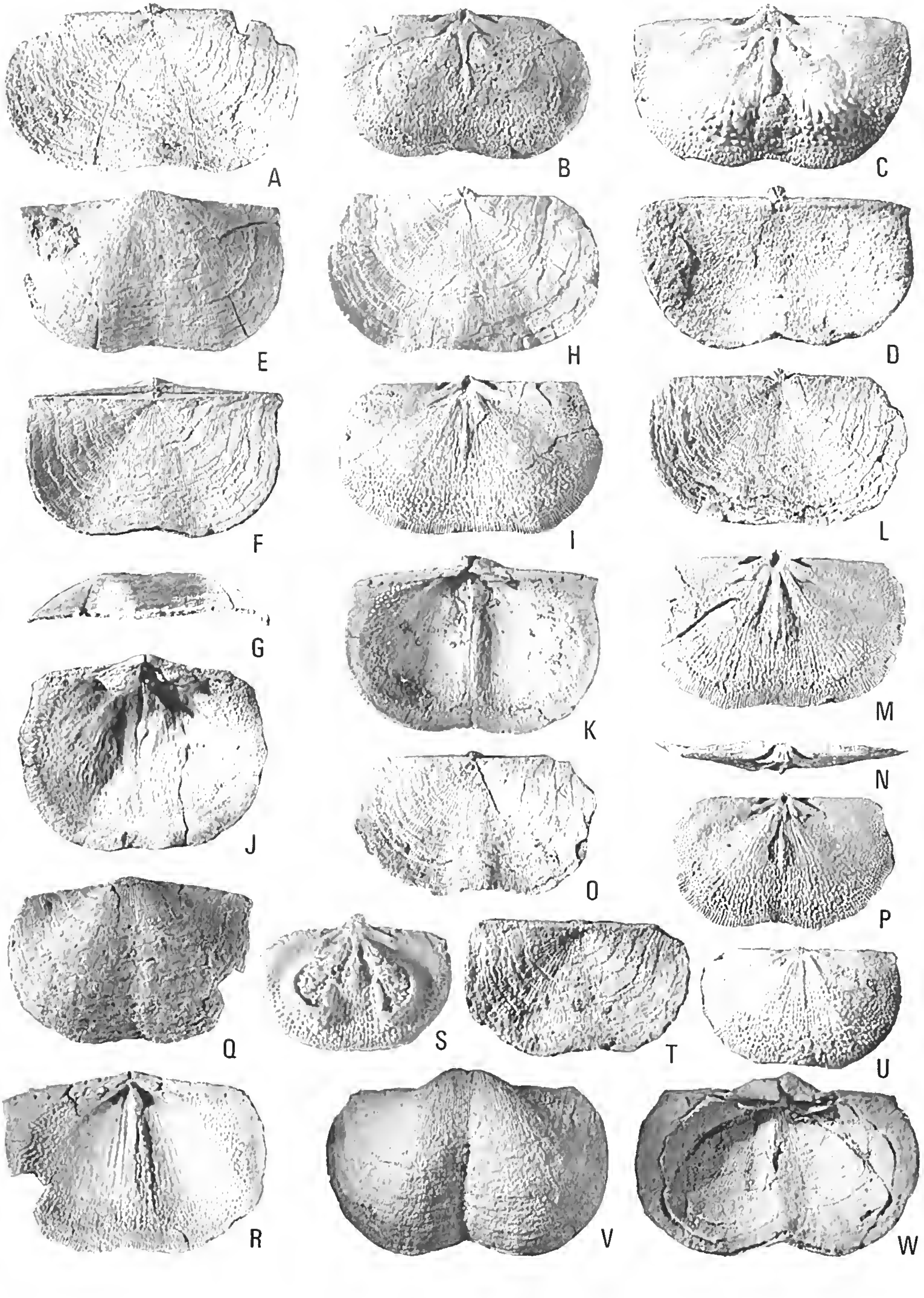
INTERNAL. The ventral median septum is up to half valve length and is high posteriorly, arising 1 to 2 mm in front of the umbo. Anteriorly two parallel vascular trunks form prominent ridges adjacent to the septum. The adductor muscle scars the indistinct while the diductors are strongly impressed. The teeth are small and sharp. With the exception of the region of the muscle scars, which is smooth or striate, the interior of the ventral valve is papillose. The cardinal process is externally quadrilobate and internally bilobed. The dorsal median septum is two-thirds valve length and arises in front of the deep alveolus as do the short lateral septa. The sockets are deep with pronounced inner socket ridges and feeble outer socket ridges. The brachial ridges are distinct. The interior of the dorsal valve is papillose, the papillae being arranged in radiating rows.

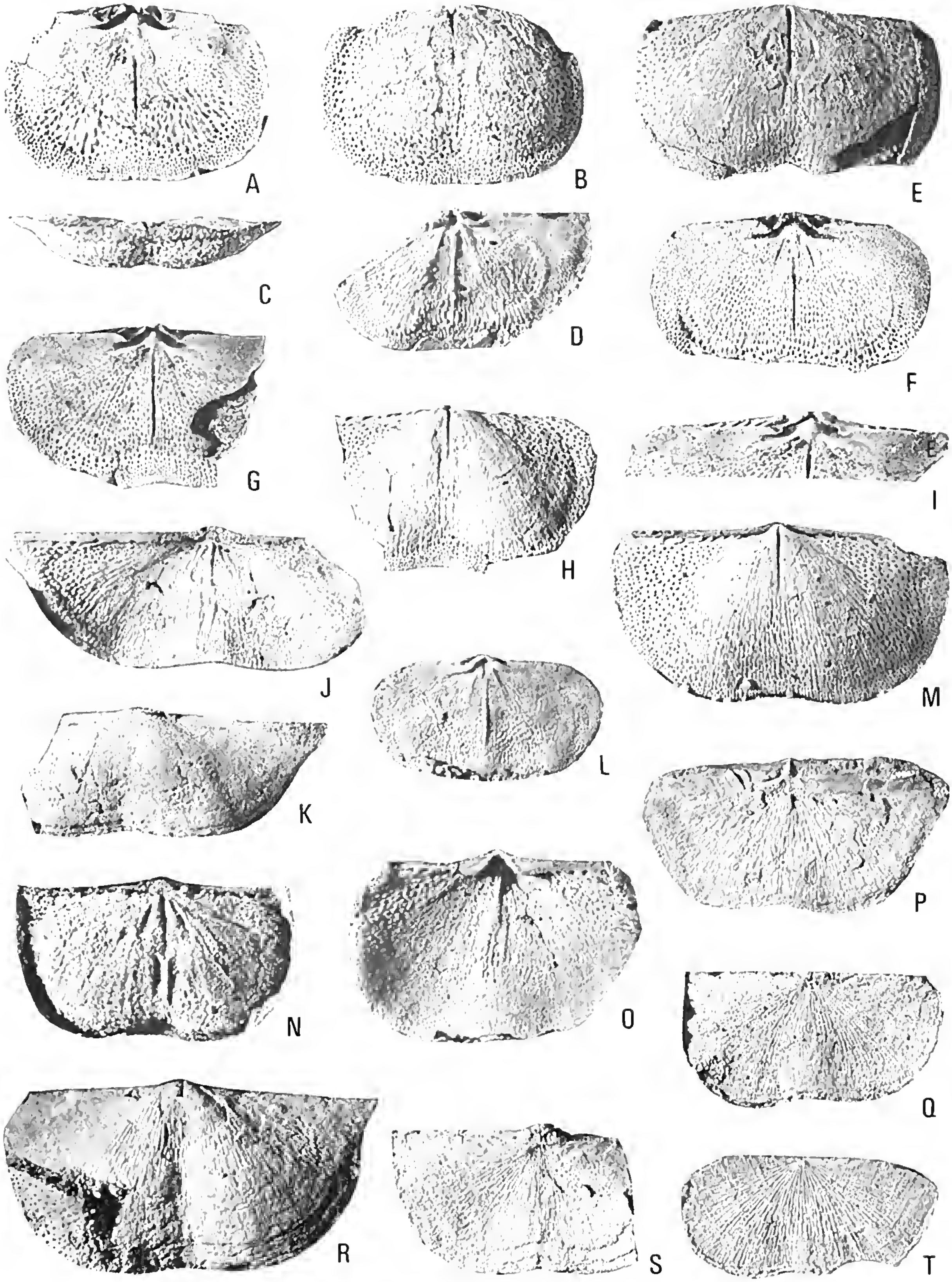
DISCUSSION: A report of the species from the Mingenew Formation, Perth Basin, by Etheridge (1907b) has been shown to refer to the strophalosiid *Mingenewia* (Archbold 1980b). The occurrence of the species in the Nura Nura Member, previously reported by Guppy *et al.* (1952), is confirmed but several individuals from that horizon are more transverse than specimens from the Fossil Cliff Member or the Callytharra Formation. Ecological factors are probably the cause of the variation. The Nura Nura specimens were found in a coarse sandstone, quite unlike the fine grained muddy marls and siltstones of the more southerly occurrences.

Zavadovsky & Stepanov (1971, pl. 23, figs 8a-8b) figured a large specimen of a *Neochonetes* from the Early Permian (Asselian) Paren horizon of the Kolyma region, far north-east USSR, as *Chonetes variolatus*

Fig. 5 — *Neochonetes* (*Sommeria*) *pratti* (Davidson)

A-U from Callytharra Formation, Carnarvon Basin; V-W from Jimba Jimba Calcarenite, Carnarvon Basin; A-B, GSWA F 11047B, Dorsal Valve in dorsal and ventral view. x1.75 and x1.5 respectively; C-D, CPC 19866, Dorsal valve in ventral and dorsal views. x2; E-G, GSWA F 11047E, Shell in ventral, dorsal and anterior views. x1.75; H-I, GSWA F 11047G, Dorsal valve in dorsal and ventral views. x1.75; J, CPC 19864, Ventral valve in dorsal view. x1.5; K, GSWA F 11047D, Ventral valve in dorsal view. x1.75; L-N, GSWA F 11047F, Dorsal valve in dorsal, ventral and posterior views. x1.75; O-P, GSWA F 11047I, Dorsal valve in dorsal and ventral views. x1.75; Q-R, GSWA F 11047C, Ventral valve in ventral and dorsal views. x1.75; S, CPC 19868, Dorsal valve in ventral view. x2.5; T-U, CPC 19867, Dorsal valve in dorsal and ventral views. x2.5 and 2.25 respectively; V-W, CPC 19869, Shell in ventral and dorsal views. x1.5.


A
B
C
E
H
D
F
I
L
G
K
M
N
J
O
P
Q
S
T
U
R
V
W


A
B
E
C
D
F
G
H
I
J
M
L
K
P
N
O
Q
R
S
T

(d'Orbigny). It is slightly more transverse than *Neochonetes* (*Sommeria*) *pratti* and possesses similar interareas. The external ornament is poorly known because of decortication of the shell.

Czarniecki (1969) compared *Neochonetes forbesi* (Gobbett), from the Asselian-Sakmarian Treskelodden Beds and the Upper and Lower Wordiekammen Limestone of Spitzbergen, with *N.* (*S.*) *pratti*. Gobbett's species is, however, much smaller (one-third the size) than the Western Australian species. Nevertheless, comparison is warranted as *Neochonetes forbesi* possesses a well rounded outline (Czarniecki 1969, pl. 4, fig. 7a). *Neochonetes* (*Sommeria*)? *superbus* (Gobbett) from the Middle Brachiopod Chert, Bunsow Land, Spitzbergen of Late Kungurian age, is a large species comparable in size with the largest specimens of *Neochonetes* (*Sommeria*) *pratti*. *Neochonetes* (*Sommeria*)? *superbus* is, however, a distinct species, by being more transverse, possessing weaker ornament and possessing a much weaker convexity in profile.

Other reports of neochonetids from the Permian of the USSR and Asia that indicate species related to *N.* (*S.*) *pratti* are mentioned briefly. Detailed comparisons are impossible since the species mentioned are usually based solely on ventral valves or on poorly preserved material. *Chonetes lobata* Grünewaldt (1860, pl. 3, fig. 6) from the Urals is a finely capillate species, widest anterior of the hinge with a shallow sulcus. *Chonetes dalmanoides* of Fredericks (1915, pl. 9, fig. 5) from beds near Krasnoufimsk, European USSR, underlying those from which in 1912 he recorded *Chonetes variolatus* d'Orbigny, is a smaller species with a rounded outline and shallow sulcus and is probably closer to *Neochonetes* (*Neochonetes*) than *N.* (*Sommeria*). *Chonetes dereimsi* Douglas 1936 of probable Kungurian age from south western Persia possesses a similar swollen ventral valve to that of *N.* (*S.*) *pratti* and is finely capillate, but, it is half the size of adult specimens of *N.* (*S.*) *pratti*. *Neochonetes variolatus* of Fantini Sestini (1965b) from the Karakorum is represented by ventral valves with a distinct sulcus and a maximum width anterior of the hinge line in some specimens. The early Permian *Neochonetes* sp. of Acharyya *et al.* (1975, pl. 2, figs H, I, J) is also similar to *Neochonetes* (*Sommeria*) *pratti* in outline but appears to have less well developed dorsal septa, and the specimens are smaller than mature individuals of the Western Australian species and hence may be juveniles. Similar comments can be made for the record of two varieties of *Chonetes carboniferus* from the Sakmarian of Sikkim recorded by Sahni & Srivastava (1956, pl. 36, figs 12-16). This is a species that possesses a sulcus invariably more weakly developed than the Western Australian species. The small Sterlitamakian species, *Chonetes arabicus* Hudson & Sudbury (1959, pl. 3, figs 6-16 and ? pl. 4, figs 14-18) also possesses a hinge line shorter than the maximum width of the shell as well as a distinct sulcus, but the Arabian species, while the same age as the Western Australian species, is much smaller in size.

Age: Latest Tastubian to Aktastinian.

Neochonetes (Sommeria) robustus sp. nov.

Fig. 7

?1912 *Chonetes pratti*; Glauert, *Rec. W. Aust. Mus.* 1:75.

1965 *Chonetes pratti*; Edgell, *Ann. Rept. geol. Surv. W. Aust.* 1964: 65, pl. 34, fig. 2.

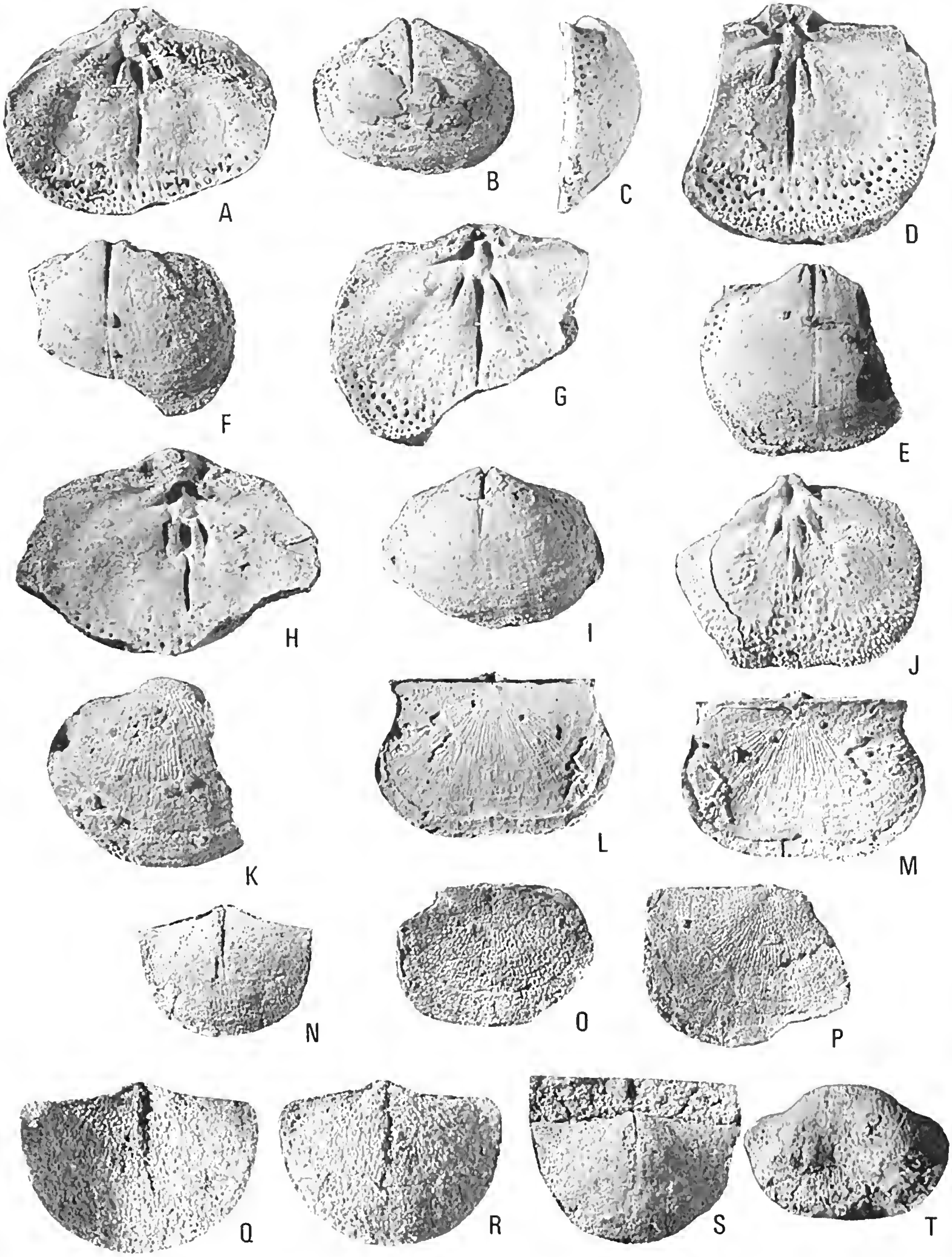
HOLOTYPE: CPC 19886M from BMR Locality WB182.
MATERIAL: Paratypes: CPC 19885A-19885C, 2 external moulds of DV and 1 internal mould of a VV, from BMR locality WB51, 3.6 km on a bearing 225° from Keogh Hill, Madeline Formation, Carnarvon Basin; CPC 19886A-P, 2 external moulds of DV, 1 internal mould of a DV, 4 external moulds of VV, 3 internal moulds of VV and 6 internal moulds of conjoined shells from BMR locality WB182, 3.5 km bearing 358° from Monument Bore, Madeline Formation; GSWA F 5285, 5287, 5288, 3 internal moulds of VV and 1 external mould of a VV from hillside 4.8 km west of Arrino, Mingenew Formation, Perth Basin.

TABLE 4
SIZE RANGES OF *N.* (*S.*) *robustus* sp. nov. (mm)

Maximum Width	Hinge Width	Ventral Length	Dorsal Length	Thickness
10.2-20.0	10.5-15.0	6.8-13.5	7.8-12.8	4.0-5.6

DIAGNOSIS: Small for genus, strongly convex ventral valve, weakly concave dorsal valve. Sulcus weak to absent. Shell outline subquadrate, globular, length of shell between 0.67 and 0.75 the maximum width.
DESCRIPTION: EXTERNAL. Maximum width is at about mid length of the shell. The sulcus is either absent or present only in the form of a gentle median flattening of the ventral valve. The interareas are narrow. Ornament consists of fine capillae, 4 per 1 mm on specimen CPC 19886A 9 mm from the umbo, and delicate growth lines. Hinge spines apparently emerge at about 40° to the hinge.
INTERNAL. The ventral septum arises close to the umbo,

Fig. 6 – *Neochonetes* (*Sommeria*) *pratti* (Davidson)
All specimens from the Nura Nura member, Poole Sandstone, Canning Basin; A-C, CPC 19881A, Internal mould of shell in dorsal, ventral and anterior views. x2; D, CPC 19881R, latex replica of dorsal valve internal mould. x2; E-F, CPC 19881B, Internal mould of shell in ventral and dorsal views. x2.25; G-I, CPC 19881C, Internal mould of shell in dorsal, ventral and postero-dorsal views. x2, x2 and x3 respectively; J-K, CPC 19881D and E, Latex replica of internal mould of ventral valve. x2.5, latex replica of external mould of ventral valve. x2; L, CPC 19881U, Latex replica of dorsal valve internal mould. x1.75; M, CPC 19881H, Internal mould of ventral valve. x3; N, CPC 19881G, Internal mould of ventral valve. x2; O, CPC 19881I, Latex replica of internal mould of ventral valve. x2.75; P, CPC 19880B, Shell in dorsal view. x2; Q, CPC 19880O, Latex replica of external mould of dorsal valve. x2; R, CPC 19880A, Shell in ventral view. x2.5; S, CPC 19880C, Shell in dorsal view. x1.75; T, CPC 19880W, External mould of dorsal valve. x2.5.


A
B
C
D
F
G
E
H
I
J
K
L
M
N
O
P
Q
R
S
T

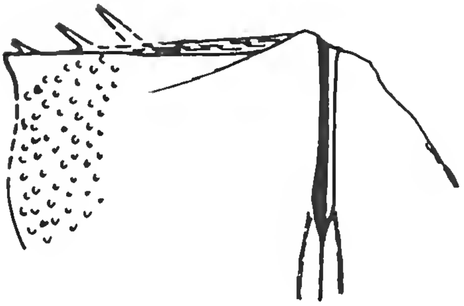


Fig. 8—*Neochonetes* (*Sommeria*) *robustus* sp. nov. Ventral spine arrangement of specimen CPC 19886 C, x8.

is high posteriorly and may extend anteriorly for three quarters of the valve length. The vascular trunk scars and muscle scars are usually weakly impressed but appear normal for the genus. The delthyrium is distinct for the size of the specimens; teeth are small and sharp. Margins of the interior of the ventral valve are only weakly papillose.

The dorsal interior possesses a strong median septum (about two-thirds valve length) a short, strong lateral septa. All three septa arise from a low platform around the deep, circular alveolus. The sockets are distinct with strong inner socket ridges which coalesce with the cardinal process. The cardinal process is normal for the genus. The brachial ridges are usually ill-defined and the anterior margin of the dorsal valve is papillose. The papillae are randomly arranged.

Discussion: The specimens from the Mingenew Formation are small, distinctly convex and without a sulcus. Traces of radial capillae are present on GSWA F 5285.

One crushed ventral valve, Fig. 7T, (maximum width 12.1 mm, length 7.9 mm), which is strongly convex and possesses a weakly developed sulcus from Locality 627/1, Lat. 14°26′, Long. 129°43′, 7.2 miles (11.5 km) north-north west of Table Hill, Port Keats district, Northern Territory is provisionally referred to *N.* (*S.*) *robustus* sp. nov. Dickins *et al.* (1972) considered the locality to be equivalent with the Noonkanbah Formation of the Canning Basin. The associated fauna includes *Wyndhamia* sp. nov. and *Neospirifer* sp. nov. that are otherwise restricted to the Madeline Formation

Table 5
Measurements of *Neochonetes* (*Sommeria*) *tenuicapillatus* sp. nov. (mm)
* = holotype; e = estimate

Specimen Number	Hinge Width	Maximum Width	Length Ventral	Length Dorsal	Thickness	Formation
CPC 19870	18.9	21.0	14.5	13.2	—	Bulgadoo
CPC 19871	17.2	18.6	—	11.8	—	Bulgadoo
CPC 19872	20.0e	22.0e	—	12.0+	—	Bulgadoo
CPC 19873	—	19.0	—	—	5.5e	Bulgadoo
CPC 19874	22.0e	25.0e	13.5	12.5	4.3	Quinnanie
CPC 19875	23.3	24.6	16.9	15.0	5.3	Quinnanie
CPC 19876	25.1	30.0	19.6	—	8.5e	Cundlego
CPC 19877	25.0	27.0	17.6	—	5.8	Cundlego
NMVP 60726	26.5e	28.0e	—	16.5	—	Wandagee
NMVP 60727	—	30.0e	—	—	—	Wandagee
NMVP 60728	23.2	25.5	16.8	15.6	4.2	Wandagee
NMVP 60729	24.0	25.0	12.5	—	—	Wandagee
NMVP 60730	18.5	24.0	14.0	12.6	—	Wandagee
NMVP 60731*	18.9	22.5	15.7	14.0	6.3	Wandagee
NMVP 60732	17.8	20.0	13.5	11.3	4.5	Wandagee
NMVP 60733	14.0	16.4	11.0	9.5	—	Wandagee
NMVP 60734	12.7	15.3	9.8	8.7	—	Wandagee
CPC 19879	17.7	19.7	14.0	12.5	5.0	Wandagee
NMVP 60735	22.0+	27.8	18.5	16.5	8.0	Noonkanbah
NMVP 60736	24.0e	27.0e	16.0	13.5	—	Noonkanbah
CPC 19878	15.0e	18.0e	12.5	11.5	4.0	Nalbia

Fig. 7—*Neochonetes* (*Sommeria*) *robustus* sp. nov.

A-M, O-P, from the Madeline Formation, Carnarvon Basin; N, Q-S from equivalents of the Mingenew Formation, Perth Basin; A-B, CPC 19886E, Internal mould of shell in dorsal and ventral views. x3 and x2 respectively; C-E, Holotype, CPC 19886M, Internal mould of shell in lateral profile, dorsal and ventral views. x2.5, x3.25 and x2.5 respectively; F-G, CPC 19886O, Internal mould of shell in ventral and dorsal views. x2.5 and x3.5 respectively; H-I, CPC 19886K, Internal mould of shell in dorsal and ventral views. x3.5 and x2.5 respectively; J, CPC 19886J, Latex replica of dorsal valve internal mould. x3.25; K, CPC 19886A, Latex replica of ventral valve external mould. x2.5; L-M, CPC 19885 B, External mould of dorsal valve and latex replica. x2.5; N, GSWA F 5287, Internal mould of ventral valve. x3; O, CPC 19885E, Latex replica of dorsal valve external mould. x4; P, CPC 19886H, Latex replica of dorsal valve external mould. x3; Q-R, GSWA F 5285, External mould and internal mould of ventral valve. x4; S, GSWA F5288, Internal mould of ventral valve. x3.5; T, CPC 19169, Decorticated ventral valve in ventral view. x3; Specimen from Locality 627/1, Port Keats Group, Bonaparte Gulf Basin.

TABLE 6. SIZE RANGES OF POPULATIONS OF *Neochonetes* (*Sommeria*) *afanasyevae* sp. nov. (mm)

Formation	Maximum Width	Hinge Width	Ventral Length	Dorsal Length	Thickness
Port Keats (L.M)	15.0-22.4	12.0-21.0	10.0-14.5	10.2-13.5	—
Lightjack	8.2-28.2	10.2-27.8	6.2-12.5	10.2-17.5	1.3-1.6
Coolkilya	15.8-22.2	15.4-20.2	12.5-15.2	11.2-15.0	2.1-2.5
Total Range	9.2-28.2	10.2-27.8	6.2-15.2	10.2-17.5	1.3-2.5

indicating an Early Baigendzinian (Early Late Artinskian) age for the locality.

N. (*S.*) *robustus* sp. nov. is retained in *N.* (*Sommeria*) on the basis of the angle of the ventral hinge spines (Fig. 8) despite the distinctive shape, convexity and general lack of sulcus.

An undescribed species from the Sirius Formation of the Bowen Basin, Queensland, (Dear 1972) appears closest to the Western Australian species.

AGE: Early Baigendzinian.

Neochonetes (Sommeria) tenuicapillatus sp. nov.

Fig. 9

1915 *Chonetes pratti*; Etheridge, *Bull. geol. Surv. W. Aust.* 58: 36.

1918 *Chonetes prattei*; Etheridge, *Proc. R. geog. Soc. Aust. Sth. Aust. Brch.* 18: 25.

HOLOTYPE: NMVP 60731 from locality WC(32)1.

MATERIAL: Paratypes: (all from Carnarvon Basin) CPC 19870-19873, 2 external moulds of DV, 1 internal mould of a DV and 1 internal mould of a VV from BMR Locality MG236 (Reg. No. F20836), 3.2 km S.E. of Donnelly's Well about 33 m above base of the Bulgadoo Shale; CPC 19874-19875, 2 conjoined shells from BMR Locality ML55, N of Minilya River, 53 m above base of Quinnanie Shale; CPC 19876-19787, 2 conjoined shells, from BMR Locality F20875, approximately 14.6 km south-east of Middalya Homestead, 0.2 km north-west of well, Cundlego Formation; CPC 19879, a conjoined shell, from BMR Locality ML58, north bank of Minilya River, 40-44 m above base of Wandagee Formation, Lat. 23°44′S, Long. 114°25′E; NMVP 60726-60734, five conjoined shells, 1 VV, 1 external mould of a DV and 1 internal mould of a DV (collected by Dr. C. Teichert (1938 to 1940) on Wandagee Station on the Minilya River. (WC = Wandagee Series, *Calceolispongia* Stage) followed by the zone number (in brackets) and then the locality number. NMVP 60726-60727 from WC(36); NMVP 60728-60729 from WC(22-25)5, NMVP 60730 from WC(22-25)30; NMVP 60731 from WC(32)1; NMVP 60732 from WC(27-32)3; NMVP 60733-60734 from WC(22-25)12. CPC 19878, a conjoined shell, from BMR Locality MG247, small syncline about 4 km NNW of Wandagee Hill Trig, Nalbia Greywacke. Canning Basin: NMVP 60735-60736, 2 conjoined shells, from Mt. Marmion, Noonkanbah Formation, Canning Basin.

DESCRIPTION: EXTERNAL. The length of the shell is between two-thirds and three quarters the maximum width. The maximum width is about mid-length of the shell and is consistently greater than the hinge width. The sulcus is distinct, broadens anteriorly and is matched by a low fold on the dorsal valve. The ventral valve is strongly convex and the dorsal valve concave. Interareas are low. The chilidium, seldom preserved, is small and curved around the base of the cardinal process. The pseudodeltidium, also seldom preserved, is low and seals the apex and sides of the delthyrium. The external ornament consists of concentric growth lines, occasionally lamellose, and very fine capillae. Very slight erosion of the shell (though growth lines may still be visible) obscures the capillae. Spinule bases are minute and randomly distributed when preserved. Hinge spines emerge at about 40° to the hinge and are short.

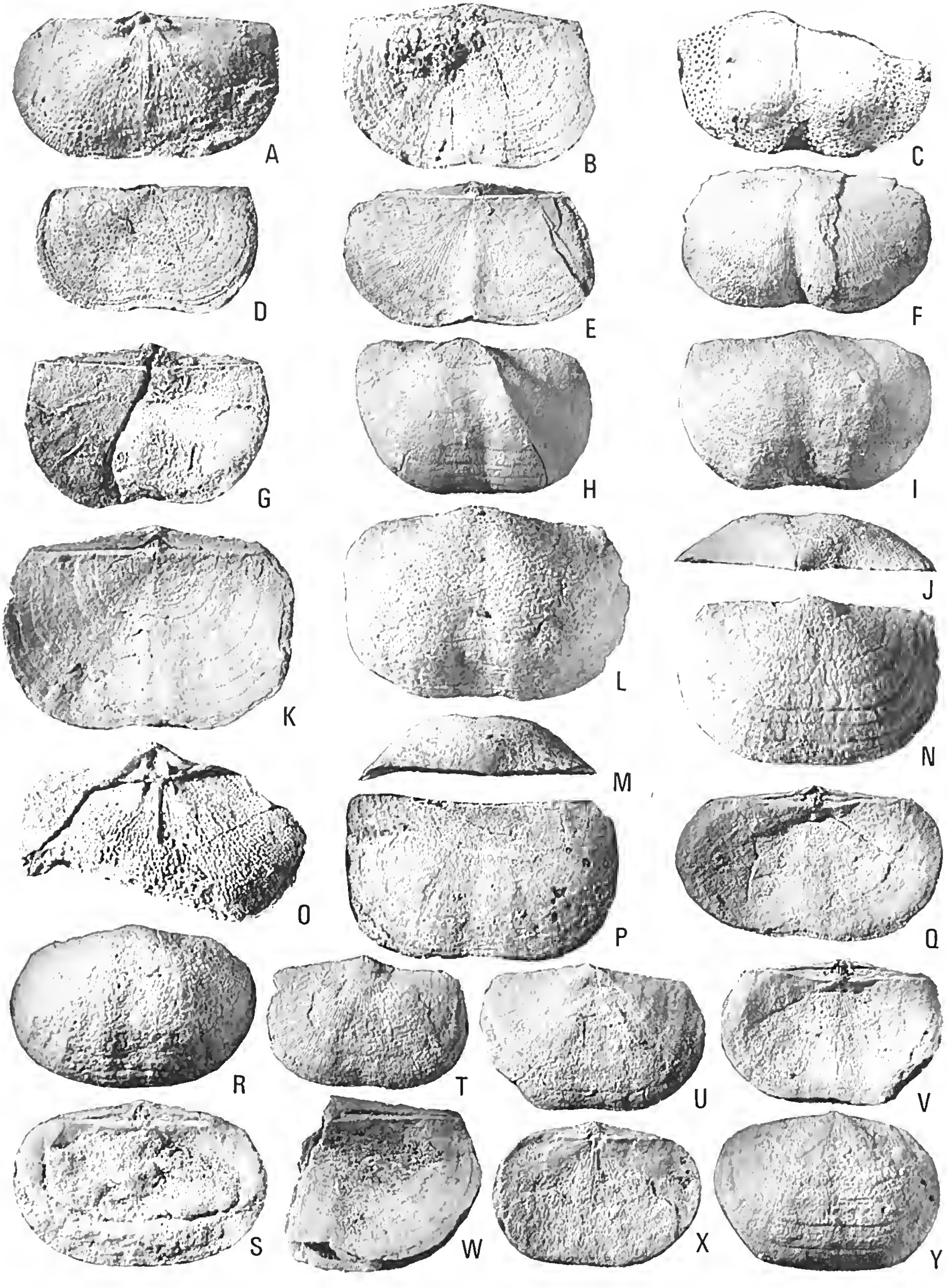
INTERNAL. The ventral septum arises close to the umbo and is up to half the valve length. Parallel vascular trunks and muscle scars are usually weakly impressed. The teeth are small and sharp; the delthyrium small. The margins of the interior of the ventral valve are papillose.

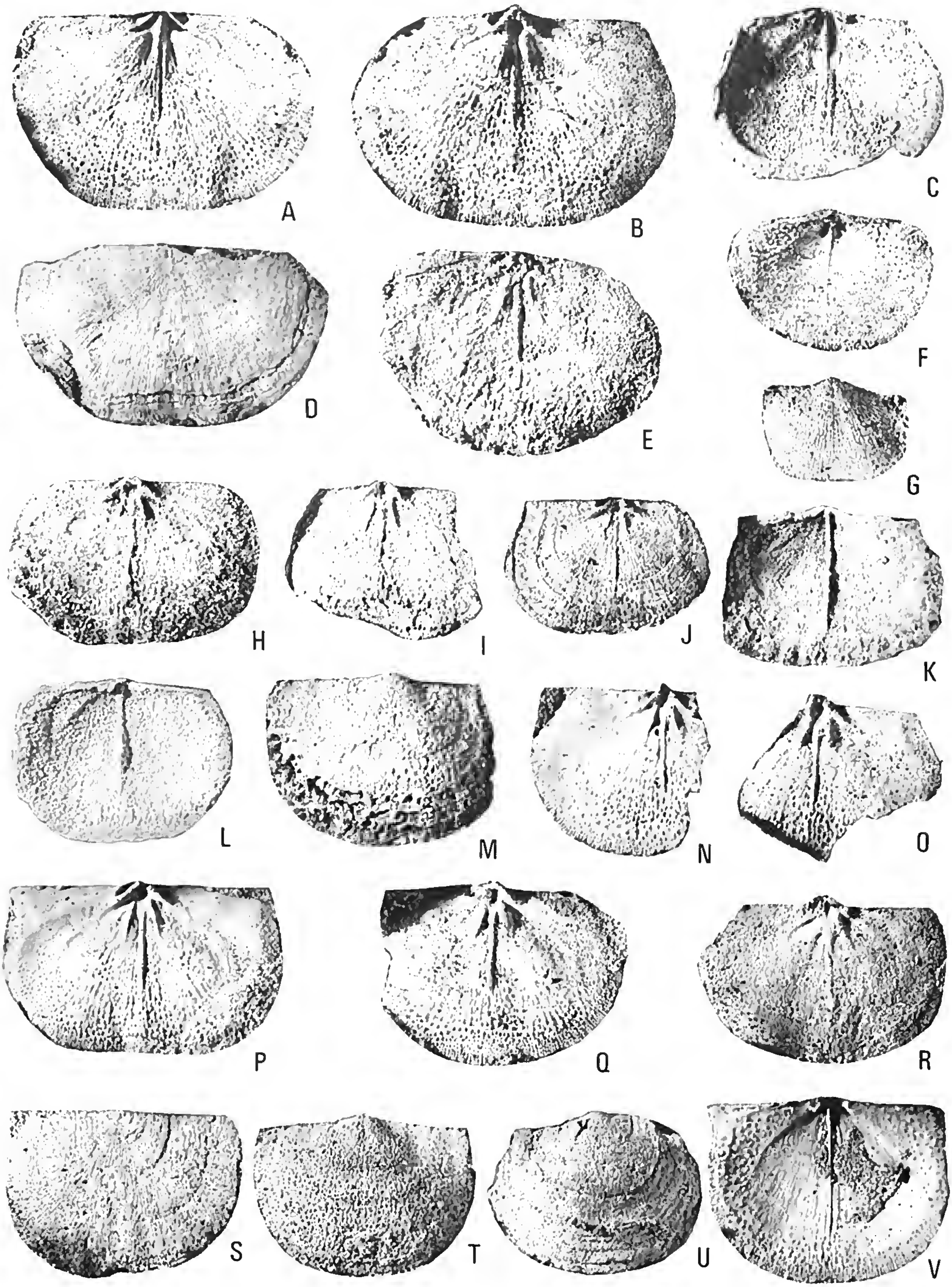
The dorsal interior possesses a median septum which is between half and two-thirds the valve length. The lateral septa are short and strong and all three septa arise anteriorly of a distinct, circular alveolus. The sockets are deep with pronounced inner socket ridges and feeble outer socket ridges. The inner socket ridges coalesce with the cardinal process which is normal for the genus. The brachial ridges are not distinct, even in mature specimens. The anterior of the interior of the dorsal valve can be thickly papillose; the papillae are randomly arranged.

DISCUSSION: *Neochonetes* (*Sommeria*) *tenuicapillatus* is

Fig. 9—*Neochonetes* (*Sommeria*) *tenuicapillatus* sp. nov.

A-D from the Bulgadoo Shale, Carnarvon Basin; E-G from the Quinnanie Shale, Carnarvon Basin; H-J from the Cundlego Formation, Carnarvon Basin; K-Q, T-V from the Wandagee Formation, Carnarvon Basin; specimens R, S, W, from the Noonkanbah Formation, Canning Basin; specimen X-Y from the Nalbia Greywacke, Carnarvon Basin; A, CPC 19872, Latex replica of dorsal valve internal mould. x2; B, CPC 19870, Latex replica of dorsal valve external mould, x2; C, CPC 19873, Internal mould of ventral valve. x2; D, CPC 19871, Latex replica of dorsal valve external mould. x1.75; E-F, CPC 19874, Shell in dorsal and ventral views. x1.75; G, CPC 19875. Shell in dorsal view. x1.75; H, CPC 19876, Shell in ventral view. x1.25; I-J, CPC 19877, Shell in ventral and posterior views. x1.5; K-M, Holotype NMV P60731, Shell in dorsal, ventral and posterior views. x2, x2 and x1.5 respectively; N. NMV P 60732, Shell in ventral view. x2; O, NMV P 60727, Latex replica of dorsal valve internal mould. x1.5; P, NMV P 60726, Dorsal valve external mould. x1.5; Q, NMV P 60730, Shell in dorsal view. x1.75; R-S, NMV P 60735, Shell in ventral and dorsal views. x1.5; T, NMV P 60734, Shell in ventral view. x2.5; U-V, NMV P 60733, Shell in ventral and dorsal views. x2.25; W, NMV P 60736, Incomplete shell in dorsal view. x1.75; X-Y, CPC 19878, Shell in dorsal and ventral views. x2 and x2.5 respectively.


A
B
C
D
E
F
G
H
I
J
K
L
N
M
O
P
Q
R
T
U
V
S
W
X
Y


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V

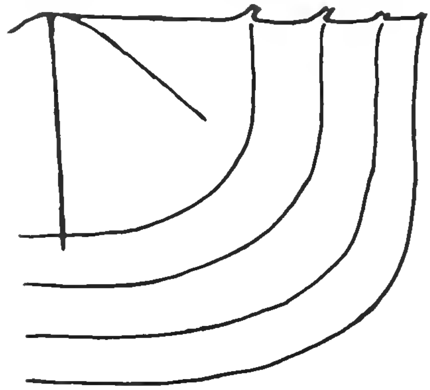


Fig. 11—*Neochonetes* (*Sommeria*) *afanasyevae* sp. nov. Ventral spine arrangement of specimen CPC 19887A, x8.

chiefly distinguished from *N.* (*S.*) *pratti* by the very fine, delicate external ornament. Brachial ridges and ventral muscle scars do not appear to be as strongly developed as in *N.* (*S.*) *pratti*, although these features are probably not of specific importance.

N. (*S.*) *tenuicapillatus* is closest to *Neochonetes* (*Sommeria*) *fredericksi* Archbold (1979) from the Artinskian (probably Aktastinian) of the Pechora Basin. The latter species has a length about two-thirds the maximum width of the shell and about 5 capillae per 1 mm.

Chonetes dubia Hamlet (1928) from Bitauni and Noil Toko, Timor, of Late Baigendzinian age is similar in outline, size and convexity to *Neochonetes* (*Sommeria*) *tenuicapillatus*, but differs by possessing higher interareas and a more prominent ventral umbo. *Chonetes dubia* exhibits weakly developed radial ornament (Hamlet 1928, pl. 1, figs 12, 14b).

RANGE: Late Baigendzinian to Early Kungurian.

Neochonetes (Sommeria) afanasyevae sp. nov.

Fig. 10

1906 *Chonetes* sp. (? *C.pratti*); Etheridge, *S. Aust. Parl. Paper* 55: 41.
1907 *Chonetes* sp. (? *C.pratti*); Etheridge, *S. Aust. Parl. Paper* 54: 7, pl. 6, fig. 9.
1909 *Chonetes pratti*(?); Basedow, *Z. deutschen Geol. Gesell.*, 61(3): 325.
1952 *Chonetes pratti*; Guppy *et al.*, *19th Int. Geol. Cong., Alger., Sym. Gond.*, 111.

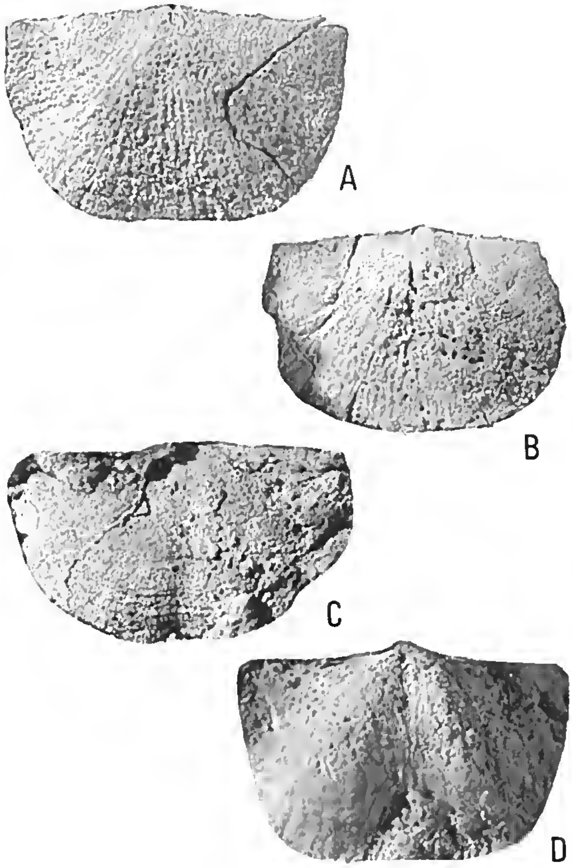


Fig. 12—A-C, *Neochonetes* (*Sommeria*) sp. A
All specimens from the Hardman Formation, Canning Basin. A, CPC 19883. Ventral valve in ventral view. x4; B, CPC 19882, Ventral valve in ventral view. x3.75; C, CPC 19884, Latex replica of ventral valve external mould. x1.25.
D, *Chonetinella* sp.
Coolkilya Greywacke, Carnarvon Basin. UWA 88108, Decorticated ventral valve in ventral view. x4.25.

1957 *Chonetes* sp. Thomas, *J. Pal. Soc. India*, 2: 180.
1958a *Chonetes* sp. Thomas, *Abstracts ANZAAS* 1958, Sec. C., p. 2.

HOLOTYPE: CPC 19902A from locality 1027A or 1095. These are similar sections some 2 to 4 km apart on the same ridge. The collections were inadvertently mixed.

Fig. 10—*Neochonetes* (*Sommeria*) *afanasyevae* sp. nov.
A-G from the Lightjack Formation, Canning Basin; H-M from the Lower Marine Beds, Port Keats Group, Bonaparte Gulf Basin; N-V from the Coolkilya Greywacke, Carnarvon Basin. A-B, Holotype CPC 19902A, Dorsal valve internal mould and latex replica, x2.25; C, CPC 19901A, Latex replica of ventral valve internal mould, x2; D, CPC 19900, External mould of dorsal valve, x2; E, CPC 19889B, Natural cast of dorsal valve, x2; F, CPC 19902C, Latex replica of ventral valve internal mould, x3.5; G, CPC 19902E, Latex replica of ventral valve external mould, x3; H, CPC 19887C, Natural cast of dorsal valve, x2.5; I, CPC 19888C, Latex replica of dorsal valve internal mould, x2; J, CPC 19888D, Latex replica of dorsal valve internal mould, x2.5; K, CPC 19887B, Natural cast of ventral valve, x2.5; L, SMP 2131, Natural cast of ventral valve, originally figured by Etheridge (1907a, pl. 6 fig. 9), x2; M, CPC 19887A, Latex replica of ventral valve external mould, x2.5; N, CPC 19904D, Latex replica of dorsal valve internal mould, x2.25; O, CPC 19908B, Latex replica of dorsal valve internal mould, x2.25; P, CPC 19907A, Latex replica of dorsal valve internal mould, x2; Q, CPC 19909C, Latex replica of dorsal valve internal mould, x2.5; R, CPC 19905B, Latex replica of dorsal valve internal mould, x2; S, CPC 19907D, Latex replica of dorsal valve external mould, x2.5; T, CPC 19905A, Latex replica of ventral valve external mould, x2.5; U, 19909A, Latex replica of ventral valve external mould, x2; V, CPC 19907B, Latex replica of ventral valve internal mould, x2.75.

Etymology: For Dr. G. A. Afanas'yeva for her substantial contributions to the study of chonetacean brachiopods.

Material: Paratypes. CPC 19887A-19887D, 19888A-19888D 1 natural ferruginous cast of a DV and 2 natural casts of VV, 1 external mould of a DV, 2 internal moulds of DV and 1 internal mould of a VV from Fossil Head, south of Port Keats Mission, Bonaparte Gulf, Northern Territory, Lower Marine Beds, Port Keats Group; CPC 19889A-19889B, 1 natural cast of a DV and 1 natural cast of a VV, from BMR Locality 1027A, Lat. 17°54′15″S, Long. 123°52′15″E, Lightjack Formation, Liveringa Ridge, Canning Basin; CPC 19901A-19901C, 19902B-19902E, 3 internal moulds of VV, 3 external moulds of VV and 1 internal mould of a DV, from BMR Locality 1027A or Locality 1095, Lat. 18°04′40″S, Long. 124°03′00″E, Lightjack Formation, Liveringa Ridge; CPC 19900, 1 external mould of a dorsal valve, from BMR Locality KLA3, Bore near Liveringa Homestead, Lightjack Formation; CPC 19903, 19904A-D, 19905A, B, 19906, 19907A-D, 3 internal moulds of VV, 1 external mould of a VV, 4 internal moulds of DV and 4 external moulds of DV from BMR Locality F 17060, ridge and outliers of Kennedy Range, traverse NW of Paddy's Outcamp by Teichert, Thomas and Johnstone 1948, Coolkilya Greywacke, Carnarvon Basin; CPC 19908A, B, 19909A-D 3 internal moulds of VV, 2 internal moulds of DV and 1 external mould of a DV, from BMR Locality F 17082, 1.2 km SE of Southern Cross Bore, Middalya Station, Coolkilya Greywacke.

Diagnosis: Planar-convex; ventral valve weakly convex; sulcus obsolescent; exterior ornament of fine capillae; ventral and dorsal septa distinct but thin and sharp.

Description: External. Length of the shell is between 0.67 and 0.75 of maximum width. Maximum width is about mid-length of the shell and is greater than hinge width. Interareas are low. Pseudodeltidial and chilidial structures have not been preserved on any specimens. The external ornament consists of concentric growth lines, occasionally lamellose, and fine capillae which are spaced, on average, 5 per mm at 1 cm from the umbo and between 4 and 5 per mm at 2 cm from the umbo; they increase in number by both bifurcation and intercalation. Weathering may obscure the capillae and yet leave prominent growth lamellae. Hinge spines are poorly known, and are short and emerge at 40°-45° to the hinge.

Internal. The ventral septum arises close to the umbo, under the delthyrium, and is up to three-quarters of the valve length. The septum is thin and sharp. Parallel vascular trunks are usually absent and smooth muscle scars are weakly impressed. The teeth are small and sharp and the delthyrium is small. Interior margins of the ventral valve are weakly papillose.

The dorsal interior possesses a median septum which is about two-thirds the valve length; it is thin and sharp. The lateral septa are short, at a small angle to the median septum, and are thin and strong. All three septa arise anteriorly of a distinct, circular alveolus. The sockets are small, yet distinct, with small, sharp inner socket ridges and feeble outer socket ridges. The inner socket ridges coalesce with the cardinal process which is small, externally quadrilobate and internally bilobate. The brachial ridges are never strongly developed and the anterior of the interior of the valve is finely papillose.

Discussion: *Neochonetes* (*Sommeria*) *afanasyevae*, is a distinctive species of the genus, with few recorded species possessing comparable morphological characters. *Neochonetes* sp. of Bamber & Waterhouse (1971, pl. 19, figs. 13-18) from the Lower Ufimian of the North Richardson Mountains, Yukon Territory is similar in size, shell outline, dorsal interior and development of the brachial ridges, weakly developed sulcus, and weak external ornament.

The near absence of the sulcus makes *N.* (*S.*) *afanasyevae* atypical for the subgenus *Sommeria*. However, the species is retained in the subgenus because of the angle of the hinge spines (Fig. 11).

Range. Middle Kungurian.

Neochonetes (Sommeria) sp. A.

Fig. 12 A-C.

Material: CPC 19882-19883, 2 small VV, from BMR Locality KLB 11, Mount Hardman, from beds 1.25 m thick at about 40 m below top of hill, Hardman Formation, Canning Basin; CPC 19884, external mould of large VV, from BMR Locality CR 1188, Lat. 19°30′00″S, Long. 125°32′15″E, Hardman Formation, Canning Basin.

Table 7

Measurements of *Neochonetes* (*Sommeria*) sp. A (mm)

Specimen Number	Hinge Width	Mid Width	Ventral Length	Locality
CPC 19882	8.6	9.8	6.8	KLB 11
CPC 19883	10.9	10.3	7.3	KLB 11
CPC 19884	31.0e	29.0e	17.6	CR 1188

Observations: This distinct species is large, the maximum width is not always coincident with the hinge width. The sulcus is broad and deep in its centre. Exterior ornament of capillae is relatively coarse with between 2 and 3 per mm. Convexity of the ventral valve is not pronounced.

Comparisons: Despite the inadequate material these specimens appear closely comparable with *Neochonetes* (*Sommeria*) *wageri* (Muir-Wood, in Muir-Wood & Oakley 1941) in outline and thickness. However, Muir-Wood's species possesses finer ornament and a shallower sulcus.

Age: Chhidruan.

Subfamily CHONETINELLINAE Muir-Wood 1962

Genus **Chonetinella** Ramsbottom 1952

Type Species: *Chonetes flemingii* Norwood & Pratten 1855.

Diagnosis: Strongly concavo-convex, capillate rugosochonetids with a prominent, narrow ventral sulcus and distinct dorsal fold.

Discussion: *Chonetinella* has been broadly interpreted by Grant (1976) to include species which approach representatives of *Neochonetes* (*Sommeria*) subgen.

nov. However, as no material from Western Australia adds to the understanding of the genus, *Chonetinella* is not discussed further here.

Chonetinella sp.

Fig. 12 D.

Material: UWA 88108, one decorticated VV, from UWA Locality WF 8.5 (registered no. 28011); *Thamnopora* horizon, 1300 links south of gate in Shed Paddock, Wandagee Station, (collector Dr. C. Teichert), Coolkilya Greywacke, Carnarvon Basin.

Measurements: Maximum width 11 mm, hinge width 10 mm, length of valve 7 mm, thickness estimated at 3.5 mm.

Observations: Its small size, distinct convexity and narrow deep sulcus refer it to *Chonetinella*. Traces of capillae are visible on the anterior portion of the valve. The specimen indicates the presence of a distinct, highly sulcate chonetid in the higher portion of the Permian sequence of the Carnarvon Basin.

Age: Middle Kungurian.

ACKNOWLEDGEMENTS

I thank Dr. J. M. Dickins, Bureau of Mineral Resources, Geology and Geophysics, Dr. P. Jell, National Museum of Victoria and Dr. A. E. Cockbain, Geological Survey of Western Australia, for providing specimens from collections in their care. Dr. G. A. Thomas, University of Melbourne, and two reviewers provided fruitful comments. The assistance of the staff of the Baillieu Library, University of Melbourne is acknowledged. Val Le Maitre and Isabel McDonald typed the manuscript. The work was carried out while the author was in receipt of a University of Melbourne Postgraduate Award.

REFERENCES

References supplementary to those in Archbold 1980a.

Acharyya, S. K., Ghosh, S. C., Ghosh, R. N. & Shah, S. C., 1975. The Continental Gondwana Group and associated marine sequences of Arunuehal Pradesh (NEFA) Eastern Himalaya. *Himalayan Geology* 5: 60-81.

Afanas'yeva, G. A., 1975b. Chonetacea (Brachiopoda) srednego i pozdnego karbona Russkoy platformy. *Paleont. Zhur.* 1975(2): 96-113.

Archbold, N. W., 1979. Revision of two Permian brachiopod species names. *J. Paleont.* 53: 1260.

Archbold, N. W., 1980a. Studies on Western Australian Permian brachiopods. 1. The family Anopliidae (Chonetidina). *Proc. R. Soc. Vict.* 91: 181-192.

Archbold. N. W., 1980b. *Mingenewia* n. gen. (Strophalosiidina, Brachiopoda) from the Western Australian Permian. *J. Paleont.* 54: 253-258.

Archbold, N. W., 1981a. *Quinquenella* (Chonetidina, Brachiopoda) from the Permian of Western Australia. *J. Paleont.* 55: 204-210.

Archbold, N. W., 1981b. *Svalbardia* (Chonetidina, Brachiopoda) from the Kungurian (Permian) of Western Australia. *Alcheringa* 5: 1-8.

Archbold, N. W., 1981c. Western Australian Geology: An historical review to the year 1870. *J. Roy. Soc. W. Aust.* 63: 119-128.

Bogoslovskaya, M. F., 1976. Kungurskiya ammonoidei srednego Predural'ya. *Paleont. Zhur.* 1976(4): 43-50.

Branson, C. C., 1964. *Neochonetes oklahomensis* (Snider). *Okla. Geol. Notes.* 24: 95-97.

Cockbain, A. E., 1980. Permian ammonoids from the Carnarvon Basin—A review. *Annu. Rep. Geol. Surv. W. Aust.*, 1979: 144-149.

Crowe, R. W. A. & Towner, R. R.,1976. Permian stratigraphic nomenclature Noonkanbah 1:250,000 sheet. *Annu. Rep. Geol. Surv. W. Aust.* 1975: 56-58.

Czarniecki. S., 1969. Sedimentary environment and stratigraphical position of the Treskelodden Beds (Vestspitsbergen). *Prace Museum Ziemi, Warsaw.* 16: 201-336.

Davidson, T., 1859. Palaeontological notes on the Brachiopoda. No. 2. On the families Strophomenidae and Productidae. *Geologist* 2: 97-117.

Davidson, T., 1880. A monograph of the British fossil Brachiopoda. Volume 4, Part 3. Supplement to the British Permian Brachiopoda. *Palaeontograph. Soc. Mon.* 34: 243-248.

Dear, J. F., 1971. Strophomenoid brachiopods from the higher Permian faunas of the Back Creek Group in the Bowen Basin. *Publs. geol. Surv. Qld.*, 347, *Palaeont. Pap.* 21: 1-39.

Dickins, J. M., 1956. Permian pelecypods from the Carnarvon Basin, Western Australia. *Bull. Bur. Miner. Resour. Geol. Geophys. Aust.* 29: 1-42.

Dickins, J. M., 1976. Correlation chart for the Permian System of Australia. *Bull. Bur. Miner. Resour. Geol. Geophys. Aust.* 156B: 1-26.

Dickins, J. M. & Jell, P. A., 1974. Permian fossils from the Canning Basin, 1971 and 1972. *Bur. Miner. Resour. Geol. Geophys. Aust., Record* 1974/77: 1-14. (Unpubl.)

Dickins, J. M., Roberts, J. & Veevers, J. J., 1972. Permian and Mesozoic geology of the northeastern part of the Bonaparte Gulf Basin. *Bull. Bur. Miner. Resour. Geol. Geophys. Aust.* 125: 75-102.

d'Orbigny, A., 1842. *Voyages dans L'Amerique meridionale execute pendant les annees 1826, 1827, 1828, 1829, 1830, 1831, 1832 et 1833*. Tome 3; 4.^{r} Partie: Paleontologie. Bertrand, Paris. Levrault, Strasbourg.

Douglas, J. A., 1936. A Permo-Carboniferous fauna from Southwestern Persia (Iran). *Mem. geol. Surv. India Palaeont. indica.* N.S. 22, 6: 1-59.

Dunbar, C. O., & Condra, G. E., 1932. Brachiopoda of the Pennsylvanian System of Nebraska. *Bull. geol. Surv. Neb. Ser.* 2, 5: 1-377.

Elias, M. K., 1962. Comments on recent paleoecological studies of Late Paleozoic rocks in Kansas. *Kansas geol. Soc., 27th Field Conf., Guidebook* 106-115.

Elias, M. K., 1966. Depth of Late Paleozoic Sea in Kansas and its megacyclic sedimentation. *Bull. geol. Surv. Kansas* 169(1): 87-106.

Fantini Sestini, N., 1964. Diagnosi di forme nuove, *Neochonetes asseretoi* sp. n. *Riv. Ital. Pal. Strat.* 70: 899.

Fantini Sestini, N., 1965a. The geology of the Upper Djadjerud and Lar Valleys (North Iran). II Paleontology. Bryozoan, brachiopods and molluscs from Ruteh Limestone (Permian). *Riv. Ital. Pal. Strat.* 71: 13-110.

Fantini Sestini, N., 1965b. Permian fossils of the Shaksgam Valley. In, *Italian Expedition to the Karakorum (K2) and Hindukush. Sci. Rep. IV, Paleont. Zool. Bot.* 149-215. E. J. Brill, Leiden.

Fredericks, G. N., 1915. Fauna verkhne paleozoiskoi Tolshchi/okrestnostei goroda Krasnoufimska Permskoi

Gub. *Trudy geol. Kom.* N.S. 109: 1-117.

Glenister, B. F. & Furnish, W. M., 1961. The Permian ammonoids of Australia. *J. Paleont.* 35: 673-736.

Gorskii, I. I. & Timofeeva, I. L., 1950. Verkhnepaleozoiskaya fauna iz Dzhon-garskogo Alatay. *Petrozavodsk, Karelo Finskii Gos. Univ.* pp. 1-82.

Grunewaldt, M. Von., 1860. Beitrage zur kenntniss der Sedimentaren Gebirgsformationen in den Berghauptmannschaften Jekatherinburg, Slatoust and Kuschwa, sowie den angrenzenden Gegenden des Ural. *Mem. Acad. imp. Sci. St. Petersbourg. Ser.* 7, 2, 7: 1-144.

Grushenko, N. V., 1975. Brakhiopody nizhnei permi i ix znachenie dlya stratigrafii vostochno-Ukrainskogo nefterazonosnogo basseina. In, Lapkin, Yu, (ed.), *Stratigrafiya verkhnego paleozoya i nizhnego mezozoya dneprovsko-donetskoi bpadniy.* Moskva, "Nedra", pp. 83-118.

Guppy, D. J., Lindner, A. W., Rattigan, J. H. & Casey, J. N., 1952. The stratigraphy of the Mezozoic and Permian sediments of the Desert Basin, Western Australia. *19th Int. Geol. Cong. Alger., Sym. Gond.*, 107-114.

Hamlet, B., 1928. Permische Brachiopoden, Lamellibranchiaten und Gastropoden von Timor. *Jaarboek van het Mijnwezen in Nederlands Indie.* 56(2): 1-115.

Hudson, R. G. S. & Sudbury, M., 1959. Permian Brachiopoda from south-east Arabia. *Notes, Mem. Moyen-Orient, Mus. nat. Hist. nat.*, 7: 19-55.

Keyserling, A. F. M. L. A. Von, 1846. *Wissenschaftlich Beobachtung auf einer Reise in das Petschora-Land im Jahre 1843.* Carl Kray, St. Petersburg, pp. 1-336.

King, R. H., 1938. New Chonetidae and Productidae from the Pennsylvanian and Permian strata of north-central Texas. *J. Paleont.* 12: 257-279.

Koninck, L. G. de, 1847. *Recherches sur les animaux fossiles. I. Monographie des genres Productus et Chonetes.* H. Dessain. Liege. 246 pp.

Kozlowski, R., 1914. Les Brachiopodes due Carbonifere superieur de Bolivie. *Ann. paleont.* 9, 1-100.

Kulikov, M. V., 1974. O rasselenii i usloviyakh obitaniya fauny v severnoi chasti Kazanskogo morya. *Trudy Vses. ordena Lenina nauchno-issled. geol. Inst.* (VSEGEI) *n.s.* 182: 138-153.

Lapina, N. N., 1958. Nekotorye dannye o brakhiopodovoi fauna verkhnego paleozoya severnoi chasti Kharaulakhskikh gor. *Nauchno-issled. Inst. Geol. Arkt., Sb. Strat. Paleont. Biostratigr.*, 8: 21-30.

Liao Zhuo-Ting, 1979. Uppermost Carboniferous brachiopods from Western Guizhou. *Acta palaeont. sin.*, 18, 527-546.

Licharew, B. K., (Likharev, B. K.), 1913. Fauna permskikh' otlozhenii okrestnostei goroda Kirillova Novgorodskoi Gubernii. *Trudy Geol. Kom.* N.S. 85: 1-99.

Malzahn, E., 1957. Neue fossil funde und vertikale verbreitung der niederrheinischen Zechsteinfauna in den Bohrungen Kamp 4 und Friedrich Heinrich 57 bei Kamp-Lintformt. *Geol. Jb.* 73: 91-126.

Muir-Wood, H. M. & Oakley, K. P., 1941. Upper Palaeozoic faunas of north Sikkim. *Mem. geol. Surv. India. Palaeont. indica* N.S. 31, 1-91.

Newton, R. B., 1892. On the occurrence of *Chonetes pratti*, Davidson, in the Carboniferous rocks of Western Australia. *Geol. Mag.*, (3) 9: 468-469, 542-544.

Newton, R. B., 1893. On the occurrence of *Chonetes pratti*, Davidson in the Carboniferous rocks of Western Australia. *Rep. Br. Ass. Advmt. Sci. for 1892*, 725-726.

Owen, D. D., 1852. *Report of a Geological Survey of Wisconsin, Iowa and Minnesota and incidentally of a portion of Nebraska Territory.* Philadelphia, Lippincott, Grambo and Co. pp. 1-638.

Ozaki, K., 1934. On some brachiopods from the reddish purple shale of the Koten series exposed in the Heizyo coal field. *J. Shanghai Sci. Inst. Sec.* 2, 1: 89-98.

Playford, P. E., Cockbain, A. E. & Low, G. H., 1976. Geology of the Perth Basin, Western Australia. *Bull. geol. Surv. West. Aust.* 124: 1-311.

Sahni, M. R. & Srivastava, J. P., 1956. Discovery of *Eurydesma* and *Conularia* in the eastern Himalaya and description of associated faunas. *J. Pal. Soc. India* 1(1): 202-214.

Sarycheva, T. G. 1970. *Slovar' terminov po morfologii produktid* (*Brachiopoda*). Moskva, Nauka. 84 pp.

Schauroth, K. F., 1856. Ein neuer beitrag zur Paläontologie des deutschen Zechsteingebirges. *Zeit. deutsch. geol. Ges.* 8: 211-245.

Schellwein, E., 1911. Palaozoische und Triadische fossilien in Ostasian. In, Futterer, K. (ed.)., *Durch Asien*, Vol. 3, pp. 125-174. Dietrich Reimer. Berlin.

Semenova, E. G., 1972. Brakhiopody bashkirskogo yarusa i vereiskogo gorizonta Kuibyshevskoi oblasti. In, Ifanova, V. V. & Semenova, E. G. *Srednekamennougol'nye i permskie brakhiopody vostoka i severa evropeiskoi chasti SSSR* pp. 7-68. Akad. Nauk SSSR "Nauka". Moskva.

Sokolskaya, A. N., 1965. Podotryad Chonetoidea. In, Ruzhentsev, V. E. & Sarycheva, T. G., Razvitie i smena morskikh organizmov na rubezhe paleozoya i mesozoya. *Akad. Nauk SSSR, Paleont. Inst., Trudy* 108: 209-211.

Spencer, R. S., 1970. Evolution and geographic variation of *Neochonetes granulifer* (Owen) using multivariate analysis of variance. *J. Paleont.* 44: 1009-1028.

Termier, G., Termier, H., Lapparent, A. F. De & Marin, P., 1974. Monographie due Permo-Carbonifere de Wardak. *Doc. Lab. Geol. Fac. Sci. Lyon., H.S.* 2: 1-167.

Thomas, G. A., 1958. Ther Permian Orthotetacea of Western Australia. *Bull. Bur. Miner. Resour. Geol. Geophys. Aust.* 39: 1-158.

Thomas, H. D., 1930. An Upper Carboniferous fauna from the Amotape Mountains, North-Western Peru. *Geol. Mag.* 67: 394-408.

Trechmann, C. T., 1944. On some new Permian fossils from the Magnesian Limestone near Sunderland. *Q. Jl. geol. Soc. Lond.* 100: 333-354.

Waterhouse, J. B., 1964. Permian brachiopods of New Zealand. *N.Z. geol. Surv. paleont. Bull.* 35: 1-289.

Winkler-Prins, C. F., 1968. Carboniferous Productidina and Chonetidina of the Cantabrian Mountains (N.W. Spain): Systematics, stratigraphy and palaeoecology. *Leid. geol. Meded.* 43: 41-126.

Woodward, H. B., 1907. *The History of the Geological Society of London.* Geological Society. London. 336 pp.

Yeates, A. N., Crowe, R. W. A., Passmore, V. L. Towner, R. R. & Wyborn, L. I. A., 1975. New and revised stratigraphic nomenclature, northeast Canning Basin. *Annu. Rep. geol. Surv. W.Aust.* 1974: 49-51.

Zavodovsky, V. M. & Stepanov, D. L., 1971. Typ Brachiopoda. In, Kulikov, M. V. (ed.). *Polevoi Atlas permskoi fauny i flory Severo-Vostoka SSSR.* Magadanskoe Knizhnoe Izd-vo. Magadan. pp. 70-182.

STRATIGRAPHY, SEDIMENTOLOGY AND HYDROCARBON PROSPECTS OF THE DILWYN FORMATION IN THE CENTRAL OTWAY BASIN OF SOUTH EASTERN AUSTRALIA

By G. R. Holdgate
State Electricity Commission of Victoria

Abstract: A sedimentary and facies analysis from deep bore data in the central Otway Basin indicates the Early Eocene Dilwyn Formation comprises up to seven stacked deltaic cycles. The oldest, Delta Cycle A, derived much of its sediment from two main fluvial fed sources coming from north of the basin, and possibly north of the present divide. The fluvial sequences coalesced south of a hinge line at the Tartwaup Fault, and filled the deep northwest-southeast trending Portland Trough. This delta cycle comprises the prodelta sequences of the Pember Mudstone Member, grading up into two main high constructive elongate delta channels similar to those of the present day Mississippi birdfoot. Subsequent Deltas B to G are high sand-shale ratio cycles elongate parallel to the Portland Trough margins. Each cycle begins with marine shales. Size analysis and isopachs of sand suggest the constituent sand bodies of each cycle include barrier bars and delta front channels. Fluvial channel sands dominate in the upper parts of the cycles and towards the north of the basin. Each cycle was terminated abruptly by renewed marine transgression. The cycling is best explained by channel switching and abandonment of sediment supply, than by the eustacy model. Extrapolation into offshore areas of the basin indicates some hydrocarbon potential exists in the more deeply buried sands of the prodelta sequences, and an explanation for the submarine canyons on the continental slope is proposed.

INTRODUCTION AND METHODS

In the Otway Basin of south-eastern Australia Palaeocene to Middle Eocene sediments are referred to as the Wangerrip Group, including a basal Pebble Point Formation conformably overlain by the Dilwyn Formation which comprises the major portion of the Wangerrip Group. This study concentrates on the subsurface central part of the Basin between the Victoria-South Australia border and the Warrnambool Ridge (Fig. 1) which encompasses the two major onshore Gambier and Tyrendarra Embayments. Most sedimentological work was carried out on the former embayment, using 16 deep groundwater and stratigraphic exploration bores drilled by the Department of Minerals and Energy, Victoria (DMEV). Cuttings samples were examined every 3 m, as well as core samples cut approximately every 100 m, and wire line geophysical logs including gamma ray, spontaneous potential (SP) and resistivity. Similar data from other bores drilled for oil and water in the area and interpretation based on geophysical logs for most deep DMEV bores in the Tyrendarra Embayment have completed the programme. Examination of the extensive oil company seismic data coverage of this area has not been attempted in this study.

The Dilwyn Formation was first described by Baker (1943, 1950) from coastal cliffs near Princetown and later named the Dilwyn Clay (Baker 1953). Bock and Glenie (1965) introduced the name Dilwyn Formation with a lower Pember Mudstone Member and an upper Dartmoor Sand Member, to describe the subsurface sediments. In the western Otway Basin near the Glenelg River Boutakoff and Sprigg (1953) named similar strata as the Dartmoor Formation, now regarded as a junior synonym of the Dilwyn Formation (Abele *et al.* 1976). In South Australia this formation is known as the Knight Group (Ludbrook 1971). For convenience both the outcrop and subsurface occurrences are referred to as the Dilwyn Formation.

The Dilwyn Formation in the subsurface has been referred to only in general terms in well completion reports and basin summaries, and the more detailed descriptions of Abele *et al.* (1976), apply mainly to the sparse outcrops. Its depositional environment has been considered to be paralic (Bock & Glenie, 1965). This study examines the information available from bores, and makes an assessment of the depositional environments from these data using techniques developed by oil companies for similar paralic environments. The conclusions reached probably apply to the Dilwyn Formation throughout the Otway Basin.

RESULTS

Subdivisions

In the study area the Dilwyn Formation can be subdivided into three parts described below, the characteristic wire line logs of which are shown on Figs 5 & 6.

1—The Pember Mudstone Member is the oldest unit and consists of tan to grey siltstones, mudstones and shales, usually pyritic, carbonaceous, micaceous and locally glauconitic. Carbonate cemented sands are common particularly in the upper parts. Owing to later uplift and erosion many of the basin margin outcrops occur within this unit.

2—The undifferentiated Dilwyn Formation is the thickest unit generally comprising two-thirds of the total formation. It is characterised by sands predominating over shales, and cyclic repetitions of sands-silts-clays. This unit includes the Dartmoor Sand Member of Bock and Glenie (1965) which cannot be distinguished in this

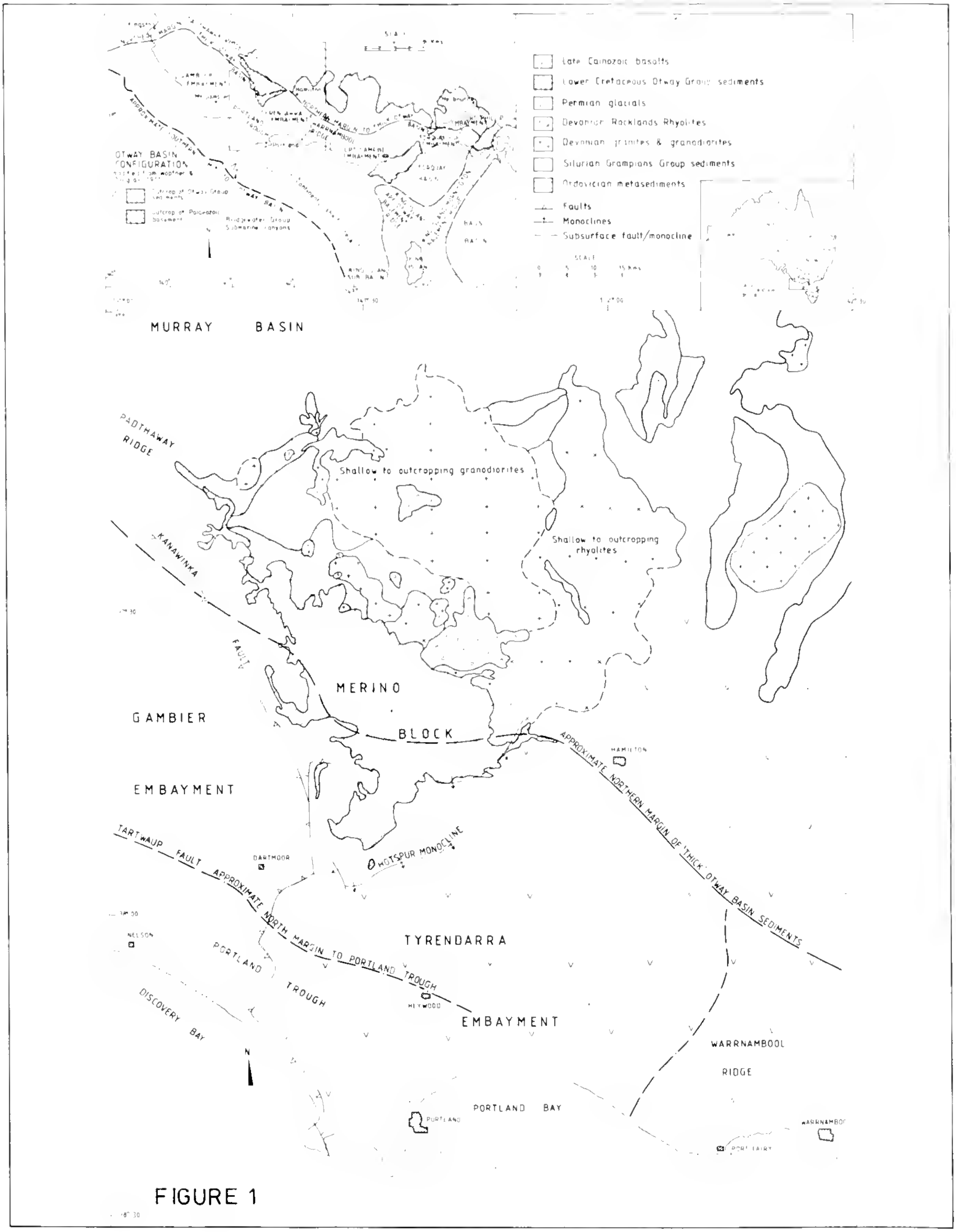


Fig. 1—Central Otway Basin general geology. (From Portland 1:250 000 Geological Sheet)

central area of the Otway Basin. It is transitional with the Pember Mudstone Member below. When the overlying Burrungule Member is absent the Dilwyn Formation appears on bore hole sections (Fig. 6) to be unconformable with overlying carbonate units such as the Gambier Limestone.

3—The Burrungule Member is mainly recognized south of the Tartwaup Fault. However, thin non-marine coaly equivalents may be present for a short distance to the north of the fault. It includes all the well burrowed grey muddy siltstones with lesser sands which conformably overlie the undifferentiated Dilwyn Formation and underlie the Mepunga Formation and other marine carbonate deposits. Not uncommonly it includes a calcareous marine fauna of foraminifera and shelly fossils. It has not been described from the Otway Basin Victoria before, but is in the South Australian portion (Harris 1966).

RECOGNITION IN THE SUBSURFACE

The Dilwyn Formation occurs in all bores throughout the study area except where removed by subsequent erosion. It underlies younger marine carbonate units such as the Mepunga Formation, Gambier Limestone and Heytesbury Group, or the Whaler's Bluff and Bridgewater Formations. North of the Tartwaup Fault these overlying carbonate sequences truncate the beds of the Dilwyn Formation. It overlies conformably the Pebble Point Formation or unconformably the Otway Group in the far north.

The Dilwyn Formation sands are readily distinguishable from those of the Mepunga Formation and Pebble Point Formation by their lack of brown oxidation and better sorting and roundness. Upper Cretaceous Paaratte Formation sands are similar to Dilwyn sands but, in all cases, the Pebble Point Formation intervenes (Holdgate 1977c). Bores in the far NW lack the Pebble Point Formation but here the Dilwyn rests unconformably on Early Cretaceous Otway Group. Tertiary uplift on basin margins and structural highs has caused truncation of the Dilwyn Formation. In some bores complete removal has occurred, e.g. Myaring 2 where Pleistocene Whaler's Bluff Formation rests unconformably on Pebble Point Formation.

DESCRIPTION OF LITHOLOGIES

Sands—typically well sorted and clean, with clear frosted well rounded quartz grains of mean size 1.0 phi in the south to 0.4 phi in the north. More detailed sand size analyses are made in subsequent sections. The sands occur in sand bodies which range from 15 m to 30 m in thickness but can exceed 80 m locally. Some sand bodies coarsen upwards but others remain constant in grain size throughout. The lower contacts can be gradational with underlying muddy sands and silts, or abrupt with clays and shales. The upper contacts are generally abrupt and overlain by ligneous clays and silts. The sand bodies comprise over half of the formation thickness but average less than one quarter of the thickness in the Pember Mudstone and Burrungule Members. Core recoveries are low in the sands but improve with depth. They often fall below 20% due to the overall lack of consolidation. On wire line logs they commonly show short normal resistivities of 20 ohms/m^2. The cemented sands can be up to 30 or 40 ohms/m^2. Most sands are fresh water flushed and on pumping can produce water flows up to 125 litres/second (Lawrence 1976). Water quality is good with low salinities. Calculations using neutron and density logs in Warrain 7 bore show porosities to decrease from 50% at 665 m to 28% at 1350 m (Laing in Holdgate 1977a).

Shales—usually tan to grey, and laminated by fine white silty interbeds. In the lower part of the Pember Mudstone the shales become massive without obvious bedding, and here can be over 100 m thick. Dark grey and black shales occur near the base of the formation in the deep parts of the basin. Gamma ray logs show the shales range between 0.015 and 0.02 mr°/hr. Maximum intensities mainly occur in shales of the Pember Mudstone, and the lower shales in the cyclic sequences.

Silts are most common in the Burrungule Member. The mottling and burrowed appearance of these silts is due to infillings of animal burrows by cleaner white silts. This lithology is also present in the rest of the formation particularly in the lower shales of the cyclic sequences.

Cemented sandstones are common in the upper parts of the Pember Mudstone and as occasional interbeds in the undifferentiated Dilwyn Formation near the base of the cyclic sequences. On the resistivity logs they have a spike-like appearance. From their stratigraphic position it can be inferred that the carbonate cementing media may be of a primary origin. Chemically, they range between dolomite, siderite, silica and pyrite.

Calcareous fossils are rare except in the Burrungule Member. Planktonic foraminifera have been obtained from this and the Pember Mudstone and more rarely from the lower shales in the undifferentiated part. Siliceous foraminifera including species of *Cyclammina* are more common throughout the formation occurring mainly in the shales. Sharks teeth can also be found.

Carbonaceous material is present in both sands and shales as disseminations and discrete beds (stringers). Thin coal seams up to a few metres thick occur in the upper parts of the cyclic sequences and in the Burrungule Member. Their poor definition from the gamma ray logs suggests they contain high ash contents.

Mica is common throughout the formation with large flakes lying parallel to bedding. In the Nelson Bore the heavy mineral fractions seldom exceed 0.5% by weight (Baker 1961), and most of this is authigenic pyrite and heavy carbonates. From Baker's table of percentage distribution (Baker 1961, Table 13), the non-authigenic minerals in the Dilwyn formation comprise about 50% zircon with the rest evenly separated between tourmaline, rutile, garnet, cassiterite and minor metamorphic minerals. This mature population distribution indicates extensive or long transport histories from a granite terrain. There appears to be no major change in the heavy mineral population throughout the Dilwyn Formation.

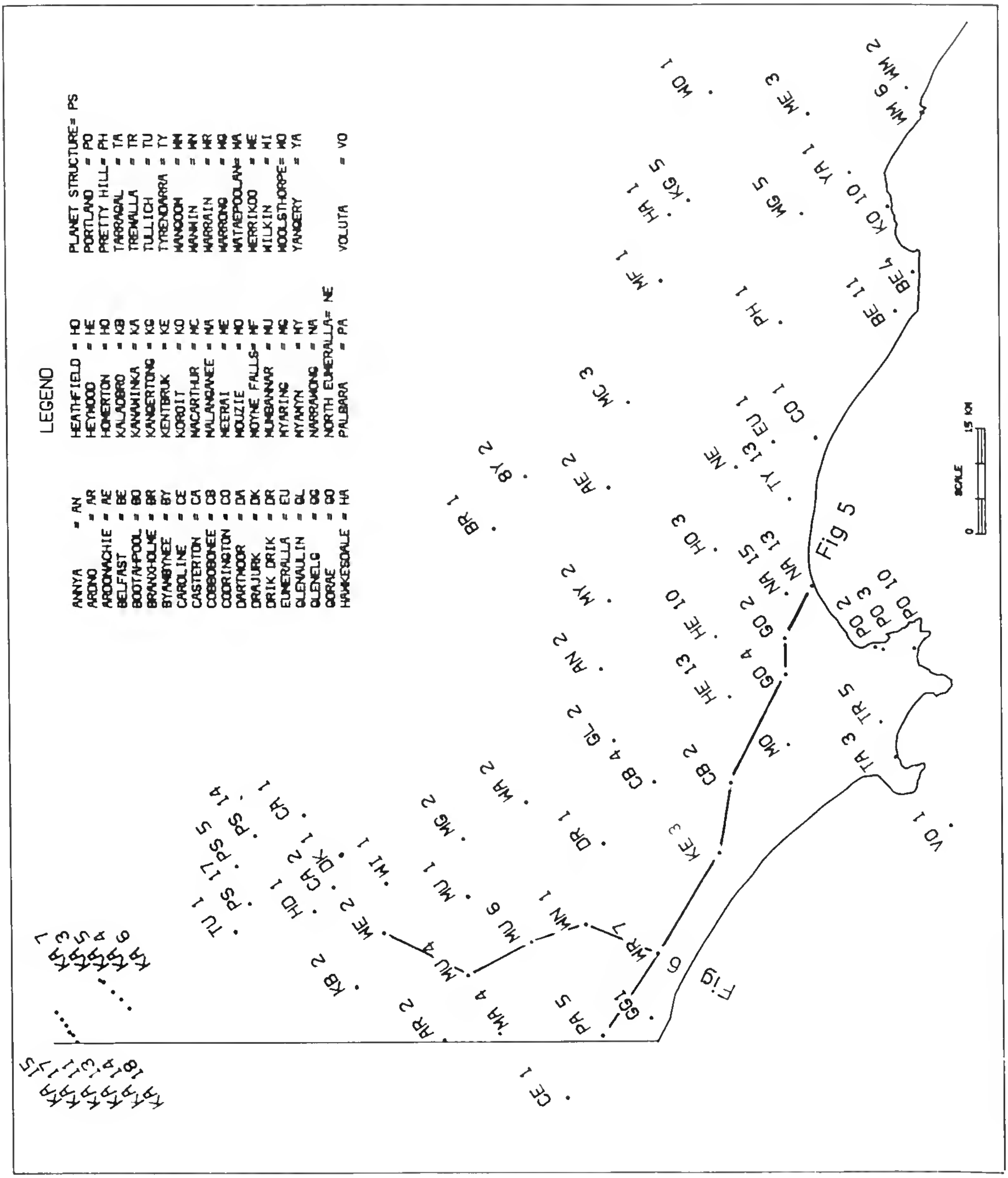


Fig. 2—Central Otway Basin bore location plan.

Distribution and Thickness

The formation ranges in thickness between 6.1 m in the north-west to greater than 1247 m in the south-east, and occurs in the subsurface throughout the study area. The isopach map (Fig. 3) shows the general distribution of sediments. Thicknesses over 600 m are limited to that part of the study area south of the Tartwaup Fault where a deep trough is developed. The depocentre for this trough occurs in the Tyrendarra Embayment. North of the Tartwaup Fault the isopach lines strike north-west parallel to and deepening south-west away from the Kanawinka Fault.

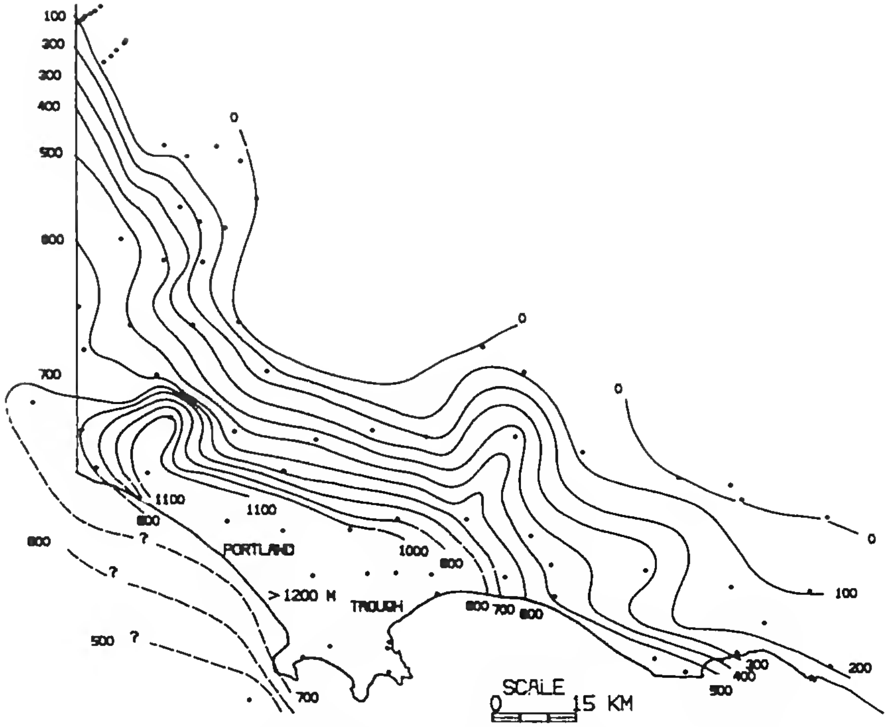


Fig. 3—Central Otway Basin isopach of Dilwyn Formation (metres).

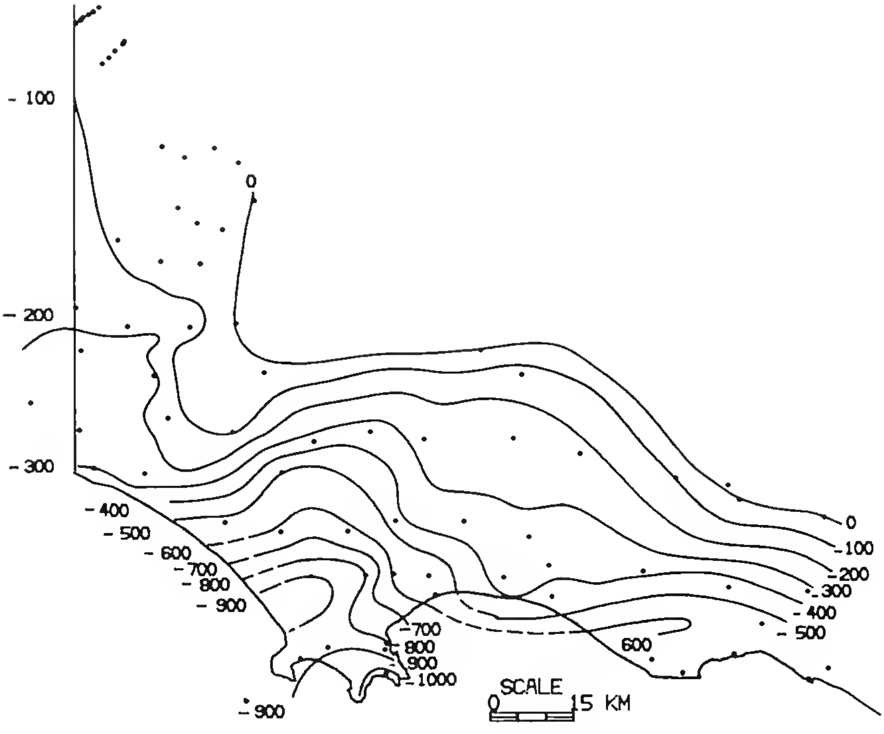


Fig. 4—Central Otway Basin structure contours to top of Dilwyn Formation (metres).

The structure contour lines on top of the Dilwyn Formation (Fig. 4) indicate a structural high around Dartmoor plunging south-west towards Nelson township, part of which has been referred to as the Stokes River Anticline (Kenley 1971). To the north of this anticline the structure lines indicate progressive deepening away from the Kanawinka Fault towards the State border. To the south there is rapid deepening into the Tyrendarra Embayment. The Dartmoor Ridge of Boutakoff (1952), which as a gravity defined structure was postulated to divide the Gambier and Tyrendarra Embayments, is not in evidence in the subsurface and has little effect on the early Tertiary formation. Portland Trough is herein proposed to describe the thick east-west Tertiary sequence which straddles this 'ridge'.

The Portland Trough commences shortly east of Nelson township as indicated by the isopach lines around Wanwin 1 and Warrain 7 bores, and deepens and broadens to the south-east in the general direction of Portland. To the north it is limited by the rapid shallowing of section along the line of the Tartwaup Fault, to the west by structural shallowing in the Nelson-Caroline area, and opens to the south and south-east into Portland Bay. All the DMEV bores in the centre of the trough failed to penetrate the full sequence, which probably exceeds 2000 m. The only offshore well south of Portland (Shell Dev. Voluta No 1) drilled a thinner sequence of Dilwyn Formation, which is taken here as indicating that a southern margin to this trough occurs offshore in Discovery Bay.

The trough has two north trending re-entrants which have important palaeoenvironment implications discussed later. One occurs on the north-western edge of the trough around the Wanwin 1 and Mumbannar 6 bore sites, and a larger re-entrant occurs in the Tyrendarra Embayment trending north towards the Hamilton area.

AGE

In the subsurface, the Dilwyn Formation generally ranges from Middle Palaeocene to Middle Eocene in age (Abele *et al.* 1976) although McGowran (1978) considers the time interval between Late Early Eocene and Early Middle Eocene may be absent. In the study area it includes the *L. balmei* and *M. diversus* spore-pollen zones of Stover and Partridge (1973) (see Ripper 1976). The *T. collactea* (Late Middle Eocene) foraminiferal zone of McGowran (1973) occurs in the Burrungule Member.

The Pember Mudstone contains planktonic foraminifera of Palaeocene to Early Eocene age which have been identified in core material from Malanganee 4 (835.5 m) by Abele in Holdgate (1977b) and Wanwin 1 (1215 m) by Abele in Holdgate (1975). Further identifications by Dr C. Abele (pers. comm.) include Ardonachie 2 (680 m), Gorae 2 (1369 m), Heywood 13 (1595.5 m), Mumbannar 1 (456 m) and Narrawong 15 (1552.8 m and 1675 m).

The undifferentiated Dilwyn Formation contains sparser foraminifera of Palaeocene to Early Eocene age including Cobboboonee 2 (1368.5 m) and Heywood 13 (900 m) (Dr C. Abele pers. comm.).

The Burrungule Member contains a planktonic foraminiferal fauna of late Middle Eocene age, in Warrain 7 (256 m and 272 m), Abele in Holdgate (1977a) and possibly Wanwin 1 (170 m), (Abele in Holdgate 1975).

CYCLIC SEDIMENTATION IN THE UNDIFFERENTIATED DILWYN FORMATION

From an examination of the wire line logs there occur characteristic gamma ray and resistivity log traces through the undifferentiated Dilwyn Formation which show cyclic repetition. These can be compared with similar cyclic gamma and electric log profiles considered to represent subsurface deltaic sequences (Galloway 1968, Fisher 1969, Weber 1971, Selley 1976). The principle used to determine the depositional environments from logs is related to the fact that gamma ray and electric log profiles reflect clay content in clastic sequences. From this the vertical changes in environment can be interpreted as well as lateral facies changes.

The correlation between vertical log profiles in a deltaic sequence and grain size obtained from side wall coring has been demonstrated by Weber (1971). To interpret Dilwyn Formation environments without the aid of sidewall cores, grain size analyses of cuttings samples were made on three bores. Cuttings samples every 3 m were washed free of drilling mud and sieved. The verticle distribution of grain sizes plotting relative distribution of the whole phi intervals in a cumulative plot coarsening from right to left is illustrated on Fig. 7 for the three bores. Cutting samples are not ideal for determining size distribution, but the correspondence between the wire line logs and size distributions is close, confirming that the cyclic sequences on the logs relate to similar cycles in the grain size. Each cycle commences with a sudden change from a sand in the preceding cycle to a shale or silty shale immediately above. In some bores this contact is associated with carbonate cemented sands and these along with calcareous planktonic foraminifera indicate the shales are of marine origin. The shales gradually decrease upwards to be replaced by two thick massive unfossiliferous sand beds at the top of the cycle, separated by a second thinner shaly interval. Grain sizes increase upwards through the transitional shaly silt and silty sand intervals but mean sizes stabilise through the massive sands.

Up to seven cycles can be recognized in each bore which can be readily correlated on logs throughout the study area and into the adjacent Tyrendarra Embayment (Figs 5 & 6). From the cuttings size analyses each cycle has a repeatable grain size distribution to the one below which is characteristic to each bore. Adjacent bores have similar vertical repeatability but different size distributions. Mean grain size appears to decrease away from the basin margins. North of the Tartwaup Fault the upper cycles are eroded from the structural highs and basin margins, so that progressively older cycles subcrop below the younger carbonate sequences. Individual cycles average 80 m in thickness but decrease towards the basin margins where there was a continuous positive influence. Basinwards there is an increase in

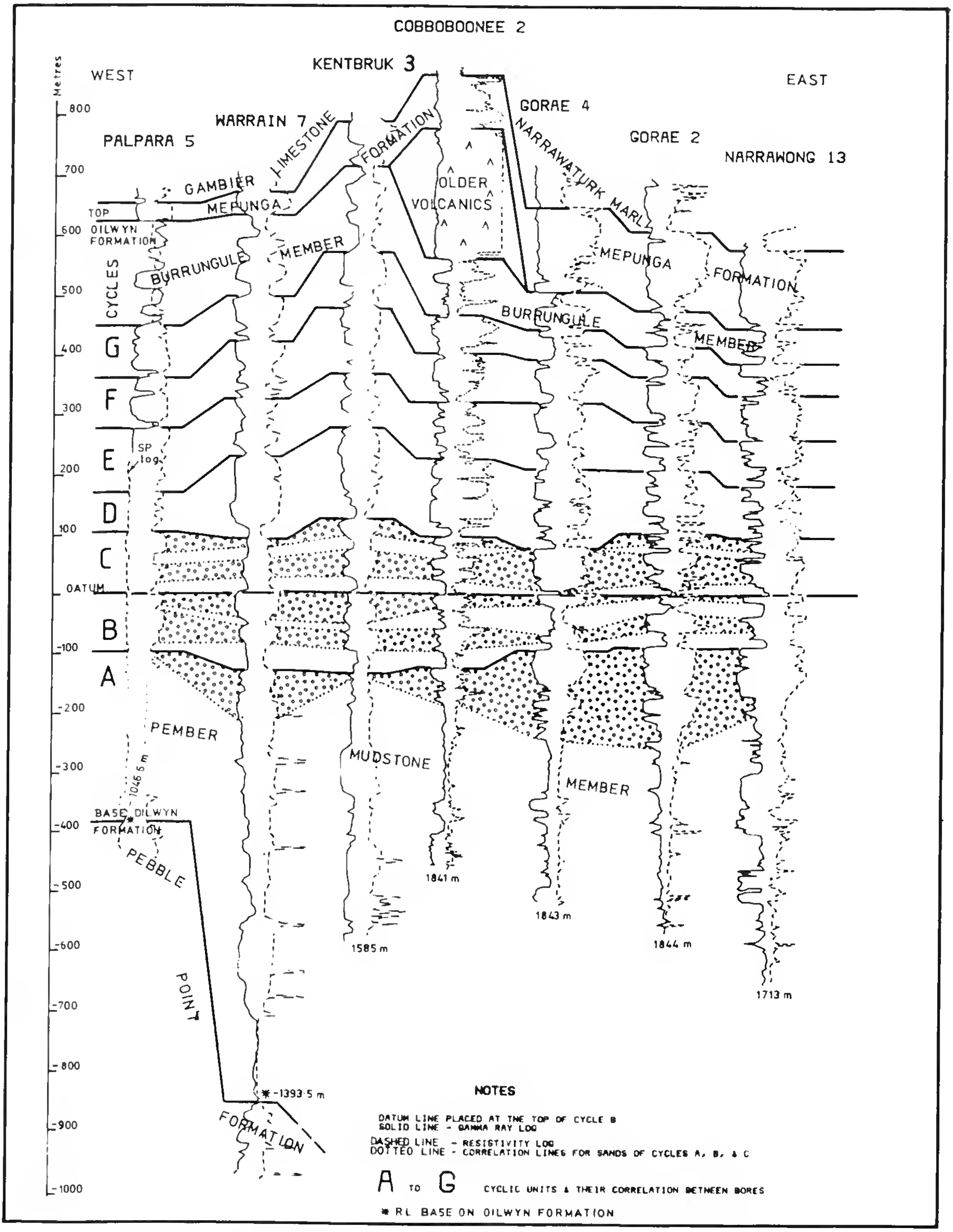


Fig. 5—Central Otway Basin Dilwyn Formation. East west log cross-section and reduced wireline logs.

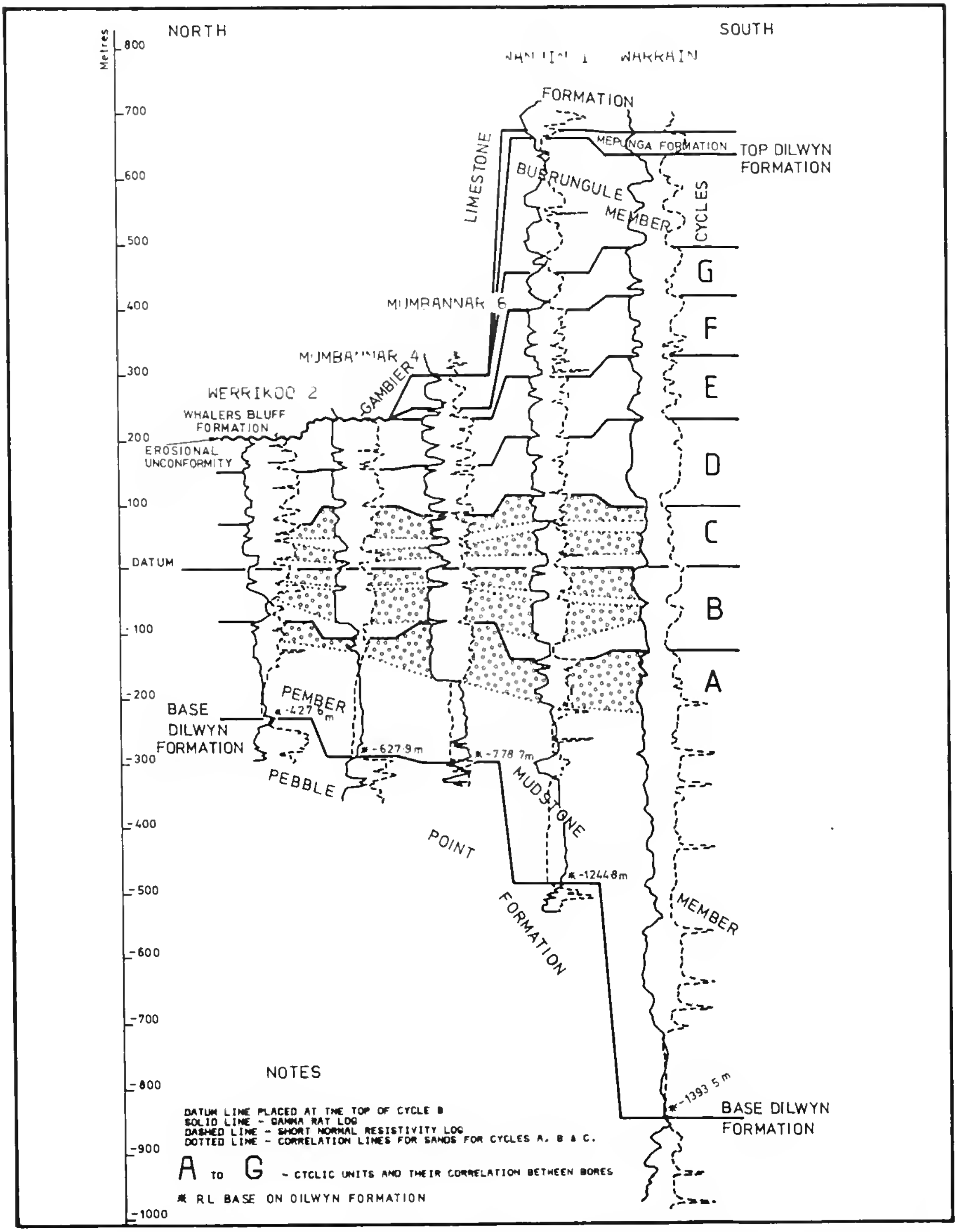


Fig. 6—Central Otway Basin Dilwyn Formation. North-south cross-section and reduced wireline logs.

shale as the proportion of sand decreases, and the major contributing factor to the thickening in the Portland Trough is the large increase in thickness of the Pember Mudstone and Burrungule Members.

The seven cycles are listed A to G in stratigraphic order. Cycles B to G characteristically have two sands and two shales. The lowest shale in each cycle has the higher gamma ray count, and can be fossiliferous and bioturbated. The lower sand in each cycle often shows a coarsening upwards sequence as indicated by grain sizes, and a gradually decreasing gamma log. In some bores the lower sand has a box-like log character produced by sharp contacts. These sand bodies are generally thicker than adjacent sands with transitional contacts. The upper sand bodies are usually box-like with sharp contacts. The lateral correlations between sand bodies for cycles A to C are shown on the bore log in Figs 5 and 6.

Cycle A differs from the other cycles whereby it can grade laterally from a single 90 m thick box-like sand body (Mumbannar 6) to a 15 m thick coarsening-up carbonate cemented sand body (Malanganee 4) (Fig. 8). Sizing the cuttings from the Mumbannar 6 bore indicates coarser sands occur in the upper and lower regions of the sand body, with little variation in grain sizes dominated by the 1 to 2 phi class range through the middle. On the bore log cross section through the Tyrendarra Embayment (Fig. 9), Cycle A consists of a series of three or more stacked box-like sand bodies, each up to 100 m thick. The relationships between vertical grain size profiles and wire-line log profiles conform to those deduced by Weber (1971) for fluvial distributary channels and barrier sands in the subsurface Niger Delta, although it should be noted that the Dilwyn sand bodies can have up to twice the thickness of the Niger Delta sand bodies.

Geometry of the Cyclic Units

Subsurface geometry of the individual cycles is depicted by a series of isopachs of each cycle (Figs 10 to 13). The Tyrendarra Embayment contains similar correlatable cycles which are included on the isopachs. Each cycle comprises a number of facies and environments, which in the sense of Busch (1971) make up an increment of sedimentation. The sum of all increments constitutes a genetic sequence of strata—in this case the undifferentiated Dilwyn Formation. It is envisaged that time-stratigraphic lines would transgress across the cycles but retain some conformity to the cycle boundaries.

Figures 11 to 13 show that for the most widespread Cycles B to D the major depocentres are coincident with the Portland Trough. The sand percentages for each cycle as derived from the gamma ray log indicate the basin margin areas are generally sandier. When considering the isopach for Cycle A (Fig. 10) some differences are apparent. This cycle has two depocentres—one in the Mumbannar/Warrain area, and one in the Gorae/Portland area. These trend at right angles across the main trough axis and contain the highest sand percentage. They are coincident with and extend southward from the re-entrants described previously at each end of the Portland Trough. Figures 8 and 9 show two bore hole log cross sections at right angles to these trends with the datum horizon placed on top of Cycle A. The channel-like nature of the sands is clearly visible, as are the lateral facies changes in these channels to the shales and carbonate cemented sands of the upper part of the Pember Mudstone.

Geometry of the Constituent Sand Bodies

Isopachs of each sand in Cycles A, B and C are shown on Figs 15 to 19, which depicts subsurface geometry of these sand bodies. Sand bodies for Cycles D to G are not shown due to partial erosion and correlation difficulties. The following points are noted:

1. The isopach of Cycle A sand body is the same as the isopach for the whole of Cycle A comprising two main depocentres opening to the south in the Mumbannar and Gorae areas. These have thicknesses over 60 m and are separated by an intervening low sand area in the Glenaulin and Kentbruck area (Fig. 15).
2. The isopach of the lower sand in Cycle B (Fig. 16) includes two parts—a SW trending depocentre with thicknesses over 60 m in the Mumbannar/Caroline area, connecting to an eastward trending depocentre through the Glenaulin, Heywood and Narrawong bores. Areas of minor sand thickness surround this sand body to the north, south and west.
3. The upper sand in Cycle B (Fig. 17) comprises a V-shaped depocentre through the middle of the study area with thicknesses exceeding 30 m. This forms a seaward perimeter to a low sand area in the north central area. A separate more localised trough occurs in the Tyrendarra bores.
4. The lower sand in Cycle C (Fig. 18) comprises a long narrow linear depocentre parallel to the Portland Trough axis, with thicknesses increasing southeastwards to 60 m in the Gorae area. It is flanked to the north and south by low sand areas.
5. The upper sand in Cycle C (Fig. 19) comprises two depocentres; one in the Wanwin/Ardno area which opens into South Australia, and the other in the Tyrendarra area. These are separated by a low to absent sand zone through the Heywood/Cobboboonee areas.
6. An isopach of the main correlatable sand body which occurs in the middle of the Pember Mudstone is included for comparison (Fig. 14). It is a narrow linear shaped body with somewhat sinuous outline approximating in position to the Portland Trough. At its centre around Kentbruck it exceeds 60 m in thickness.

Dipmeter Analysis

As an additional aid to subsurface facies analysis dipmeter logs were available to derive sedimentary dips such as crossbedding, the directions of which may be used to indicate direction of source and directions of flow in channel sands. Outlines of the techniques for examining dipmeter logs for such features are described by Schlumberger (1970). Using the methods described, sedimentary dips are divided into two main categories—those where two or more sequential dips of similar directions increase in dip downhole (red patterns), and those which decrease in dip downhole (blue patterns). Ideally for sedimentary dips in channels red patterns indicate downdip thickening towards the channel axis, the blue patterns indicate direction of fill. For beach barriers and offshore bars dip direction may occur in either direction normal to the shoreline depending on whether the sediment was derived from the landward or

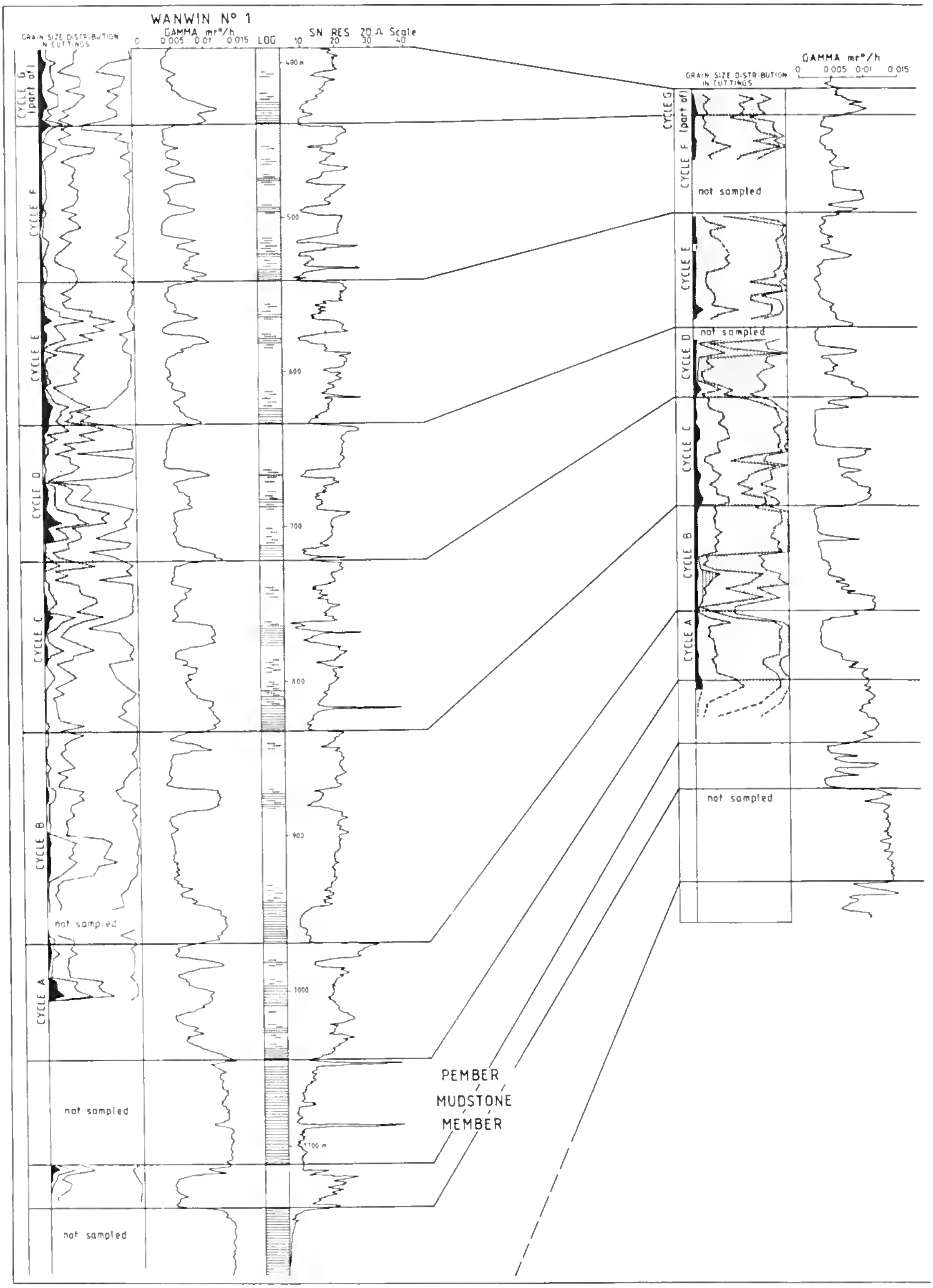


Fig. 7—Reduced wireline logs and grain size distribution of Dilwyn Formation sands in 3 Bores—Gambier Embayment (Victoria) Otway Basin.

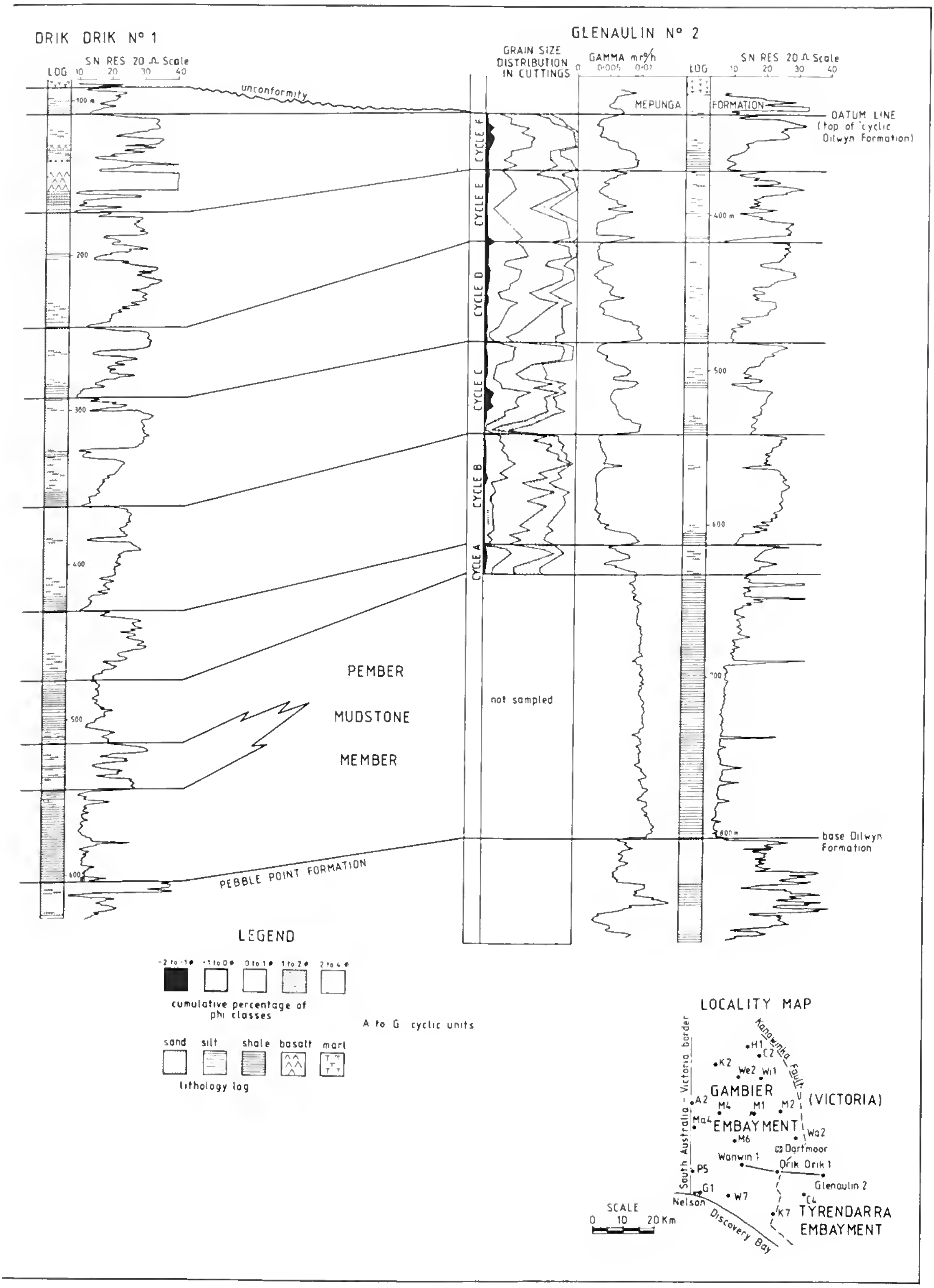


Fig. 7 (Continued)

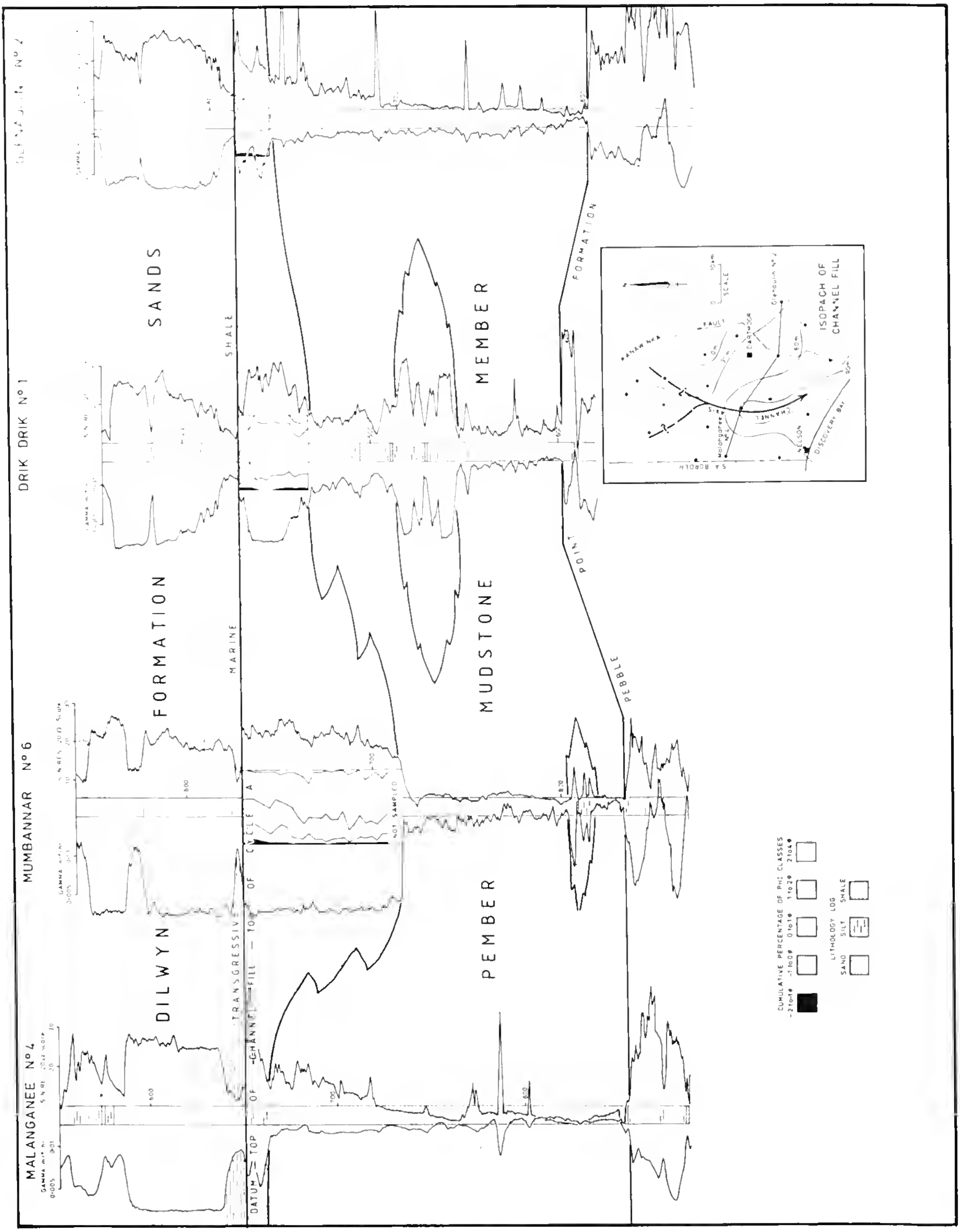


Fig. 8—Stratigraphic cross-section and grain size distribution of the Mumbannar Channel.

Table 1
Dipmeter Results

Bore Name and Sand Unit	Red Patterns	Blue Patterns	Relationship between Dip Direction and Main Trends of the Sand Isopachs (Figs 14-19)	Wire-line Log Profile of Sand Body
Voluta No 1 Pember Mudstone Sand	4°-15°@350°N 3°-13°@ 40°N	9°-13°@40°N	At right angles	Coarsening upward
Voluta No 1 Cycle A—Sand Body	2°-10°@220°S 3°- 8°@165°S	4°-17°@165°S	Parallel	Box-like
Caroline No 1 Cycle B—Lower Sand	— —	5°- 7°@105°E 2°- 5°@140°E	Parallel? (axis not clear in this area)	Box-like
Caroline No 1 Cycle B—Upper Sand	—	8°@235°	Parallel?	Box-like
Caroline No 1 Cycle C Lower Sand	9°@05°N	8°- 9°@ 05°N	Diagonal to right angles	Coarsening Upward
Caroline No 1 Cycle C—Upper Sand	2°- 6°@320°N	2°-15°@180°S	Right angles for red patterns, parallel? for blue patterns	Box-like

seaward side. In the study area only two bores have three-arm dipmeter surveys run through parts of the Dilwyn Formation. These are the oil wells of Caroline No 1 and Voluta No 1 (Fig. 2). All dips are recalculated after subtracting the structural dip as determined by the methods given by Schlumberger (1970) and the results are tabulated in Table 1. The results generally indicate that dip directions parallel the depositional axis for box-shaped sand bodies, whereas for coarsening upward sand bodies major dip directions occur at right angles and dip towards the depocentres.

DISCUSSION AND CONCLUSIONS

Depositional Environments in the Dilwyn Formation

The Pember Mudstone represents a prodelta sequence of marine shales and silty shales which grades upwards into delta front facies. These sediments partially filled a deep east-west trending trough in the central part of the Otway Basin between the Gambier and Tyrendarra Embayments. Sands within the Pember Mudstone are characterised by coarsening upwards log profiles, excellent sorting coefficients, and linear geometries parallel to the main Portland Trough margins, and hence probably represent palaeoshorelines which formed periodically with marine regressions during this depositional phase. Cross bedding dips to the north, normal to the shoreline trends may indicate the sediments were derived from the seaward side.

The cyclic sequences which typify the undifferentiated Dilwyn Formation consist of two genetically different units, subdivision of which is based on geometry and facies equivalents. The first genetic unit, Cycle A, represents the delta front and delta plain equivalents to the upper part of the Pember Mudstone—the two thus forming a single large deltaic sequence. This cycle comprises thick channel and stacked channel sands which form two large lobate deltas similar to the Mississippi birdsfoot deltas (Fisk *et al.* 1954). These are named the Mumbannar Channel and the Portland Channel for convenience. The channels prograded southwards from two distinct fluvial sources which followed down the north-south trending re-entrants at each end of the Portland Trough, and cut at right angles across the main basin trends. The channel sands eroded into and prograded over the delta front silts and shales of the Pember Mudstone. Their lateral facies equivalents between the delta lobes comprise sparsely fossiliferous laminated and cross bedded silty shales and silts interspersed by carbonate cemented sands, and represent deposition under more brackish water conditions in interdistributary bays.

A marine transgression over these birdsfoot deltas represented by the fossiliferous shales at the base of Cycle B marks the end of this Mississippi-type high constructive delta phase, and the beginning of a series of stacked tidal dominated delta cycles B to G. This second genetic sequence of strata resembles more closely the Niger Delta examples (Weber 1971) and consists of up to six high sand to shale ratio cycles, without large seaward prodelta components. The single major depocentre for each cycle is broadly coincident with the boundaries of the Portland Trough, and with each successive cycle this preferred lineation becomes more apparent (Figs 10-13).

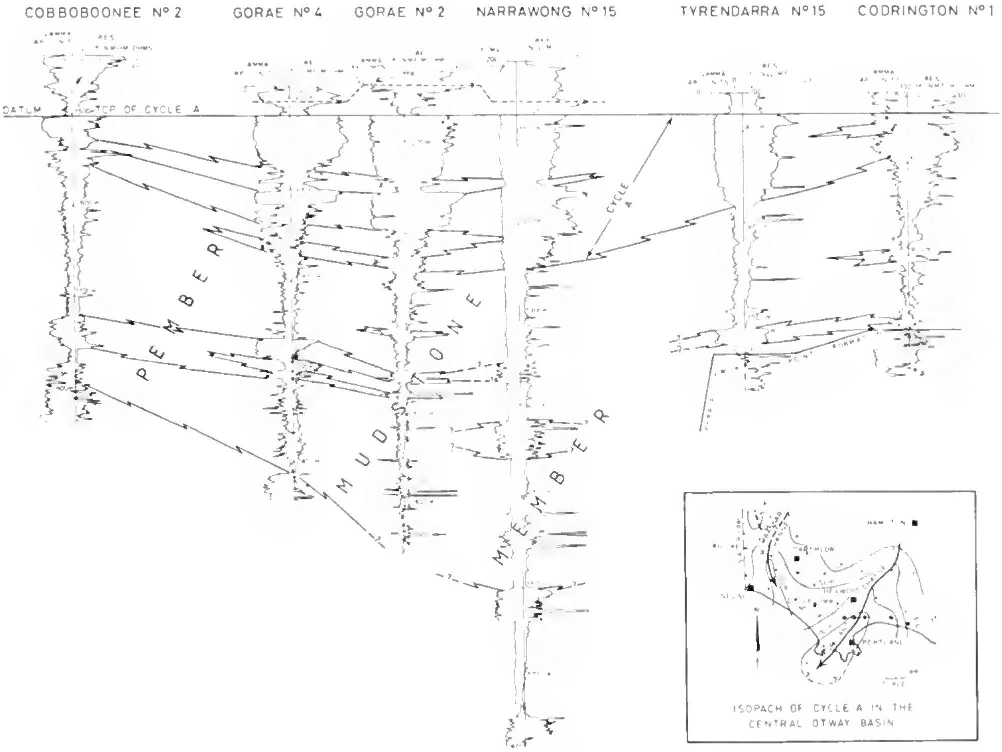


Fig. 9 — Wireline log cross-section across the Tyrendarra Embayment of the Otway Basin, below the top of Cycle A.

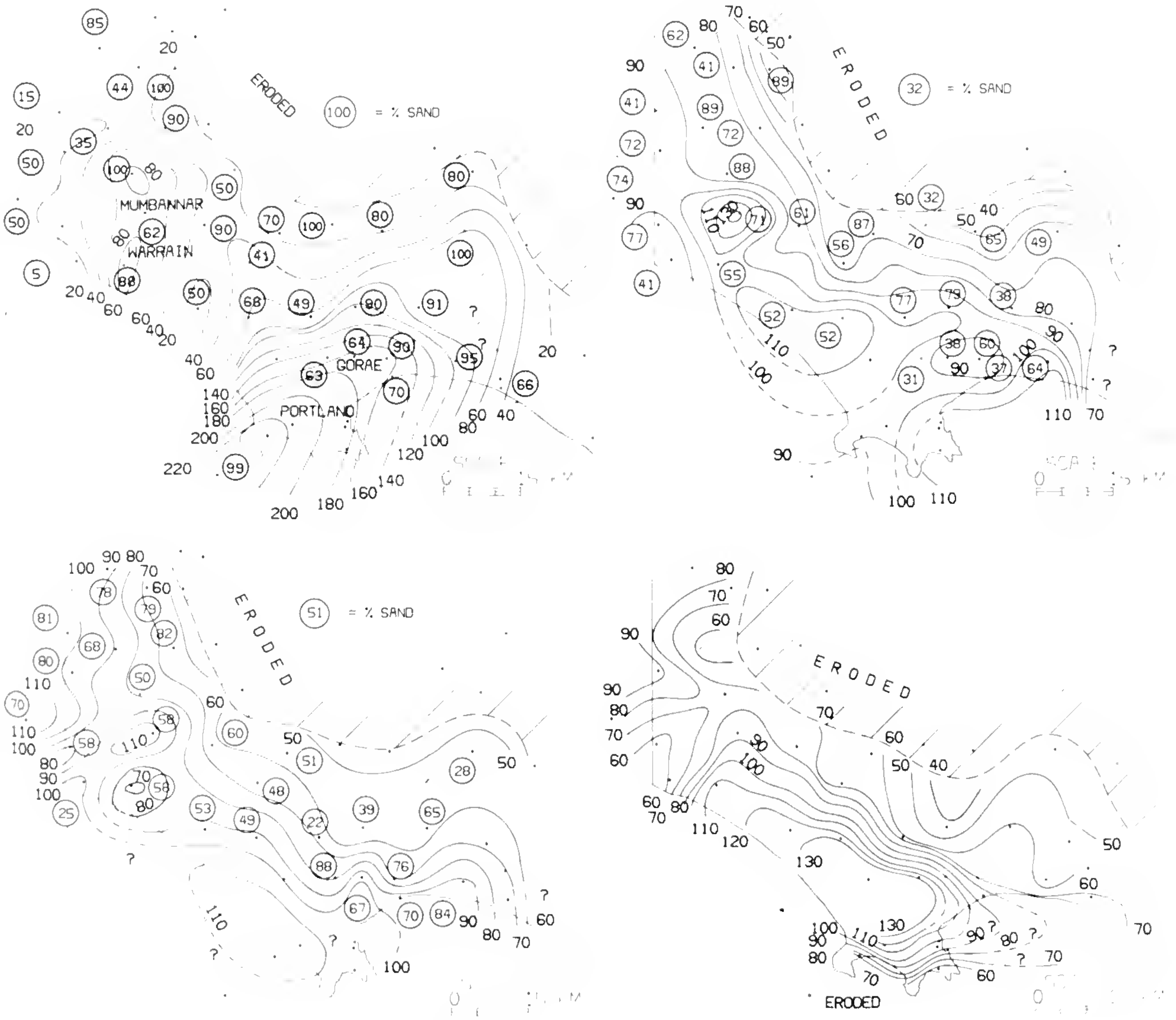
However, when the individual sand bodies which make up each delta cycle are examined, it is apparent they have multi-environmental origins.

The lower sand in Cycle B shows box-like log profiles occurring in a south-west trending depocentre through the Mumbannar-Caroline areas, indicating a westerly shift occurred to the Mumbannar channel axis of Cycle A. This large distributary channel prograded seawards through a barrier bar sequence typified by the coarsening upwards log profiles in bores which lay along the northern edge of the Portland Trough in the Glenaulin, Heywood and Narrawong areas. The lack of any similar large channel-like developments in the Gorae area indicates a diversion of the previous Cycle A Portland Channels, possibly into the Mumbannar area. Dipmeter data in Caroline 1 indicate some contradicting evidence for channel flow directions, with blue pattern dips trending south-east normal to the channel sides. This may be explained by the multi-environmental origin for this sand body, which includes some parts derived as channel deposits and others from barrier bar deposits. On the seaward side of the combined channel-barrier system there are up to 30 m thick shales which probably thicken offshore as the sands thin.

After a thin shale interval the re-establishment of the Cycle A channel directions took place. The V-shaped depocentre of the upper Cycle B sand comprises box-shaped log profiles in the western arm, suggesting mainly a fluvio-deltaic environment. Blue pattern dip directions indicate channel flows to the south in the Caroline 1 area approximately parallel to the depocentre axis. Mixed box-like and coarsening upwards profiles in the eastern arm suggest some barrier sand intervals. The sharp upper contact with the overlying marine shales is associated with carbonate cemented sands in interdistributary areas, and marks the end of the Cycle B delta phase.

The lower shales of Cycle C progressively coarsen upwards into a long linear sand body typical of delta front barrier sands. Parallel red and blue pattern dip directions to the north normal to the depositional axis suggest this barrier complex was similar to barrier sands in the Pember Mudstone, with sediments being derived primarily from offshore. The sands thin to the north probably grading into back barrier lagoonal shales, and offshore to the south into marine shales. This barrier complex is overlain by shales of probable delta front facies.

The upper sands of Cycle C show maximum development accompanied by box-like profiles at the western end of the study area. The lack of bores in the South Australian section means further environmental interpretation is difficult, although all indications suggest a re-established Mumbannar type fluvio-deltaic channel sequence flowing SSW. Blue pattern dips in Caroline 1 located near the depocentre of the channel also trend SSW. An area of no sand development in the Heywood area may represent a local unconformity or non-



Figs 10-13—Central Otway Basin isopachs (metres) of Cycles A (10), B (11), C (12), D (13). Encircled numbers are sand percentages. Numbered left to right on top then beneath.

deposition area separating the westerly channels from further channels developing in the south-east.

Cycles D to G follow similar patterns of sedimentation. Some basalts are intercalated at various levels in these cycles such as Drik Drik 1, Homerton 3, and Codrington 1. These are probably sills as the basalt date of 37 million years on the Codrington 1 basalt (Bowen 1974) is considerably younger than the palynological age of equivalent sequences elsewhere. Thicker basalts at the top of the Dilwyn Formation in the Cobboboonee 2, Heywood 10 and 13 bores are also probably sills (Abele *et al.* 1976).

The deltaic sequences ended in the Middle Eocene when a marine transgression deposited silts and shales of the Burrungule Member across the Portland Trough. Marine transgression over the area was complete by the Late Eocene. Fluvio-deltaic sequences were not re-established during or subsequent to this transgression phase.

Rates and Sources of Sedimentation

The large volumes of sediment comprising the Dilwyn Formation must have been deposited rapidly from at least two northerly sources in the vicinity of the present Western Highlands. In the centre of the Portland Trough minimum sedimentation rates for the Pember Mudstone and undifferentiated Dilwyn Formation are approximately 0.3 m/1000 yrs over a period of 4.5 million years, assuming an upper age limit at the Middle-Late Eocene boundary. Actual sedimentation rates were probably much higher considering that diastems occur at the end of each cycle, and subsequent post depositional consolidation has occurred.

The major depocentre of the Dilwyn Formation occurs in the Portland Trough which contains about 1000 km³ of sediment covering some 2400km². By comparison to present day deltaic depocentres, this is similar in area to deltas of the Brazos (Colorado), Danube or Rhone Rivers, which discharge up to 100 million tonnes of sediment per year (Smith 1966). The sizes and geometry of the sand bodies in the Dilwyn Formation are equal to and in many cases exceed the dimensions of those described for the Niger Delta (Weber 1971) which has an annual sediment discharge of 25 million tonnes. This may be owing to the Dilwyn sands being derived from only two major point sources, whereas the Niger Delta sands occur at the mouths of a multitude of smaller delta distributaries.

The lack of any major rivers of comparative size and discharge rates in this part of Victoria today presents some difficulties for the reconstruction of palaeodrainage patterns. Either the dividing range in Eocene times was higher and experienced greater precipitation and erosion to sustain large rivers with short lengths; or else the deltas of the Portland Trough were supplied from rivers with larger watersheds coming through from the Murray Basin north of the divide.

The existence of a substantially higher dividing range in the Eocene has been refuted in the Eastern Highlands by the valley filling Tertiary basalts and their ages obtained by Wellman (1974) who infers that the dividing range has maintained its heights and extent to the present. Climatically the Lower Eocene in southern Australia is considered to have experienced greater precipitation (e.g. Harris 1965, Gill 1975, Martin 1977, Kemp 1978), but for the lower lying Western Highlands is unlikely to have produced substantial river deltas unless accompanied by topographically higher and/or greater areas of watershed.

Major rivers may have come from north of the divide into this part of the Otway Basin during Eocene and pre-Eocene times (Denham & Brown 1976, Gostin & Jenkins 1980, Harris *et al.* 1980). Supportive evidence from this study includes:

1—The major re-entrant at the eastern end of the Portland Trough trends northwards towards the present low saddle in the dividing range between the Grampians to the east and the Dundas Tablelands to the west. The re-entrant at the western end of the Portland Trough trends northwesterly towards the low basement saddle of the Padthaway Ridge which divides the Otway from the Murray Basins in South Australia.

2. The cessation of deltaic sedimentation near the end of the Early Eocene coincides with folding and uplift north of the Tartwaup Fault, as indicated by the unconformity on top of the Dilwyn Formation and the suggested time break (McGowran 1978). Marine transgressions subsequently occurred from the south. This uplift could have blocked the Murray Basin river sources along the divide. The Murray rivers then became confined to the Murray Basin, and without this major sediment source open marine transgressions in the Middle Eocene could begin from the south (the Burrungule Member). It, therefore, seems likely that the postulated Early Tertiary outfall for the Murray River in the Spencer Gulf (Williams & Goode 1978) could have occurred subsequent to this Middle Eocene rise of the Eastern Highlands. This date would accord with the oldest (Late Eocene) dated channel sediments near the Mt Lofty-Flinders Block west of Morgan (Goode & Williams 1980). By Oligocene times there was negligible clastic input into the Otway Basin and marine carbonate shelf sediments (Heytesbury Group) spread right across the basin reaching practically to the edge of the divide. Failure of the river systems to re-establish their large deltas subsequent to the Late Miocene marine regression indicate that the Eocene sediment regime was reliant upon a large sediment supply such as from north of the divide and was not repeated.

EUSTACY AND CYCLIC SEDIMENTATION

The cyclical sedimentation may be attributed to two types of related causes:

i, those from outside the local area, e.g. tectonic changes, or world wide eustatic sea level changes;

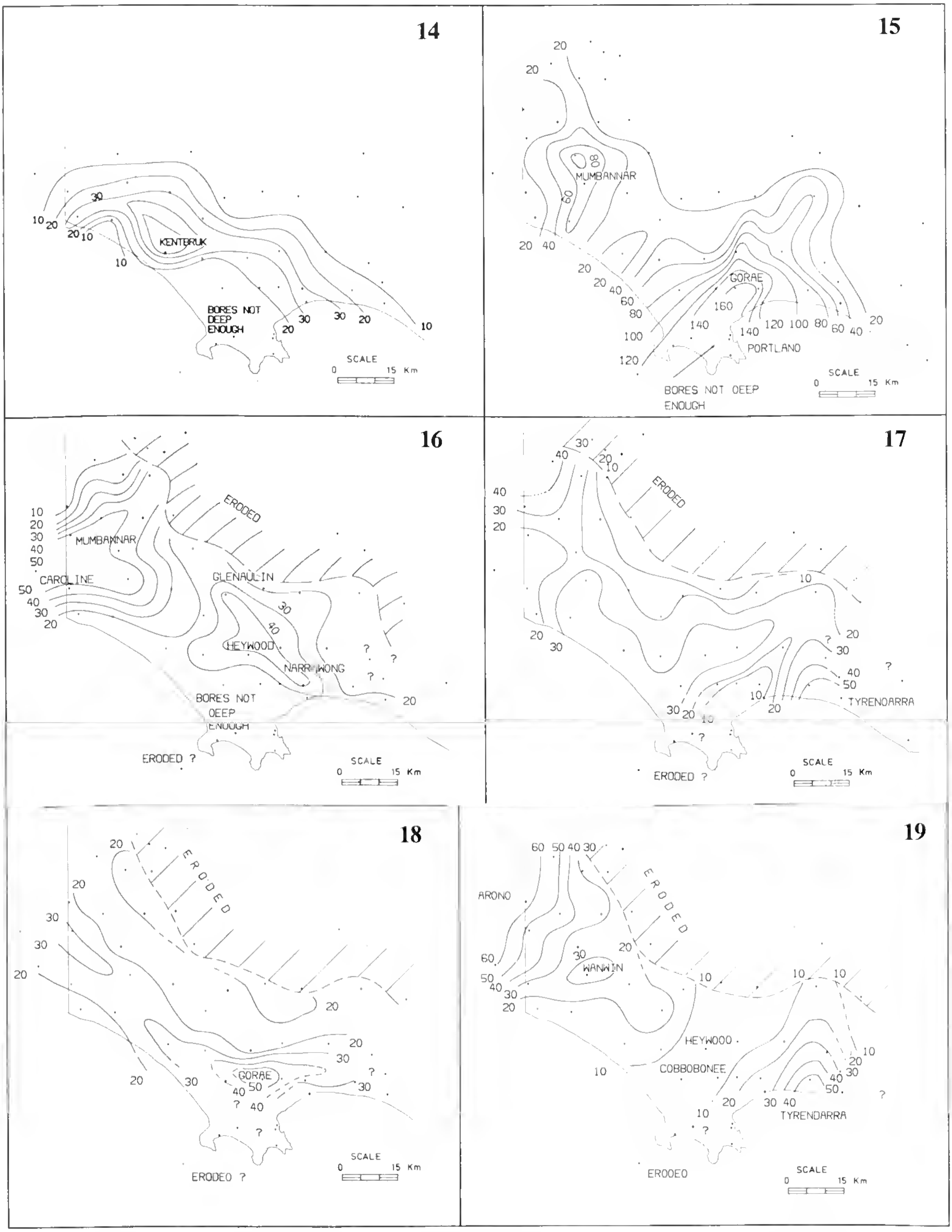
ii, those entirely within the local environment, e.g. delta cycles produced by the shifting and abandonment of successive delta lobes.

The relative contribution each one makes to any given sequence of strata is subject to individual interpretation. In the Otway Basin cyclic sedimentation is considered in terms of time, stratigraphic thickness and area distribution.

The primary cycles consist of four main transgressive-regressive events (Bock & Glenie 1965), which relate to tectonics and eustacy and their interactions with basin development (Glenie *et al.* 1968). The Dilwyn Formation is described by them as one major coarsening upward-decreasing marine influenced regressive cycle, commencing with a rapid transgressive phase at the base (Pebble Point Formation, and Pember Mudstone Member), grading up into a slow regressive phase (undifferentiated Dilwyn Formation and Dartmoor Sand Member). The Burrungule Member was not recognised at this time and the Mepunga Formation became the base of a new cycle of marine transgression.

Second order cycles were referred to by Bock & Glenie (1965) as subcycles, but were not elaborated upon. The time span and stratigraphic thickness of second order cycles are probably more closely analogous to the eustatic cycles identified in the Gippsland Basin (Partridge 1976). As these eustatic cycles are best defined from good quality seismic and palynological data they are not so easily identified in the study area. By inference some of the major intra-Dilwyn Formation events may relate to contemporaneous eustatic events in the Gippsland Basin as suggested by Partridge (1976), but remain to be better defined.

Third order cycles are those created by local changes in depositional environment. These are the fundamental



Figures 14-19—Central Otway Basin isopachs (metres) of Pember sand (14), Cycle A sand (15), Cycle B lower sand (16), Cycle B upper sand (17), Cycle C lower sand (18), Cycle C upper sand (19).
]

factors which contribute to the cyclic sedimentary sequences in the Dilwyn Formation. Each cycle commences with a rapid marine transgression across the area followed by slower regression which accompanied the differential filling by clastic sediments of the newly created basin. These transgressive events are interpreted to have been similar to those occurring in modern lobate deltas such as the Mississippi Delta (Fisk *et al.* 1954). In the Mississippi case a series of overlapping delta lobes were created by the shifting of distribution channels into new areas during Pleistocene to Recent times. Once abandoned, each delta lobe continued to subside and hence underwent subsequent partial destruction during renewed marine transgression.

Reworking of the topmost sand in each Dilwyn cycle accompanies the seven transgressive phases, as identified by the sharp upper contacts associated with carbonate cemented sands. This contact signals the start of a new cycle by abandonment of sediment supply. The earliest transgressive phase was the deepest and most stable and was accompanied by the deposition of more than 100 m of prodelta shales (the Pember Mudstone) in interdistributary areas, and more than 600 m of sands and shales at the lobate delta mouths of the main distributaries (Cycle A and Pember Mudstone). In this cycle the rate of deposition would necessarily exceed the rate of subsidence (Curtis 1970).

A major intra-formational event at the end of Cycle A occurred and altered the depositional pattern from one of thick lobate high constructive deltas to one of thinner, individually more linear and parallel to the palaeoshorelines, stacked delta cycles with characteristics similar to tidal dominated deltas. It is tempting to associate this change with one of the Gippsland Basin's eustatic events within the *M. diversus* Zone, but equally its causes may be related to fundamental changes in the local distribution patterns. Each cycle averages about 80 m in thickness (which may tentatively indicate approximate water depths by the methods outlined by Klien 1974), even though the component lithologic units show marked lateral thickness variations. By comparison with examples given by Curtis (1970) this is more likely to indicate a widespread and uniform subsidence rate with an equal rate of sediment supply. The relative influence of the marine environment does not appear to decrease from one cycle to the next, rather grain size analyses show that each cycle is a replica of the one below. This appears to contradict the overall first order cycle scheme of Bock & Glenie (1965) which predicts a decrease upwards in marine influence concurrent with an increase in grain size. In fact, at no time was the Portland Trough remote from marine influence. Areas peripheral to the trough became ones of non-deposition and erosion as subsidence continued without an adequate sediment supply, so that when marine transgression did occur throughout the basin in the Late Eocene a major unconformity had been formed.

Hence in the study area, and also probably throughout the Otway Basin, the depositional cycles of the Dilwyn Formation can be considered more in terms of the depositional processes acting within, rather than the vertical and lateral facies changes being a consequence of any basin wide tectonic or eustatic cycle. By analogy the underlying Late Cretaceous Sherbrook Group which comprises a similar clastic sequence could also be considered in these terms.

OFFSHORE TRENDS

Despite the lack of adequate well control offshore (1 only), the following trends are considered likely to occur:

The Portland Trough is open to the southeast and probably extends some distance offshore into Portland Bay. In doing so it may close against the offshore extension of the Warrnambool Ridge, or it may cross the front of this ridge to connect with a secondary Tertiary depocentre off the Port Campbell Embayment (Fig. 1).

North to south bore hole cross sections (Wopfner *et al.* 1971, Abele *et al.* 1976) and seismic interpretations (e.g. Robertson *et al.* 1978) indicate that the Wangerrip Group thins out beneath the middle and outer continental shelf areas. Offshore wells in the Port Campbell Embayment and South Australian part of the Gambier Embayment indicate this to be the case. In most instances deltas are observed to thin offshore in a similar manner.

It can be anticipated from the delta model that in the offshore areas the Dilwyn Formation would become increasingly shaly to the detriment of sands. The only offshore well in the study area (Voluta 1) was sited along the line of the major distributary channel of the Pember Mudstone and encountered a sand section over 250 m thick, indicating this lobate delta extended seawards of the present shoreline by up to 7 km. Similar thick sand sequences occur in the closest DMEV bores at Portland and near Cape Bridgewater. From palynological results (Ripper 1976) and lithostratigraphic correlation (this paper) none of these DMEV bores reached the base of the Tertiary as previously suggested by Glenie and Reed (1961) and Leslie (1966). This is due to the substantial thickening in the overlying Heytesbury Group, and the depth limits of the DMEV drilling rigs. The full Dilwyn sequence has not been penetrated in this area. Criteria for recognition of the Pebble Point Formation have been discussed by Holdgate (1977c). Similar lithologies have not been observed in any of the Portland bores, but are present in the sidewall cores in Voluta 1 at 1300 m and 1320 m.

The suspected lack of delta cycles B through G in Voluta 1 indicates either they did not prograde this far offshore, or else were removed by subsequent erosion prior to deposition of the Late Eocene Mepunga Formation. The closing of the isopach contours on Fig. 3 suggests considerable thinning of the total Dilwyn Formation offshore in Discovery Bay. No Middle Eocene (Burrungule Member) sediments are present in Voluta 1 suggesting that it is on a structurally high position relative to the Portland Trough similar to areas north of the Tartwaup Fault. This fact would suggest some erosion of the topmost Dilwyn beds has occurred between the Lower and Upper Eocene.

Deep water canyons (Bridgewater canyons), and buried canyons on the continental slope 36 km southwest of Cape Bridgewater (Fig. 1) have been discussed by Hopkins (1966) and Von der Borch (1968). Both authors assign a later Tertiary age for the canyons. It appears more than coincidental that as river cut features in an area where substantial rivers onshore are lacking, they should occur on line to the major Early Eocene channels of the Dilwyn Formation. This age is similar to that assigned to other canyon cutting episodes in southern Australia (Von der Borch 1968). It, therefore, could be argued that while the present canyon sediment fill has a Late Tertiary age they reflect deeper subsurface early Tertiary cutting events when larger rivers occurred in this area, and when a marked shelf break may not have existed. In this way they are similar to the association of past and present canyons on the continental slopes off the Gippsland Basin.

Hydrocarbon Prospects

In Otway Basin summaries (Wopfner *et al.* 1971, Robertson *et al.* 1978) the Dilwyn Formation is considered to be less attractive as a hydrocarbon prospect than the underlying Cretaceous sediments, due mainly to fresh water flushing and the lack of sufficient overburden.

The Portland Trough has not been drilled for oil, and its definition has only recently been established by DMEV drilling. For the following reasons this trough may hold more promise:

1. The Dilwyn Formation is thicker here, and buried deeper than other parts of the basin. If trends continue, the offshore extensions to the trough should see the lower part of the Pember Mudstone reach burial depths over 2000 m, giving a better chance to find these sediments at sufficient maturity.
2. The Tertiary sediment pile in the trough is thick, and was deposited more rapidly than in surrounding areas of the basin. In the Dilwyn Formation the sediments were deposited in a deltaic environment. These factors are considered to have an important bearing on the hydrocarbon producing areas in the offshore Gippsland Basin (Kantsler *et al.* 1978).
3. As a source rock the thick shales of the Pember Mudstone contain abundant coaly organic matter. Some vitrinite reflectance values (Ro max %) in the centre of the onshore trough are up to 0.56% at 1560.9 m (A. J. Kantsler pers. comm.). Deeper burial offshore could see these values increased to bring the sediments into the oil window at 0.60%.
4. The sands of the Pember Mudstone have porosities of 28% or above (Laing in Holdgate 1977a), and include beach and offshore bar environments. They occur as lenses and linear bodies which in the more distal regions of the trough away from the main distributary centres are likely to be isolated from major fresh water flushing paths. They are also likely candidates for porosity pinchouts.
5. None of the deeper Tertiary sands in the Portland Trough have been tested, although shows of hydrocarbons on gas detectors and encouraging wire line log interpretations have been made (Laing in Holdgate 1977a). The upper beds of the Sherbrook Group and the Pebble Point Formation also contain some potential as provided by the shale seals of the Pember Mudstone and the unconformable relationship between the Upper Cretaceous and Tertiary sediments.

ACKNOWLEDGEMENTS

This paper is published with permission of the Director of Geological Survey Division, Department of Minerals and Energy, Victoria. The writer also wishes to thank colleagues in the Survey who participated in discussions on this work, and the draughting group of E. & G. Division, State Electricity Commission of Victoria.

REFERENCES

Abele, C., Kenley, P. R., Holdgate, G. R. & Ripper, D., 1976. Otway Basin. In Geology of Victoria. J. G. Douglas & J. A. Ferguson, eds, *Geol. Soc. Aust. Spec. Publ.* 5: 198-229.

Baker, G., 1943. Features of a Victorian limestone coastline. *J. Geol.*, 51: 359-386.

Baker, G., 1950. Geology and physiography of the Moonlight Head district. *Proc. R. Soc. Vict.* 60: 17-44.

Baker, G., 1953. The Relationship of *Cyclammina* bearing sediments to the older Tertiary deposits south-east of Princetown, Victoria. *Mem. natn. Mus. Vic.* 18: 125-134.

Baker, G., 1961. Studies of Nelson Bore Sediments, Western Victoria. *Bull. geol. Surv. Vict.* 58.

Bock, P. E. & Glenie, R. C., 1965. Late Cretaceous and Tertiary depositional cycles in south-western Victoria. *Proc. R. Soc. Vict.* 79: 153-163.

Boutakoff, N., 1952. The structural pattern of south-west Victoria. *Min. Geol. J. Vict.* 4(6): 21-29.

Boutakoff, N. & Sprigg, R. C., 1953. Summary report on the petroleum possibilities of the Mount Gambier Sunklands. *Min. Geol. J. Vict.* 5(2): 28-42.

Bowen, K. G., 1974. Potassium—argon dates—determinations carried out for the Geological Survey of Victoria. *Rep. geol. Surv. Vict.* 1974/79 (Unpubl).

Busch, D. A., 1971. Genetic Units in delta prospecting. *Bull. Am. Assoc. Petrol. Geol.* 55: 1137-1154.

Curtis, D. M., 1970. Miocene deltaic sedimentation, Louisiana Gulf Coast. In Deltaic sedimentation modern and ancient. J. P. Morgan & R. H. Shaver, eds, *Soc. Eco. Pal. and Miner, Spec. Publ.* 15: 293-308.

Denham, J. I. & Brown, B. R., 1976. A new look at the Otway Basin. *APEA J.* 16: 91-98.

Fisher, W. L., 1969. Facies characterisation of Gulf Coast Basin delta systems, with some Holocene analogues. *Trans. Gulf Cst Ass. geol. Socs* 19: 105-125.

Fisk, H. N., McFarlan, E., Jr, Kolb, C. R., & Wilbert, L. J., Jr, 1954. Sedimentary framework of the modern Mississippi delta. *J. sedim. Petrol.* 24: 76-99.

Galloway, W. E., 1968. Depositional systems of the Lower Wilcox Group, North Central Gulf Coast Basin. *Trans. Gulf Cst Ass. geol. Socs* 18: 275-289.

Gill, E. D., 1975. Evolution of Australia's unique flora and fauna in relation to the Plate Tectonics Theory. *Proc. R. Soc. Vict.* 87: 215-234.

Glenie, R. C. & Reed, K. J., 1961. Bores 2 & 3 Portland, Victoria—subsurface geology and engineering data. *Min. Geol. J. Vict.* 6: 37-46.

Glenie, R. C., Schofield, J. C. & Ward, T. W., 1968. Tertiary sea levels in Australia and New Zealand. *Palaeogeogr. Palaeoclimat. Palaeoecol.* 5: 141-163.

Goode, A. D. T. & Williams, G. E., 1980. Possible western outlet for an ancient Murray River in South Australia 3. Reply. *Search* 11: 227-230.

Gostin, V. A. & Jenkins, R. J. F., 1980. Possible western outlet for an ancient Murray River in South Australia 1. An alternative viewpoint. *Search* 11: 225-226.

Harris, W. K., 1965. Basal Tertiary microfloras from the Princetown area, Victoria, Australia. *Palaeontographica B* 115: 75-106.

Harris, W. K., 1966. New and redefined names in South Australian Lower Tertiary stratigraphy. *Quart. geol. Notes. geol. Surv. S. Aust.* 20: 1-3.

Harris, W. K., Lindsay, J. M., & Twidale, C. R., 1980. Possible western outlet for an ancient Murray River in South Australia 2. A discusion. *Search* 11: 226-227.

Holdgate, G. R., 1975. Wanwin No 1. Water bore completion report. *Rept. geol. Surv. Vict.* 1975/25 (unpubl.).

Holdgate, G. R., 1977a. Warrain No 7. Well completion report. *Rept. geol. Surv. Vict.* 1977/54 (unpubl.).

Holdgate, G. R., 1977b. Malanganee No 4. Well completion report. *Rept. geol. Surv. Vict.* 1977/66 (unpubl.).

Holdgate, G. R., 1977c. Subsurface stratigraphy of the Victorian section, Gambier Embayment—Otway Basin. Part 1 The Pebble Point Formation. *Rept. geol. Surv. Vict.* 1977/10 (unpubl.).

Hopkins, B. M., 1966. Submarine canyons. *BHP Tech. Bull.* 26: 39-43.

Kantsler, A. J., Cook, A. C., & Smith, G. C., 1978. Rank variation, calculated palaeotemps. *The Oil & Gas Jour.* 20 Nov.: 196-205.

Kemp, E. M., 1978. Tertiary climatic evolution and vegetation history in the south-east Indian Ocean region. *Palaeogeogr. Palaeoclimat. Palaeoecol.* 24: 169-208.

Kenley, P. R., 1971. Cainozoic geology of the eastern part of the Gambier Embayment, south-western Victoria. In *The Otway Basin of south-eastern Australia.* H. Wopfner & J. G. Douglas, eds, Spec. Bull. geol. Survs. SA & Vict., 89-153.

Klien, G. de V., 1974. Estimating water depths from analysis of barrier island and deltaic sedimentary sequences. *Geology* 2: 409-412.

Lawrence, C. R., 1975. Geology, hydrodynamics and hydrochemistry of the southern Murray Basin. *Mem. geol. Surv. Vict.* 30.

Lawrence, C. R., 1976. Groundwater. In Geology of Victoria. J. G. Douglas & J. A. Ferguson, eds, *Geol. Soc. Aust. Spec. Publ.* 5: 411-417.

Leslie, R. B., 1966. Petroleum exploration in the Otway Basin. *Proc. 8th Comm. Min. Metall, Congr., Aust & NZ.* 5: 203-216.

Ludbrook, N. H., 1971. Stratigraphy and correlation of marine sediments in the western part of the Gambier Embayment. In *The Otway Basin of south-eastern Australia.* H. Wopfner & J. G. Douglas, eds, Spec. Bull. geol. Survs. SA & Vict. 47-66.

Martin, H. A., 1977. The Tertiary stratigraphic palynology of the Murray Basin in New South Wales. 1. The Hay-Balranald-Wakool Districts. *J. Proc. R. Soc. N.S.W.* 110: 41-47.

McGowran, B., 1973. Observation bore No 2, Gambier Embayment of the Otway Basin. Tertiary micropaleontology and stratigraphy. *SA. Min. Res. Rev.* 135: 43-55.

McGowran, B., 1978. Early Tertiary foraminifera biostratigraphy in Southern Australia. A progress report. *Bull. Bur. Miner. Resour. Geol. Geophys. Aust.* 192: 83-95.

Partridge, A. D., 1976. The geological expression of eustacy in the Early Tertiary of the Gippsland Basin. *APEA J.* 1976: 73-79.

Ripper, D. T., 1976. Otway Basin, Victoria/South Australia—spore pollen, microplankton bar-chart compilation for Otway Basin bores. *Rept. geol. Surv. Vict.* 1976/90 (unpubl.).

Robertson, C. S., Cronk, D. K., Mayne, S. J., & Townsend, D. G., 1978. A review of petroleum exploration and prospects in the Otway Basin region. *Bur. Min. Resour. Geol. Geophys. Record* 1978/91 (unpubl.).

Schlumberger, 1970. *Fundamentals of dipmeter interpretation.* Course notes to dipmeter interpretation conference, Melbourne July 1972. Schlumberger Ltd.

Selley, R. C., 1976. Subsurface environmental analysis of North Sea sediments. *Bull. Am. Assoc. petrol. Geol.* 60: 184-195.

Smith, A. E., Jr, 1966. Appendix. Modern Deltas: Comparison Maps. In *Deltas in their geological framework,* M. L. Shirley, ed., Houston geol. Soc., 233-251.

Stover, L. E., & Partridge, A. D., 1973. Tertiary and Later Cretaceous spores and pollen from the Gippsland Basin, south-eastern Australia. *Proc. R. Soc. Vict.* 85: 237-286.

Von Der Borch, C. C., 1968. Southern Australian submarine canyons: their distribution and ages. *Marine Geol.* 6: 267-279.

Weber, K. J., 1971. Sedimentological aspects of oil fields in the Niger Delta. *Geologie Mijnb.* 50: 559-576.

Wellman, P., 1974. Potassium-argon ages on the Cainozoic volcanic rocks of eastern Victoria, Australia. *J. geol. Soc. Aust.* 21: 359-368.

Williams, G. E., & Goode, A. D. T., 1978. Possible western outlet for an ancient Murray River in South Australia. *Search* 9: 442-447.

Wopfner, H., Kenley, P. R., & Thornton, R. C. N., 1971. Hydrocarbon occurrences and potential of the Otway Basin. In *The Otway Basin of south-eastern Australia.* H. Wopfner & J. G. Douglas, eds, *Spec. Bull. Geol. Survs. SA & Vict.* 385-435.

TERTIARY FLUVIAL SEDIMENTS AT MORRISON, VICTORIA

By Paul Bolger

Geological Survey of Victoria, 107 Russell Street, Melbourne, Victoria, 3000

(*Present Address*: Herman Research Laboratory, State Electricity Commission of Victoria, Howard Street, Richmond, Victoria 3121)

Abstract: Tertiary fluvial sediments underlying the Newer Volcanics in the Morrison area, Victoria, are subdivided into two units. The basal Ballark Conglomerate is very coarse grained, consisting of locally derived Ordovician bedrock clasts. Originally considered to be of Permian age its conformable relationship to the overlying 'Sub-basaltic sediments' suggests a Tertiary age. The 'Sub-basaltic sediments' grade vertically from the Ballark Conglomerate, are finer grained and contain abundant vein quartz and subordinate Ordovician sandstone clasts. Extensive areas of the sediments have been silicified. Clasts of the silcrete occur in the upper beds of the 'Sub-basaltic sediments', enabling subdivision into an upper and lower unit. Palaeocurrent analyses in the Ballark Conglomerate and the basal beds of the 'Sub-basaltic sediments' and examination of the distribution of Newer Volcanic flows in this area and further west, suggest a major drainage reversal from northward to southward prior to basalt extrusion.

INTRODUCTION

Tightly folded Ordovician bedrock is overlain by flat-lying Tertiary conglomerate, gravel, sand, silt and clay and basalts of the Newer Volcanics in the Meredith-Morrison-Elaine area. The area is located within an elevated block of Lower Palaeozoic bedrock that is marginal to the Tertiary Otway and Port Phillip Basins and the 'Ballan Graben' (Fig. 1).

The Tertiary sequence is subdivided into a thick, massive basal conglomerate, named the Ballark Conglomerate (Bolger 1977), and an overlying unit of interbedded gravel, sand, silt, clay and rare tuff referred to informally in this paper as 'the Sub-basaltic sediments'. These units are exposed along the valleys of the Moorabool River and Tea Tree Creek at Morrison (Fig. 1). Selwyn and Ulrich (1866), Brough-Smyth (1869), Dunn (1907), Hunter (1909), Harris and Thomas (1949), Makram and Neilson (1970) and Jahnke (1973) all referred to the massive conglomerate at Morrison, but it was never described in detail. The purpose of this paper is to describe the Ballark Conglomerate and the overlying sediments and to discuss their age, and depositional environment.

BALLARK CONGLOMERATE

The Ballark Conglomerate (Bolger 1977) is a coarse grained deposit, cropping out along the valleys of the Moorabool River and Tea Tree Creek and exposed in a water race on the slopes leading down to Dolly's Creek at Morrison (Fig. 1). It is also known from bores and mine workings in the area. The type locality of the Ballark Conglomerate is the exposure on the south side of the valley of Tea Tree Creek (Grid reference 166.393, Meredith 1:63 360 map).

The Ballark Conglomerate (Fig. 3) is a poorly sorted orthoconglomerate with a maximum observed clast diameter of 1 m and a median maximum diameter between 10 and 15 cm. The framework consists of 70% arenaceous clasts (quartzitic sandstone and greywacke), 15% slate and siltstone and 15% quartz. Sandstone and quartz cobbles and boulders are rounded to well rounded and tend to be ellipsoidal. Slate casts are platey, often have rounded edges and are strongly imbricated. Quartz pebbles are usually equant and subrounded. The matrix consists of angular to subangular, coarse to very coarse sand and granule gravel consisting of quartz, muscovite and deeply weathered, platey, slate clasts weakly bound by interstitial clay and silt. The Ballark Conglomerate is usually friable, although 3.5 km north of Morrison along the east bank of the Moorabool River, the clasts are closely compacted and cemented by limonite. It is massive and homogeneous and apart from trough-crossbedded coarse-sand lenses up to 0.5 m thick, bedding is not recognisable. Along the Moorabool River, exposures of the conglomerate are up to 30 m high and at the type locality are 8 m high. Selwyn and Ulrich (1866) recorded about 120 m of 'Miocene gravel' from Tea Tree Creek. Brough-Smyth (1896) recorded a thin basal unit comprising gravel, black clay containing fossil trees and grey sandy clay containing gold, overlain by more than 100 m of conglomerate in the Golden Rivers mine along Tea Tree Creek. This basal unit is not exposed but is here included in the Ballark Conglomerate.

The base of the Ballark Conglomerate is not exposed but it overlies Ordovician bedrock along Tea Tree Creek (Brough-Smyth 1869). In the Borhoneyghurk 1 bore near Morrison 135 m of conglomerate rests on Ordovician bedrock. The basal 35 m contains granite boulders, up to 1.5 m in diameter, which may be glacial erratics. The basal 35 m is thus inferred to be of glacigene origin, and excluded from the Ballark Conglomerate. Although the contact between the Ballark Conglomerate and the Ordovician bedrock is not exposed, outcrops along the Moorabool River suggest a sharp, steep boundary and a high angular unconformity is inferred. The Conglomerate grades into the overlying sub-basaltic sediments with a decrease in the percentage of slatey clasts. The top of the Ballark Conglomerate is taken to be the uppermost bed of coarse conglomerate containing sandstone, quartz and more than 8% slatey clasts.

SUB-BASALTIC SEDIMENTS

Up to 40 m of terrigeneous sediments comprising poorly consolidated interbedded gravel, sand, silt, clay and rare tuff underlie the Newer Volcanics along the Moorabool River and Tea Tree Creek and are known from the bores between Morrison and Elaine. To the east and west of Morrison, silicified quartz gravel and sand forms part of an extensive plateau (Fig. 1). Ferruginous sands and gravels occur north of Morrison.

The gravels consist mostly of quartz clasts with smaller amounts of sandstone, slate and siliceous sandstone and conglomerate. Quartz pebbles are usually less than 10 cm in diameter and occur either as equant, subangular to rounded, or as well rounded, platey and rodlike grains. Platey clasts are imbricated. Sandstone and silcrete clasts are usually less than 10 cm in length and are well rounded and ellipsoidal. The coarsest beds are at the base of the unit, where there are well rounded cobbles and pebbles of sandstone and quartz up to 30 cm in length (Fig. 4). Fine to medium grained cross-bedded and horizontally-bedded sand, pebbly sand, clayey sand, silt and clay are interbedded with the gravel. Sand beds are composed almost exclusively of common ('plutonic') quartz. Massive silt and clay units are up to 15 m thick. A 1 m thick planar-laminated tuff band exposed on the Moorabool River about 5 km north of Morrison consists largely of subangular quartz and plagioclase sand grains and pebbles of basalt in a clayey matrix.

The sub-basaltic sediments, at least in part, are considered to conformably overlie the Ballark Conglomerate. Locally the base of the sub-basaltic beds is transitional with the underlying Ballark Conglomerate, and comprises massive homogeneous pebble to cobble conglomerate, containing coarse sandstone and quartz but rare to absent slate or siltstone clasts. The basal coarse units grade vertically into interbedded gravel, sand, silt and clay (Fig. 4). The decrease in grain size is accompanied by a decrease in the number of lithic clasts.

Silcrete clasts do not occur in the Ballark Conglomerate, the transitional gravels at the base of the sub-basaltic sediments, nor in the silcretes on either side of the Moorabool River, but they are present in the upper beds of the sub-basaltic sediments. This suggests the existence of two units within the sub-basaltic sediments (Fig. 2), although the sparsity of silcrete clasts in the sediments makes detailed mapping difficult. It is suggested that a period of silcrete formation took place between deposition of the lower and upper units of the sub-basaltic sediments and that the upper unit disconformably overlies the lower. The duration of this break in deposition is not known.

PALAEONTOLOGY AND AGE

BALLARK CONGLOMERATE

The age of the Ballark Conglomerate has been disputed for many years. Dunn (1907), Kenny (1937), Harris and Thomas (1949) and Makram and Neilson (1970) considered the Ballark Conglomerate to be of Permian age. Harris and Thomas (1949) inferred a Permian age largely on the basis of large granite boulders in the basal 35 m of the Borhoneyghurk 1 bore. The abundance of slatey clasts in the Ballark Conglomerate gives it a similar appearance to Permian glacigene conglomerates in the Ballan and Bacchus Marsh areas to the north of Morrison. However, the wide variety of erratics recorded in the Permian beds (Bowen & Thomas, 1976) is not found in the Ballark Conglomerate, nor are faceted or striated pebbles. There is therefore no direct evidence in the exposures at Morrison to suggest either a glacial origin or a Permian age for the Ballark Conglomerate.

Selwyn and Ulrich (1866) and Brough-Smyth (1869) regarded the Ballark Conglomerate as Miocene, underlying Pliocene auriferous gravels and Newer Basalt. Hunter (1909, p. 116) concluded that 'the presence of large boulders and fossil logs tend to show that this material is of early Tertiary age'. The conformable relationship with the Tertiary sub-basaltic sediments establishes a Tertiary age for the Ballark Conglomerate.

No megafossils have been collected from the Ballark Conglomerate, but plant spores have been recovered from one sample of the conglomerate matrix in the top 5 m outcropping on the north side along Tea Tree Creek. The samples contained very few species but included a single specimen of *Tubuliforidites antipodica* which suggests a late Miocene age (*Triporopollenites bellus* Zone) (D. T. Ripper, V. Archer pers. comm. 1978). However, the micro-flora is not diagnostic and the precise age of the Ballark Conglomerate is still uncertain.

A basaltic tuff overlying the conglomerate contains clasts of basalt which resemble the early Miocene Maude Basalt, exposed 17 km south of Morrison (Bowler 1963), rather than the Older Volcanics of the Ballan Graben or the Newer Volcanics within the Morrisons area (R. A. Day pers. comm. 1981). The presence of these clasts supports the notion that the Ballark Conglomerate and the basal beds of the sub-basaltic sediments are of Early to Middle Tertiary age.

SUB-BASALTIC SEDIMENTS

The sub-basaltic sediments contain rare indeterminate compressions of fossil wood, but there are no palaeontological data to determine their precise age. However, similar sediments which are intimately associated with the Plio-Pleistocene Newer Volcanics throughout Victoria are customarily regarded as Pliocene (Abele *et al.* 1976) and are probably older in some areas. Thomas and Baragwanath (1950) partly equated gravel, sand and clay underlying the Newer Volcanics with the Rowsley Formation, in which they include sandy sediments overlying the brown coal in the Maddingley No. 1 Open Cut at Bacchus Marsh. The upper part of the sub-basaltic sediments at Morrison is considered to be partly equivalent to the Rowsley Formation. The basal beds

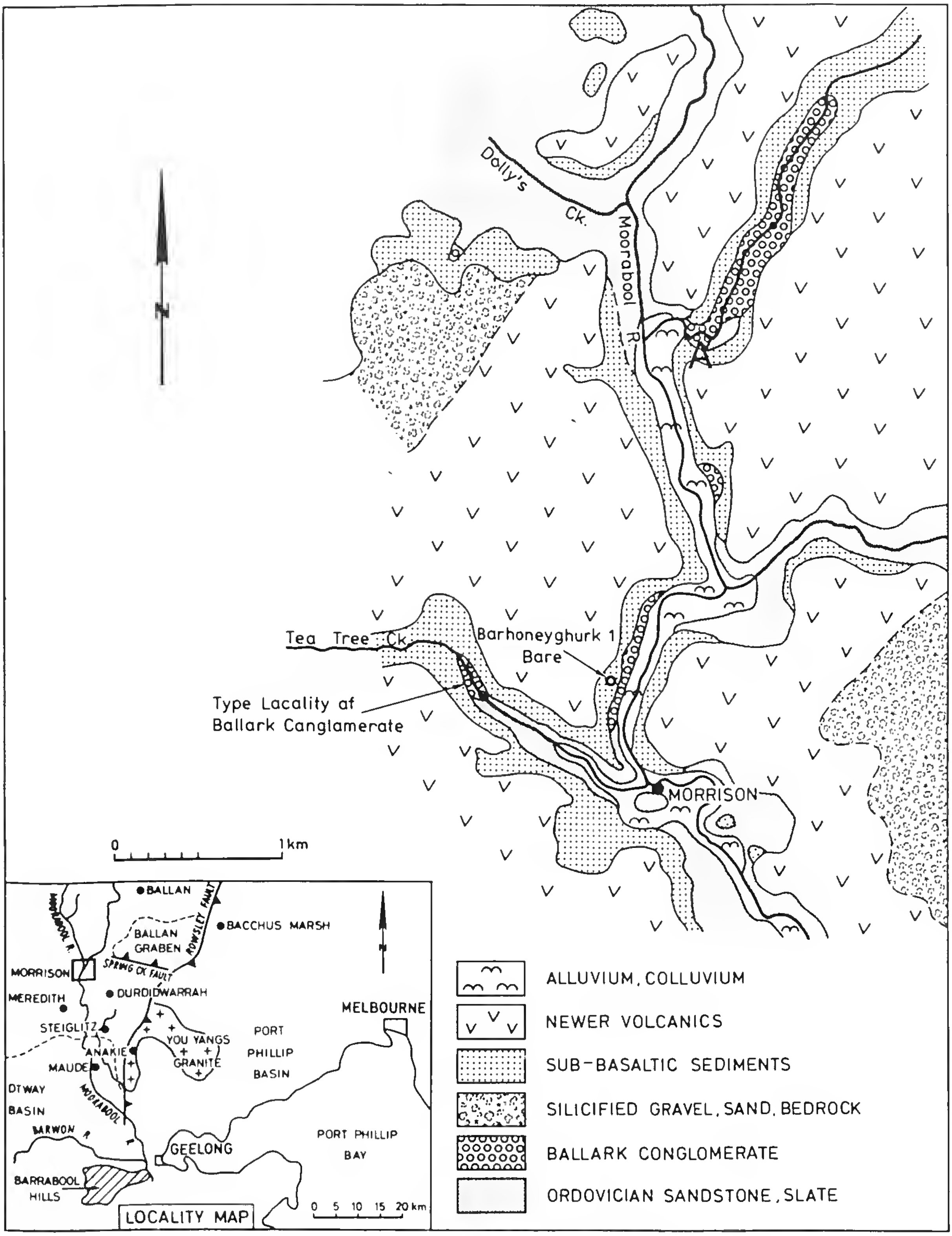


Fig. 1 – Geological map of the Morrison area. A marks site of section A of Fig. 2 and section B is at and in the vicinity of Borhoneyghurk No. 1 Bore.

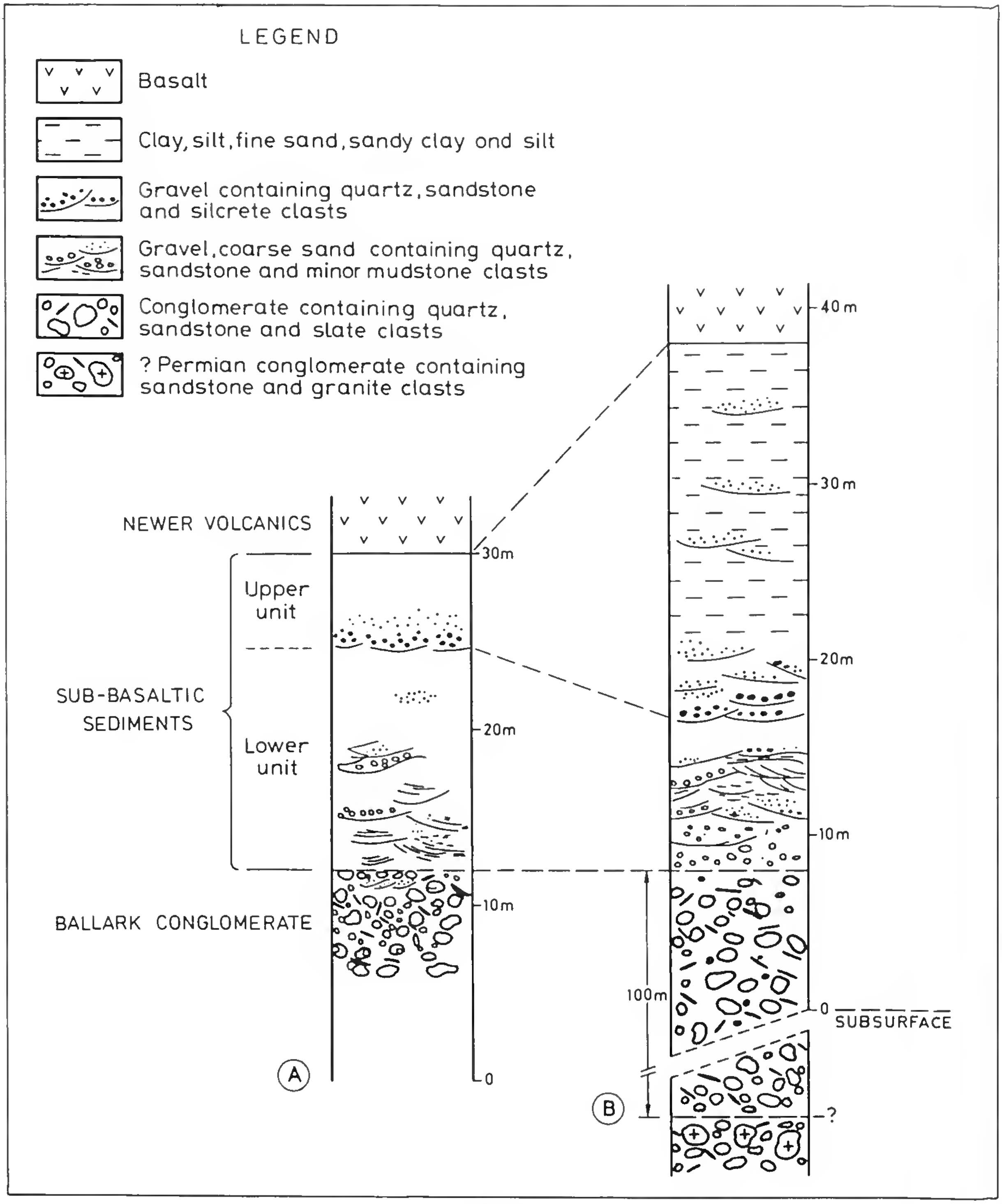


Fig. 2—Columnar sections of Tertiary rock units located on Fig. 1.

may be considerably older, perhaps Early to Middle Tertiary.

LITHOFACIES AND DEPOSITIONAL ENVIRONMENT

Poor exposure along the Moorabool River and Tea Tree Creek does not allow detailed facies analysis of the Tertiary sediments. However, 8 lithofacies are recognised in the sediments at Morrison and are briefly described below. Lithofacies nomenclature is after Miall (1977).

Fig. 3—Poorly sorted Ballark Conglomerate, Tea Tree Creek, Morrison.

Fig. 4—Basal units of Sub-basaltic sediments showing fining upward into interbedded gravel and sand.

LITHOFACIES TYPES

Lithofacies *Gm(bc)* comprises the coarse, poorly bedded and sorted, clast supported conglomerate of the Ballark Conglomerate. Platey clasts are strongly imbricated. Individual depositional units are generally unrecognisable although there are very rare trough cross-bedded coarse-sand lenses up to 1 m thick (Fig. 5).

Lithofacies *Gm(sb)* comprises the coarse cobble to pebble, upward fining conglomerates in the sub-basaltic sediments. Imbricated pebbles are present but less abundant in this lithofacies than in lithofacies *Gm(bc)* due to the smaller number of slate clasts. Individual units are 1-2 m thick (Fig. 4).

Trough cross-bedded gravels ranging from granule to pebble size comprise lithofacies *Gt*. Individual troughs with theta cross-bedding are up to 1 m deep. Gravel bands have erosional bases and thin lenticles of clay and silt are common.

Lithofacies *St* comprises trough cross-bedded very coarse sand with intercalated lenses of granule gravel up to 0.5 m thick. Troughs are generally less than 1 m deep. The sands are often clayey.

Units of horizontally bedded medium sand less than 1 m thick comprise lithofacies *Sh*, and planar cross-bedded coarse sands with individual sets up to 0.7 m, comprise lithofacies *Sp*. These occur locally in the sub-basaltic sediments.

Lithofacies *Fm* occurs in both the Ballark Conglomerate and the sub-basaltic sediments and comprises structureless clay, silt, silty and sandy clay, carbonaceous clay containing some plant remains and very thin gravelly bands. It occurs at the base of the Ballark Conglomerate (Brough-Smyth 1869) but is not exposed and is known only from old mining records. In the sub-basaltic sediments it occurs in thin units interbedded

Fig. 5—Trough cross-bedded sand in top 2m of Ballark Conglomerate, Moorabool River, Morrison.

with gravel and sand and also in thick units up to 15 m thick on the west bank of the Moorabool River.

Lithofacies Distribution and Interpretation of Depositional Environment

Three lithofacies assemblages are recognised, one in the Ballark Conglomerate and two in the sub-basaltic sediments.

Assemblage 1 comprises lithofacies *Gm(bc)*, rarely *St* and *Fm* at the base and is restricted to the Ballark Conglomerate. This assemblage is characteristic of deposits accumulated by superposition of longitudinal bars in gravel rivers (Miall 1977).

Assemblage 2 comprises the lithofacies *Gm(sb)*, *Gt*, *St*, *Sh*, *Sp* and *Fm* and is restricted to the sub-basaltic sediments. Lithofacies *Gm(sb)* appears to be common at the base of the sub-basaltic sediments and comprises much of the transition zone overlying the Ballark Conglomerate. Assemblage 2 contains graded cycles with basal *Gm(sb)* and *Gt* units overlain by *St* or less commonly *Sp* or *Sh* and sometimes *Fm* units. These cycles are considered to represent channel filling events in gravel streams.

The thick lithofacies *Fm* and locally *St* and *Gm(sb)* comprise Assemblage 3, which occurs within the uppermost beds of the sub-basaltic sediments. This assemblage represents deposition largely under conditions of low flow, with some point bar deposition. Its thickness in this area suggests prolonged deposition of fine sediment from suspension in standing water. The lithofacies represent abandoned channel and overbank deposits.

PALAEOCURRENT ANALYSIS

Pebble imbrication, determined by measuring the dip direction of the AB plane of platey clasts, was used to infer transport directions for both the Ballark Conglomerate and the basal gravel units of the sub-basaltic sediments. The data are summarised in Fig. 6.

The results suggest that currents depositing both the Ballark Conglomerate and the overlying sub-basaltic

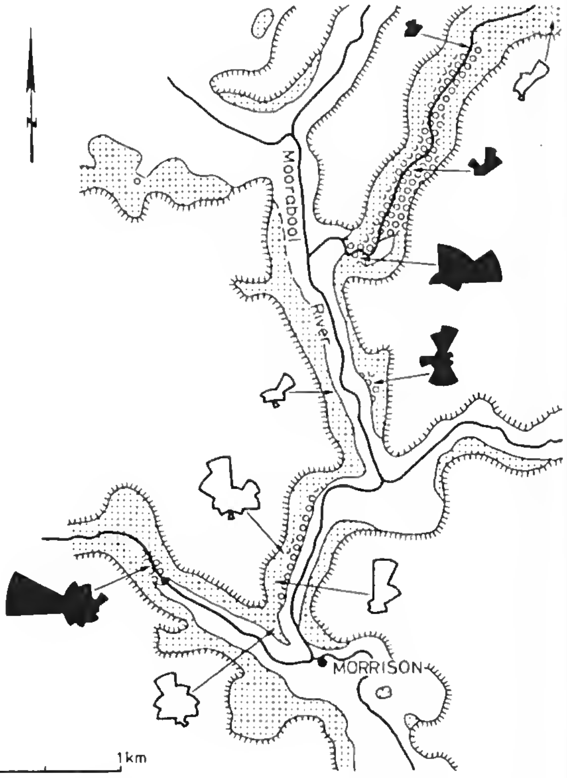


Fig. 6—Summary of palaeocurrent data. Filled roses refer to Ballark Conglomerate. Open roses refer to lower unit, Sub-basaltic sediments.

sediments moved from south to north, implying a drainage divide south of Morrison. This would suggest an uplifted zone to the south of Meredith, with streams transporting detritus into the 'Ballan Graben'. The orientation of poorly exposed trough cross-beds is consistent with transport directions from the south and south-west.

However, this interpretation of the palaeogeography is not consistent with the interpretation of the drainage system based on the distribution of Newer Volcanics in this area, which suggests a southerly palaeoslope. The basalt flows and associated deep leads in the Ballarat-Rokewood area, west of Morrison have southerly trends and flowed between elevated areas of Ordovician bedrock often capped with ferruginised Tertiary sediments. The youngest basalt flow at Morrison was also a valley flow restricted by cappings of silcrete, ferruginous Tertiary sediments and Ordovician bedrock. The modern Moorabool River system north of Morrison, comprising two lateral streams around this basalt flow, is southward flowing and follows the pre-basaltic drainage system.

It is suggested that the drainage system changed from northward flowing streams which deposited the Ballark Conglomerate and lower beds of the sub-basaltic sediments, to a southward flowing system reflected by the distribution of Newer Volcanic flows. It is considered to be largely the result of uplift on the Rowsley and Spring Creek Faults.

A drainage reversal of this type is problematical. There is no topographic evidence to support widespread river capture in the areas to the north of Morrison. Other than the appearance of silcrete clasts in the upper unit of the sub-basaltic sediments, no change in provenance reflected by the petrography of the sediments is recognised above or below the disconformity. However, this is not surprising as the likely source rocks both to north and south of Morrison are Ordovician sandstones, slates and associated quartz veins.

The timing of the inferred drainage reversal is not known, although it may coincide with final marine regression from the Durdidwarrah-Anakie area to the south in the late Miocene-Pliocene (Bolger & Russell in prep.).

The widespread occurrence of silcretes and their possible time relationship to the drainage reversal raises the possibility of silcrete formation resulting from severe alteration of the hydrological system imposed by the drainage reversal. Although spatially related to basalts of the Newer Volcanics, the genetic affinities of the silcretes and basalts are not clearly established (Bolger 1977).

CONCLUSION

Up to 120 m of coarse grained lithic detritus derived largely from the local Ordovician bedrock was deposited at Morrison to form the Ballark Conglomerate. The high lithic content in the Ballark Conglomerate is atypical of most Tertiary clastic deposits in Victoria and has led to some confusion about its age. However, its conformable relationship with more typical quartzose Tertiary fluvial deposits suggests that the Ballark Conglomerate is Tertiary.

The linear distribution of the Ballark Conglomerate and the nature of the basement topography suggest that it was deposited in a steep-sided narrow channel. The Conglomerate was deposited by a high energy gravel river flowing to the north or north-east. The single narrow channel eventually filled and a more widespread stream system was established. Extensive sheets of gravelly quartzose sediments comprising the basal beds of the sub-basaltic sediments were deposited above the Ballark Conglomerate and the Ordovician bedrock. Current directions remained northward. These deposits and the surrounding Ordovician bedrock were subsequently extensively silicified to form silcrete.

A southward flowing drainage system was initiated, probably in response to movement of the Spring Creek and Rowsley Faults. Incision into the lower units of the sub-basaltic sediments and the Ballark Conglomerate produced terraces. Detritus eroded from the silcrete cappings was deposited by southward flowing streams to form the upper parts of the sub-basaltic sediments at Morrison. Sedimentation at Morrison was terminated by the extrusion of the youngest basalt flow over the sub-basaltic sediments. Lateral streams with deep valleys have subsequently been entrenched.

ACKNOWLEDGEMENTS

The author thanks Dr J. G. Douglas for encouragement during the course of this investigation and T. G. Russell for constructive criticism of the manuscript. Figures were drafted by Mr G. Held of the S.E.C.V. The work was undertaken and the paper published with the permission of the Director of the Geological Survey of Victoria.

REFERENCES

Abele, C., Kenley, P. R., Holdgate, G. & Ripper, D., 1976. Otway Basin. *Spec. Publ. geol. Soc. Aust.* 5: 198-229.

Bolger, P. F., 1977. Explanatory notes on the Meredith and You Yangs 1:50 000 geological maps. *Rept. geol. Surv. Vict.* 1977/14.

Bolger, P. F. & Russell, T. G. (in prep). Late Tertiary marine transgression in the Brisbane Ranges, Victoria.

Bowen, R. L. & Thomas, G. A., 1976. Permian. *Spec. Publ. geol. Soc. Aust.* 5: 123-142.

Bowler, J. M., 1963. Tertiary stratigraphy and sedimentation in the Geelong-Maude area, Victoria. *Proc. R. Soc. Vict.* 76: 69-137.

Brough-Smyth, R., 1869. *The goldfields and mineral districts of Victoria.* John Ferres, Govt Printer, Melbourne.

Dunn, E. J., 1907. Geological parish plan, Ballark. *Mines Dept. Melb.*

Harris, W. J. & Thomas, D. E., 1949. Geology of the Meredith area. *Min. geol. J. Vict.* 3: 43-51.

Hunter, S., 1909. Deep leads of Victoria. *Mem. geol. Surv. Vict.* 7.

Jahnke, F. M., 1973. Structural geology of the Morrisons area. BSc (Hons) Univ. Melb. (unpubl).

Makram, A. E. & Neilson, J. L., 1970. Notes on the geology of the Meredith 1:63 360 military sheet. *Rept. geol. Surv. Vict.* 1970/84 (unpubl.).

Miall, A. D., 1977. A review of the braided river depositional environment. *Earth-Sci. Rev.* 13: 1-62.

Selwyn, A. R. C. & Ulrich, G. H. F., 1866. Notes on the physical geography, geology and mineralogy of Victoria. *Intercolonial Exhibition Essays* 1866-67, 83.

Thomas, D. E. & Baragwanath, W., 1950. The geology of the brown coals of Victoria—Part 3. *Min. geol. J. Vict.* 4: 41-63.

SHORT COMMUNICATIONS

TAXONOMIC STATUS OF THE VICTORIAN FOSSIL WHALE, *ZIPHIUS (DOLICHODON) GEELONGENSIS* McCOY 1882

Frederick McCoy (1882) based *Ziphius* (*Dolichodon*) *geelongensis* on a supposed mandibular tooth of a beaked whale (Family Ziphiidae, Suborder Odontoceti). The holotype and only described specimen is now curated as NMV P7464, National Museum of Victoria, Melbourne. It was collected by either Mr Legge, Mr Price, or Mr Nelson, from 'Waurn Ponds Quarries", near Geelong, Victoria, Australia (grid reference about BT611682 (1:100 000 map, Series R 652, Sheet 7721, Geelong) or about 38°16'S, 144°16'E). The holotype almost certainly came from the Waurn Ponds Member of the Jan Juc Formation (Torquay Group), which Abele *et al.* (1976, fig. 13) indicated is of Late Oligocene to earliest Miocene age. The description of the specimen given by McCoy (1882) obviates the need for discussion of all but a few morphological details, below. Collection details of the holotype were outlined by Mahoney and Ride (1975).

DISCUSSION

McCoy believed the holotype of *Z. geelongensis* to be a mandibular tooth similar to those of the extant strap-toothed whale, *Mesoplodon layardi* (Gray 1865) (Ziphiidae) as shown, for example, by Gray (1865, fig. b) and McCann (1962, fig. 5a).Presumably, for this reason, Chapman (1917, p. 32) employed the combination *Mesoplodon geelongensis*. Unlike these authors, however, I believe the holotype to be a fragment of bone, probably rib. Haversian canals are seen in a thin section of a fragment of the specimen, and there is no trace of enamel or dentine prisms. While most of the element is dense and compact, macroscopic vacuities like those of cancellous bone are present near the axis at both ends of the element. These are not evident in McCoy's figures (1882, pl. 69). Although teeth of adult ziphiids often lack an enamel crown and do not retain an open pulp cavity at the apical end of the tooth when the more basal part of the cavity is occluded (e.g. Flower 1872, Christensen 1973, fig. 2), McCoy (1882, p. 25) assumed the "crown" (enamel?) to have "surmounted the large pulp cavity on the outer face of the distal end". McCoy stated that the surface consists of a very thin layer of cement, but none is identifiable, and the surface layer appears to be weathered bone. Finally, there is no evidence, in section, of occlusion of the axial "pulp cavity" by layers of cementum which, in other odontocetes, form axially concentric rings.

It is impossible to ascertain to which taxon the undiagnostic holotype should be referred, although its large size, anteroposterior flattening, and the occurrence of other cetacean bones in the Waurn Ponds Limestone Member indicate that it is probably a cetacean. Thus, I suggest that the name *Ziphius* (*Dolichodon*) *geelongensis* McCoy 1882 is a *nomen dubium* and that it should be allowed to lapse. This suggestion is unlikely to affect even the more obscure aspects of cetacean systematics for the species has received little mention in literature. It has been mentioned only occasionally in local literature (e.g. Tate 1888, p. 247, Hall & Pritchard 1894, p. 185, Dennant & Kitson 1903, Gregory 1914, Mulder 1914, Richards 1922, Mahoney & Ride 1975, p. 163), and this supposed record of *Ziphius* and *Mesoplodon* was not included in standard lists of fossil and recent cetacean taxa (e.g. Kellogg 1928, Simpson 1945, Romer 1966).

REFERENCES

Abele, C., Gloe, C. S., Hocking, J. B., Holdgate, G., Kenley, P. R., Lawrence, C. R., Ripper, D. & Threlfall, W. F., 1976. Tertiary. 177-274. *In* DOUGLAS, J. G. & FERGUSON, J. A. (Eds.). Geology of Victoria. *Geol. Soc. Aust., Spec. Publ.* 5. 528 p.

Chapman, F., 1917. New or little-known Victorian fossils in the National Museum. Part XXI. Some Tertiary cetacean remains. *Proc. R. Soc. Vict.* 30: 32-43.

Christensen, I., 1973. Age determination, age distribution and growth of bottlenose whales, *Hyperoodon ampullatus* (Forster), in the Labrador Sea. *Norw. J. Zool.* 21: 331-340.

Dennant, J., & Kitson, A. E., 1903. Catalogue of the described species of fossils (except Bryozoa and Foraminifera) in the Cainozoic fauna of Victoria, South Australia and Tasmania. *Rec. Geol. Surv. Vict.* 1: 87-147.

Flower, W. H., 1872. On the recent ziphioid whales, with a description of the skeleton of *Berardius arnouxi*. *Trans Zool. Soc. Lond.* 8: 203-234.

Gray, J. E., 1865. Notes on the whales of the Cape; By E. L. Layard, Esq., of Cape-Town, Corr. Memb. With descriptions of two new species. *Proc. Zool. Soc. Lond.* 1865: 357-359.

Gregory, J. W., 1914. The correlation of the Australian marine Kainozoic deposits—evidence of the echinoids, bryozoa, and some vertebrates. *Rep. Brit. Assoc. Adv. Sci., Australia* 84: 376.

Hall, T. S. & Pritchard, G. B., 1894. The older Tertiaries of Maude, with an indication of the sequence of the Eocene rocks of Victoria. *Proc. R. Soc. Vict.* 7: 180-196.

Kellogg, A. R., 1928. The history of whales—their adaptation to life in the water. *Quart. Rev. Biol.* 3: 29-76, 174-208.

McCann, C., 1962. Key to the Family Ziphiidae. Beaked whales. *Tuatara* 10: 13-18.

McCoy, F., 1882. *Ziphius* (*Dolichodon*) *geelongensis* (McCoy). *Prodromus of the palaeontology of Victoria; or, figures and descriptions of Victorian organic remains*, Decade 7: 23-26.

Mahoney, J. A., & Ride, W. D. L., 1975. Index to the genera and species of fossil Mammalia described from Australia and New Guinea between 1838 and 1968 (including citations of type species and primary type specimens). *W. Aust. Mus. Spec. Publ.* 6. 250 p.

Mulder, J. F., 1914. Notes on the Waurn Ponds Limestone fossil beds. *Geelong Nat. (ser. 2)* 6: 23-26.

Richards, H. C., 1922. Post-Cretaceous rocks of Australia. *Proc. Pan-Pacific Sci. Congr., Bernice P. Bishop Mus., Honolulu, Spec. Publ.* 7: 744-753.

Romer, A. S., 1966. *Vertebrate Paleontology* (3rd Edn.) Univ. of Chicago Press, Chicago. 468 p.

Simpson, G. G., 1945. The principles of classification and a classification of mammals. *Bull. Amer. Mus. Nat. Hist.* 85: 1-350.

Tate, R., 1888. Census of the fauna of the older Tertiary of Australia. *J. Proc. R. Soc. N.S.W.* 22: 240-253.

R. Ewan Fordyce
Dept. of Earth Sciences
Monash University,
Clayton, Victoria 3168

ROYAL SOCIETY OF VICTORIA

1981

Patron: His Excellency Sir Henry Winneke, KCMG, OBE, QC, KStJ, Governor of Victoria.

President: G. D. Aitchison, ME, PhD.

Vice-Presidents: D. M. Churchill, BSc, BA, PhD.
Professor J. W. Warren, MA, PhD.

Immediate Past President: Professor L. L. Stubbs, DAgrSc.

Hon. Secretary: T. A. Darragh, MSc, DipEd.

Hon. Treasurer: H. G. Stevens, FCA.

Hon. Librarian: J. G. Douglas, MSc, PhD.

Hon. Editor: L. A. Frakes, MA, PhD.

Hon. Research Secretary: I. A. Staff, MSc, PhD, DipEd.

Hon. Development Manager: Professor G. Seddon, BA, MSc, PhD.

Hon. Assistant Secretary: P. A. Jell, BSc, PhD.

The above Office-bearers are *ex officio* members of the Council of the Society.

Other members of the Council are:

J. K. Aitken, LLM.
Sir Robert Blackwood, MCE, BEE.
Professor M. J. Canny, MA, PhD.
M. G. Lay, BCE, MEngSc, PhD.
M. J. Littlejohn, PhD.
Professor J. F. Lovering, MSc, PhD.
Professor J. D. Morrison, PhD, DSc, FAA.
A. E. Perriman, BSc.
Mrs. Delys B. Sargeant, BSc, MEd.
G. A. Sklovsky, IngChem, ESCIL, LiciSci, IngDoc.
J. H. Thompson, BCom.

Executive Officer:
R. R. Garran, MSc, PhD.

Honorary Architect: F. Suendermann, FRAIA, MRAPI.

Honorary Financial Adviser: D. S. Clarebrough.

Honorary Solicitors: Phillips, Fox and Masel.

Honorary Auditor: I. J. Curry, AASA.

Trustees: D. M. Churchill, BSc, MA, PhD.
Professor J. S. Turner, OBE, MA, PhD, MSc, FAA.
Professor J. W. Warren, MA, PhD.
The Hon. Mr. Justice A. E. Woodward, LLM, QC, OBE.

INDEX TO VOLUME 93

PROCEEDINGS

OF THE

ROYAL SOCIETY OF VICTORIA

Volume 94

ROYAL SOCIETY'S HALL
9 VICTORIA STREET, MELBOURNE 3000

Contents of Volume 94 Number 1

Contents of Volume 94 Number 2

Contents of Volume 94 Number 3

Contents of Volume 94 Number 4

INSTRUCTIONS TO AUTHORS

Papers considered for publication may be Reviews, Reports of experimental or descriptive research, or Short Communications. Length of papers may vary; Short Communications should not be longer than 1500 words.

SUBMISSION

The original and two duplicates of the typescript and all Tables and Figures should be submitted initially to the Executive Officer at the Society's Hall, 9 Victoria Street, Melbourne 3000. Use International A4 bond paper for the first copy; machine-copied duplicates are preferred to carbons. Use double space throughout; leave wide margins; number all pages. Underline only those words to be italicised in running text.

FORMAT

Papers are to be written in concise, simple English and should be organised as follows: 1, a brief title, capitalised, and if possible beginning with a key word. 2, author's name and address, using superscripts to distinguish addresses of multiple authors. 3, short abstract (200 words or less) describing the results of the work. 4, the main text; if necessary use four or fewer grades of headings as follows:

GRADE ONE HEADING

Grade Two Heading: May be followed by running text on the same line or used as a superior heading.

Grade three heading

Grade four heading: Followed by running text on the same line. In taxonomic works headings in an hierachical classification should be centred but not underlined; at Genus level and above the taxonomic category should precede the name; refer to other references in the text as Gill (1968), (Gill 1968), or (Gill 1968, p. 162, fig. 1), and refer to illustrations of the paper in the text as "Fig. 1", "Figs 1, 2" or "Figs 1-4"; all measurements are to be expressed in the Metric System (SI units); footnotes are not allowed; group all acknowledgments at the end and keep them brief. 5, references should conform to the examples below; abbreviations of titles of periodicals must conform with those in *A World List of Scientific Periodicals* (1963-4, 4th ed., London, Butterworths). 6, captions for Tables and Figures typed on a separate sheet or sheets.

ILLUSTRATIONS

Maximum size is 15.5 × 21.0 cm and single column width is 7.5 cm; all Tables and Figures to be reproduced directly from copy must be designed for these sizes leaving room for captions below if possible and must be supplied at reproduction size; photographs should be supplied as glossy prints, unmounted, labelled on back; Figures that are composites of several individual photographs should be mounted on thin flexible cardboard or supplied as glossy prints of the whole figure; line drawings should be made in black ink and supplied as glossy or flat prints at reproduction size; scales must be included and compass directions must be indicated where necessary; illustrations will be designated Figures or Tables; on composite Figures items should be labelled A, B, C, etc. (not a, b, c,).

Oversized illustrations, tables or maps may be accepted for publication as Foldouts only with the understanding that the author must meet all costs involved in their production. Maximum size for Foldouts is 21 × 31.5 cm.

Short tables will be typeset within the text. Extensive Tables which are likely to cover one page of print should be typed on an electric typewriter to ensure clarity and evenness, within the dimensions 28 × 22.5 cm. They should then be photographed to reduce them to printed page size (15.5 × 21 cm) and submitted as glossy prints. They must be finally correct when submitted as they cannot be corrected in proof.

REFERENCES

Gill, E. D., 1968. Radiocarbon dating. *Victorian Nat.* 85: 161-164.

MacPherson, J. H. & Gabriel, C. J., 1962. *Marine molluscs of Victoria*. Melbourne University Press, Melbourne, xv + 475 p.

Parsons, W. T., 1982. Weeds. In *Atlas of Victoria*, J. S. Duncan, ed., Victorian Government Printing Office, Melbourne, 122-125.

REPRINTS

The Society supplies authors with 25 Reprints free of charge; joint authors receive a total of 30. Additional reprints may be ordered by returning the order blank that accompanies the galley proofs. The author of a paper or the Institution from which a paper is received may be requested to contribute towards the cost of publication of the paper.

PROC. R. SOC. VICT. vol. 94, no. 1, 1-9, March 1982

CLASSIFICATION AND EVOLUTION OF THE BRACHIOPOD FAMILY RUGOSOCHONETIDAE MUIR-WOOD 1962

By N. W. Archbold

Department of Geology, University of Melbourne, Parkville, Victoria 3052

Abstract: The Rugosochonetidae are reclassified into six subfamilies namely: Rugosochonetinae Muir-Wood 1962, Plicochonetinae Sokolskaya 1960, Undulellinae Cooper & Grant 1975, Lamellosiinae Cooper & Grant 1975, Quinquenellinae Archbold 1981 and Svalbardiinae subfam. nov. The Chonetinellinae Muir-Wood 1962 should be allowed to lapse. Phylogeny of the Rugosochonetidae is discussed and its geographic distribution and possible migration routes are also documented.

The brachiopod family Rugosochonetidae, with a history spanning some 160 million years from the Middle Devonian until the end of the Permian, became the most diverse (generic level) family of the Chonetidina during the Carboniferous and maintained this dominance in Permian brachiopod faunas (Afanas'yeva 1975a, 1978a). At present, the family includes 29 genera with 19 having been identified since the major studies of Sokolskaya (1960) and Muir-Wood (1962).

Elevation of the Rugosochonetinae Muir-Wood (1962) to family status (Cooper & Grant 1975) is justified because of the change in scope and content of the family. Nevertheless, considerations of the content and phylogeny of the family indicate the necessity of modifying the existing sub-familial classification. The scheme discussed below differs substantially from that given by Cooper & Grant (1975) whose review was restricted to North American Permian genera.

For this review the summary papers on Carboniferous and Permian chonetaceans by Afanas'yeva (1975a, 1978a) have been an invaluable compilation of data on the ranges and distributions of rugosochonetid genera. As a result the discussions herein on generic distributions and migrations are supplementary to those papers, and supply necessary corrections and more recent information. The terminology applied to the Rugosochonetidae is that used by Archbold (1981c).

Taxonomic Criteria

Cooper (1970) demonstrated the value of the dorsal internal structures of articulate brachiopods for generic and higher levels of classification of the phylum and hence it is not surprising that the Rugosochonetidae was defined by Cooper & Grant (1975) on those structures. However, dorsal internal structures of the Chonetidina change through ontogeny (Greene 1908, Sokolskaya 1949) and therefore analysis of genera should be based on large collections.

Sokolskaya (1946) stressed external ornament in distinguishing stocks of chonetids, a character also used by Cooper & Grant (1975) in their classification of subfamilies within the Rugosochonetidae. Many members of the Rugosochonetidae lack true radial ornament but the dorsal valve of most smooth genera is pseudocapillate when worn which reflects the distribution of fine radiating taleolae, the long axis of which is parallel to, rather than normal to, the exterior surface of the valve. These fine taleolae, which occur just below the thin primary layer of the dorsal valve, are found in all members of the Undulellinae, Lamellosiinae and the majority, if not all, of the Svalbardiinae subfam. nov. I consider pseudocapillate ornament to be a significant taxonomic criterion within the Rugosochonetidae.

PROPOSED CLASSIFICATION

Suborder Chonetidina Muir-Wood 1955
Superfamily Chonetacea Bronn 1862
Family Rugosochonetidae Muir-Wood 1962
Subfamily Rugosochonetinae Muir-Wood 1962

Genera Included: *Rugosochonetes* Sokolskaya 1950 (= *Nix* Easton 1962); *Waagenites* Paeckelmann 1930 (= *Dienerella* Reed 1931); *Mesolobus* Dunbar & Condra 1932; *Chonetinella* Ramsbottom 1952; *Neochonetes* Muir-Wood 1962; *Arctochonetes* Ifanova 1968; *Schistochonetes* Roberts 1971; *Paramesolobus* Afanas'yeva 1975; *Jakutochonetes* Afanas'yeva 1977; *Dagnachonetes* Afanas'yeva 1978; *Tenuichonetes* Jing & Hu 1978.

Subfamily Plicochonetinae Sokolskaya 1960

Genera Included: *Plicochonetes* Paeckelmann 1930; *Striatochonetes* Mikryukov 1968; *Rugaria* Cooper & Grant 1969.

Subfamily Svalbardiinae subfam. nov.

Genera Included: *Svalbardia* Barkhatova 1970; *Lissochonetes* Dunbar & Condra 1932; *Dyoros* Stehli 1954; *Quadrochonetes* Stehli 1954; *Eolissochonetes* Hoare 1960; *Sulcataria* Cooper & Grant 1969; *Chonetinetes* Cooper & Grant 1969; *Komiella* Barkhatova 1970; *Capillonia* Waterhouse 1973; *Leurosina* Cooper & Grant 1975; *Leiochonetes* Roberts 1976.

Subfamily Undulellinae Cooper & Grant 1975

Genera Included: *Undulella* Cooper & Grant 1969; *Micraphelia* Cooper & Grant 1969.

Subfamily Lamellosiinae Cooper & Grant 1975

Genera Included: *Lamellosia* Cooper & Grant 1975.

Subfamily Quinquenellinae Archbold 1981

Genera Included: *Quinquenella* Waterhouse 1975.

DISCUSSION AND DIAGNOSIS FOR PROPOSED CLASSIFICATION

Family RUGOSOCHONETIDAE Muir-Wood 1962

(nom. trans. Cooper & Grant 1975, p. 1212 ex. Rugosochonetinae Muir-Wood 1962, pp. 32, 64.)

AMENDED DIAGNOSIS: Small to medium sized, costate, capillate, smooth or lamellose chonetaceans. Dorsal interior with pronounced lateral septa, long median septum and deep alveolus. Cardinal process externally quadrilobed and internally bilobed; it may be externally bilobed in early members of the family. Ventral sulcus absent to strongly developed; median septum of variable length, high posteriorly; hinge spines oblique to nearly vertical. Pseudodeltidium and chilidium may be present.

DISCUSSION: Cooper & Grant (1975) raised the taxon from sub-family to family status but did not provide a diagnosis although it is clear from their comments (Cooper & Grant 1975, p. 1212) that the family was recognised on the basis of internal structures, especially the nature of the cardinal process.

The family Rugosochonetidae contains a diverse group of genera united by common internal dorsal features. Six subfamilies can usefully be recognised at present.

Subfamily RUGOSOCHONETINAE Muir-Wood 1962

AMENDED DIAGNOSIS: Small to large sized rugosochonetids with radially capillate or costate external ornament. Ventral sulcus feebly to strongly developed. Hinge spines at low to moderate angle. Dorsal fold present in several genera; brachial ridges often well developed.

DISCUSSION: The Rugosochonetinae is restricted to include only those genera with an external ornament varying from capillate to costate. The Chonetinellinae Muir-Wood (1962) is permitted to lapse. Muir-Wood (1962) assigned three genera to that subfamily: *Neochonetes, Chonetinella* and *Waagenites.* The first was reassigned to the Rugosochonetinae by Cooper & Grant (1975). *Chonetinella* is a broadly interpreted genus (Grant 1976) and includes species which approach Western Australian Permian species of *Neochonetes* (Archbold 1981c). *Waagenites* is still poorly known, its dorsal interior never having been adequately illustrated, and is provisionally assigned to the Rugosochonetinae. At present the genus is broadly interpreted (Waterhouse & Piyasin 1970, Grant 1976) and includes species with poorly developed sulci. The Chonetinellinae as characterised by Cooper & Grant (1975), grouped together rugosochonetids with a distinct sulcus. They also included *Chonetinetes* Cooper & Grant (1969) within the subfamily because of that genus being similar in gross morphology to *Chonetinella.* To group chonetid genera together on the basis of the presence of a prominent sulcus is a dubious criterion; the development of heterochronous, homeomorphic ventral sulci in different stocks of chonetaceans has previously been discussed by Archbold (1980a). *Chonetinetes* is provisionally assigned herein to the *Svalbardiinae* subfam. nov.

Discussion of remaining rugosochonetids is restricted to poorly understood genera. The variable external ornament of *Mesolobus* has been extensively discussed by many authors. Hoare (1960) demonstrated that North American, early Pennsylvanian species are capillate while younger species are smooth. The type species, from high in the Pennsylvanian, was considered by Weller & McGehee (1933) and King (1965) to be smooth, whereas Girty (1915) and Dunbar & Condra (1932) agreed with Norwood & Pratten (1855) in considering the species to be capillate. The query remains; how smooth are the smooth species? Girty (1915, p. 63) noted that "when large series of specimens from different horizons are examined, individuals more or less intermediate in character are found. That is, associated with the smooth variety are a few shells which show faint, yet unmistakable traces of radial sculpture". Sutherland & Harlow (1973) showed that even smooth species of *Mesolobus* occasionally show faint capillae commonly near the anterior margin. Following Dunbar & Condra (1932) the ornament of *Mesolobus* is considered to be finely capillate, at times "obsolescent".

Arctochonetes Ifanova (1968) is assigned to the Rugosochonetinae. The bifurcating ventral median septum of *Arctochonetes* appears to be a stronger development of the short median septum and pair of ridges on either side of the adductor muscle field of *Neochonetes.*

A new genus belonging to the Rugosochonetinae (Fig. 1) is typified by *Neochonetes unbonoplicatus,* from the Sakmarian Nenets Beds, Sula River, Northern Timan Mountains, as figured by Barkhatova (1964). The ventral valve is capillate, possesses a distinct, posteriorly developed sulcus which changes anteriorly to a swollen fold, separated from the lateral flanks of the valve by a valley on either side. The species has not been formally described and hence is a *nomen nudum,* but rather than describe the new species and genus here, on the basis of the only figured specimen, description is left to those with access to a collection of specimens so that the ontogeny of the ventral valve can be fully assessed.

Subfamily PLICOCHONETINAE Sokolskaya 1960

AMENDED DIAGNOSIS: Small, strongly convex capillate to costate rugosochonetids. Hinge spines oblique to high angle. Fold and sulcus absent. Interior generalised, often poorly known.

DISCUSSION: Although not adopted by Muir-Wood (1962), this subfamily was redefined and reconstituted by Cooper & Grant (1975). The subfamily still appears to include a heterogeneous group of genera and further work is required to define the scope of the subfamily. *Plicochonetes* appears morphologically far removed from *Dagnachonetes,* regarded herein as the ancestral rugosochonetid, and this suggests that the Rugosochonetidae may be polyphyletic. Muir-Wood (1962) showed that the hinge spines of *Plicochonetes* are slightly curved and extended at a high angle to the hinge. *Striatochonetes* Mikryukov (1968), a finely costellate genus with high angle hinge spines, is inadequately known internally and hence is provisionally included in

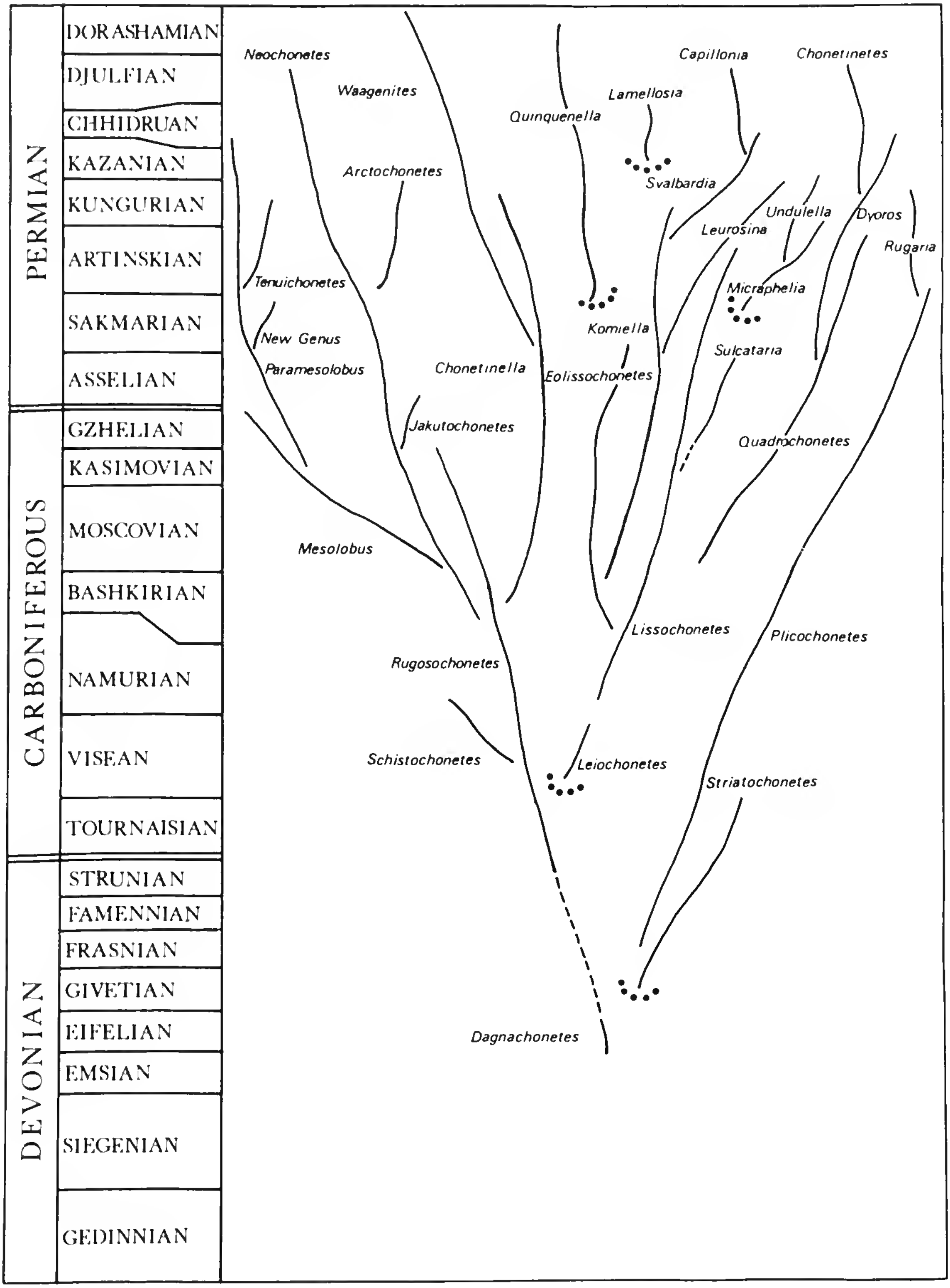


Fig. 1—The inferred phylogeny of the Rugosochonetidae Muir-Wood showing the relationship of the constituent genera. Subfamilies are separated by curved, dotted lines.

the Plicochonetinae following Mikryukov (1968). The type species, *Strophomena setigera* Hall 1843, well figured externally by Hall (1843, 1862), possesses hinge spines at a high angle which may indicate a relationship for the genus with either the Strophochonetinae or the Retichonetinae, both of the Chonetidae, although it does not preclude the genus from the Rugosochonetinae. *Rugaria* Cooper & Grant (1969), with oblique hinge spines, was well described by its authors and is interpreted herein as a direct descendant of *Plicochonetes*.

Subfamily Svalbardiinae subfam. nov.

Diagnosis: Small to medium sized, externally smooth rugosochonetids. Dorsal exterior pseudocapillate when worn. Hinge spines at low to moderate angle.

Discussion: Members of this subfamily are distinguished from the Quinquenellinae by the absence of accessory septa and the presence of dorsal pesudocapillae when worn, and the Undulellinae by the possession of hinge spines at a much lower angle to the hinge. The Undulellinae are also characterised by pronounced development of the brachial ridges and subtle variations in the arrangement of the dorsal septa. Probably all the constituent genera of the Svalbardiinae possess the distinctive taleolate shell structure which results in a pseudocapillate shell ornament, especially of the dorsal valve when the shell is worn. This is considered to be a unifying feature of this stock of the Rugosochonetidae and is shared with the Undulellinae and the Lamellosiinae. Confirmation of the pseudocapillate ornament is required for the dorsal valves of *Quadrochonetes* and *Leiochonetes*. Pseudocapillate shell structure may be noted for the following genera as figured and/or discussed by the various authors:

Lissochonetes Dunbar & Condra (1932, p. 171, pl. 20, fig. 48)
Sulcataria Cooper & Grant (1975, pl. 478, fig. 62)
Dyoros Stehli 1954, Cooper & Grant (1975, pl. 481, fig. 10, pl. 485, figs 12, 13; subgenus *Lissosia* Cooper & Grant 1975, pl. 487, fig. 18; subgenus *Tetragonetes* Cooper & Grant 1975, pl. 489, figs 26, 32 and pl. 490, fig. 72)
Chonetinetes Cooper & Grant (1975, pl. 477, figs 2, 49)
Leurosina Cooper & Grant (1975, pl. 495, fig. 3)
Komiella Barkhatova 1970, Licharew (1934, pp. 12, 100)
Capillonia Waterhouse 1973 (see Waterhouse 1964, pl. 3, figs 1, 10 as discussed by Archbold 1981b)
Svalbardia Barkhatova, as discussed by Archbold (1981b)

Chonetinetes and *Dyoros* both possess a pseudocapillate ventral valve as well as dorsal valve suggesting a close relationship for the two genera.

Eolissochonetes Hoare 1960 is stated to possess "no trace of *true* radial striation" (my italics). A hint of a pseudocapillate ornament is shown for *Quadrochonetes* Stehli by Cooper & Grant (1975, pl. 502, fig. 17).

The shell structure of *Leiochonetes* Roberts (1976) is not known but Roberts' description indicates a comparable feature may be present.

Following Brunton (1972) I consider that the microstructure of the brachiopod shell is important to systematics. The distinctive shell structure in the Svalbardiinae, Undulellinae and Lamellosiinae, possibly reflecting the positions of setae along the mantle edge, just below the primary layer of the shell, which were differentially filled with shelly material, structurally different to that of the remainder of the secondary layer, appears to unite the three subfamilies closely. Similar shell structure has not been noted for true capillate rugosochonetids which, when worn, are smooth.

Lissochonetes, despite good illustrations of the type specimens by Geinitz (1867) and Mudge & Yochelson (1962) and discussions by Dunbar & Condra (1932), Muir-Wood (1962) and Cooper & Grant (1975), remains poorly known. It should be restricted to weakly sulcate species with delicate dorsal internal structures until large collections are available. *Komiella*, with stout lateral septa and a long median septum fused anteriorly of a deep alveolus (Archbold 1981b), appears useful for separating species from the ill-defined *Lissochonetes*. The type species of *Komiella*, of Kazanian age, has been recorded from as early as the Middle Carboniferous (Afanas'yeva 1977) indicating that the genus spans a considerable time interval.

Subfamily Undulellinae Cooper & Grant 1975

Amended Diagnosis: Small smooth rugosochonetids. Exterior of dorsal valve pseudocapillate when worn. Hinge spines at high angle (nearly 90° to the hinge). Brachial ridges and dorsal median septum prominent; cardinal process small.

Discussion: The Undulellinae are morphologically close to the Svalbardiinae, being distinguished from that subfamily by details of the hinge spines and dorsal interior. The pseudocapillate appearance of the dorsal valve when worn is added to the subfamilial diagnosis, in order to emphasise the relationship of the Undulellinae to the Svalbardiinae.

Subfamily Lamellosiinae Cooper & Grant 1975

Amended Diagnosis: Concentrically lamellose rugosochonetids with no radial ornament. Pesudocapillate shell when worn.

Discussion: I follow Cooper & Grant (1975) and include this subfamily in the Rugosochonetidae, but as the dorsal interior is unknown, the familial assignment is only tentative. Support for the rugosochonetid affinities of *Lamellosia* comes from the pseudocapillate nature of the shell when worn.

Subfamily Quinquenellinae Archbold 1981

Amended Diagnosis: Small, smooth rugosochonetids, not pseudocapillate when worn. Dorsal interior with short lateral septa, long accessory septa and a variably developed median septum.

Discussion: The development of long accessory septa and the lack of a pesudocapillate dorsal valve when worn sets this subfamily apart from other smooth rugosochonetids. Phylogenetic implications of the lack of pseudocapillae are discussed below.

PHYLOGENY OF THE RUGOSOCHONETIDAE

INTRODUCTION

The inferred phylogeny of the Rugosochonetidae is shown in Fig. 1.

While it is beyond the scope of the present review to discuss fully the applicability of particular stage names in subdividing the Carboniferous and Permian Periods, it should be noted that several of the subdivisions in Fig. 1 are provisional and serve merely as a guide to time control for the development of the family.

The problem of the relationship of the Gzhelian and Asselian Stages, especially with respect to the "Orenburgian" stage, has been reviewed by Waterhouse (1978a). The view that much of the Orenburgian is basal Asselian is strongly indicated by the re-examination of the classic brachiopod faunas, and a review of other fossil groups, of the Samara Bend by Prokof'ev (1975), who maintained that the Gzhelian is the youngest stage of the Carboniferous, a view consistent with the most recent monographic study of the Carboniferous of Fergana (Sikstell *et al.* 1975).

The Chhidruan as used herein equals the Punjabian of Stepanov (1973) and Waterhouse (1976). Use of the name Punjabian is avoided because of the earlier informal use of the same name by Reed (1936, 1939) for early Permian faunas of the Salt Range.

The phylogeny diagram is dendritic in style. Diverging branchlets do not necessarily imply that two genera or subfamilies become less similar to each other through time. Several genera appear to result from small changes to the ancestral genus; e.g. *Neochonetes* from *Rugosochonetes* (Archbold 1981e). Other genera appear abruptly with no obvious antecedent (e.g. *Quadrochonetes*) as do the two subfamilies, Lamellosiinae and Quinquenellinae. No scale of variation is intended by the curved branchlets although genera do not exhibit a constant morphology, but rather show changes in morphology from species to species. These trends will not be in a constant direction—as might be inferred from straight lines. A species may show a constant morphology (reflecting a constant gene pool); a genus, of more than one species, never will. Diverging branchlets may be interpreted from Fig. 1 to imply divergent evolution of two genera although, as stated above this is not *necessarily* the case.

Variations in the external gross morphology of the shell from genus to genus within chonetacean families such as the strength of the sulcus is probably related to environmental factors, such as the nature of the substrate. The development of heterochronous homeomorphs occurred in different families and subfamilies (Archbold 1980a).

The ancestry of the Rugosochonetidae is likely to lie within the Chonetidae. The Parachonetinae of Johnson (1970) appear an ideal group to be the ancestor of the Rugosochonetidae because of the similarity of the dorsal internal structures of the two groups. *Parachonetes*, common in Emsian age rocks (Johnson 1970), is a suitable ancestor for the Rugosochonetinae. It seems likely that the Rugosochonetidae is polyphyletic in origin, but it appears possible, judging from illustrations of *Parachonetes* by Johnson (1966, 1970) that the Plicochonetinae and the Rugosochonetinae may have both arisen independently from the Parachonetinae by modification of the external ornament and convexity of the ventral valve. The earliest member of the Rugosochonetidae appears to be the Eastern European, Eifelian genus *Dagnachonetes* which possesses a simplified, bilobed cardinal process (Afanas'yeva 1978b) but the derivation of the Plicochonetinae from *Dagnachonetes* appears unlikely. *Striatochonetes*, appearing in the Givetian, may not belong to the Plicochonetinae and is certainly far removed morphologically from *Dagnachonetes* and yet both genera are close in time. Similarly the origin of the small, highly convex Frasnian genus *Plicochonetes* is obscure and appears distinct from *Dagnachonetes*. *Plicochonetes* has a subtantial time range if the referral of the Artinskian *Plicochonetes minor* to the genus is correct (Ting 1965). *Rugaria* was probably derived from *Plicochonetes* by modification of the hinge spines and cardinal process.

EVOLUTION OF THE RUGOSOCHONETIDAE

The Rugosochonetidae first appear in the Eifelian, and then reappear in the earliest Carboniferous with the genus *Rugosochonetes*. *Rugosochonetes* has a substantial time range and early species of *Neochonetes* are similar to species of *Rugosochonetes*. The local development of *Schistochonetes* in northwestern Australia, from *Rugosochonetes* occurred in the Visean by modification of the external ornament (Roberts 1971). *Neochonetes* arose from *Rugosochonetes* in the Bashkirian, or a little earlier, and various stocks subsequently developed within the genus (Archbold 1981e). *Jakutochonetes* appears to have been a local development, in northeastern USSR, from *Neochonetes* during the Late Carboniferous by slight modification of the sulcus and fold (Afanas'yeva 1977). *Arctochonetes*, by modification of the ventral median septum, developed from a *Neochonetes* ancestor in the Artinskian.

Mesolobus (Sutherland & Harlow 1973) is most closely related to *Neochonetes* and probably evolved from that genus in the early Moscovian. Hoare (1960) considered that *Eolissochonetes* evolved from *Mesolobus* but *Eolissochonetes* has been shown to be older than *Mesolobus* (Afanas'yeva 1975a, Hoare *et al.* 1979). In the late Pennsylvanian, members of *Mesolobus* with an obsolescent ornament died out in North America but in the Kasimovian of the Moscow Basin *Paramesolobus*, with a stronger radial ornament flourished (Ivanov & Ivanova 1936, Afanas'yeva 1975b) and has been widely recorded from the Late Carboniferous of southern Europe including Spain (Winkler-Prins 1968, 1970), and the Karnic Alps (Schellwein 1892, Heritsch 1931, Vinassa de Regny & Gortani 1905). Species of *Paramesolobus* are usually poorly known but an approximate assessment of the Permian range of the genus can be made from illustrated accounts of chonetids usually referred to either of Schellwein's species *Chonetes sinuosa* or *Chonetes latesinuata. Paramesolobus* is known from the Asselian-Sakmarian of Thailand (Yanagida 1967), Japan (Nakamura 1959, Tazawa 1976), Spitzbergen (Gobbett 1964, pl. 15, fig. 10) and the Karnic Alps (in the form of *Chonetes* sp. nov. Heritsch 1938). It has been reported from the Artinskian of the Karakorum (Renz 1940) and the Kungurian of China, in the form of *Chonetes plicatiformis* Chan & Lee (1962). Younger Permian forms have been described by Coogan (1960) from California (a form with weaker capillae), by Cooper & Grant (1975) from Texas, in the form of *Mesolobus*? *permianus* and a Chhidruan form is known from Japan (Hayasaka 1925, pl. 5, figs 5, 6). Cooper & Grant (1975) considered that *Mesolobus*? *permianus* represented a convergence towards *Mesolobus,* but the Texan occurrence can be explained as a descendant species of *Paramesolobus.* The new genus, discussed above within the Rugosochonetinae, was apparently derived from the *Paramesolobus* stock during the Sakmarian by modification of the fold and sulcus. *Tenuichonetes* may have evolved from either *Mesolobus* or *Paramesolobus* during the Artinskian.

Chonetinella evolved during the Bashkirian, possibly from the same stock of *Rugosochonetes* that gave rise to *Neochonetes,* by the development of a distinct sulcus and fold. The origin of *Waagenites* is obscure. The earliest species, from the Sakmarian of the Urals, is *Chonetes (Dienerella) fasciger* Mirskaya *et al.* (1956) which possesses the characteristic deep sulcus and very coarse costae of the genus. *Waagenites fasciger* has invariably been overlooked by subsequent authors who have assumed that *Waagenites speciosus* from the late Artinskian or Kungurian of Thailand was the earliest species of the genus. Waterhouse & Piyasin (1970) and Grant (1976) noted that *Waagenites speciosus* was very different from *Waagenites grandicosta* (Waagen) the type species of the genus, Muir-Wood (1962) was not able to elucidate all the dorsal internal structures of *Waagenites* but she did indicate that the dorsal interior was unlike that of *Neochonetes.* Grant (1976) stated that the dorsal interior possessed short lateral septa, and a short median septum, low and near the valve centre, but unfortunately he did not figure any of his topotypes and from his diagnosis one cannot determine the precise relationship of the three dorsal septa. It appears that *W. speciosus* does not belong in *Waagenites* s.s. Illustrations of the species by Grant (1976) and Yanagida (1971) revealed that the ventral sulcus (strongly developed in the ancestral and type species of the genus) is weakly developed or even absent in the Thai species. Two comments can be offered regarding the taxonomic position of *Waagenites speciosus.* Firstly, the dorsal interior structures of *W. grandicosta* (Waagen) require full description and need to be figured. Secondly, the present author agrees with Yanagida (1971) who considered that the species is close to *Neochonetes* in details of morphology of the shell and dorsal internal structures. Nevertheless the relatively coarse costellae of the Thai species would result in a modification of the generic diagnosis of *Neochonetes* in order to accommodate the species in that genus. A new generic name is probably required for the species, the new genus being a development from a neochonetid stock. Huang (1932) described and Liao (1980) recorded several species of "*Chonetes*" or "*Waagenites*" from the Late Permian of Kweichow, China, some specimens of which are large, coarsely costate and possess a weak sulcus and hence they are possibly descendants from the Thai species. *Waagenites* is a generic name that should be applied with caution until the type species is well understood. The evidence of Mirskaya *et al.* (1956) strongly suggests that the genus already possessed a well developed, deep sulcus in the Sakmarian and hence reports of the genus from the Chhidruan of Primorya (Licharew & Kotlyar 1978) and Japan (Tazawa 1976) also require re-examination.

The Svalbardiinae first appeared with *Leiochonetes* during the middle Visean in New South Wales, although Roberts (1976) discussed two other poorly known Early Carboniferous occurrences of smooth chonetaceans that may be allied. *Leiochonetes* is a small, unspecialised smooth rugosochonetid and hence is an ideal ancestor for the group. *Leiochonetes* which possibly does not possess a pseudocapillate dorsal valve or a similar genus, may also have independently given rise to the Quinquenellinae by modification of the dorsal septa (Archbold 1981a). Two principal lineages may be delimited within the Svalbardiinae.

The *Dyoros* lineage, appearing in the Kasimovian with *Quadrochonetes,* is characterised by the development of a pronounced ventral sulcus. Arising from *Quadrochonetes* in the late Sakmarian, *Dyoros* became a major element of Texan Permian chonetacean faunas (Cooper & Grant 1975). *Dyoros* possesses prominent dorsal septa and this trend appears to have been accentuated by the development of *Chonetinetes* with a modified elevated cardinal process. The dorsal septal arrangement of *Chonetinetes* is consistent with an origin for the genus from *Dyoros.* The ancestry of *Quadrochonetes* is not well understood as the genus possibly lacks pseudocapillate shell structure which suggests an origin from *Leiochonetes* or an unknown ancestor. *Dyoros* and *Chonetinetes* are unusual for the Svalbardiinae in that they both possess pseudocapillate shell structure of both valves.

The *Svalbardia* lineage represents a broader, more varied development with subgroupings, although relationships are obscured because of uncertainty over the internal morphology of *Lissochonetes.* Accepting the diagnosis of *Lissochonetes* given by Muir-Wood (1962, p. 77), it appears possible to derive *Sulcataria* from *Lissochonetes* as *Sulcataria* also possesses poorly developed lateral septa with a more prominent, posteriorly placed, dorsal median septum. Species of *Lissochonetes* and *Sulcataria* are generally small.

Eolissochonetes possibly evolved from *Lissochonetes* by modification of the lateral septa and production of a long thin median septum. However, early species of *Eolissochonetes* are close to representatives of *Komiella* and both genera appeared at about the same time. The earliest species of *Lissochonetes* is *Lissochonetes montinis* (McKellar 1965) occurring as early as the late Visean (Roberts 1975) and probably the species evolved directly from *Leiochonetes*. *Lissochonetes montinis* has a dorsal septal arrangement similar to that in *Eolissochonetes morsei* (Hoare *et al.* 1979) and is also similar to species assigned to *Lissochonetes* from the Late Carboniferous of Kazakhstan by Sokolskaya (1968) and the Late Carboniferous Magarsk Horizon of the Gizhiga River Basin by Afanas'yeva (1977) that would now be assigned to *Komiella*. Younger species of *Eolissochonetes* (Hoare 1960, 1961) exhibit the distinctive internal morphology of the genus and are larger. *Komiella* may be derived from early species of *Eolissochonetes* or both genera may be derived directly from early species of *Lissochonetes*.

Leurosina is internally similar to *Komiella* suggesting derivation from that genus; it differs in anterior curvature of the ventral valve and the prominent raised anterior recurved portions of the brachial ridges (Cooper & Grant 1975, pl. 479, fig. 78). The latter feature also occurs in *Svalbardia* and *Capillonia*. *Svalbardia* possesses short hinge spines while the younger and larger *Capillonia* possesses long delicate hinge spines.

The two representatives of the *Undulellinae* are morphologically close to the Svalbardiinae, differing only in details of the hinge spines and the dorsal interior, and hence the Undulellinae can be derived from the Svalbardiinae, probably from an unspecialised *"Lissochonetes"* or perhaps *Leurosina*. The origin of the Lamellosiinae is obscure but the pseudocapillate shell structure of *Lamellosia* suggests an origin within the *Svalbardiinae*.

MIGRATIONS AND ENDEMISM

With the origin of the family in eastern Europe, the descendant genus, *Rugosochonetes*, attained a cosmopolitan distribution during the Carboniferous. One descendent of *Rugosochonetes* namely *Schistochonetes* remained a localised endemic development in northwestern Australia while another, *Neochonetes*, attained a wide distribution in the Permian. *Mesolobus* reveals endemic development and then extinction in the North American Pennsylvanian, with a re-introduction of the descendent, essentially European genus *Paramesolobus* into Japan and North America in the Late Permian. *Chonetinella* has been reported widely from the Late Carboniferous and Early Permian but it appears premature to determine stocks within the genus and possible migration effects. *Waagenites* appeared in the Early Permian as a rare element in the Ural seas, later spreading its range to the Tethys, including the Caucasus (Licharew 1936), the Salt Range, Pakistan (Waagen 1894, Reed 1944), the Himalaya (Waterhouse & Gupta 1979) and Burma (Diener 1911). *Jakutochonetes* is an endemic development in the Late Carboniferous of the Kolyma-Omolon region of the USSR, while *Arctochonetes* is restricted to the Artinskian of the Boreal region of the USSR.

The Svalbardiinae appeared in eastern Australia in the Visean and became widely distributed by the Late Carboniferous. *Lissochonetes* and/or *Komiella* had penetrated North America, Kazakhstan, northeastern USSR, European USSR (Ivanov & Ivanova 1936), Spain (Winkler-Prins 1968) and South America (Amos 1960, Mendes 1959) by the Late Carboniferous. Endemic development took place in North America in the Late Carboniferous with the development of *Quadrochonetes*. During the early Permian, endemic development of the *Quadrochonetes* stock continued in North America with the development of the genus *Dyoros* which subsequently penetrated the Boreal sea in the Late Artinskian and Kungurian (Ifanova 1968, 1972). Solomina (1978, p. 106, pl. 9, fig. 3) recorded, with some question, the possible occurrence of *Dyoros* in the Late Carboniferous Khaldan Suite from the Southern Orulgan region of northeastern USSR. Her specimens are inadequate for precise determination, nevertheless, the illustration indicates a strongly sulcate form that may be a species of *Quadrochonetes* or *Dyoros*. *Dyoros* entered northern Gondwana waters during the Chhiduran in the form of *?Sulcataria pentagonalis* (Waterhouse 1978b, Waterhouse & Gupta 1979). *Sulcataria* and *Leurosina* appear to be endemic developments of the Svalbardiinae in North America. *Svalbardia* exhibits a bipolar or disjunct distribution in the Kungurian (Archbold 1981b), while *Capillonia* is restricted to the Kazanian and younger Permian of New Zealand (Waterhouse 1973) and eastern Australia in the form of *Lissochonetes semicircularis solida* (Dear 1971).

The Undulellinae are restricted to the Permian of North America as are the Lamellosiinae. The Quinquenellinae exhibit a bipolar or disjunct distribution in the Permian, being found in Western Australia, the Himalaya, possibly south-east Asia and northeastern USSR (Archbold 1981a). The occurrences of *Paramesolobus*, *Dyoros* and *Rugaria* on both sides of the Pacific at times during the Permian indicate some potential for migration between the two regions by several rugosochonetid genera.

ACKNOWLEDGEMENTS

I thank Dr. G. A. Thomas, University of Melbourne, for critically reading an earlier draft of the manuscript. The assistance of the staff of the Baillieu Library is acknowledged. Isabel McDonald typed the manuscript.

REFERENCES

References not listed here will be found in Archbold (1981e).

Afanas'yeva, G. A., 1978b. Novyye Khonetatsei is devona Nakhichevanskoy ASSR. *Paleont. Zh.* 1978(3): 64-71.

Amos, A. J., 1960. Algunos Chonetacea y Productacea del Carbonifero Inferior y Superior del Sistema de Tepuel, Provincia de Chubut. *Revta. Assoc. geol. argent.* 15: 81-107.

Archbold, N. W., 1981c. Studies on Western Australian Permian brachiopods. 2. The family Rugosochonetidae. *Proc. R. Soc. Vict.* 93: 109-128.

Brunton, C. H. C., 1972. The shell structure of Chonetacean brachiopods and their ancestors. *Brit. Mus. (Nat. Hist.) Bull. Geol.* 21(1): 1-26.

Chan, Li Pei & Li, Li, 1962. Early Permian brachiopods from the Maokou Suite of east Uchatka Chin Lin. *Acta. Palaeont. Sin.* 10(4): 472-493.

Coogan, A. H., 1960. Stratigraphy and paleontology of the Permian Nosoni and Dekkas formations. *Geol. Dept. Univ. Calif. Publ.* 36(5): 243-316.

Cooper, G. A., 1970. Generic characters of brachiopods. *Proc. Nth. Amer. Paleont. Conv. C.*: 194-263.

Cooper, G. A. & Grant, R. E., 1969. New Permian brachiopods from West Texas. *Smithson. Contrib. Paleobiol.* 1: 1-20.

Easton, W. H., 1962. Carboniferous formations and faunas of central Montana. *Prof. Pap. U.S. geol. Surv.* 348: 1-126.

Geinitz, H. B., 1867. Carbon formation und Dyas in Nebraska. *Nova. Acta Leopold., deutsche Akad. Natur. Leopold., Halle* 33: 1-91.

Girty, G. H., 1915. Fauna of the Wewoka formation of Oklahoma. *Bull. U.S. geol. Surv.* 544: 1-353.

Hall, J., 1843. *Geology of New York. Part IV. Comprising the Survey of the Fourth Geological District.* Carroll & Cook, Albany. 783p.

Hall, J., 1867. Natural History of New York. Palaeontology. Containing descriptions and figures of the fossil Brachiopoda of the Upper Helderberg, Hamilton, Portage and Chemung Groups. *Nat. Hist. N.Y. pt. VI, palaeont.* 4(1): 1-428.

Heritsch, F., 1931. Versteinerungen aus dem Karbon der Karawanken and Karnischen Alpen. *Abhand. Geol. Bundesanst. Wien* 23(3): 1-56.

Heritsch, F., 1938. Die stratigraphische stellung des Trogkofelkalkes. *N. Jahr. Min. Geol. Palaeont.*, B 79: 63-186.

Hoare, R. D., 1960. New Pennsylvanian Brachiopods from south west Missouri. *J. Paleont.* 34: 217-232.

Hoare, R. D., 1961. Desmoinesian Brachiopoda and Mollusca from south west Missouri. *Univ. Missouri Studies* 36: 1-263.

Hoare, R. D., Anderson, J. R. & Sturgeon, M. T., 1979. *Eolissochonetes morsei* n. sp. (Brachiopoda) from the Pennsylvanian of Kentucky. *J. Paleont.* 53: 1179-1181.

Huang, T. K., 1932. Late Permian brachiopoda of south west China. *Palaeont. Sinica, Ser.* B. 9(1): 1-138.

Ifanova, V. V., 1968. Nekotoryye Rannepermskiye Chonetidae Pechorskogo Basseyna. *Paleont. Zh.* 1968 (3): 29-33.

Ifanova, V. V., 1972. Permskie brakhiopody Pechorskogo Basseina. In, Ifanova, V. V. & Semenova, E. G. *Srednekamennougol'nye i Permskie brakhiopody vostoka i severa evropeiskoi chasti SSSR.* Akad. Nauk. SSSR. Izd-vo "Nauka", Moskva, pp. 72-161.

Jing, Y. & Hu, S., 1978. Brachiopods of the Kuhfeng Formation in South Anhui and Nanking Hills. *Acta Palaeont. Sinica* 17: 101-127.

Johnson, J. G., 1966. *Parachonetes,* a new lower and middle Devonian brachiopod genus. *Palaeontology* 9: 365-370.

Johnson, J. G., 1970. Great Basin lower Devonian Brachiopoda. *Mem. geol. Soc. Amer.* 121: 1-421.

King, R. H., 1965. The chonetid brachiopod *Mesolobus* and some of its species. *J. Paleont.* 39: 293-295.

Liao Zhuo-Ting, 1980. Brachiopod assemblages from the Upper Permian and Permo-Triassic boundary beds, South China. *Can. J. Earth Sci.* 17: 289-295.

Licharew, B. K., (Likharev, B. K.), 1934. Fauna permskikh otlozhenii Kolymskogo Kraya. *Akad. Nuak. SSSR, Trudy Sov. izuchen. proizvod. sil. ser. Yakutskaya* 14(1) 1-148.

Licharew, B. K., (Likharev, B. K.), 1936. Permskie Brachiopoda severnogo Kavkaza. Semeistva: chonetidae Hall et Clarke i Productidae Gray. *Mono. po Paleont. SSSR* 39(1): 1-151.

Licharew, B. K. & Kotlyar, G. V., 1978. Permskie brakhiopody Yuzhnogo Primor'ya. In, *Verkhnii Paleozoi Severo Vostochnoi Azii.* Vladivostok. pp 63-75, 96-99.

Mikryukov, M. F., 1969. Novye rod i vid khonetid Russkoi Platformy. In, Markovsky, B. P., (ed.). *Novye Vidy Drevnikh Rastenni i Beznozvoiochnykh SSSR.* "Nedra" Moskva, Vyp. 2: 90-92.

McKellar, R. G., 1965. An upper Carboniferous brachiopod fauna from the Monto District, Queensland. *Publ. geol. Surv. Qld.* 328: 1-15.

Mendes, J. C., 1959. Chonetacea e Productacea Carboniferous de Amazonia. *Univ. Sao Paulo, Fac. Filos., Cienc. Letras, Bol.* 236, *Geol.* 17: 1-83.

Mirskaya, M. F., Shestakova, M. F. & Chudinova, I. I., 1956. O nekotorykh novykh okamenelostyakh is nizhnepermskikh otlozhenii Kamskogo Priural'ya. *Uchenye Zapiski Molotovskogo Gos. Un-ta.* 7(4): 27-43.

Mudge, M. R. & Yochelson, E. L., 1962. Stratigraphy and paleontology of the uppermost Pennsylvanian and lowermost Permian rocks in Kansas. *Prof. Pap. U.S. geol. Surv.* 323: 1-213.

Nakamura, K., 1959. Some Lower Permian Sakamotozawa brachiopods. *J. Fac. Sci. Hokkaido Univ. Ser.* 4 10: 199-207.

Norwood, J. G. & Pratten, H. 1855. Notice of the genus *Chonetes* as found in the western states and territories with descriptions of eleven new species. *J. Acad. nat. Sci. Philadelphia,* Ser. 2 3: 23-32.

Paeckelmann, W., 1930. Die Brachiopoden des deutschen Unterkarbons. I Teil: Die Orthiden, Strophomeniden und Choneten des mittleren und oberen Unterkarbons. *Abh. Preuss. Geol. Landesanst. N.F.* 122: 143-326.

Prokof'ev, V. A., 1975. Brakhiopody verkhnego Karbona Samarskoi Luki. *Trudy Vses. Nauchno-issled. Geol.-razved. Neft. Inst. (VNIGNI)* 162: 1-144.

Ramsbottom, W. H. C., 1952. The fauna of the Cefn Coed Marine band in the coal measures at Aberbaiden, near Tondu, Glamorgan. *Bull. geol. Surv. Gt. Br.* 4: 8-32.

Reed, F. R. C., 1931. New fossils from the *Productus* Limestone of the Salt Range with notes on other species. *Mem. geol. Surv. India, Palaeont. Indica, N.S.* 17: 1-56.

Reed, F. R. C., 1936. Some fossils from the *Eurydesma* and *Conularia* beds (Punjabian) of the Salt Range. *Mem. geol. Surv. India, Palaeont. Indica, N.S.* 23(1): 1-36.

Reed, F. R. C., 1939. Non-marine lamellibranchs etc., from the "Speckled Sandstone" Formation (Punjabian) of the Salt Range. *Rec. geol. Surv. Ind.* 74: 474-491.

Reed, F. R. C., 1944. Brachiopods and Mullosca of the *Productus* Limestone of the Salt Range. *Mem. geol. Surv. India, Palaeont. Indica,* N.S. 23(2): 1-678.

Renz, H., 1940. Die Palaozoischen faunen von 1935. Metazoen. *Wiss. Ergeb. Niederland. Exped, Karakorum.* 3(1), 2: 118-247. E. J. Brill, Leiden.

Roberts, J., 1971. Devonian and Carboniferous brachiopods from the Bonaparte Gulf Basin, North western Australia. *Bull. Bur. Miner. Resour. Geol. Geophys. Aust.* 122, vol. 1: 1-319, vol. 2, 59 plates.

Roberts, J., 1975. Early Carboniferous brachiopod zones of eastern Australia. *J. geol. Soc. Aust.* 22: 1-31.

Roberts, J., 1976. Carboniferous chonetacean and productacean brachiopods from eastern Australia. *Palaeontology* 19: 17-77.

Schellwien, E., 1892. Die Fauna des Karnischen Fusulinenkalks. *Palaeontographica* 39: 1-56.

Sikstell, T. A., (ed.), 1975. *Biostratigrafiya verkhnego paleozoya gornogo obramleniya yuznoi Fergany.* Minist. Geol. Uzbek. SSR, Sred. nauchno-issled. inst. geol. i mineral. Syr'ya, (SAIGIMS). Tashkent.

Sokolskaya, A. N., 1946. Osnovnye puti evolyutsii semeistva Chonetidae. *Akad. Nauk SSSR, Otdel biol Nauk, Izv.* 6: 731-740.

Sokolskaya, A. N., 1949. Vozrastiye izmeneniya khonetid i ikh taksonomicheskoe znachenie. *Akad. Nauk SSSR, Paleont. Inst., Trudy* 20: 268-278.

Sokolskaya, A. N., 1950. Chonetidae russkoi platformy. *Akad, Nauk SSSR, Paleont. inst., Trudy.* 27: 1-108.

Sokolskaya, A. N., 1960. Nadsemeistva Chonetacea. In, Orlov, Yu. A. (ed.). *Osnovy Paleontologii* 15: 221-223. Moskva.

Sokolskaya, A. N., 1968. Podotryad Chonetidina. In, Sarycheva, T. G. (ed.) Brakhiopody verkhnego paleozoya vostochnogo Kazakhstana. *Akad. Nauk SSSR, Paleont. Inst., Trudy* 121: 66-73.

Solomina, R. V., 1978. Nekotorye sredneverkhnekamennougol'nye brakhiopody severnogo verkhoyan'ya. *Akad. Nauk SSSR, Sibirsk. Otdel., Inst. Geol. Geofiz., Trudy* 386: 99-123.

Stehli, F. G., 1954. Lower Leonardian Brachiopoda of the Sierra Diablo. *Bull. Amer. Mus. Nat. Hist.* 105: 261-358.

Stepanov, D. L., 1973. The Permian System in the USSR. *Mem. Can. Soc. Petrol. Geol.* 2: 120-136.

Sturgeon, M. J. & Hoare, R. D., 1968. Pennsylvanian brachiopods of Ohio. *Bull. geol. Surv. Ohio* 63: 1-95.

Sutherland, P. K. & Harlow, F. H., 1973. Pennsylvanian brachiopods and biostratigraphy in southern Sangre de Cristo Mountains, New Mexico. *Mem. New Mexico Bur. Mines Miner. Resour.* 27: 1-173.

Tazawa, J., 1976. The Permian of Kesennuma, Kitakami Mountains; a preliminary report. *Earth Science (Chikyu Kagaku)* 30(3): 175-185.

Ting, P., 1965. The Permian and Triassic brachiopods from Yangkang Valley, Tienching District, Tsinghai Province, *Acta Palaeont. Sinica* 13: 260-290.

Vinassa De Regny, P. & Gortani, M., 1905. Fossili carboniferi del M. Pizzul e del piano di Lanza nelle Alpi Carniche. *Bull. Soc. Geol. Ital.* 24: 521-597.

Waterhouse, J. B., 1973. New brachiopod genera from the New Zealand Permian. *J. Roy. Soc. N.Z.* 3: 35-42.

Waterhouse, J. B., 1975. New Permian and Triassic brachiopod taxa. *Pap. Dep. Geol. Univ. Qld.* 7: 1-23.

Waterhouse, J. B., 1978a. Chronostratigraphy for the world Permian. *Amer. Assoc. Petrol. Geol., Studies in Geology* 6: 299-322.

Waterhouse, J. B., 1978b. Permian Brachiopoda and Mollusca from north west Nepal. *Palaeontographica Abt. A.* 160: 1-175.

Waterhouse, J. B. & Gupta, V. J., 1979. Late Middle Permian brachiopods from Marbal Pass, Kashmir, India. *Bull. Ind. Geol. Assoc.* 12(1): 1-42.

Waterhouse, J. B. & Piyasin, S., 1970. Mid-Permian brachiopods from Khao-Phrik, Thailand. *Palaeontographica Abt. A.* 135: 83-197.

Weller, J. M. & McGehee, R., 1933. Typical form and range of *Mesolobus mesolobus. J. Paleont.* 7: 109-110.

Winkler-Prins, C. F., 1970. Brachiopod descriptions. In, Wagner, R. H. & Winkler-prins, C. F. The stratigraphic succession, flora and fauna of Cantabrian and Stephanian A rocks at Barruelo (prov. Palencia) N.W. Spain. *Univ. Liege, Colloquie Strat. Carbonifere, Cong. Colloques* 55: 531-542.

Yanagida, J., 1967. Early Permian brachiopods from north-central Thailand. *Geol. Palaeont. S.E. Asia* 3: 46-97.

Yanagida, J., 1971. Permian brachiopods from Khao-Phrik near Rat Buri, Thailand. *Geol. Palaeont. S.E. Asia* 8: 69-96.

NOMENCLATURAL NOTE

Sommeriella, a new name for the Permian chonetacean brachiopod subgenus *Sommeria* Archbold 1981

It has been pointed out by Dr. R. W., Huddleston (Chevron Oil Field Research Company, La Habra, California) that the subgeneric name *Sommeria* Archbold 1981 is a junior homonym of *Sommeria* Huebner 1825, a genus of African Lepidoptera. I therefore propose the new name *Sommeriella* to replace *Sommeria* Archbold 1981 for the Permian brachiopod subgenus.

REFERENCES

ARCHBOLD, N. W. 1981. Studies on Western Australian Permian brachiopods. The Family Rugosochonetidae Muir-Wood 1962. *Proc. R. Soc. Vict.* 93: 109-128.

HUEBNER, J., 1818-1825. *Zuträge zur Sammlung exotischer Schmetterlinge bestehead in Bekundigung einzelner Fliegmuster neuer oder rarer Nichteuropäisher Gattungen.* Drittes Hundert. 40 p. 172 pls. Augsburg.

N. W. Archbold
Department of Geology
University of Melbourne
Parkville, Victoria 3052

PROC. R. SOC. VICT. vol. 94, no. 1, 11-22, March 1982

CHANNEL INCISION AT EAGLEHAWK CREEK, GIPPSLAND, VICTORIA, AUSTRALIA

By Juliet F. Bird

Department of Geography, Melbourne State College, 757 Swanston Street, Carlton, Victoria 3053

Abstract: A hundred years ago, when the land around Glengarry was subdivided into small farms, Eaglehawk Creek was a shallow shifting watercourse interspersed with patches of swamplands. Efforts to drain the land and contain the creek have led to incision, creating a channel up to 15 m deep. The progress of incision can be documented from historical evidence including the personal recollection of residents of the area. Phases of rapid deepening associated with major floods have alternated with periods of stability recorded as terraces in the channel sides. The present phase of relatively slow erosion probably reflects the absence of high flows in the last three years rather than the attainment of a stable grade.

Many of the river channels in Gippsland, in eastern Victoria have undergone extensive geomorphological change since the area was settled by Europeans 150 years ago. Among the most striking examples of change is the channel incision which has occurred along the northern tributaries of the Latrobe River. This paper describes the history of that erosion with particular reference to Eaglehawk and Stoney Creeks (Fig. 1), and discusses the factors that have led to the conversion of the shifting surface streams of the pre-agricultural landscape into the gullies up to 15 m deep which are seen in the area today (Fig. 2).

In the United States there have been many studies of channel changes in the post settlement period: while most researchers have concluded that human interference has been the main cause, a few, such as Bull (1964) have suggested that in some cases climatic events, such as periods of exceptionally heavy rainfall, may have been significant. Cooke and Reeve (1976) reviewed the extensive literature on arroyos, deep gullies which are widespread in the western USA. They concluded from their own studies in Arizona and California that arroyos resulted from floristic change, particularly that associated with livestock grazing, and destruction of valley floor vegetation with a consequent increase in the susceptibility of channels to erosion. Malde and Scott (1977), in a study of contemporary arroyo development near Santa Fe in New Mexico, analysed the processes of gullying but emphasised the problem of isolating any single cause, because the onset of erosion in the 1880s coincided with several other changes, including a transition from grassland to scrub vegetation, and a general lowering of water tables in the area. In the mid-west of the United States channel erosion is also prevalent. Daniels (1960) presented a case study of Willow County Ditch in Iowa, which has entrenched several metres into its former floodplain since the beginning of the century; he considered that while regional modification of run off may have been a contributory factor, the most important cause was an increase in stream gradient resulting from channel straightening.

In Europe eroding channels are less common, but an example is the Devon gully described by Gregory and Park (1976) which was believed to be due to modification of run off caused by urbanisation. Incision of channels in a forested area in Luxembourg was also ascribed to change in surface run off, in this case the result of concentration along culvert underpasses and drainage ditches (Imeson & Jungerius 1977).

Recognition of the impact of settlement on river channels in Australia came early, and the remarks of John Robertson (1853, quoted in Bride 1898) concerning the development of gullying in the Western District of Victoria are often quoted. Abbott (1884, p. 105) was more specific when he described changes in run-off in inland New South Wales: "The difference between stocked country and that which has never been stocked is apparent even after a few years. The surface becomes firmer and water runs where it never ran before . . . it does not now take half the amount of rain to put water in the rivers that it did thirty years ago, just after it was first settled."

More recently Woodyer (1968) emphasised the dominance of incised channel forms in New South Wales; he quoted Dury as saying that these had developed in the 200 years since European settlement. Pickup (1975) analysed the process of incision along Crawfords Creek, near Picton, where instability was initiated by a severe flood in 1949. In a later paper Pickup (1976) described a regional prevalence of incision with particular reference to the Cumberland Basin, but here analysis of precipitation records, which extend back as far as 1880, suggested a recent increase in rainfall with consequent growth in the magnitude and frequency of flooding as the most likely cause.

Goede (1972), in a study of Tea Tree Rivulet in northeastern Tasmania, emphasised the role of vegetation clearing, particularly alongside the gullied sector, in promoting channel instability, which was probably also influenced by a trend towards an increased number of small rain falls since about 1917. In South Australia channel deepening over the past century was described

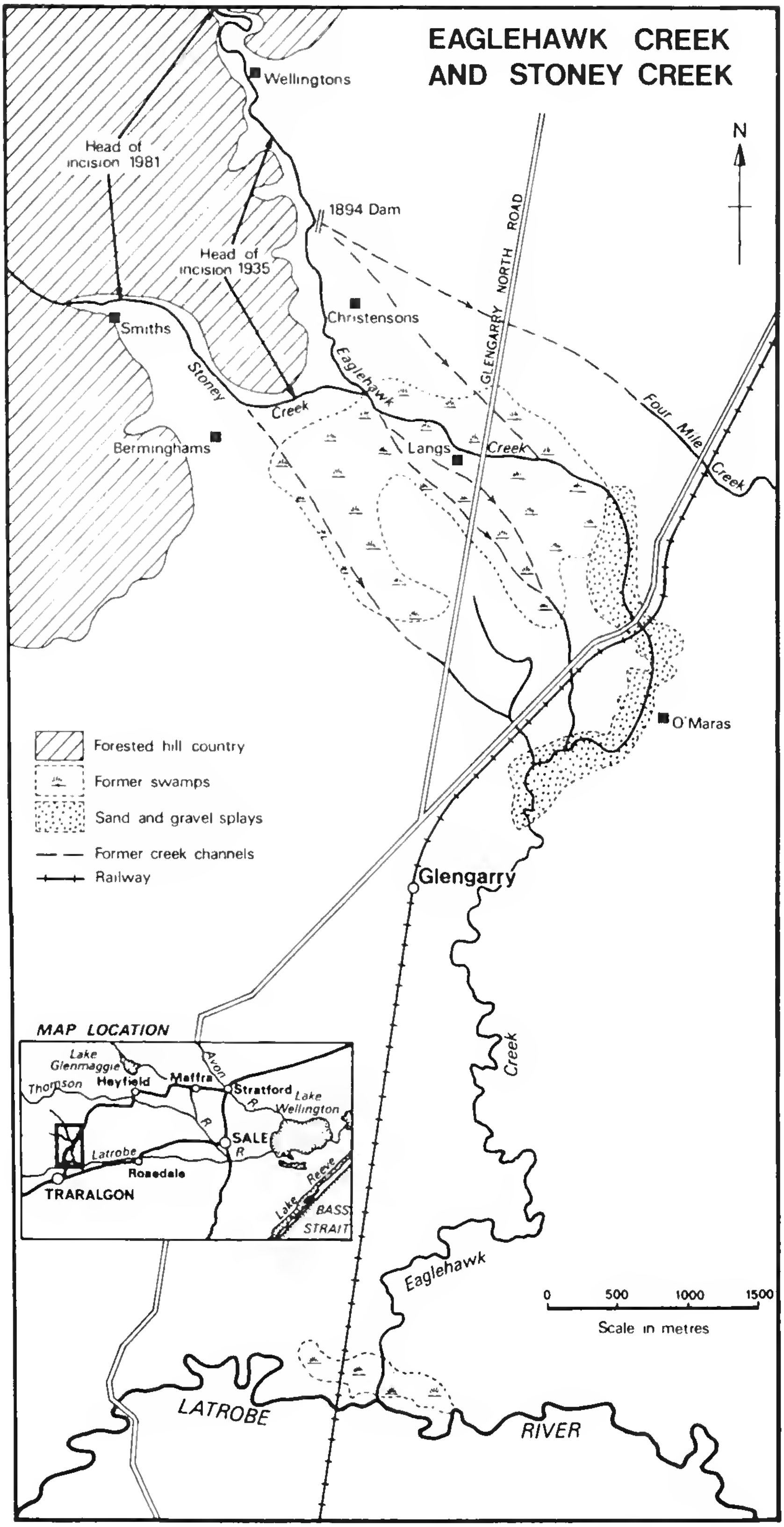


Fig. 1—Study area on Eaglehawk and Stoney Creeks.

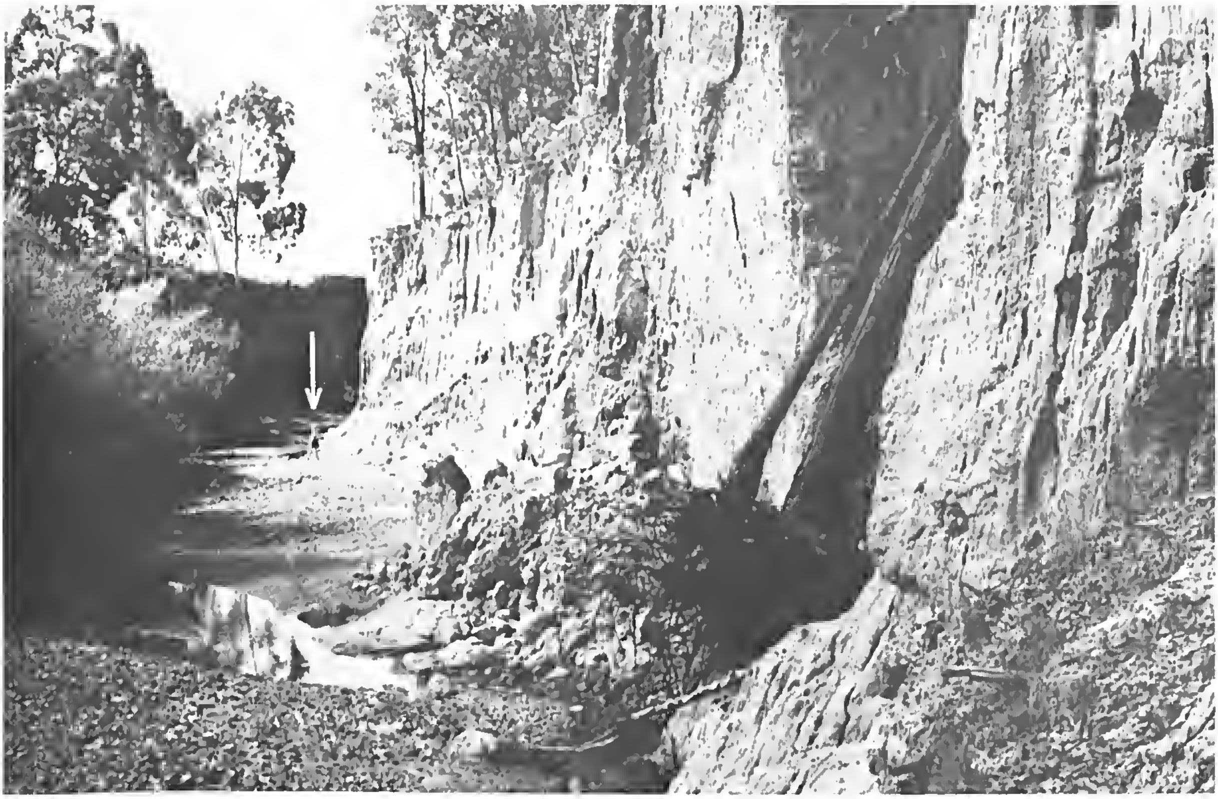


Fig. 2—Eaglehawk Creek 200 m downstream from Christensons, looking downstream. Figure arrowed for scale.

by Bourmann (1976) who attributed it to increased runoff following deforestation and ploughing. Bourmann also cited specific cases of erosion developing along channels dug to drain swamplands.

In Victoria Bird (1980) concluded that incision along the Lang Lang River had several causes, which she was unable to rank in order of importance. In the lower part of the valley, swamps had been drained and the river course had been straightened, which resulted in lowered base levels and increased channel gradient. Upstream sectors had also been straightened, while construction of a levee bank blocked a depression which formerly permitted egress of flood waters from the Lang Lang channel onto swamplands to the north.

Eaglehawk and Stoney Creeks are particularly favourable for a study of geomorphological change. Air photographs are available for 1935, 1964, 1970 and 1976. A railway line, built in 1883, crosses Eaglehawk Creek just below the main incised sector and maintenance surveys made by the Victorian Railway Authority record erosion and sediment deposition at the bridge site at frequent intervals. Most of the changes have occurred within the last seventy years, so that farmers in the area today recall them either personally, or through stories related by their parents, many of whom were the original settlers who opened up the land for agriculture. While personal memory is often an unreliable source of evidence, it is likely to be accurate where events, such as destruction of important access tracks, seriously affect farm management.

THE LOCAL SETTING

Eaglehawk and Stoney Creeks rise in Palaeozoic hill country, at an altitude of about 380 m and in the upper part of their courses they flow through dissected terrain covered with open eucalypt forest which has been extensively logged. Part of the area has been cleared and replanted with conifers for a nearby paper mill. On leaving the forest the streams cross a foothill zone formed by coalescing fans with surface gradients of 0.010. Under natural conditions the fans enclosed swampy tracts (Fig. 1), where stream courses became indistinct before re-emerging as defined channels to cross the terraces of the Latrobe. Eaglehawk Creek flows directly into the Latrobe River, unlike the other watercourses in this region, which terminate in the back-swamps at the edge of the flood plain.

The foothill zone was originally occupied by squatters in the 1840s but little vegetation clearing occurred until after the land was resumed for release under the Selection Acts of the 1860s. Small farmers were then encouraged to settle in the area to grow food for the miners who passed through on their way to the Walhalla goldfields, but the swampy terrain proved unsuitable for cropping, and there was little progress until the construction of the railway in 1883. After that improved transport ensured rapid development, mainly of dairy farming to supply local butter factories, and by the 1930s most of the forest had been cleared and replaced with improved pasture.

THE DEVELOPMENT OF EROSION

The shifting stream courses (Fig. 1) (The information on flow routes and vegetation derives from the land selection files of the 1860s, many of which include plans of the individual subdivisions.) were a nuisance to the local farmers, and in 1894 they tried to control Eaglehawk Creek by constructing a dam to block the flood overflow which formerly travelled across a low col into the catchment of Four Mile Creek. About the same time, the farmer who owned the land west of the Glengarry North Road enlarged one of the channels taking Eaglehawk Creek across his property with the dual aim of eliminating the changes of course and draining the swamps. The local Shire Council (Rosedale) then extended this channel east of the road, directing the water into the depression leading to the northernmost of the three bridges which carried the railway across branches of Eaglehawk Creek. Present stream alignment still follows this northern route, though subsequent erosion and meandering have eliminated the signs of its man-made origin.

The first record that Eaglehawk Creek was changing dates from 1910, when engineers noted instability beneath the railway bridge; nine years later the bridge had to be partially rebuilt following a flood which widened the underlying waterway. Thereafter it was sediment deposition rather than erosion which caused bridge maintenance problems. Incision becomes evident about 1 km above the railway, though in this lower part the incised channel is partially infilled with sediment. Evidence for the early development of erosion is sparse, but in 1914 Eaglehawk Creek was still small enough to be crossed by a minor footbridge at Christensons, while each winter floods caused problems when they overflowed down the access track to the local school. By 1920 there was a large waterfall 300 m above Langs, and in 1929 the channel just above the Glengarry North Road was said to be very deep. (Mrs Timmins pers. comm.). The 1935 air photographs show active incision extending to about 500 m below Wellingtons, and ground photographs taken at this time indicate that the channel was already 10 m deep above the junction with Stoney Creek. By 1939 the Forest (now Frasers) Road crossing at Wellingtons was threatened, and ten years later erosion at this point was described as severe. Above the bridge, bedrock outcropping in the channel slowed the progress of erosion, but where the valley is infilled incision is still evident 1 km upstream.

Under natural conditions Stoney Creek, like Eaglehawk, lacked a defined channel across the fan zone and was prone to change its course. At the time of settlement it flowed on an alignment similar to the present one as far as the site of Bermingham's Farm, then became dispersed in a swamp before reforming into a channel just above the railway. According to a local farmer (Jack Lang pers. comm.) his father, in 1932 or 1933, had been impressed with the effectiveness of the eroding Eaglehawk channel for swamp drainage and the rapid removal of floodwater from the hills so he decided to direct Stoney Creek into it by way of a ditch around the base of the spur dividing the two catchments. Incision spread rapidly back up the ditch into the old channel with the head of the erosion already 500 m above the confluence by 1935. By the early 1940s incision extended back to Berminghams, where it repeatedly cut the access track to the hills: attempts to maintain a bridge at this point (Fig. 3) were finally abandoned about 1952. (Date from Raymond Smith, son of the owner of a property upstream from this point, who depended on this bridge for access.) Figure 4 includes a cross section of the channel at the bridge site today. Like Eaglehawk, Stoney Creek has now cut down to bedrock in several places, and although further upstream extension of incision is likely, it will be a much slower process than in the lower course.

An average figure for the rate of upstream transmission of the head of gullying can be deduced from the historical evidence. Over the period 1920-1935 it moved from the vicinity of the Glengarry North road bridge to above Christensons, a distance of 2 km, a rate of about 133 m a year. Between 1935 and 1939, when erosion is recorded at Wellingtons, the head of the incision migrated a further 500 m, indicating a similar annual rate. In Stoney Creek movement in the first 3 years was very rapid — 500 m — but it subsequently slowed to a rate comparable to that in Eaglehawk Creek.

Average figures for headward extension though useful for comparison with gully development elsewhere, are somewhat misleading, because it is clear that incision has been an episodic process, with periods of rapid development in high flows interspersed with years of near stability when no major floods occurred. Valley side benches in the channel of Eaglehawk Creek between Stoney Creek and Wellingtons are relics of former channel floor levels temporarily stabilised behind weirs. In the early years incision appears to have been accomplished through the headward migration of prominent knickpoints, which may have originated on harder bands within the fan sediments, or behind weirs which became breached. About 1952 the headwall which had marked the upstream limit of incision became degraded into a series of rapids and though a few steps persist behind intact drop structures, or associated with rocky sectors or blocking logs, none are more than 40-60 cm high. Even the upper limit of incision is ill defined, as above Frasers Road stable rocky sectors alternate with patches of infill where the former valley floor is preserved as a terrace 1-2 m above the present channel floor. The contrast between the present smooth profile, and the irregular one described in early records may be due to diminution of downcutting due to the attainment of a stable grade, or may reflect a change in the nature of the sediment load. In the early years incision in the lower part of the fan released a load dominated by silt, sand and gravel; as erosion has extended back into the hills it has cut into increasingly coarse material so that it is likely that a greater proportion of the sediment now moves as bedload. Goede (1972) suggested that the absence of a prominent headwall in an eroding gully may be attributed to a preponderance of coarse material

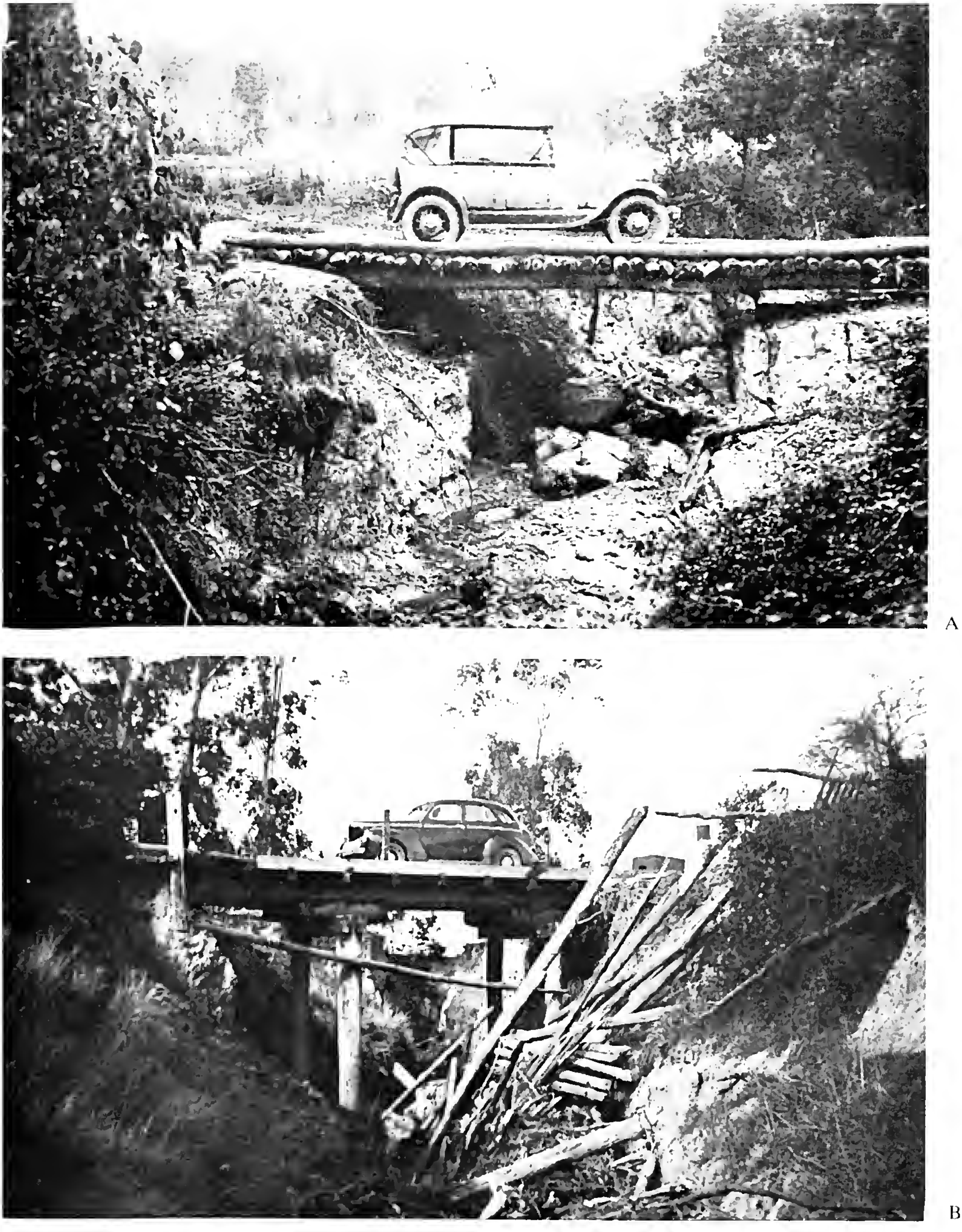


Fig. 3—A, Bridge across Stoney Creek at Berminghams, looking upstream. About 1936. (Source: R. Smith, Glengarry). B. Same site in August 1944. Remains of the old bridge in the foreground. (Source: State Rivers and Water Supply Commission photograph collection).

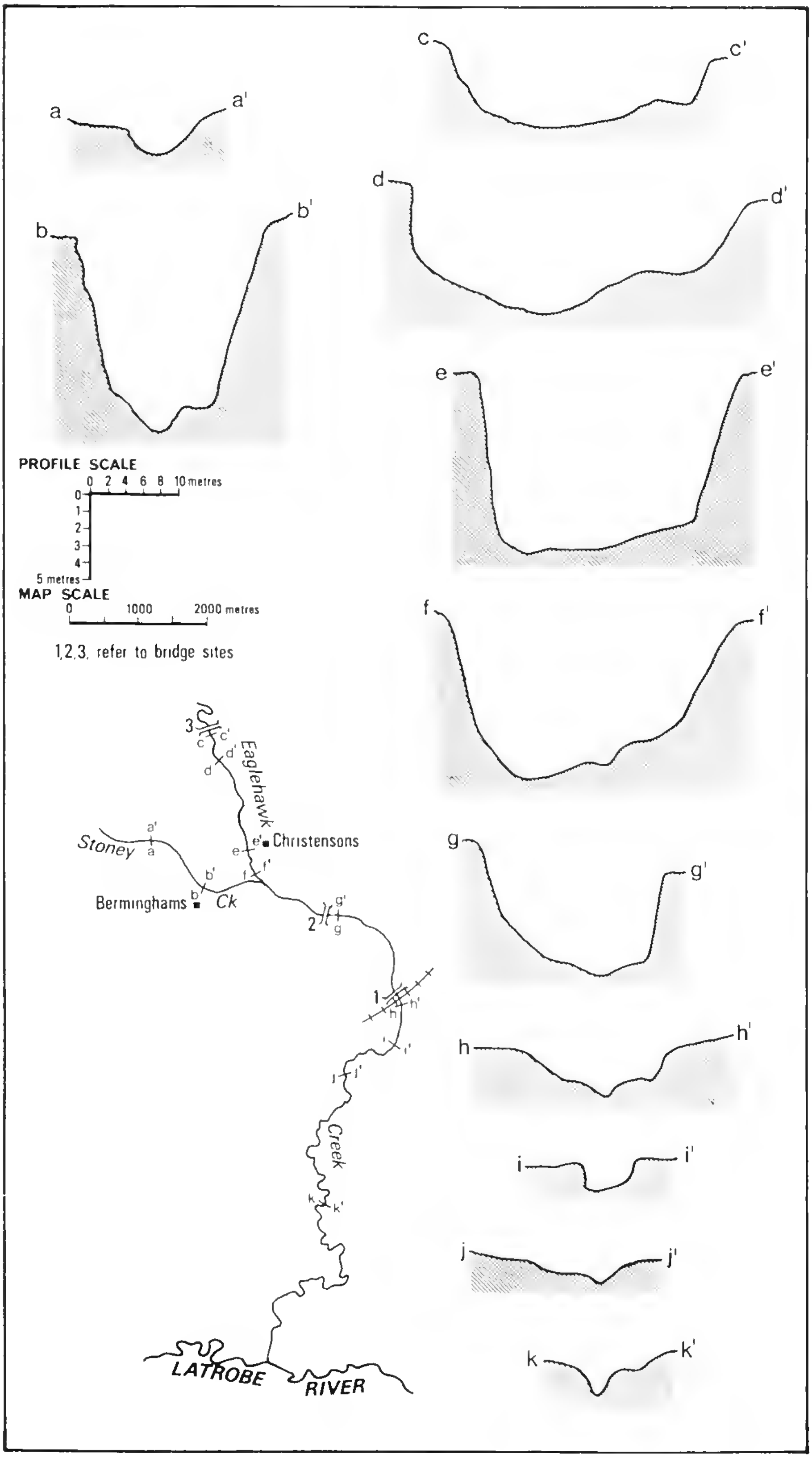


Fig. 4—Cross-sections of Eaglehawk and Stoney Creeks at the positions indicated.

in the sediment load. The change in sediment size may also be reflected in the the changing shape of the cross profile. Historical data suggest that deepening was dominant in the early years, so that sections attained a depth of 10 m or more by 1935; since that time the maximum depth has only increased to around 15 m, but the rate of sediment delivery downstream, together with the visible signs of bank undercutting, show that widening, particularly on bends, is still active. Schumm (1977) has demonstrated that channel width-depth ratios are related to sediment size, and the transition from dominant down-cutting to dominant widening may be associated with the increasing proportion of bed load in transit. This may also explain the lower width-depth ratios noted in Stoney Creek, which is deeper and narrower (Fig. 4) and carries finer debris.

SEDIMENT DEPOSITION

Erosion along Eaglehawk and Stoney Creeks has mobilised an estimated 750 000 m³ of sediment ranging in size from cobbles 6 cm or more in diameter down to fine sand and silt. While the former remain on the bed of the higher reaches, and much of the silt has been carried as suspended load through to the Latrobe River, redeposition of the sand and gravel components of the load has created many problems. Where the creek bed has deepened most of this material has been retained on the channel floor, forming a deep, porous infill, so that surface water flow is much less common than it used to be, thereby reducing the value of the stream as a source of stock water. The area within which this has occurred is shown as a slight convexity on the long profile. The most damaging effect of sediment deposition has been the blocking of the waterway beneath the rail and main-road bridges. The original 1881 railway survey and a profile of the bridge site drawn in 1919 both show a clearance of nearly 3 m between river bed and bridge deck. By 1933 this waterway had been almost obliterated by deposition within the channel and early in 1934 floods banked up behind the bridge to flood 10 hectares of land, leaving 1.5 m of sediment in places. Later that year a flood of even greater magnitude swept the channel clear, transporting sediment further downstream and restoring the waterway profile of 15 years earlier. The improvement was shortlived, and by 1935 railway authorities were forced to excavate material from beneath the bridge to re-establish the channel and prevent the creek from flooding over the line and disrupting train services. For a time it looked as if Eaglehawk Creek might abandon this course altogether and revert to one of its old routes to the south. The railway authorities were unconcerned; they already had bridges that would cope with such a change because when the line was constructed the creek still sometimes flowed in this direction. It was seen as more of a threat by the Shire Council and the Country Roads Board, which maintained the road. The road, built after the railway, had made no provision for an alternative waterway, so that a course diversion would necessitate the construction of a new bridge.

The deposition of sediment across farmland in the region known locally as the "delta" has been detrimental to those farmers directly affected, as the value of pasturelands is reduced when they are blanketed by several centimetres of coarse sand and gravel. The cumulative effect of sediment deposition has been to raise land levels by 2 or 3 m in places, burying fence posts and tree trunks.

ATTEMPTS TO CONTROL EROSION AND SEDIMENTATION

In the 1930s attempts to deal with problems resulting from the erosion of Eaglehawk and Stoney Creeks were confined to periodic excavation of the waterway beneath the main-road and rail bridges, but it became increasingly evident that the problem of infilling could only be solved by the insertion of sediment traps and erosion controls upstream. At first attempts to do this were on a very small scale consisting mainly of brushwood weirs across the channel floor. None of the structures lasted more than a few months before they were washed out by floods, and though the Rosedale Shire Council had consultations with the Soil Conservation Board and the State Rivers and Water Supply Commission in 1942 over a proposal for construction of a major dam across Eaglehawk Creek, no further action was taken for some years. In 1949 the Country Roads Board replaced the old main-road bridge with a new one having a 2 m clearance above the river bed; the following year the Railways, too, replaced their bridge with a new, higher level structure on what was considered an improved alignment. Floods in 1952 washed out the approach to the new road bridge (Fig. 5) and went over the raised rail bridge, but problems at the bridge sites have subequently diminished.

In 1950, following the failure of the early attempts to check erosion and sedimentation, local farmers met to form the Eaglehawk Creek Control League; in 1953 this was taken over by the Latrobe River Improvement Trust when its area of jurisdiction was extended to include Eaglehawk Creek. In 1956 the Trust, in conjunction with the State Rivers and Water Supply Commission, constructed extensive new erosion control works, consisting of about 45 stone and wire-mesh weirs, placed at intervals along Eaglehawk and Stoney Creeks, but within a few months of completion more than two-thirds had been rendered useless because the river outflanked them by undercutting the soft bank sediments. The broken weirs then made the situation worse, because they trapped tree trunks and branches which fell into the river as the forested bank eroded, forcing the creek to migrate around them. By 1957 Eaglehawk Creek just upstream from the confluence with Stoney Creek occupied a vertical sided slot 13 m deep and 30 m wide. For a decade attempts to control erosion were abandoned because it was clear that only a large dam and sediment trap would be effective, and its cost was more than was justified now that the new road and rail bridges had been constructed overcoming the problem of severing the major transport link through the area.

In 1968 a further attempt to control erosion

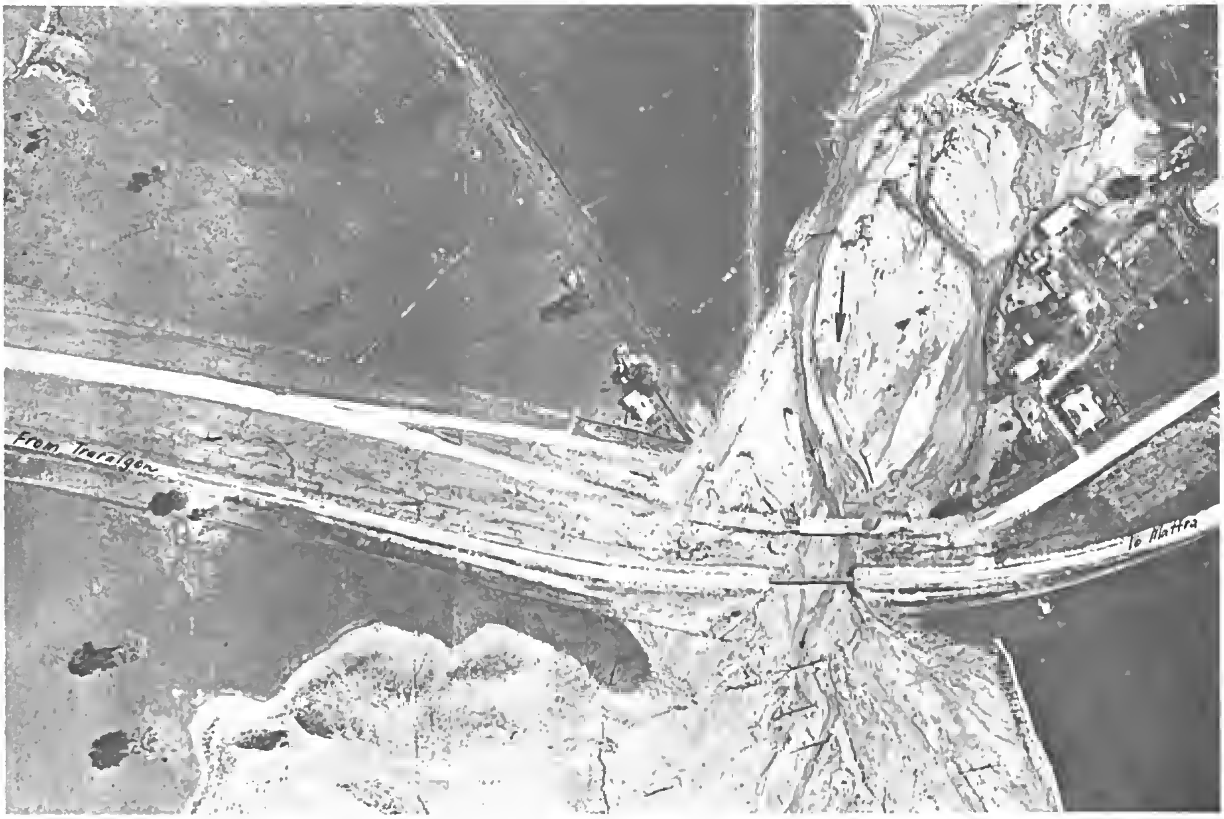


Fig. 5—Aerial photograph of the main road and rail bridges taken just after the 1952 floods, showing sand splays. (Source: Victorian Railways).

through insertion of concrete drop structures was made using Drought Relief Funds to provide local employment, but a flash flood of January 1971 caused severe damage to the new weirs (Fig. 6), and today there are none on Stoney Creek, and only two intact on the upper part of Eaglehawk. A concrete block structure protects the Glengarry North Road Bridge, while a low concrete wall across the creek bed just above the main bridge traps some of the sediment arriving from upstream. Current erosion "control" is limited to annual bulldozing by the Latrobe River Improvement Trust designed to remove obstacles from the channel floor, and redirect the current away from the eastern bank where undermining results in the loss of valuable farmland. The enlarged waterway beneath the bridges and periodic straightening of the channel through the sediment splays has resulted in progressive downstream migration of the toe of the "delta" or sand splay area. If the process continues coarse sediment may eventually be delivered onto the flood plain of the Latrobe River or even, like the silt, into the Latrobe River itself.

CAUSES OF INSTABILITY AT EAGLEHAWK AND STONEY CREEKS

The historical and field evidence so far reviewed indicates that erosion began along Eaglehawk Creek about the turn of the century, with a phase of rapid deepening lasting until about 1940 since when channel widening has been dominant except in peak flood years such as 1952, 1971 and 1978, when a new channel has been incised into the pre-existing creek floor. Incision of Stoney Creek started in the early 1930s, but like Eaglehawk Creek it is now tending to widen, rather than deepen its channel.

It is unlikely that precipitation in the area has changed sufficiently to trigger channel instability. Local rainfall recording began in the 1880s (Rainfall figures analysed include Toongabbie (daily and monthly) 1889-1920, 1929-1930; Morwell (monthly) 1888-1891, 1899-1915, 1934-80; Traralgon (monthly) 1903-1962.) and analysis of five year running means shows no significant increase since then. Retention of a forest cover over the upper part of the catchments makes it unlikely that the flow regime within the creek has changed greatly, though logging may have had a temporary effect on the magnitude of flood peaks. Bank erosion is widespread along the Latrobe River, but has not been transmitted up Eaglehawk Creek. Two weirs on the lower end of the Creek stop any headward migration of instability and serve as partial silt traps.

Early maps show that the fans once carried open forest vegetation interspersed with denser areas described as "scrub" or "fern" most of which had been cleared by 1935. The impact of this clearing on river flow is unlikely to have been great; the fans occupy only a small and relatively dry part of the catchment and peak flows in the streams, both of which are prone to flash flooding, coincide with periods of heavy rain in the upper catchment associated with prolonged spells of easterly weather and the development of cut off low pressure cells. While it is clear that flash floods may form the main erosive force, the climatic events which lead to flash flooding are not a post-settlement phenomenon, and the fact that the floods have become such an effective agent of erosion must be due to other change.

Destruction of bank vegetation is one contributory factor. In the past many local farmers considerd scrub growth along creeks was undesirable because it limited access by stock and harboured vermin, but today its role in bank stabilisation is acknowledged. Trees are only removed where they have been undermined and are liable to fall into the river, because when this happens they are expensive to remove and there is a risk that they will promote channel widening by diverting the water flow against the bank. In many places today the sides of Eaglehawk and Stoney Creeks are unvegetated because they are too steep for plants to become established, but the absence of any severe flood in the last three years has enabled a number of riparian species to colonise higher sections of the channel floor. While they persist these will assist bed stabilisation, but if they are damaged either by flooding or bulldozing there is a risk that increased sediment mobilisation will follow.

The excavation of a continuous channel through the swamp which once formed a local base level for the upper part of Eaglehawk Creek has also caused erosion. Water now flows to a new base level at the Latrobe River. Figure 7 shows evolution of the new long profile in diagrammatic form. This erosion began in the upper part of the natural channel across the terrace as the relatively steep gradients of the head of a water course became adjusted to the lower gradients of a middle reach. The deepening was then transmitted upstream through headward migration of knickpoints. The channel is deepest where it passes through higher parts of the undulating surface of the fan. This adjustment of long profile is complicated by the redeposition of eroded material as regional gradients diminish from fan to terrace. The redeposition creates a new and steeper gradient at the lower end of the sand splays. As deepening upstream diminishes and the rate of arrival of new sediment declines, the channel starts to erode back through this oversteepened sector creating a new, lower, sand splay as this material in turn is redeposited downstream. Erosion of the channel back up into the fan is comparable to the sequence described by Schumm and Hadley in Wyoming and New Mexico (1957): trenching appears to be initiated at the toe of fan once surface gradients exceed a threshold value, which in the case of Eaglehawk Creek lies at about 0.012. Below the lowest splay the water emerges minus its coarser sediment load, and possessed of superfluous energy. Several authors,

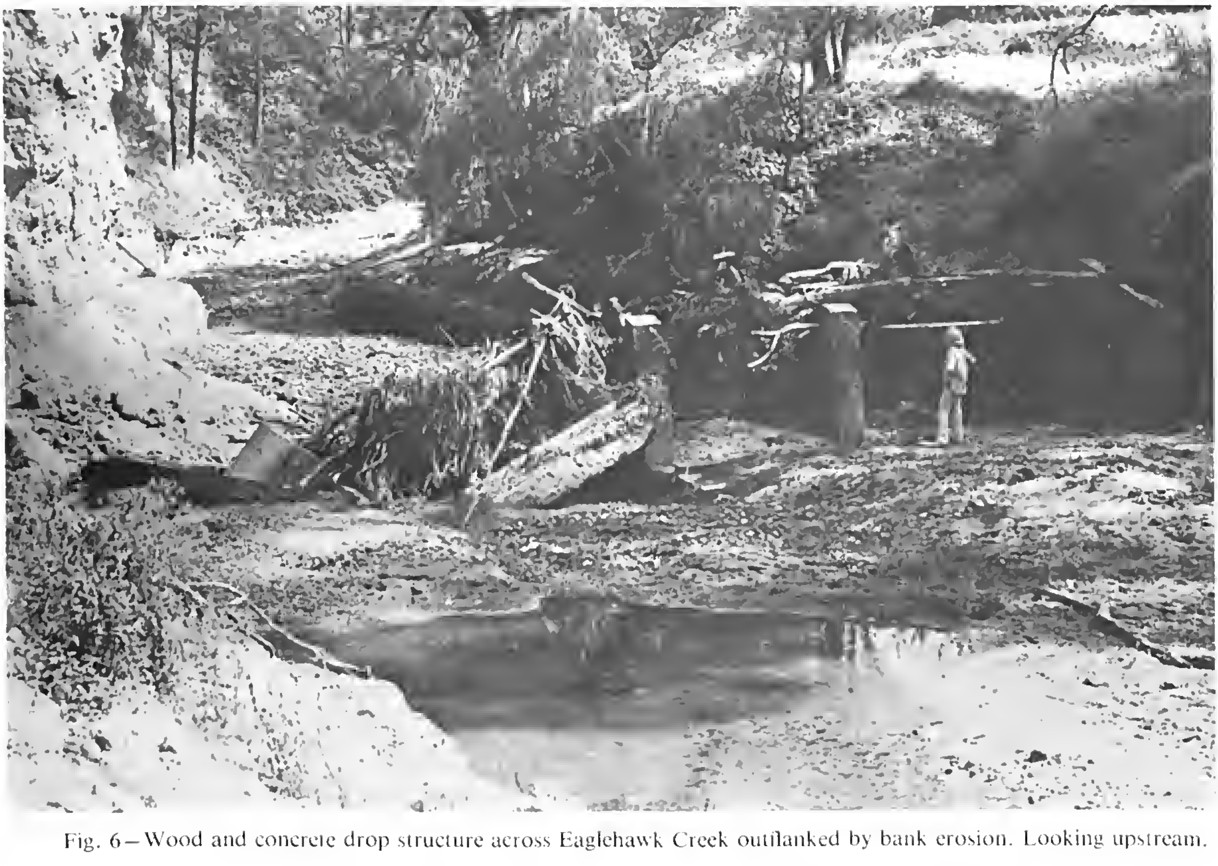


Fig. 6—Wood and concrete drop structure across Eaglehawk Creek outflanked by bank erosion. Looking upstream.

including Komura and Simmins (1967) and Gregory and Park (1974) have shown that this leads to local channel degradation, and this is evident in Eaglehawk Creek. Basalt boulders have been dumped at the head of the channel below the splays in an attempt to prevent the development of deep water holes in the channel floor, eroded by clear water emerging from the depositional zone.

Stoney Creek underwent changes in long profile similar to those of Eaglehawk Creek. It, too, once flowed into a swamp which provided a local base level, but when it was diverted into Eaglehawk Creek in 1933 it adjusted to the changes within the main stream. A photograph taken in 1935 shows the confluence at a stage when they were still at different levels, with the mouth of Stoney Creek about a metre above the channel of Eaglehawk. This disjunction was the origin of a knickpoint which was rapidly transmitted upstream. Stoney Creek began to deepen later than Eaglehawk Creek, and the cross profile (Fig. 4) together with the comparative lack of channel floor vegetation suggests that the transition from a dominance of deepening to one of widening occurred more recently. Much of the recent sediment deposited in the splays downstream probably originated form Stoney Creek rather than Eaglehawk Creek.

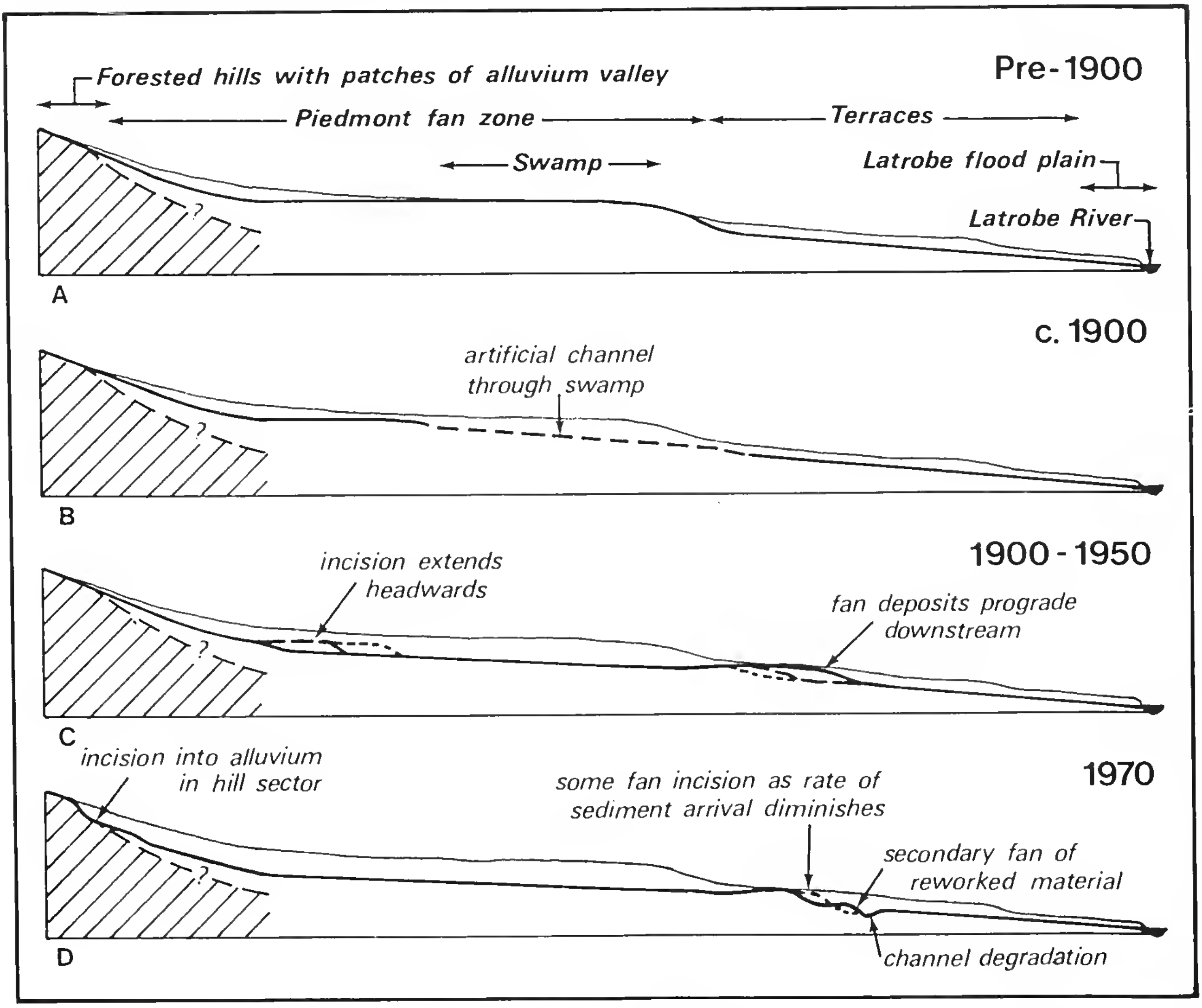


Fig. 7—A, Under natural conditions Eaglehawk Creek had two sectors with a clearly defined channel separated by a swamp which served as base level for the upper channel. B, About 1895 a drain was cut through the swamp, linking the upper and lower channels. C, The steepened reach of the man-made channel through the swamp began to incise back into the upper part of the fan zone. At the same time redeposition of eroded materials built up a new prograding fan across the terrace below the swamp. D, As the incised channel extended back into the hills the rate of erosion slowed, and supply of sediment to the downstream depositional area diminished. The channel at the lower end of the post-settlement fan then began to cut back, creating a secondary sediment splay at the downstream end. Water minus its sand and gravel load emerging from the toe of this secondary splay caused degradation of the channel immediately downstream.

Changes in long profile have not been the only cause of channel instability in Eaglehawk Creek. Although, as stated earlier, there is no evidence for changes in the stream hydrograph due to rainfall trends or catchment modification, interference within the fan zone itself has accentuated variations in run off. One factor in this has been the elimination of the local swamps which formerly served as natural flood retarding basins. Even more important is the retention of run off within the one main channel. Earlier in this paper the natural pattern of run off was described: as is common in fan terrain, watercourses were subject to frequent lateral shifts, so that when flood waters overtopped one channel they created a new one off to the side. When measures were taken to prevent this all the flood flows were retained within the one alignment. The dam built in 1894 to block the overflow into Four Mile Creek ensured that an increased proportion of the floodwater was retained within Eaglehawk Creek; a corollary of this is that flood peaks in Four Mile Creek have diminished and this is one of the few streams in the area today which shows no signs of incision, but rather of having an over-fit channel. A further major increment to the flow of Eaglehawk Creek occurred with the diversion into it of Stoney Creek, effectively increasing the catchment of the middle reaches from 39 km² to 53km². This diversion did not affect lower Eaglehawk Creek, because, as the map (Fig. 1) shows, it already carried the Stoney Creek flow under natural conditions.

Eaglehawk Creek between the railway bridge and the Stoney Creek confluence is therefore receiving the runoff from an additional 14 km² of catchment, as well as containing the flood peaks which formerly passed out of the channel. There is no evidence from which to estimate the magnitude of the flood formerly required to overtop the banks and flow into alternative channels, but it is known to have occurred several times each year. This implies that even moderate floods with a return period of less than a year used to be dispersed, but were thereafter retained within the main creek, and as Dury (1977) has suggested, these are particularly important in determining channel capacity.

CONCLUSION

In suggesting that river channels in Victoria were stable over the few hundred years prior to European settlement it is necessary to clarify the definition of stability. Course changes took place, and fan construction was actively occurring in many areas. A corollary of this is that the rivers were carrying sediment, so that catchment erosion must have been quite widespread. The post-settlement onset of vertical instability has often been initiated through attempts to control pre-settlement lateral instability. Channelling and swamp drainage have created stream-bed gradients considerably steeper than those occurring naturally and the response of many rivers has been to incise their former channel floors.

The rate of incision diminishes as streams again approach a stable grade, or when they encounter bedrock. Minor control structures are rarely effective on channels prone to flash flooding, particularly if they are located in poorly consolidated sediments, and stabilisation can only be achieved with massive dams, the cost of construction of which usually far outweighs the benefits obtained. Many problems result from the less visible end of the process, the redeposition of eroded material, which masks farmland, devalues creek water supplies, obliterates fence lines, and threatens road and rail links. The insertion of small sediment traps along the channel may help by retaining some of the sediment within the creek bed at the cost of transforming surface into subsurface flow.

Eaglehawk and Stoney Creeks have passed through the phase of maximum instability as they adjusted to human modification, but their present near-stable condition is a precarious one. Another severe flood is likely to wash out the two remaining intact drop structures which together hold a head of just over a metre, and initiate a knickpoint which, as it migrates headwards, will threaten the causeway crossing at Frasers Road. A flood of this magnitude could be caused by a recurrence of the meteorological conditions experienced in 1952, or by a less rare climatic event exacerbated by human interference in the catchment such as renewed logging or a re-opening and enlargement of the old quarry just above Frasers Road. The answer to the difficulties posed by eroding channels appears to be to adapt to changes that have occurred rather than attempt to reverse them, but also to guard against any environmental modifications which might result in the initiation of a further phase of marked instability.

ACKNOWLEDGEMENTS

The author would like to thank the following Victorian organisations for permission to consult relevant files: State Rivers and Water Supply Commission; Latrobe River Improvement Trust; Victorian Railways; Education Department; Department of Crown Lands; Public Record Office. Jennie Wragge and Neville Green assisted with the surveying. Tony Boyd printed the photographs and Rob Bartlet prepared the diagrams. Many local landowners also assisted with historical information.

REFERENCES

ABBOTT, W. E., 1884. Water supply in the interior of New South Wales *J. Proc. Roy. Soc. N.S.W.* 18: 85-111.

BIRD, J. F., 1980. Some geomorphological implications of flood control measures on the Lang Lang River, Victoria. *Aust. Geogr. Stud.* 18: 169-183.

BOURMAN, R., 1976. Environmental geomorphology: examples from the area south of Adelaide *Roy. Geogr. Soc. Austr., Proc. S. Aust. Branch* 75: 1-23.

BRIDE, T. F., 1898. *Letters from Victorian Pioneers.* Heinemann, Melbourne.

BULL, W. B., 1964. History and causes of channel trenching in western Fresno County, California. *Am. J. Sci.* 262: 249-258.

COOKE, R. U. & REEVE, R. W., 1976. *Arroyos and environmental change in the American Southwest.* Clarendon Press, Oxford.

DANIELS, R. B., 1960. Entrenchment of the willow drainage ditch, Harrison County, Iowa. *Am. J. Sci.* 258: 161-176.

DURY, G., 1977. Peak flows, low flows and aspects of geomorphic dominance. In *River channel changes*, K. J. Gregory, ed., Wiley, Chichester, 61-74.

GOEDE, A., 1972. Discontinuous gullying of the Tea-tree Rivulet, Buckland, Eastern Tasmania. *Pap. Proc. R. Soc. Tasm.* 106: 5-15.

GREGORY, K. J. & PARK, C. C., 1974. Adjustment of river channel capacity downstream from a reservoir. *Water Resources Res.* 10: 870-873.

GREGORY, K. J. & PARK, C. C., 1976. The development of a Devon gully and Man. *Geography* 61: 77-82.

IMESON, A. C. & JUNGERIUS, P. D., 1977. The widening of valley incisions by soil fall in a forested Keuper area, Luxembourg. *Earth Surf. Proc.* 2: 141-152.

KOMURA, S. & SIMMONS, D. B., 1967. River bed degradation below dams. *J. Hydrol. Div. Am. Soc. Civil Eng.* 93-HY4: 1-14.

MALDE, H. E. & SCOTT, A. G., 1977. Observations of contemporary arroyo cutting near Santa Fe, New Mexico, U.S.A. *Earth Surf. Proc.* 2: 39-54.

PICKUP, G., 1975. Downstream variations in morphology, flow conditions and sediment transport in an eroding channel. *Z. Geomorph. N.F.* 19: 443-459.

PICKUP, G., 1976. Geomorphic effects of changes in river runoff, Cumberland Basin, New South Wales. *Aust. Geogr.* 13: 188-193.

SCHUMM, S. A. & HADLEY, R. F., 1957. Arroyos and the semiarid cycle of erosion. *Am. J. Sci.* 255: 161-174.

SCHUMM, S. A., 1977. *The fluvial system.* Wiley, New York.

WOODYER, K. D., 1968. Bankfull frequency in rivers. *J. Hydrol.* 6: 114-142.

PROC. R. SOC. VICT. vol. 94, no. 1, 23-34, March 1982

THE PEAK OF THE FLANDRIAN TRANSGRESSION IN VICTORIA, S.E. AUSTRALIA—FAUNAS AND SEA LEVEL CHANGES

By E. D. Gill* and J. G. Lang,* with an appendix by S. E. Boyd†

* CSIRO Division of Applied Geomechanics, Institute of Earth Resources, P.O. Box 54, Mount Waverley, Victoria 3149

† National Museum of Victoria, 285-321 Russell Street, Melbourne, Victoria 3000

Abstract: The peak of the Flandrian Transgression (ca. 6000 years ago in Australia) has been studied at two sites on the Victorian coast 440 km apart in a direct line. The Warrnambool site in the west is on a stable high where marine Upper Miocene strata are still horizontal, while the Seaspray site in the east is in an area of known earth movements over the same period of time. The sediments at Warrnambool are characterized by calcarenite, and at Seaspray by quartz arenite.

When the sea reached its peak, Warrnambool Bay extended over the Lake Pertobe flats where open bay fossils establish the facies. Two spits of different coloured sands (separate sand systems) enclosed the western end of Warrnambool Bay, and so established a lagoonal system where shell beds were deposited at the peak of the transgression. At Seaspray a similar lagoonal shell bed was emplaced behind a coastal dune.

At Warrnambool the present emergence of the top of the shell bed is 1.76 m. Taking into account compaction and other factors, an emergence of 2 m at the peak of the Flandrian Transgression is estimated. A similar figure was obtained at Seaspray, indicating that for the past 6000 years measurable earth movement has not occurred.

Following a line of latitude the coast of Victoria covers a little over 900 km, but following the coast it is about twice the distance. The peak of the Flandrian Transgression in Australia was about 6000 years B.P. (Gill & Hopley 1971, Thom & Chappell 1975). Around the coast of Victoria the commonest evidence is shell beds of quiet water facies behind coastal dunes and in inlets of various kinds. These shell beds are one of the best categories of evidence for sea level change because (1) they are low energy deposits, (2) the shells were laid below water level, and (3) except near the entrances, lagoons have a water level at or near mean sea level except in flood time. As such shell beds were laid down below water level, and upon draining the fine-grained sediments compacted appreciably (Gill & Lang 1977), the level of the top of the shell bed was usually below mean sea level at the time of deposition.

These shell beds have been studied along the whole coast of Victoria and beyond, but two sites have been chosen for special treatment. At both sites undisturbed cores of the shell beds have been taken, the faunas have been studied, and precise levelling has been carried out. The recently established Australian Height Datum (A.H.D.) (Roelse *et al.* 1971) makes it possible to relate accurately the surveys of the two sites, although 440 km apart in a straight line. One site is at Warrnambool in western Victoria and the other at Seaspray in eastern Victoria (Fig. 1).

WARRNAMBOOL SITE

The remarkable sequence of onlapping calcarenite formations at Warrnambool (Gill 1977 and Fig. 2) in an embayment eroded by a Pliocene river may be a suitable world Quaternary standard section. They onlap a basalt dated at 1.95 million years old. For section with dates see Reeckmann and Gill (1981). The formations of the past 400 000 years have been shown to be couplets of shallow marine to beach deposits overlain by aeolian sediments. Because of the rapid cementing of these highly calcareous formations, they retain their original morphology to a high degree, so that their facies can be demonstrated. Their superposition, plus relative dating with C^{13} and O^{18} isotopes, and chronometric dating with C^{14} and U/Th provide a time framework. Each of these couplets marks the peak of an interglacial transgression, of which the Flandrian Transgression is the latest.

The bedrock is a shelf calcisiltite, the Port Campbell Limestone, which is still horizontal for about 100 km. Also no seaward warping is discernible because the declivity from the Miocene shore near Hamilton to the present coast is of the order of 1.5 m/km. This is a remarkable stability even for mid-plate Australia. The Warrnambool sequence overlies the Warrnambool High, a platform of ancient rocks (Kenley 1976), and so is an ideal place to study the peak of the Flandrian Transgression and consider geoidal changes. By contrast the Seaspray site is in an area of continuing tectonic movement.

Other evidence of a higher level for the peak of the Flandrian Transgression are relict cliffs, emerged shore platforms, channels in Holocene platforms extending up into the coastal scrub, overgrown honeycomb weathering in the lichen and dicotyledon zones, dune building seaward of Holocene cliffs, and penetration by the sea of river tracts not now intruded by it.

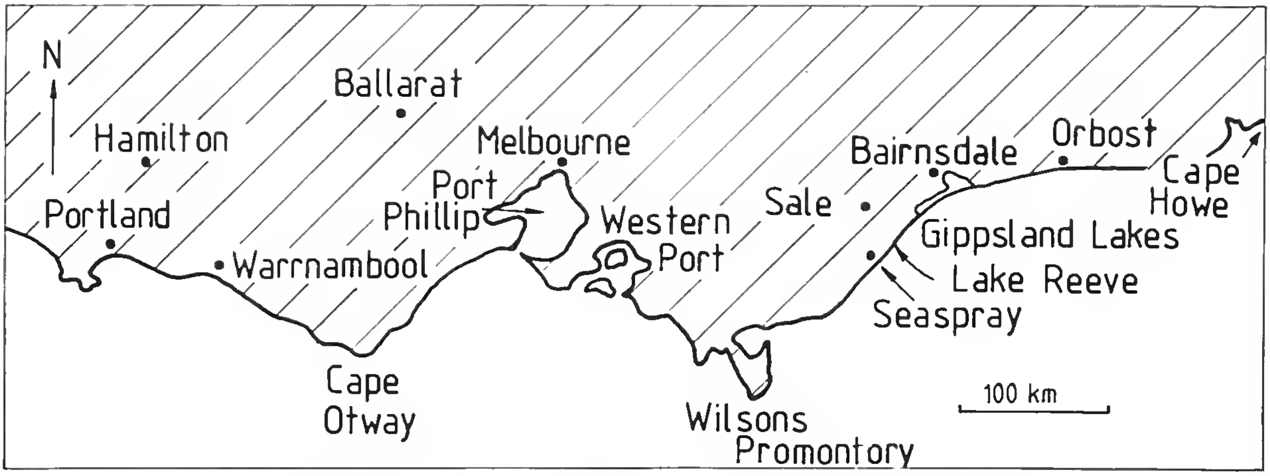


Fig. 1—Map showing localities of Warrnambool and Seaspray, Victoria, Australia.

LAKE PERTOBE

Three years before the settlement of Warrnambool began, William Pickering reported on the site to Governor La Trobe on 7 December 1844. He described the ample supplies of fresh water, and referred to the "lake which is at present salt, but by throwing a dam across its mouth . . . it could be kept fresh all the year." This is apparently the earliest reference concerning Lake Pertobe, which lies on flats 1-3 m above the sea at the western end of Warrnambool Bay. Following variations in rainfall, it ranges from a body of fresh water to (rarely) a dry lake bed. Under natural conditions it emptied via Pertobe Creek into the Merri River, which debouches at the S.W. corner of Warrnambool Bay (also called Lady Bay). In the Latrobe Library, Melbourne, an unfinished water colour (or draft) made in 1879 is preserved, and Fig. 3 is a pen and ink copy. It shows Lake Pertobe, Pertobe Creek and the Merri River in their natural condition (cf. Fig. 2). The spring tidal range in Warrnambool Bay is 0.9 m.

The Lake Pertobe sediments are sandier to the east, nearer the sand spits that formed the lagoon. The sea entered through a gap between the two termini of the spits 6000 years ago (Fig. 7), and since the sea departed from the lagoon, waves have broken through from time to time. A photograph by Thomas Washbourne taken between 1872 and 1879 (date limits determined by Thomas Wicking from structures in the photo) shows a wide gap with a sandy floor. Such intrusions could not have been frequent or sustained for long, otherwise there would be more sand in Lake Pertobe.

Auger holes have been sunk at a number of places in this area (e.g. see Gill 1953, figs 13, 14), and in 1979 CSIRO drilled a number of bores in the Lake Pertobe flats and the present estuary of the Merri River. Years ago bores were sunk in the Lake Pertobe flats to explore the possibility of building a harbour there, but none of the organizations concerned have been able to produce the logs. In recent years the City of Warrnambool has built an Adventure Park in the area. This involved extensive testing and excavations which have shown the wide extent of the shell bed and the various facies.

CARAVAN PARK SECTION

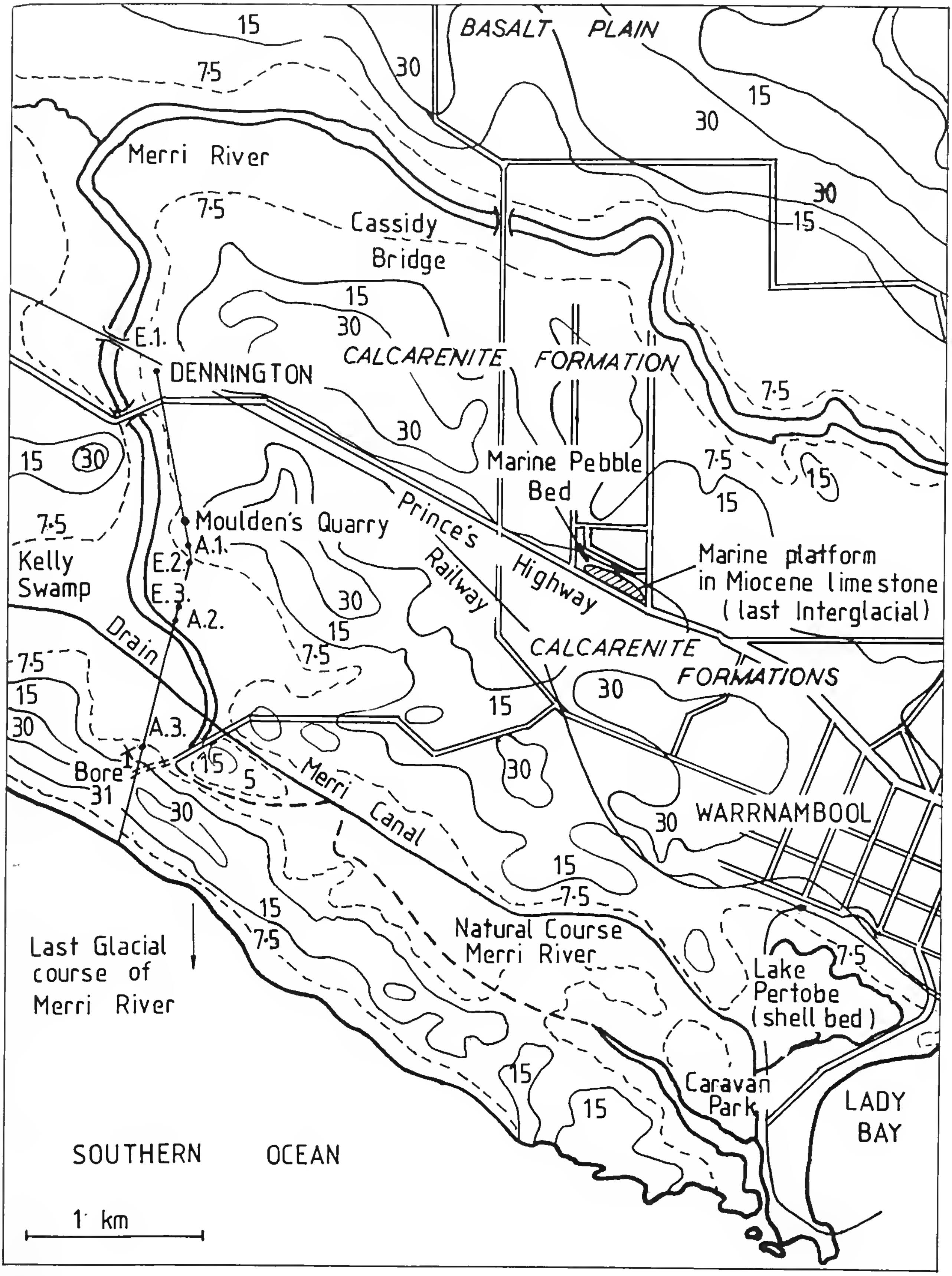
Sewerage trenches dug at the Ocean Beach Caravan Park in Pertobe Road provided an opportunity to study a section in detail and relate it to A.H.D. (Fig. 5). For the general stratigraphy of the area see Gill (1976). The shell bed and its equivalents elsewhere were given the stratigraphic name Pertobe Coquina, following Pettijohn, but now Schreiber (1978) defines a coquinoid as "an autochthonous (in situ) deposit of shelly material, usually having a fine-grained matrix, which may build up, under certain conditions, to biostromes." This description fits the Lake Pertobe deposit very well, so it is re-named Pertobe Coquinoid.

Figure 5 shows the stratigraphic section with a disconformity between the lagoonal coquinoid and the freshwater peat. During the interval, the shell bed was drained (or partly so), and compacted, with some development of secondary carbonate, i.e. an incipient soil formed. The time gap is given approximately by the radiocarbon dates (6570 years for the coquinoid, and 1875 years for the middle and lowest third of the peat). The shells for the C^{14} assay were from 0.27 to 0.37 m above A.H.D. As the area was tectonically stable for the period concerned, the fall in water table to allow the incipient soil to develop infers a fall in sea level. Evidence for this fall is widespread.

Pertobe Coquinoid

Below the Lake Pertobe flats, including the estuary of the Merri River, there is a bed of mostly muddy lagoonal sediments rich in shells, 1-5 m thick, dated 7040 to 5850 years B.P. by radiocarbon (Gill 1971a,

Fig. 2—Locality plan of Warrnambool and Dennington. At Excavation 2 (E.2) is a fossil shore platform with estuarine shells dated 3750 years B.P. The Lake Pertobe shell bed is 6000 years B.P. For description of Dennington section line see Gill 1967a.


BASALT PLAIN
Merri River
Cassidy Bridge
E.1.
DENNINGTON
CALCARENITE FORMATION
Marine Pebble Bed
Moulden's Quarry
A.1.
E.2.
E.3.
A.2.
Kelly Swamp
Drain
Prince's Railway
Highway
Marine platform in Miocene limestone (last Interglacial)
CALCARENITE FORMATIONS
A.3.
Bore 31
Merri Canal
WARRNAMBOOL
Natural Course Merri River
Last Glacial course of Merri River
Lake Pertobe (shell bed)
Caravan Park
LADY BAY
SOUTHERN OCEAN
1 km
15
7·5
30
5

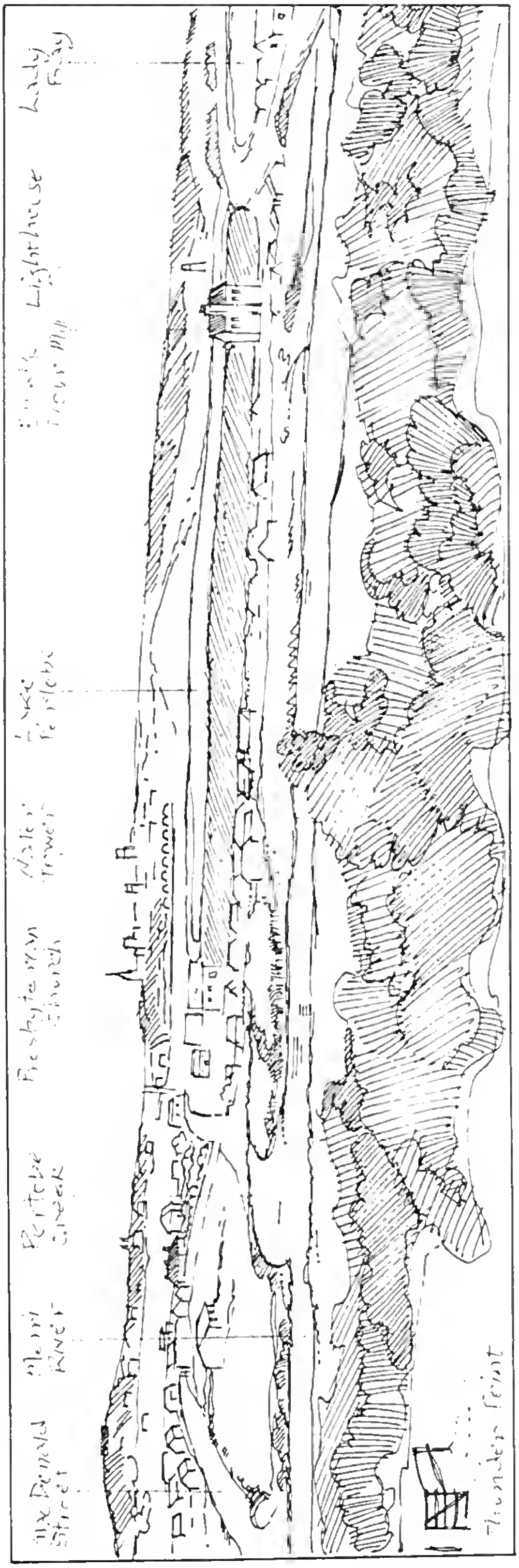


Fig. 3—Line drawing by Don Miller of unfinished water colour made in 1879 showing Lake Pertobe, Pertobe Creek and the Merri River under natural conditions. By courtesy of the Latrobe Gallery, Melbourne.

1973). The base of the shell bed is characterized by open bay shells such as *Katelysia, Ostrea* and *Mytilus,* whereas the major part of the bed is characterized by the lagoonal genera such as *Homalina, Notospisula, Velacumantus, Bembicium,* and *Salinator,* succeeded by fine sandy, muddy and peaty brackish to freshwater sediments as indicated by *Hydrococcus tasmanicus* (tidal saltmarsh), *Coxiella australis* (brackish lake) and *Potomopyrgus niger* (freshwater, usually just above tidal influence). The usual ecological range of these species is given in the Appendix.

Below the shell bed is a layer of fine sand. Although most of the sands in this area are calcarenites, this deposit is entirely siliceous and very well sorted. Its origin is probably in the dry period of about 21 000 to 8500 years ago when a *terra rossa* with calcrete subsoil formed over the calcarenites (Gill 1975). At present, carbonates are not held in the subsoil, but in that dry period a calcrete 0.5-1 m thick accumulated. At the peak of the dry period the A horizon of the *terra rossa* was winnowed away except in the valley floors. Leaching during pedogenesis removed most of the carbonate from the A horizon, leaving essentially quartz and clay. As the bedrock is a consolidated dune sediment, this quartz sand is fine to medium and very well sorted, and the winnowed sand was washed into Warrnambool Bay area while sea level was lower. The sand is grey, except for that on a fossil shore platform under the Pertobe Coquinoid at the foot of Cannon Hill (Gill 1953, fig. 13), where it is red. This red sand was probably washed from Cannon Hill and collected on the platform following a small drop in sea level, and/or because the growth of the spits that created the lagoon lowered the tidal range, although the distance from the entrance of the lagoon is so short that the latter is unlikely.

Tower Hill Tuff

Under the Pertobe Coquinoid at the foot of Cannon Hill is a deposit of Tower Hill Tuff (Gill 1950, 1967a, 1972, 1976, 1978, 1979). Pieces of stratified tuff were noted in the spoil from the dragline excavation of a channel for the Johnson Adventure Park below Cannon Hill. Three characteristics of the tuff are significant:

1. It is stratified with different grain sizes in the various layers, as seen in the airlaid tuff in many places on the Warrnambool terrain.
2. It has the open texture of airlaid tuff, and not the compact texture of waterlaid tuff, as revealed by sewerage trenches in the housing area north of the Princes Highway and east of McGregors Road, East Warrnambool, where fossil water weeds, ripple marks and trails were found.
3. The top of a large piece of tuff brought up by the dragline was oxidized to a yellow colour, suggesting short-term pedological activity. The difference between the C^{14} date for the tuff and that for the oyster bed is 720 years.

In a bore at the foot of Cannon Hill on the Pertobe flats, where the surface is 1.88 m above A.H.D. (virtually mean sea level), the shell bed occupied the top

Fig. 4—Oblique aerial photograph showing the gap through which, under natural conditions, the sea occasionally broke through. On the right of the gap is the spit of light grey sand, and on the left is the spit of light brown sand (Fig. 7). Photo by courtesy "The Standard", Warrnambool.

2.26 m, including some fill which formed the path where the boring was done. A C^{14} shell sample from 0.3 m below A.H.D. was dated 6250 ± 160 years B.P. Stratified tuff was cored from 2.26-2.87 m, the tuff being mottled red (2.5 YR 8/4) at the base. Below the tuff was red (10 YR 4/6) calcarenite grading to pink (7.5 YR 8/4) and then into normal very pale brown (10 YR 8/3) at 3.77 m, typical of a *terra rossa* soil on calcarenite. If the sea had been present at that time, the soil would have been washed away, and the tuff also, but 7300 years B.P. sea level was lower and the tuff fell on a land surface. Secondary tuff was described over the Pertobe Coquinoid and piled against the Cannon Hill cliff (Gill 1950); it is better to refer to this as tuffaceous colluvium.

On the top of the cliff immediately east of the Thunder Point trigonometrical station is a hollow containing well stratified tuff. East of this is higher ground with traces of tuff on a calcrete surface. Further east is a slope in the lee of the prevailing winds where a layer of unstratified tuff lightly cemented by calcarenite overlies finely laminated mammillary calcite as described from Dennington, the western suburb of Warrnambool and dated 8700 ± 150 years B.P. (GaK-3920) (Gill 1975). At various levels in this unstratified tuff are edible marine shells of moderate size accompanied by charcoal, which are therefore Aboriginal middens. The shells are from two contrasting facies. *Subninella undulata* came from the open ocean rock platforms to the south, while *Mytilus edulis planulatus*, a bay facies shell, must have come from Warrnambool Bay to the north. Sea level was appreciably lower when the Tower Hill Tuff was emplaced, as is shown by the bore at the foot of Cannon Hill cited above, by airlaid stratified tuff at Tower Hill beach extending down below L.W.L., and by similar tuff below L.W.L. under the Kelly Swamp deposits (Fig. 2).

The dune ridge at Thunder Point, on which the tuff deposits lie, is Last Interglacial in age, left stranded as the sea retreated. As the dune bedding extends to about 3 m below present sea level, its age is estimated to be about 95 000 years. Following the return of the sea to its present level, this dune has been cut back just past its centre-line, so that all the dips are landward. The island platforms of this rock left in the sea, and the dips of the dune rock make it possible to reconstruct the dune. Thus, 7300 years ago, the south edge of the dune was about 0.25 km further seaward and, instead of the present islands off Point Pickering, the dune ridge extended

FORMATION & COMPACTION	COLOUR & THICKNESS	LITHOLOGY & FACIES	A.H.D. LEVEL	AGE IN C14 YEARS B.P.
	0.28 m	FILL	Surface + 1.85 m	Modern
Moyne Alluvium 4.8-8.4 kg/cm^2	0.26 m Black	PEAT Freshwater swamp	+ 1.57 m	1875 yr
Pertobe Coquinoid 7.2-10 kg/cm^2* some leaching and deposition of secondary carbonate; elongate concretions up to 8 cm in long diameter.	1.46 m Light gray 2.5 yr 7/2 with irregular mottles of strong brown 7.5 yr 5/6 Juvenile soil formed on chemically reduced lagoonal deposit before peat formed	At top muddy lagoon with *Homalina* SHELL BED At base open bay facies with *Ostrea* and *Katelysia*	+ 1.31 m ← H.W.L. springs in open sea ← A.H.D.	6570 yr on shell sample from + 0.27 to + 0.37 m
At the base of Cannon Hill the Pertobe Coquinoid overlies subaerially deposited, fine bedded, surficially oxidized TOWER HILL TUFF (7300 yr)		Bottom of excavation 2 m from surface. A nearby excavation penetrated to quartz silt.	- 0.15 m ← L.W.L. springs in open sea	Other dates in same shell bed 6500 yr in Merri Canal near Woollen Mill. Shells about HWM 5850 yr. Shells over fossil shore platform at foot of Cannon Hill

*Penetrometer Readings

Fig. 5 – Geological section in Lake Pertobe area at the Ocean Beach Caravan Park, Warrnambool, Western Victoria.

over 1 km east of the present tip of Point Pickering (Figs 6, 7). The middens show that the Aborigines chose a high point for their eating place, yet protected from the cool prevailing S.W. winds. They gathered food from the open coast to the south and from the bay to the north. As the water deepened in the bay, beds of large oysters flourished there, but as yet their shells have not been found in the middens.

Palaeogeography

When the sea first returned from the Last Glacial low level, Warrnambool Bay was more extensive as it occupied also what are now the Lake Pertobe flats, and a shore platform was formed on the north side (Gill 1953, figs 13, 14). It now remains to explain how the Pertobe flats came into existence. Two processes are possible: 1, the prograding of the shore, whereby the land is progressively built seawards; 2, the growth of a sand barrier or spits which cut off the area, after which it gradually infilled with stillwater sediments. A small fall in sea level aids both processes (Gill 1981a), and there is evidence that this occurred. As the muddy Pertobe Coquinoid covers the whole of the area, and is bounded on the seaward side by two opposing spits of different coloured sands, the second process is the one that occurred. A spit of light grey calcarenite grew north from the Pickering promontory (the Merri River was not there then) to near where the Surf Life Saving Club is now (west shore), while from the Last Interglacial calcarenite on the west side of the Hopkins River mouth a spit of light brown calcarenite grew west to near the S.L.S.C. site (north shore). Behind these spits was a lagoon in which the Pertobe Coquinoid was deposited; the sea entered through the gap between them (Fig. 7). When the sea retreated the gap filled, but has always been a weak point. Under natural conditions the sea used to break through there and cross Pertobe Road into the lake. Captain Barrow's original survey of the harbour (1854) shows a submarine sand spit in this area. The aerial photograph (Fig. 4) shows that in spite of foreshore works the gap between the two spit ends can still be readily recognized. From a high point it is easy to see the fine light grey sand of the west shore as distinct from the coarser light brown of the north shore (Fig. 7). The presence of two sand systems has not been previously recognized. At one time it was thought that the source of the sand filling the harbour was to the east, so a seawall was built opposite the Pertobe Cutting in 1919. This was not successful because it was at the end of the light brown sand system; the movement of brown sand finished there and did not continue on into the harbour.

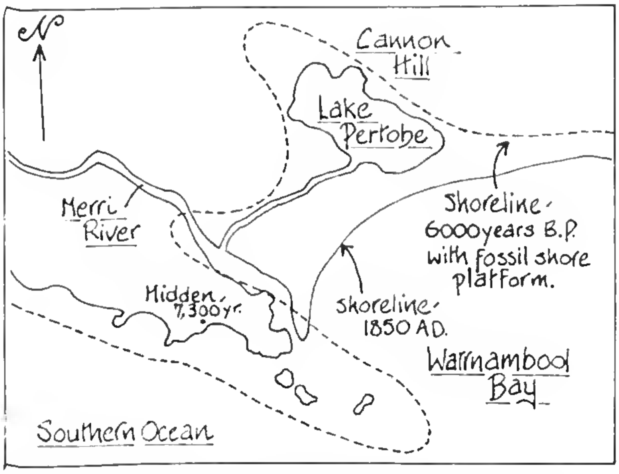


Fig. 6—Superimposed on map of Lake Pertobe area is the shore line of about 6000 years B.P. (dashed line).

CHRONOLOGY

Seven radiocarbon dates (uncorrected for seawater age—about 450 years provide time control for the geological history of the Lake Pertobe flats:

5850 ± 320 (PIC-9) *Homalina*, foot of Cannon Hill, over fossil shore platform.

6250 ± 160 (GX-6788) *Ostrea, Mytilus* and *Notospisula*, bore, foot of Cannon Hill.

6460 ± 110 (SUA-985) *Ostrea*, N. end Lake Pertobe (date recalculated).

6500 ± 200 (PIC-10) *Homalina*, Merri Canal near Warrnambool Woollen Mill.

6570 ± 200 (SUA-780) Fauna with *Mytilus*, Ocean Beach Caravan Park excavation.

7040 ± 205 (GX-6789) Peaty layer (weed bed) with pieces of large shells (including *Katelysia*, open bay genus) plus whole weed shells (cerithiids) under Merri River estuary.

7300 ± 150 (GaK-2856) *Mytilus* and *Subninella* midden in Tower Hill Tuff with calcarenite, E. of Thunder Point.

During the rise of the sea to the peak of the Flandrian Transgression, the two spits that border the Lake Pertobe flats were initiated. As they grew, stillwater areas were created behind them with consequent changes in flora and fauna. The peaty layer dated 7040 years B.P. is the first evidence of this in the excavations. As the spits extended, so the area of lagoon behind them increased. Practically no waves reached this zone, and the tidal currents were weak because of a spring range of only 0.9 m. Shells were moved, but not far, as most are complete and many paired. The shells are so packed in some places that gentle winnowing to remove the mud is suspected. But the large heavy oyster shells provide a biocoenosis, as there was certainly not enough energy to move them. When the buildings at the corner of Pertobe Road and Price Street were constructed, an extensive oyster bed was encountered ("Warrnambool Standard" 17 April 1944). Another oyster bed was recently revealed in excavations at the north end of Lake Pertobe near the railway gates (C^{14} date 6460 years).

Thus in various parts of the Lake Pertobe flats the *Katelysia-Ostrea-Mytilus* open bay facies is dated 7040-6250 years, while the *Homalina-Notospisula-Velacumantus* lagoonal facies is dated 6500-5850 years. This time overlap is to be expected because of the gradual growth of the spits, but the dates do suggest that open bay conditions did not last very long. The spits must soon have extended far enough to establish a stillwater regime with mud deposition (Fig. 7).

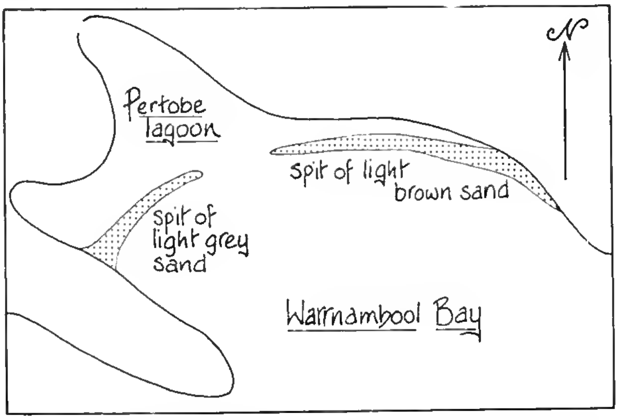


Fig. 7—The palaeogeography of the Lake Pertobe area, Warrnambool, showing the more extensive Warrnambool Bay at the peak of the Flandrian Transgression about 6000 years B.P., and the two spits that created the lagoon (the area now occupied by the Pertobe flats).

The dates so far obtained for the top and bottom of the shell bed give a formation time for the thickest part of 1190 years, but for the greater part of it only 730 years.

ROLE OF THE MERRI RIVER

The Merri River flows across the south end of the Pertobe flats, and debouches into Warrnambool Bay. While the Pertobe Coquinoid was being deposited the river did not enter this area, but debouched near Dennington 4 km N.W. of the present mouth. Three bores sunk through the present bed of the river (which is now diverted through the Merri Canal) on the east side of the road to Thunder Point penetrated only Pertobe Coquinoid. There is no proper channel and practically no riverine sediments; the river just floods across the lagoonal shell bed.

During the Last Glacial period the Merri River flowed through the water gap at Dennington and directly south to the sea. The contours on the continental shelf define the valley through which it flowed (Gill 1967a, fig. 15.1). When the sea returned to its present level, the Dennington Spit (Gill 1981b) began to grow to the N.W., forcing the river to flow around it. About 4000 years ago the sea was still reaching the back of what is now Kelly Swamp (Fig. 2), because sea shells overlying an aeolianite shore platform south of Dennington (Gill 1967a, fig. 15.7) were dated at 3980 ± 150 years B.P. (GX-58). That the genus *Homalina* was common indicates that the Dennington Spit had grown far enough to create a sheltered area at the mouth of the river. The Merri River continued to arch round the growing spit until this course became too difficult, and it diverted S.E. along an old interdune swale to Warrnambool Bay. The dating of sediments along this course could determine approximately when the diversion occurred.

INTERPRETATION OF SEA LEVEL STAND

Although the top of the shell bed is now emerged, it was below low water when deposited because the shells are mostly low water to subtidal species. The top of the shell bed at the Caravan Park is 1.31 m above A.H.D., which is 1.78 m above low water level. The emergence is thus 1.76 m plus (1) the depth of water above low tide, (2) the compaction due to draining on emergence (probably not very much here), (3) any reduction of the top of the shell bed by erosion as the sea retreated, (4) the lowering of the top of the bed by subaerial weathering following exposure (as shown by secondary carbonate deposition) and (5) leaching by acids following deposition of the peat. To allow 0.24 m for these five factors to round off the emergence at 2 m is a conservative figure. The figure most difficult to quantify is the depth of water over the shell bed. As the distance from the sea into the Lake Pertobe lagoon was so very short, no difference in tidal range from that in Warrnambool Bay is to be expected.

The geology cannot be explained as a function of progradation because of (1) the emergence of the shell bed, and because (2) the western part of the post-Flandrian embayment was cut off by a bay bar, then the enclosed area infilled with muddy sediments, i.e. there was not a gradual migration seaward of the beach ridge due to progradation.

SEASPRAY SITE

The Gippsland Lakes form an extensive body of water behind a siliceous sandy beach and barrier about 7 m high (Bird 1978, Jenkin 1968, Ward 1977). It is a quartz sand system and not a calcarenite system as at Warrnambool. The beach is of open ocean type with high energy waves due to the Southern Ocean swell. A high contrast thus exists between the quiet waters of the lakes system and the surf of the open beach; the differences are clear in both the sediments and the biota. It is thus easy to distinguish which Quaternary beds were

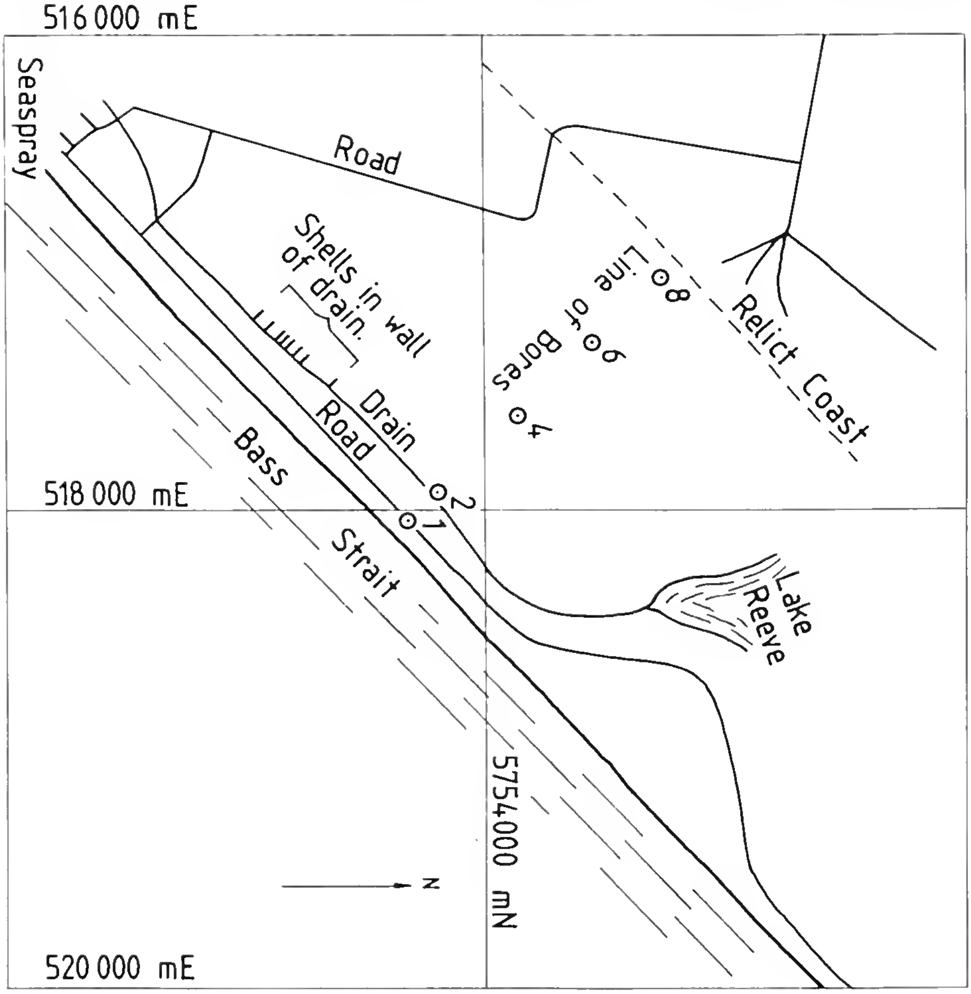


Fig. 8—Map of drain and bore sites between Seaspray and Lake Reeve.

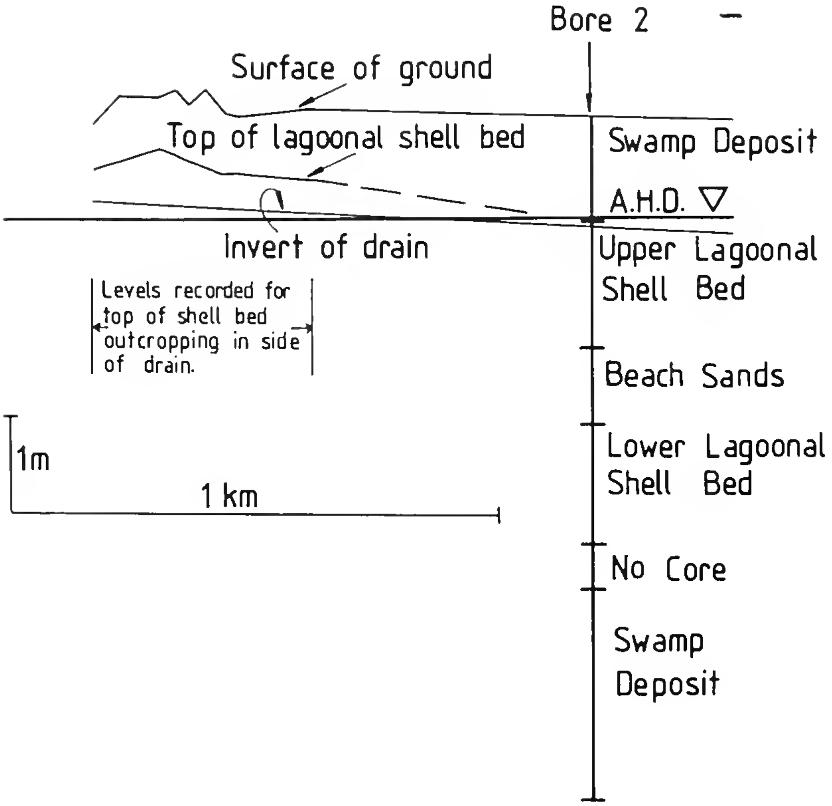


Fig. 9—Longitudinal section along drain from Seaspray to Lake Reeve as shown in Fig. 8.

deposited inside the barrier and which outside (Figs. 8-10).

At the peak of the Flandrian Transgression about 6000 years B.P. the lakes system was far more extensive than now, reaching some 30 km further southwest. The village of Seaspray stands on the lagoonal deposits of this more extensive system, and on a riverine terrace of Merriman's Creek. In 1962 a drain some 3 km long was excavated from Seaspray to Lake Reeve, which is the S.W. end of the present lake system. Under natural conditions the delta of Scott Creek prevented this drainage. This drain provided an excellent section through the emerged shell beds, which were studied and dated by radiocarbon (Gill 1966, 1970, 1971a, b). The CSIRO Division of Applied Geomechanics drilled a series of bores (with undisturbed cores at critical places) normal to the coast across this shell bed in the vicinity of Scott Creek, where the mid-Holocene shore is 1.7 km inland from the present shore (Fig. 8). The delta of Scott Creek provided the only access across the swamp for the drill rig.

Since this work was done, A.H.D. permanent bench marks have been established, and these have been used to determine the height of the shell bed surface in the area. All the pegs put in during our original survey of points of geological interest have now gone. Fortunately our survey was tied into the engineering survey made by the Shire of Rosedale for the engineering works, and it is now possible to relate the local arbitrary engineering datum to A.H.D., and hence also the geological sites (Figs 8, 9).

On the transect the original pegs have also gone, but it has been possible to relate the bore sites to A.H.D. through the level of the road. From photographs of the drilling rig when in position at the site of Bore 1 it has been possible to fix within 1 m the point where the transect crossed the centre of the bitumen road. Another layer of bitumen (without screenings) has been added since the survey, but considering the wear of the road and the thickness of the bitumen, the pavement level can be only 1 or 2 mm different, and this can be ignored. The survey from a permanent survey mark to the transect (0.6 km) and back closed within 1mm, and the level of the centre of the road was determined as 1.773 m A.H.D.

Figure 10 shows a cross-section along the transect, and indicates the relationship of the shell bed to A.H.D. The shell bed is lower along the transect across the flats than it is in the drain behind the dune (Fig. 9). Scott Creek crosses this area and the bed has evidently suffered erosion following fall in sea level. Note that bore sites 3, 5 and 7 of the eight pegged out were not drilled. Fig. 9 shows the levels obtained for the top of the shell bed along the drain parallel to the coast, and along the transect normal to the coast.

Interpretation of Sea Level Stand

It should be noted that the top of the shell bed was surveyed and not the top of the marine bed. At the Lake Pertobe Caravan Park site there is a sharp break between the shell bed and the overlying freshwater peat, but at Seaspray the shell bed is followed by a gradual transition from lagoonal to terrestrial deposits, as also occurs over most of the Lake Pertobe flats. To define the top of the marine bed would require a great deal of micro-palaeontological work. Mr. A. C. Collins determined *Ammonia* and *Trochammina inflata* from this zone; they are estuarine foraminifera. So it is important to observe that the figures for the top of the shell bed are all minimal figures for the height of the marine deposits.

Lake Reeve has a tidal range of only about 15 cm and is virtually at mean sea level. As the water in the drain flows freely down to A.H.D. (M.S.L.) at Lake Reeve, and the shell bed was visible in the side of the drain, and the spoil was crowded with shells, the top of the shell bed there was well above A.H.D. (Fig. 9). This has now been confirmed and quantified by the detailed survey. As most of the species of molluscs lived at low water or below, the shell bed is emerged. As it is a quiet water regime, waves could not lift a whole shell bed above the level at which it was deposited. The fauna indicates that the sea had free access to the area, the spring tidal range is 2.4 m, and the top of the shell bed in the drain is 0.58 m A.H.D. The amount of emergence must therefore be of similar order to that at Warrnambool, where it is given as 2 m. The shell bed was not a result of progradation. During the Holocene the barrier has migrated to and fro a short distance (Gill 1967b), but otherwise there is a bed over 1 km wide of homogeneous coquinoid built up in quiet water behind a coastal barrier.

COMPARISON OF SHELL BEDS 440 km APART

Around the Victorian coast there are numerous similar unoxidized mid-Holocene shell beds which are slightly emerged. Their correlation is clear. However, the precise surveys of two distant sites in contrasting tectonic environments provided an opportunity for comparison. For a long distance through the Port Fairy and Warrnambool districts of S.W. Victoria the Last Interglacial 7 m shoreline can be shown to be without displacement, and the mid-Holocene beds are undisturbed. Although Seaspray in Eastern Victoria is in an area of tectonic movements, no displacement of the mid-Holocene shell bed could be detected, which suggests that the coast there has been stable for the past 6000 years.

ACKNOWLEDGEMENTS

We are indebted to Mrs. S. E. Boyd of the National Museum of Victoria for the Appendix on Lake Pertobe fossils, to Miss Rhyllis Plant of the Museum for drafting Figures 6 and 7, and to Mr. T. A. Wicking of Warrnambool for historical information on that area.

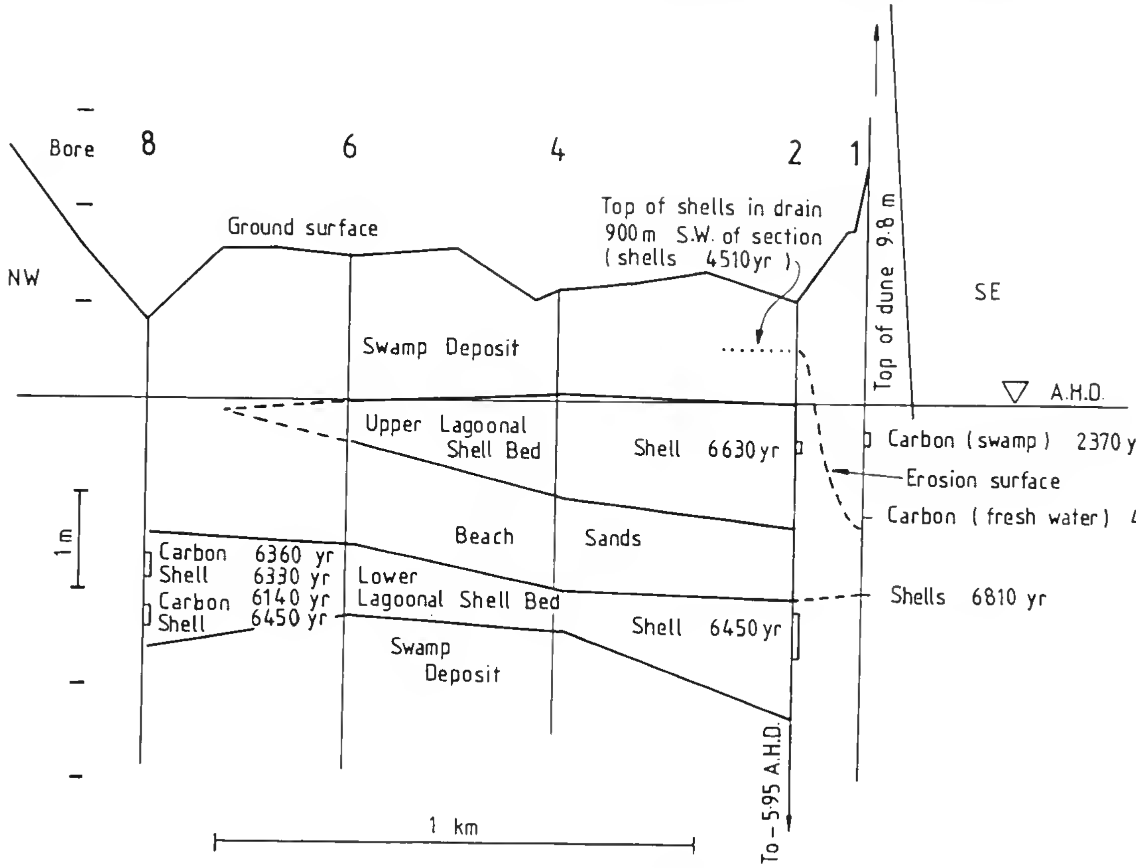


Fig. 10—Cross section from relict coast to present shore, N.E. of Seaspray as shown in Fig. 8.

REFERENCES

Barrow, J., 1854. Survey of Lady Bay, Warrnambool. *Votes Proc. Leg. Council* 1853-4, vol. 3.

Bird, E. C. F., 1978. The geomorphology of the Gippsland Lakes region. *Ministry Conservation Vict. Publ.* 186.

Gill, E. D., 1950. An hypothesis relative to the age of some Western District volcanoes. *Proc. R. Soc. Vict.* 60: 189-194.

Gill, E. D., 1953. Geological evidence in Western Victoria relative to the antiquity of the Australian Aborigines. *Mem. Nat. Mus. Melb.* 18: 25-92.

Gill, E. D., 1966. Australian research in Quaternary shorelines. *Aust. J. Sci.* 28: 407-411.

Gill, E. D., 1967a. Evolution of the Warrnambool-Port Fairy coast and the Tower Hill eruption, Western Victoria. *Landform Studies from Australia and New Zealand.* A.N.U. Press. 340-364.

Gill, E. D., 1967b. Evolution of shoreline barriers. *Vict. Naturalist* 84: 282-283.

Gill, E. D., 1970. Current Quaternary shoreline research in Australasia. *Aust. J. Sci.* 32: 426-430.

Gill, E. D., 1971a. Application of radiocarbon dating in Victoria, Australia. *Proc. R. Soc. Vict.* 84: 71-85.

Gill, E. D., 1971b. The far-reaching effects of Quaternary sea level changes on the flat continent of Australia. *Proc. R. Soc. Vict.* 84: 188-205.

Gill, E. D., 1972. Eruption date of Tower Hill volcano, Western Victoria, Australia. *Vict. Naturalist* 89: 188-192.

Gill, E. D., 1973. Second list of radiocarbon dates on samples from Victoria, Australia. *Proc. R. Soc. Vict.* 86: 133-136.

Gill, E. D., 1975. Calcrete, hardpans and rhizomorphs in Western Victoria. *Pacific Geol.* 9: 1-16.

Gill, E. D., 1976. Quaternary: Warrnambool-Port Fairy District. *Geol. Soc. Aust. Spec. Publ.* 5: 299-304.

Gill, E. D., 1977. Quaternary shorelines report—Victoria. *Aust. Quat. Newsl.* 10: 20-23.

Gill, E. D., 1978. Radiocarbon dating of the volcanoes of Western Victoria, Australia. *Vict. Naturalist* 95: 152-158.

Gill, E. D., 1979. 1978-9 research on Quaternary shorelines in Australia and New Zealand—Victoria. *Aust. Quat. Newsl.* 13: 53-57.

Gill, E. D., 1981a. The separation of progradation due to fall of sea-level from progradation due to sand oversupply. *Oceanis* 7: 367-371.

Gill, E. D., 1981b. The contribution of geology to the search for the 'Mahogany Ship'. *Warrnambool Inst. Adv. Educ. J. Social Issues* 1: 13-15.

Gill, E. D. & Hopley, D., 1971. Holocene sea levels in Eastern Australia—a discussion. *Mar. Geol.* 12: 223-242.

Gill, E. D. & Lang, J. G., 1977. Simple measurement of compaction in marine geological formations from engineering data commonly available. *Mar. Geol.* 25: M1-M4.

Jenkin, J. J., 1968. The geomorphology and Upper Cainozoic geology of Southeast Gippsland, Victoria. *Mem. Geol. Surv. Vict.* 27.

Kenley, P. R., 1976. Otway Basin, western part. *Geology of Victoria. Geol. Soc. Aust. Spec. Publ.* 5: 147-152.

Reeckmann, S. A. & Gill, E. D., 1981. Rates of vadose diagenesis in Quaternary dune and shallow marine calcarenites, Warrnambool, Victoria, Australia. *Sedim. Geol.* 30: 157-172.

Roelse, A., Granger, H. W. & Graham, J. W., 1971. The adjustment of the Australian Levelling Survey 1970-1971. *Div. Nat. Mapping Tech. Rep.* 12.

Schreiber, B. C., 1978. *Encyclopedia of Sedimentology* (Ed. R. W. Fairbridge & J. Bourgeois). Stroudsburg, Pa.

Thom, B. G. & Chappell, J., 1975. Holocene sea levels relative to Australia. *Search* 6: 90-93.

Ward, W. T., 1977. Geomorphology and soils of the Stratford-Bairnsdale area, East Gippsland, Victoria. *CSIRO Soils & Land Use Ser.* 57.

APPENDIX

THE FOSSIL MOLLUSCA

By S. E. BOYD

Austrocochlea constricta (Lamarck 1822) – usually found on intertidal rock platforms, but the species has a wide tolerance of habitat and salinity.

Bembicium auratum (Quoy & Gaimard 1834) – quieter waters of sheltered muddy inlets and estuaries, in the upper littoral zone.

Velacumantus australis (Quoy & Gaimard 1834) – found in the shallow waters of estuaries, mangrove swamps and mud flats.

Coxiella striata (Reeve 1842) – brackish water lakes usually away from direct marine influence.

Potomopyrgus niger (Quoy & Gaimard 1838) – freshwater streams, usually just above the region of tidal influence in coastal streams.

Hydrococcus tasmanicus (Tenison-Woods 1876) – on mud between plant roots in tidal saltmarsh areas in sheltered bays and inlets.

Parcanassa burchardi (Philippi 1851) – found on intertidal mud flats.

Salinator fragilis (Lamarck 1822) – mid to upper littoral zone in sheltered marine inlets, on mud and seagrass flats.

Mytilus edulis planulatus (Lamarck 1819) – in sheltered waters attached to rocks and jetty piles. Able to take advantage of very small areas of shelter.

Ostrea angasi Sowerby 1871 = *O. sinuata* Cotton & Godfrey 1938 (non Lamarck) – usually found in estuaries, but marine beds are also found. In Port Phillip Bay it occurs in areas of silty sand and silty clay from low water to approximately 11 fathoms.

Notospisula trigonella (Lamarck 1818) – a very tolerant species occurring in the sands and sandy muds of the shallows of sheltered bays and estuaries.

Homalina deltoidalis (Lamarck 1818) – estuaries, in the mud and muddy sand of the middle to lower littoral zone.

Eumarcia fumigata (Sowerby 1853) – found in shallow water in sand and sandy mud.

Venerupis crenata Lamarck 1818 – in holes and crevices of rocks.

Katelysia rhytiphora Lamy 1937 – intertidal and subtidal in sand and sandy mud, in areas of *Zostera*, etc.

Soletellina biradiata (Wood 1815) – found buried in silty mud in shallow water.

PROC. R. SOC. VICT. vol. 94, no. 1, 35-47, March 1982

ORDOVICIAN AND SILURIAN STRATIGRAPHY AND STRUCTURE IN THE WOMBAT CREEK–BENAMBRA AREA, NORTHEAST VICTORIA

By Paul F. Bolger

Geological Survey of Victoria, 107 Russell Street, Melbourne, Victoria 3000
Present address: Herman Research Laboratory, State Electricity Commission, Howard Street,
Richmond, Victoria 3121

Abstract: Undifferentiated Ordovician low grade metasediments are unconformably overlain by a Silurian succession consisting of the Middle (?) Silurian Mitta Mitta Volcanics and the Late Silurian Wombat Creek Group. The Ordovician beds have undergone several periods of folding, regional metamorphism and granitic intrusion in the Benambran Deformation. Silurian rocks are preserved in a graben which is considered to have been active during deposition. The Wombat Creek Group consists of three newly described formations, in ascending order, the Toaks Creek Conglomerate, Gibbo River Siltstone and Tongaro Sandstone. Facies relationships of these units suggest it is a transgressive sequence with the fluvial(?) to shallow marine Toaks Creek Conglomerate overlain by the shallow marine Gibbo River Siltstone and "deeper" marine Tongaro Sandstone. The Silurian sequence in the Graben correlates with a similar sequence at Limestone Creek (VandenBerg *et al.* in press) and other Silurian sequences in southeastern Australia.

A thick Silurian sequence exposed in the Wombat Creek-Gibbo River area about 20 km north of Benambra is preserved in a structure here named the Wombat Creek Graben. The graben is bounded by the Wombat Creek and Morass Creek Faults and trends northwest-southeast, extending from Soldier Creek to near Taylors Crossing (Fig. 1). There is a small outlier along Morass Creek near Benambra (Fig. 1). The Silurian sequence unconformably overlies multiply deformed Ordovician sandstone, slate and siltstone and consists of the Middle(?) Silurian Mitta Mitta Volcanics and the Upper Silurian Wombat Creek Group.

The Ordovician beds were deformed during the Early(?) Silurian Banambran orogeny of Browne (1947). To the west they grade into high grade regional metamorphic and granitic rocks of the Omeo Metamorphic Complex. The Silurian sequence in the Wombat Creek Graben was tightly folded during the Early Devonian Bindian Deformation (VandenBerg *et al.* in press) and was also intruded by acid to intermediate plutonic rocks. Syenite, trachyte and granite porphyry were emplaced east of Benambra during the Triassic. Cainozoic faulting in the area has resulted in rejuvenation of the mature topography, accompanied by stream diversion and river capture, and in the late Pliocene, the Morass Creek Basalt was extruded north of Benambra.

The purpose of this paper is to define and describe the poorly known Silurian stratigraphy within the Wombat Creek Graben, and to discuss the depositional environments of the sediments and the structural relationships of the Silurian sequence to older rocks.

Map grid references are quoted in the text with the prefix (GR...) and refer to the Benambra 1:100 000 topographic sheet, No 8424, Series R652, Division of National Mapping, Department of National Development.

PREVIOUS WORK

The earliest investigations in the area were made by Stirling (1887, 1888, 1889) and Ferguson (1899) who compiled the first stratigraphic column of the Wombat Creek Group. Dunn (1907a, b) made a brief study of the distribution of ore minerals in limestones of the Wombat Creek Group. Whitelaw mapped the isolated limestone outcrops in detail in 1913, but his work was not published until 1954. Chapman (1906, 1912, 1917, 1920) identified fossils collected from the Wombat Creek Group by earlier workers. While examining possible sites for the location of a dam on the Mitta Mitta River, Kenny (1937) examined the contact between the volcanics and the Wombat Creek Group at the junction of the Gibbo and Mitta Mitta Rivers, and suggested that the volcanics unconformably overlie the sediments.

Andrews (1938) described the stratigraphy and structural relationships of the Silurian and Ordovician and suggested that an intense deformation event, which he named the Mitta Mitta Movement, affected the Ordovician prior to the accumulation of the Silurian sequence. This event was later named the Benambran Orogeny by Browne (1947).

Crohn (1950) gave the name Wombat Creek Formation to the sequence of conglomerate, limestone, sandstone and shale exposed along the Mitta Mitta River. Talent (1959a) upgraded this to group status without defining constituent formations, and suggested a Middle to Late Silurian age, thus inferring an Early Silurian age for the Benambran Orogeny. Beavis (1962) discussed the structure of the Wombat Creek Group in his regional study of the Omeo metamorphic Complex, and Singleton (1965), and Talent (1965, 1969) briefly described the stratigraphy of the Wombat Creek Group and its relationship to the Mitta Mitta Volcanics. Talent *et al.* (1975) discussed the stratigraphy and correlation of the Silurian rocks in the Wombat Creek Graben.

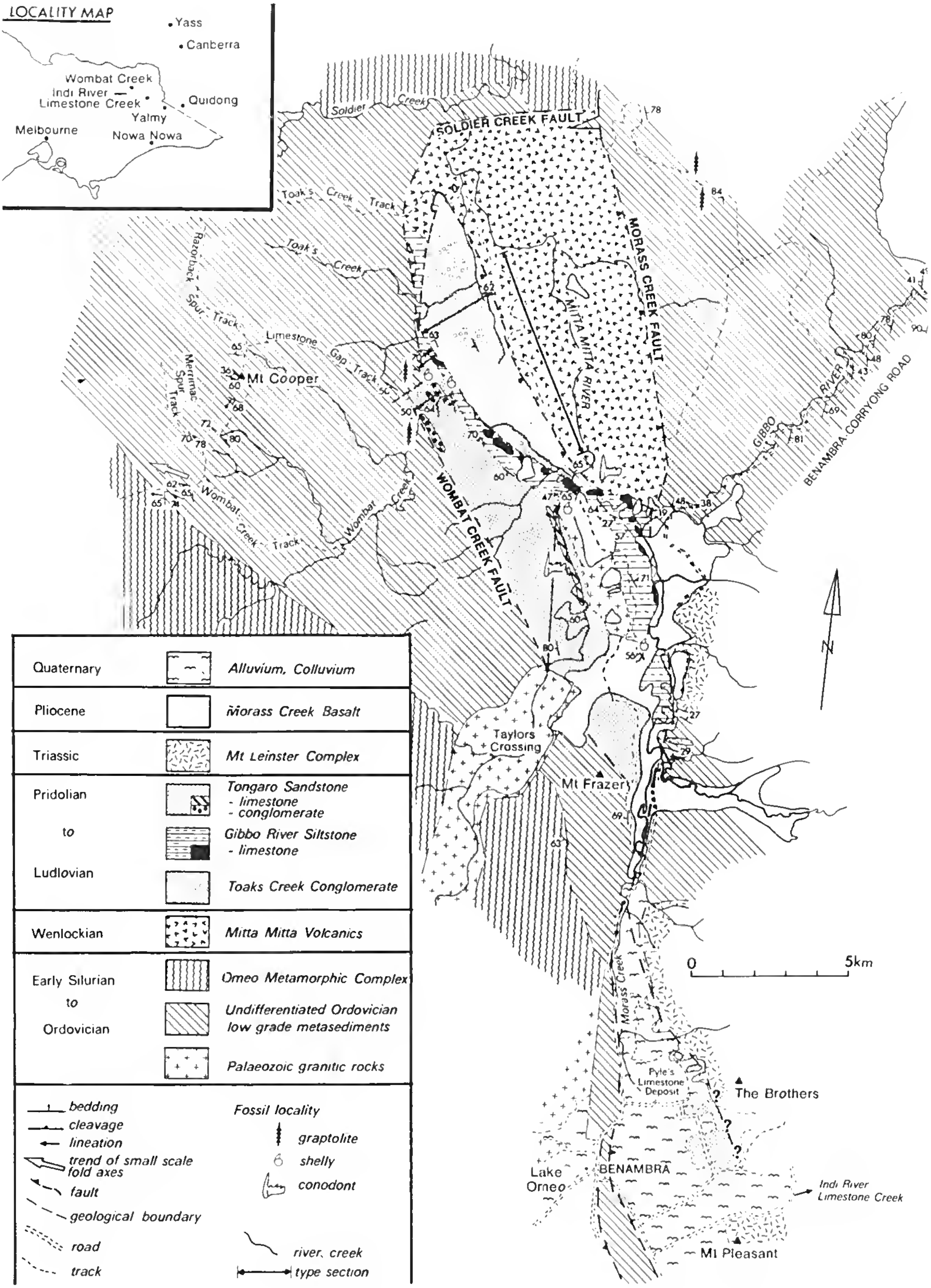


Fig. 1—Geological map of the Wombat Creek—Mitta Mitta River area, Benambra, Victoria.

STRATIGRAPHY

ORDOVICIAN

DISTRIBUTION: Ordovician sedimentary and low grade metasedimentary rocks surround the Wombat Creek Graben and outcrop extensively in eastern Victoria beyond the study area. The Ordovician rocks have been regionally metamorphosed to biotite grade, and pass westwards into higher grade regional metamorphic rocks of the Omeo Metamorphic Complex.

LITHOLOGY: The Ordovician sequence in northeastern Victoria comprises an undetermined thickness of well bedded sandstone and mudstone. The beds are steeply dipping and tightly, often isoclinally folded. Slaty cleavage is well developed in many of the finer beds. No attempt has been made to subdivide the Ordovician lithologically.

Grey to yellow coarse to fine sandstone beds up to 1 m thick, are usually graded and sometimes contain internal lamination, convolute lamination and ripple marks. The upper parts of some massive beds display gently undulating bedding. Laminated and thinly bedded grey-green argillites form the upper parts of graded beds. Thin, medium to fine grained sandstones are sometimes graded and often display ripple-drift cross-lamination, planar lamination and ripple marks. The sandstones generally have planar bases with occasional load casts. Sole marks are not commonly observed but this may be due to lack of exposure of the undersides of beds. There are shaly intraclasts in some sandstones. The sandstones are quartz rich (quartzose wackes in the classification of Okada, 1971), with quartz comprising up to 70% of the rock and 95% of the framework. Quartz grains are mostly equant to elongate, angular to subangular, monocrystalline grains with undulose extinction. Weathered feldspars comprise up to 15% of some rocks, but are generally less than 5%. In thin section, alkali feldspar appears to be subordinate to plagioclase (andesine (?) to labradorite). There are occasional biotite plates and muscovite is common. Equigranular and foliated quartzite occurs as uncommon sand sized grains. The matrix, comprising up to 40% of some rocks, consists of clays, muscovite, chlorite, rare biotite and very fine quartz. Platy minerals and some bladed quartz grains are stongly aligned. Massive grey to yellow quartzites up to 2 m thick are usually structureless but occasionally contain internal lamination. They are coarse to fine sandstones composed almost entirely of quartz with rare feldspar, muscovite and heavy minerals. The quartzites have usually been recrystallized with framework grains within a fine grained polycrystalline quartz aggregate. They are often intersected by quartz veins. Finer beds may be cherty. The Ordovician sediments exhibit abundant AE, subordinate AB and ABC, rare BC and interturbidite E divisions of Bouma's (1962) turbidite cycle. No complete A→E Bouma sequences have been recorded.

Discrete units of laminated grey to black slate, more than 20 m thick on the Eustace Gap track, contain poorly preserved graptolites. These units have not been mapped in detail, but they may represent marker horizons within the Ordovician sequence. The slates are composed of varying proportions of silt-sized angular quartz and detrital muscovite, set in a very fine matrix of clays, muscovite, biotite and chlorite. A strongly developed slaty cleavage is due to alignment of platy minerals and some quartz grains. Some very dark grey beds contain abundant carbon and often contain oxidized pyrite cubes.

AGE: Graptolites have been found at a number of localities in the Mitta Mitta River area. They are generally poorly preserved and strongly distorted by slaty cleavage. Black slate units within the area contain species including *Climacograptus affinis*, *C.* cf. *tubuliferus*, *C. spiniferus*, *C. bicornis*, *C. caudatus*, *Orthograptus* cf. *quadrimucronatus*, *O.* cf. *amplexicaulis*, *Dicranograptus ramosus*, *D. hians*, *Dicellograptus* sp., and numerous unidentifiable diplograptids (Bolger 1978). These suggest a broad age range of Gisbornian to Eastonian. One rather dubious occurrence of *Phyllograptus nobilis* associated with species of "*Diplograptus*" and "*Climacograptus*" has been recorded from the Gibbo River (Harris & Keble 1932) and suggests a Darriwilian (Da3) age for the Ordovician in this area. More recently Kilpatrick and Fleming (1980) have found early Bendigonian graptolites including *Tetragraptus fruticosus* in knotted schist in the Eskdale area west of the Wombat Creek Graben, indicating that a large part of the Ordovician sequence (so far unfossiliferous) may be of Early Ordovician age.

SILURIAN

Silurian rocks in the area are confined to the Wombat Creek Graben and comprise a thick sequence of acid volcanics (Mitta Mitta Volcanics) and terrigeneous and carbonate sediments (Wombat Creek Group).

Mitta Mitta Volcanics (Singleton 1965)

DISTRIBUTION, THICKNESS AND LITHOLOGY: The Mitta Mitta Volcanics comprise a suite of dacite and rhyodacite outcropping from the junction of the Mitta Mitta and Gibbo Rivers to near Yankee Point. They form steep bluffs and resistant ridges on both sides of the Mitta Mitta River. The rocks are massive and apart from an outcrop of columnar jointed rhyodacite on the Mitta Mitta River (GR 595327) the volcanics are structureless. They are fine grained, with small phenocrysts of quartz, plagioclase and rare K-feldspar and biotite in a chloritic devitrified groundmass. The sparsity of structural data and lack of younging criteria in the Mitta Mitta Volcanics do not allow an accurate estimation of thickness although the sequence is considered to be at least 500 m thick on the Mitta Mitta River.

TYPE SECTION: The best exposures of the Mitta Mitta Volcanics were along the Mitta Mitta River prior to inundation by the Dartmouth Dam, and this would have been the logical type section had flooding not occurred. The only other accessible area of exposure is along the main ridge east of Limestone Gap between the Mitta Mitta River and Toak's Creek Track and this is proposed as the type area for the Mitta Mitta Volcanics (between GR 555388 and 588327).

RELATIONSHIPS: The Mitta Mitta Volcanics are faulted against Ordovician metasediments in complex fault zones near Eustace Gap (GR 585428, 589425) and on the Mitta Mitta River near Yankee Point (GR 538414) where there is a fault zone 100 m wide. Contacts with the Wombat Creek Group are also faulted, with much deformation of the latter at the contact along the Mitta Mitta River (GR 592322). The presence of pebbles of Mitta Mitta Volcanics within the basal conglomerate of the Wombat Creek Group suggest that the Wombat Creek Group post-dates the volcanics.

AGE: The Mitta Mitta Volcanics post-date the Ordovician beds and pre-date the Upper Silurian Wombat Creek Group, but a more accurate age determination is not possible. The volcanics are considered on regional grounds to be correlatives of the Thorkidaan Volcanic Group (VandenBerg *et al.* in press) outcropping east of Benambra. Tentative correlation with the Douro Group (Pogson & Baker, 1974) in the Yass area of New South Wales implies a Middle Silurian (Wenlockian) age for the Mitta Mitta Volcanics.

Wombat Creek Group (Crohn 1950)

DISTRIBUTION, TYPE SECTION, THICKNESS: The Wombat Creek Group comprises three formations: the Toaks Creek Conglomerate, the Gibbo River Siltstone and the Tongaro Sandstone, which all outcrop within the Wombat Creek Graben from the Toaks Creek track southwards to near Mt Frazer. A small outlier along Morass Creek, Benambra, near "The Brothers" contains sediments referred to the Tongaro Sandstone (Fig. 1).

The proposed type section is a composite section comprising three segments (Fig. 1): (i) a section along the Toaks Creek walking track from Toaks Creek (GR 553380) to near Limestone Gap (GR 537363); (ii) the exposures along the Limestone Gap Track from Limestone Gap (GR 542355) to the Wombat Creek Fault (GR 541359); (iii) exposures along Wombat Creek from GR 547342 to GR 541336. The thickness in this composite section is probably in excess of 3800 m (Fig. 2) although this may be an overestimate due to repetition by tight folding.

RELATIONSHIPS AND BOUNDARY CRITERIA: The presence of pebbles of Mitta Mitta Volcanics within conglomerates of the Wombat Creek Group indicates that the sediments post-date the Volcanics although the contact is now a low angle thrust fault. At the contact the Mitta Mitta Volcanics have behaved competently and were little deformed by the faulting, whereas the Wombat Creek Group sediments are faulted, folded and intensely fractured. Along the Gibbo River, the Mitta Mitta Volcanics have been thrust over the Wombat Creek Group to give the false appearance of an unconformity and reversed superposition. The contact with the Mitta Mitta Volcanics along the Toak's Creek track is complexly faulted.

The top of the Wombat Creek Group is faulted against graptolitic Ordovician sediments along the Wombat Creek Fault, which has a crush zone 50 m wide well exposed along the Limestone Gap track (GR 541349). Further south, the boundary with the Ordovician rocks is difficult to locate accurately as the Ordovician beds adjacent to the western edge of the Wombat Creek Graben are often quartz-rich and difficult to distinguish from the Tongaro Sandstone. It is possible that the graptolitic Ordovician shales exposed along the Limestone Gap Track and Wombat Creek may be preserved in narrow fault slivers, with the Tongaro Sandstone having a more widespread distribution west of the Wombat Creek Fault, than is depicted in Fig. 1.

AGE: Etheridge (in Ferguson 1899) examined fossils from the Wombat Creek Group and assigned them a Late Silurian age. Chapman (1920) suggested that some beds were Middle Devonian, while the remainder were "Yeringian", which was then considered to be Late Silurian. Talent (1960) re-examined Chapman's faunas and concluded that there was no evidence for a Devonian age. The age of the Group is presently considered to be Late Silurian (Ludlovian-Pridolian), although the Toaks Creek Conglomerate may even be as old as Llandoverian (Talent 1959a, 1965, Talent *et al.* 1975).

Toaks Creek Conglomerate

(New name, named after Toaks Creek, Benambra district)

DISTRIBUTION, TYPE SECTION, THICKNESS: The Toaks Creek Conglomerate is a wedge shaped unit of massive conglomerate with subordinate sandstone, siltstone and pebbly mudstone which outcrops in the area from the Toaks Creek Track to the junction of the Mitta Mitta and Gibbo Rivers. The thickest section and best exposures of the Toaks Creek Conglomerate are along the Toaks Creek walking track between Limestone Gap and Toaks Creek in the northern part of the graben, and this is the proposed type section (GR 537363 to GR 553380). Its thickness is probably up to 2300 m. Good exposures along the Mitta Mitta River are now inundated by the waters of the Dartmouth Dam.

LITHOLOGY: The Toaks Creek Conglomerate is characterized by massive, clast-supported conglomerate consisting of well rounded pebbles, cobbles and occasional boulders of quartzite, vein quartz, black and green chert, rhyodacite, rare andesite, argillaceous and rare granitic clasts in a very coarse to fine sandy matrix. The clast composition becomes less variable towards the top of the unit where the conglomerate consists almost entirely of quartzite pebbles. Thin sandstone units consisting of common quartz as well as some vein quartz, chert and siltstone grains, are interbedded with conglomerates and have the same composition as the conglomerate matrix.

The conglomerates are massive and usually poorly bedded. Some thin beds grade upwards from lenticular pebble conglomerate to coarse and medium grained sandstone. Bedding thickness varies from 5 cm to several metres. Large conglomerate-filled channels with erosional bases into siltstone are recognizable along the spur between the Mitta Mitta and Gibbo Rivers. Elsewhere scour and fill structures, pebble imbrication and rare cross stratification are observed.

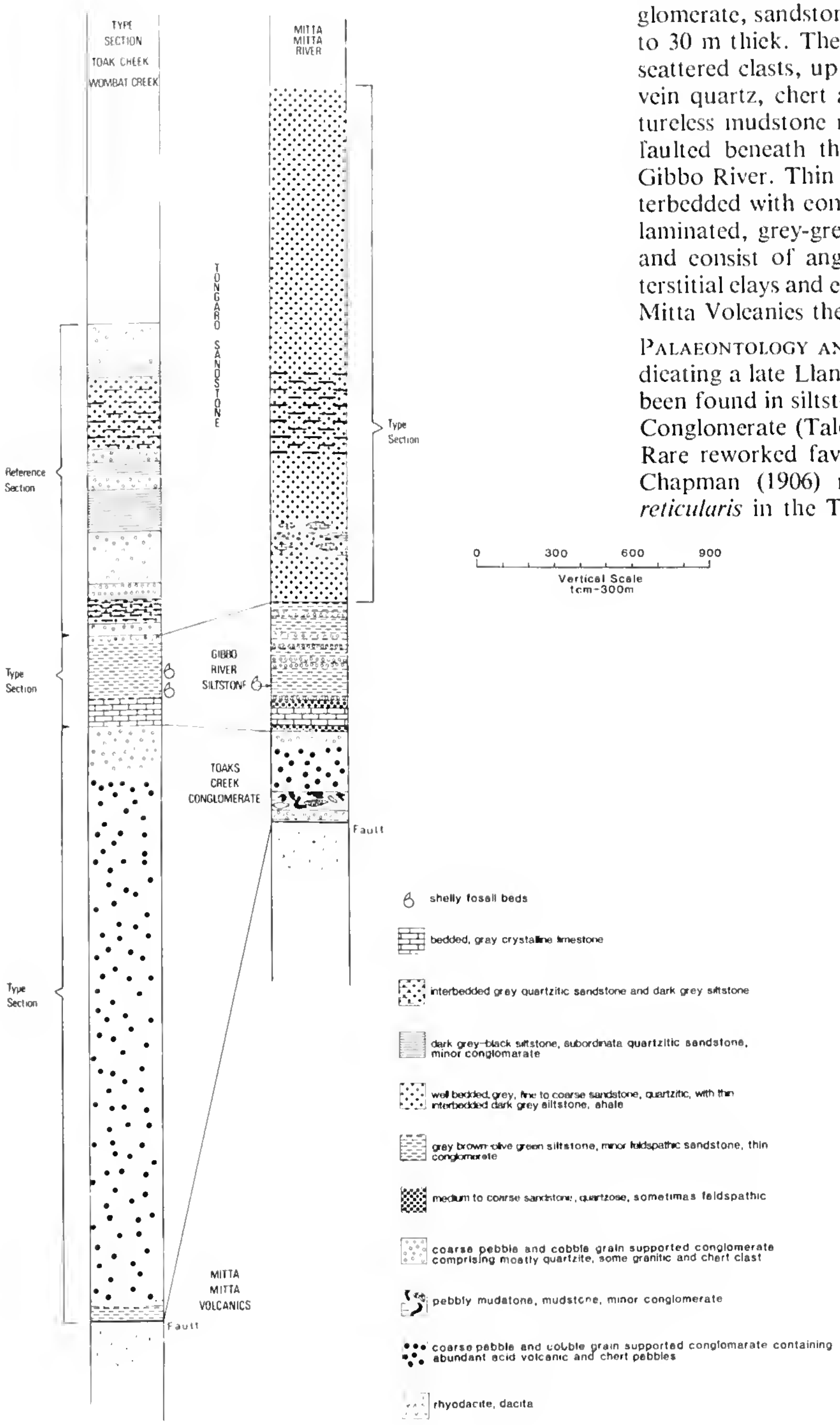


Fig. 2—Columnar sections through the Wombat Creek Group.

A thin unit of siltstone and feldsparthic sandstone occurs at the base of the Toaks Creek Conglomerate near Toaks Creek. This unit is continuous for several kilometres southwards to the Mitta Mitta-Gibbo River junction where it passes into interbedded conglomerate, sandstone, siltstone and pebbly mudstone up to 30 m thick. The pebbly mudstone contains sparsely scattered clasts, up to 0.5 m, of limestone, rhyodacite, vein quartz, chert and quartzite in a green grey structureless mudstone matrix. This unit wedges out and is faulted beneath the Mitta Mitta Volcanics along the Gibbo River. Thin discontinuous siltstone units are interbedded with conglomerate. They are structureless to laminated, grey-green in colour, locally partly silicified and consist of angular to subangular quartz with interstitial clays and chlorite. At the contact with the Mitta Mitta Volcanics the siltstones are strongly fractured.

Palaeontology and Age: Trimerellid brachiopods indicating a late Llandovery or younger Silurian age have been found in siltstones intercalated in the Toaks Creek Conglomerate (Talent 1959a, 1965, Talent *et al.* 1975). Rare reworked favositid corals have also been found. Chapman (1906) reported the long ranging *Atrypa reticularis* in the Toaks Creek Conglomerate. A limestone clast in the pebbly mudstone unit at the Mitta Mitta-Gibbo River junction yielded a single simplexiform element of *Panderodus unicostatus* but this did not enable determination of an older age limit for the Toaks Creek Conglomerate (Cooper 1977).

Gibbo River Siltstone

(New name, named after Gibbo River, Benambra district)

DISTRIBUTION, TYPE SECTION, THICKNESS: The Gibbo River Siltstone is a thin unit of siltstone, calcareous siltstone, conglomerate, sandstone and, at the base, a number of limestone lenses. It is best exposed in its type section along the Limestone Gap Track, where it is 350 m thick (GR 542355 to GR 541352). In the Gibbo River area and the eastern flank of the Lower Tableland, its outcrop width is exaggerated by folding, but it is probably more than 700 m thick. Individual limestone lenses are up to 100 m thick (Whitelaw 1954).

LITHOLOGY: The dominant lithology is grey-green to buff coloured siltstone and calcareous siltstone, consisting of silt-sized angular-subangular quartz grains and some shell fragments in a clay-chlorite-mica matrix. Beds are generally massive, often bioturbated, with some planar lamination and rare small scale cross lamination and scour-and-fill structures. Near the Wombat Creek Fault, the siltstones possess a well developed slaty cleavage. Lenses of fossiliferous grey and white crystalline limestone occur at the base of the Gibbo River Siltstone and directly overlie the Toaks Creek Conglomerate in the western part of the Graben. A thin fossiliferous sandstone underlies the limestone, along the Mitta Mitta River. Eastwards along the Gibbo River, limestone lenses are enveloped by conglomerate and fossiliferous siltstone. The limestone lenses outcrop as broad mounds in the Limestone Gap-Quart Pot Flat area, but form vertical bluffs in the Mitta Mitta and Gibbo River exposures. They are planar bedded with beds up to 30 cm thick. The limestones are usually bioclastic (mostly corals, crinoids and brachiopods), and range from grainstones to packstones. Pelletal grains are abundant in limestone near Quart Pot Flat (GR 563332). The lens at Limestone Gap (GR 542355) contains angular irregularly shaped clasts of calcareous mudstone, and is strongly silicified and dolomitized. Recrystallized dolomitic limestone occurs at the hairpin bend of the Gibbo River (GR 608314). Coarse-grained marble with its original depositional texture completely obliterated outcrops near the mouth of Morass Creek.

Numerous thin conglomerates up to 10 m thick are interbedded with siltstones in the Morass Creek and Gibbo River areas. They contain well rounded quartzite and rare chert clasts. Along the Mitta Mitta River, the Gibbo River Siltstone becomes coarser grained near the top and comprises siltstone interbedded with graded and cross laminated fine to coarse quartz sandstone, a thin intraformational conglomerate, and a massive structureless cobble conglomerate, up to 25 m thick, contain-

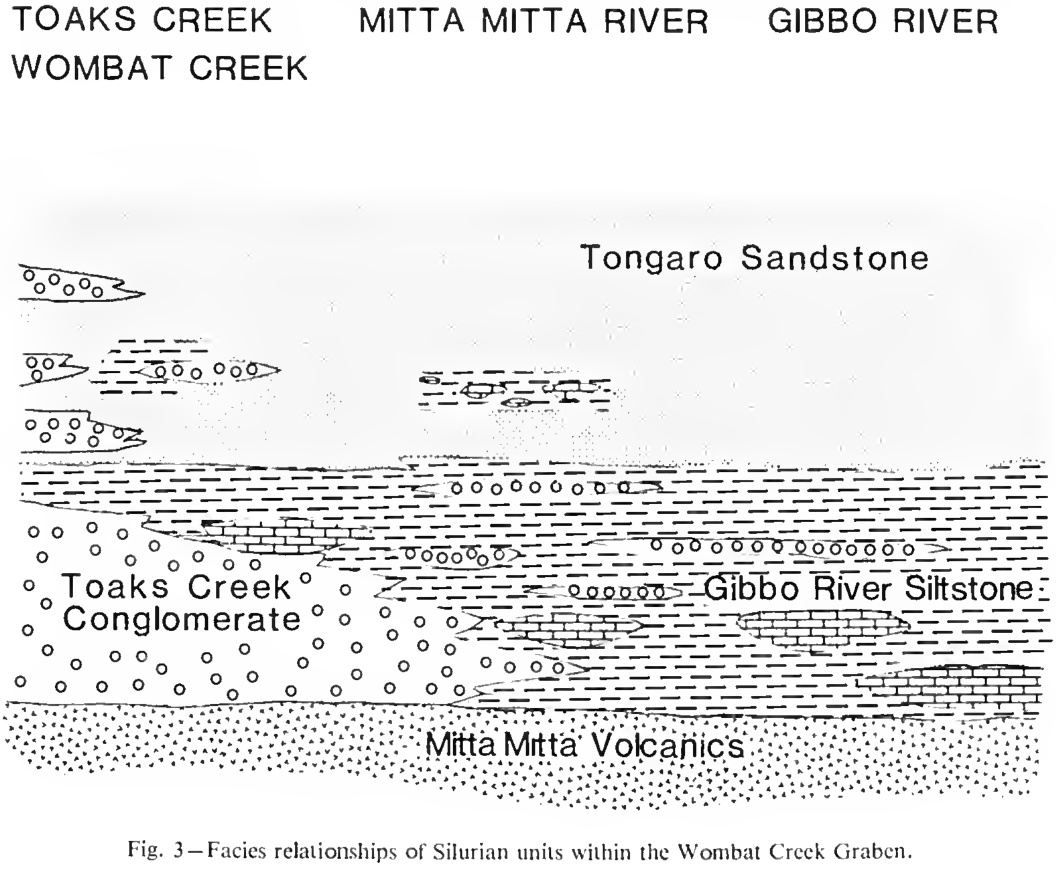


Fig. 3—Facies relationships of Silurian units within the Wombat Creek Graben.

ing mostly quartzite and some granitic clasts.

RELATIONSHIPS: The Gibbo River Siltstone conformably overlies the Toaks Creek Conglomerate along the Mitta Mitta River and in the Limestone Gap-Quart Pot Flat area, although in the Gibbo River area, the basal beds are laterally equivalent to parts of the Toaks Creek Conglomerate (Fig. 3). VandenBerg (1976) suggested that the limestones are allochthonous blocks contained in the upper units of the Toaks Creek Conglomerate. However, although the contacts with the surrounding rocks are not well exposed, the limestone lenses appear to be enclosed in fossiliferous, often calcareous siltstone of the Gibbo River Siltstone and are considered to be autochthonous.

The boundary with the overlying Tongaro Sandstone is sharp along Limestone Gap track, but along the Mitta Mitta River, the Gibbo River Siltstone is sandy towards the top and appears to grade into the Tongaro Sandstone.

PALAEONTOLOGY AND AGE: The Gibbo River Siltstone contains a diverse fauna including brachiopods, crinoids, trilobites and corals in the siltstones, and corals, stromatoporoids, crinoids, brachiopods and rare conodonts in the limestone lenses. The fauna has not been examined in detail and awaits future study.

The siltstones contain species of *Isorthis, Platystrophia, Hesperorthis, Atrypoidea,* (?) *Pentamerus, Howellella* and *Nucleospira* (M. J. Garratt pers. comm. 1974) which suggest a Late Silurian (Ludlow) age. *Mucophyllum liliiforme, Propora conferta* and *Favosites allani* have been identified from limestones and indicate a Wenlock to Ludlow age (Talent 1959a, 1960, Talent *et al.* 1975). Cooper (1977) extracted elements of the conodonts *Ozarkodina excavata, Panderodus unicostatus,* and *Walliserodus* sp. but only a broad Early Silurian to Early Devonian age could be inferred from this collection.

Chapman (1906) described a species of a cephalaspid fish from siltstones in the formation, but this was later reidentified as a cast of a compound coral (Hills 1958).

Tongaro Sandstone

(New name, named after Parish of Tongaro)

DISTRIBUTION, TYPE SECTION, THICKNESS: The Tongaro Sandstone, comprising sandstone, siltstone, conglomerate and limestone is the uppermost unit of the Wombat Creek Group and outcrops between the Limestone Gap Track and the Mitta Mitta River. The proposed type section on the Mitta Mitta River between GR 586312 and GR 588260 contains good exposures on the spurs overlooking the river. The thickness in this section is approximately 2000m and a sequence 1200 m thick is exposed in a reference section along Wombat Creek (between GR 547342 and GR 541336).

LITHOLOGY: The Tongaro Sandstone is characterized by well bedded quartzitic sandstone and interbedded grey to black siltstone. The sandstones are grey coloured, fine to medium grained quartz wackes (*sensu* Okada 1971) consisting of common quartz sand, rare muscovite, altered feldspar, chert and mudstone in a muddy matrix. Some sandstones have a bimodal framework consisting of well rounded coarse sand and angular fine sand grains. Beds are usually less than 30 cm thick with planar boundaries. Sedimentary structures include planar lamination, cross lamination and ripple marks. Graded units are rare. Lenses of well-bedded dark grey limestone up to 30 m thick (Whitelaw 1954) outcrop sporadically along the Mitta Mitta River and northwest towards Wombat Creek. They are planar bedded, with beds up to 50 cm thick. A fossiliferous packstone-wackestone exposed along the Mitta Mitta River is strongly foliated.

The Tongaro Sandstone varies laterally. In the northwest along Wombat Creek, quartz sandstone is less abundant than along the Mitta Mitta River, while thinly bedded dark grey to black siltstones increase in thickness. Massive, poorly bedded lenticular conglomerates, which wedge out southwards, form steep bluffs and strike ridges near Wombat Creek southwest of Limestone Gap. The conglomerates consist of randomly orientated, well rounded cobbles and pebbles of quartzite. Individual conglomerate lenses are up to 200 m thick.

A small outlier of the Wombat Creek Group is exposed along Morass Creek near Benambra township and is tentatively referred to the Tongaro Sandstone. It consists of a thin, poorly exposed grey limestone, known as Pyle's limestone deposit, slaty siltstone and quartzite pebble conglomerate. The limestone has been completely recrystallized and contact metamorphosed to skarn by the intrusion of the Triassic Mount Leinster Complex. Wollastonite is recognizable in thin section and Whitelaw (1954) reported the occurrence of garnet.

RELATIONSHIPS: The Tongaro Sandstone conformably overlies the Gibbo River Siltstone along the Mitta Mitta River. The base of the Tongaro is marked by the first plane bedded structureless quartzitic sandstone. The relationships are complicated by faulting and overturning along the Limestone Gap Track, although here the Tongaro Sandstone also appears to overlie the Gibbo River Siltstone. Along strike, the Tongaro grades laterally into the upper parts of the Gibbo River Siltstone. The top of the Tongaro Sandstone is faulted by the Wombat Creek Fault against graptolitic Upper Ordovician quartzite, sandstone and slate along Wombat Creek and along the Limestone Gap Track where there is a 50 m wide crush zone. Due to the lithological similarity with the Ordovician the faulted boundary is more difficult to locate between Wombat Creek and the Mitta Mitta River.

PALAEONTOLOGY AND AGE: Apart from unidentifiable fragmentary shelly fossils in sandstones along the Limestone Gap Track, the non-calcareous part of the Tongaro Sandstone is unfossiliferous. Limestones outcropping along the Mitta Mitta River contain halysitid corals (Talent 1959a, 1965, Talent *et al.* 1975) and pentamerid brachiopods.

Conodonts recovered from limestone along the Mitta Mitta River include a single costate element of *Panderodus unicostatus*, which has ornament of a type only found in post-Wenlockian collections (Cooper 1977). The presence of halysitid corals indicates a Silurian age, thus confining the Tongaro sandstone in the Mitta Mitta River to the Late Silurian. Pyles limestone deposit near Benambra contains poorly preserved spiriferid brachiopods and conodonts including *Spathognathodus remscheidensis*?, *S. inclinatus inclinatus*, *Hindeodella priscilla* and *Neoprionodus* sp., which suggest a Pridolian or younger age (Bischoff, in Talent *et al.* 1975) for this deposit.

CORRELATION

The Mitta Mitta Volcanics and the Wombat Creek Group can be broadly correlated with other Silurian successions in southeastern Australia. The most similar sequence is exposed in the Indi River-Limestone Creek area east of Benambra, where the Silurian sequence comprises an acid volcanic unit, the Thorkidaan Volcanic Group, conformably overlain by the Enano Group, which consists of terrigenous and carbonate sediments with thin interlcalated volcanics (A. H. M. VandenBerg *et al.* in press). Tentative correlation between units in the Wombat Creek and Indi River successions (Table 1) is based more on lithological similarities than on palaeontological evidence, although the Gibbo River Siltstone at Wombat Creek and the Cowombat Siltstone along the Indi River contain similar faunas and are probably contemporaneous units (Talent 1959a).

Further east in the Yalmy area, possible equivalents to the Wombat Creek Group are the Sardine Beds (Talent *et al.* 1975) while Silurian sediments are known in bores near Nowa Nowa (Talent 1959a). A poorly known succession at Quidong north of Yalmy contains beds of similar age to the Wombat Creek Group (Talent *et al.* 1975).

Precise correlation with the better known succession at Yass in New South Wales is not possible although the regional stratigraphy suggests possible correlation of the Mitta Mitta Volcanics with the Hawkins Volcanics of the Douro Group, and the Gibbo River Siltstone is probably equivalent to parts of the Silverdale Formation and Black Bog Shale.

DISCUSSION OF THE WOMBAT CREEK GROUP

DEPOSITIONAL ENVIRONMENTS

The Toaks Creek Conglomerate forms a wedge-shaped body in the northwest of the Wombat Creek Graben. Sedimentary structures include graded bedding, channels, rare cross-stratification and imbrication. The conglomerate has probably been deposited largely by traction currents although one pebbly mudstone unit near the base suggests mass movement. The Toaks Creek Conglomerate could be a type of "delta-fan" deposit accumulated at the margins of the marine basin. The occurrence of shelly fossils in interbedded mudstones indicates a marine origin for at least part of the Toaks Creek Conglomerate, but the possibility that part of the unit is of fluvial origin cannot be overlooked. The Gibbo River Siltstone comprises siltstone, limestone and thin conglomerate and sandstone. The lenticular limestones are mostly grainstones, and some packstones, cemented by ferroan calcite. They are interpreted to be carbonate buildups deposited under open shelf conditions. Siltstones for the most part are considered to be deposits settled from suspension onto a shelf inhabited by a diverse benthonic biota which has bioturbated the substrate. However they do contain rare sedimentary structures such as scour and fill structures, which suggest some current activity. The conglomerates in the Gibbo River Siltstone are massive, structureless closed framework deposits. Sandstones exposed near the top are graded, cross-laminated and associated with thin intra-formational conglomerate and show evidence of deposition by turbidity currents.

The Tongaro Sandstone in the Mitta Mitta River area consists of thin bedded quartz sandstone and interbedded dark siltstone enclosing small randomly distributed carbonate bodies. The sandstones contain few sedimentary structures, although small scale cross-stratification and planar lamination are observed. In the Wombat Creek area to the northwest the Tongaro Sandstone contains lenticular closed framework conglomerates. The conglomerates are interbedded with thinly bedded dark mudstone and thin, sometimes ripple marked, laminated and small scale cross-stratified quartz sandstone containing fragmented shelly fossils. Insufficient data are available to conclusively determine the depositional environment of the Tongaro Sandstone. The sandstones do not display well developed Bouma sequences. However, they are thin, laterally continuous and internally planar and cross-laminated, and resemble turbidites of Facies D and E described by Mutti and Ricci Lucchi (1978).

It is therefore suggested that the sandstones are mass-flow deposits. The association of turbiditic sandstones with conglomerates near Wombat Creek suggests that the conglomerates were deposited below wave base. It is not clear whether the limestone bodies along the Mitta Mitta River are allochthonous or were deposited *in situ*.

NATURE AND ORIGIN OF TERRIGENOUS DETRITUS

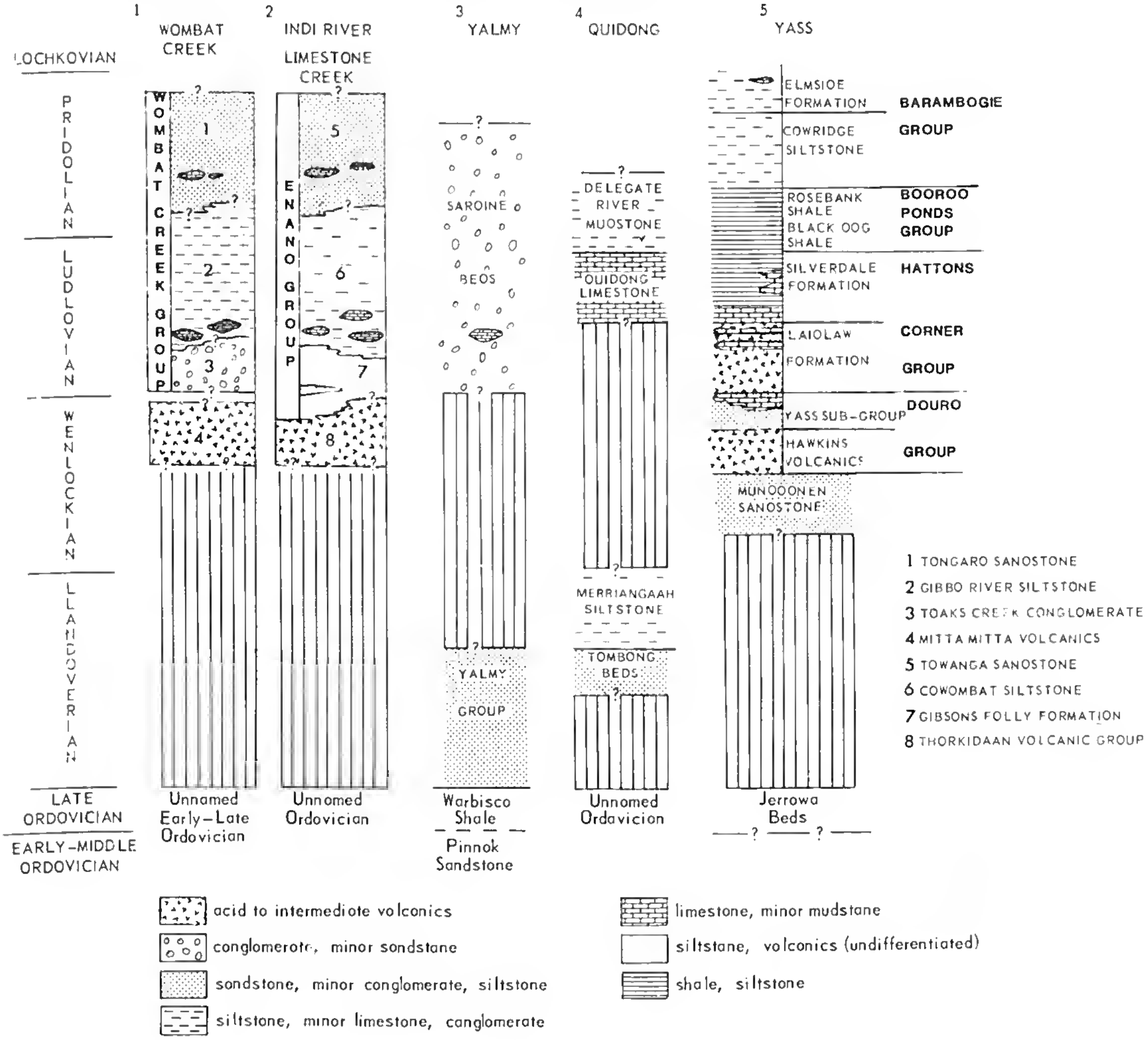
The basal Toaks Creek Conglomerate contains abundant pebbles of acid volcanic rocks derived from the underlying Mitta Mitta Volcanics. Towards the top of the unit the conglomerates become compositionally more mature and contain mostly quartzite and some chert pebbles.

The source of the quartzite clasts is uncertain, although clearly they are less muddy and less micaceous than the local Ordovician sandstones. Similarly chert, which is a major component of the Toaks Creek Conglomerate, is rare to absent in the Ordovician nearby. Argillaceous clasts in the Toaks Creek Conglomerate are not strongly foliated, although some have a weak fissil-

TABLE 1

CORRELATION OF WOMBAT CREEK GRABEN SEQUENCE WITH OTHER SILURIAN SEQUENCES IN SOUTHEASTERN AUSTRALIA.

1, Nomenclature this paper. 2, Nomenclature, VandenBerg *et al.* 1981. 3, Nomenclature, VandenBerg (unpubl.). 4, Nomenclature, Campbell in Talent *et al.* 1975. 5, Nomenclature, Pogson & Baker 1974.



ity, and no clasts of higher grade regional metamorphic rocks have been observed.

The Gibbo River Siltstone is considered to be a transgressive facies which has covered the coarse clastic wedge of the Toaks Creek Conglomerate with a thin cover of siltstone and limestone. Further offshore there was continued settling of silt and clay from suspension with intermittent influx of coarse detritus transported into the basin by mass flows. It is in part laterally equivalent to the Toaks Creek Conglomerate, but represents a more offshore marine environment.

Towards the top of the Wombat Creek Group the coarse sediments become compositionally mature, consisting almost entirely of quartzite and rare granitic clasts. Again the quartzite clasts are less muddy than the Ordovician sandstones.

The quartzite clasts are petrographically similar to quartzitic sandstones of the Lower Silurian Yalmy Group (A. H. M. VandenBerg pers. comm.) which conformably overlies Upper Ordovician graptolitic shales in the Yalmy area to the east. It is suggested that deposition in the Early Silurian may have continued as far west as the Wombat Creek Graben, covering the Ordovician sediments. Following extrusion of the Mitta Mitta Volcanics, erosion of the volcanics occurring outside the graben, as well as the Lower Silurian sediments and minor high level intrusions provided detritus to the subsiding basin. However, erosion did not proceed to sufficient depth to expose Ordovician beds or high grade regional metamorphic rocks.

STRUCTURAL RELATIONSHIPS BETWEEN ORDOVICIAN AND SILURIAN

Ordovician Structures

The most prominent structural element in the Ordovician is bedding which is folded into tight to isoclinal folds with steeply dipping to vertical axial surfaces. Isoclinal fold hinges have not been observed, but are inferred from changes of facing of beds. Major folds in the Ordovician trend between 120° and 200°, with the dominant direction NW-SE (Fig. 4a, b, c). Small scale, variably plunging folds, which may be minor folds on the flanks of major structures, are common in some areas and have an east-west trend. The folds are characterized by an axial plane slaty cleavage, defined by a preferred orientation of platy minerals and elongate quartz grains. The cleavage is strongly developed and penetrative in the slates, but is only weakly developed in the sandstones.

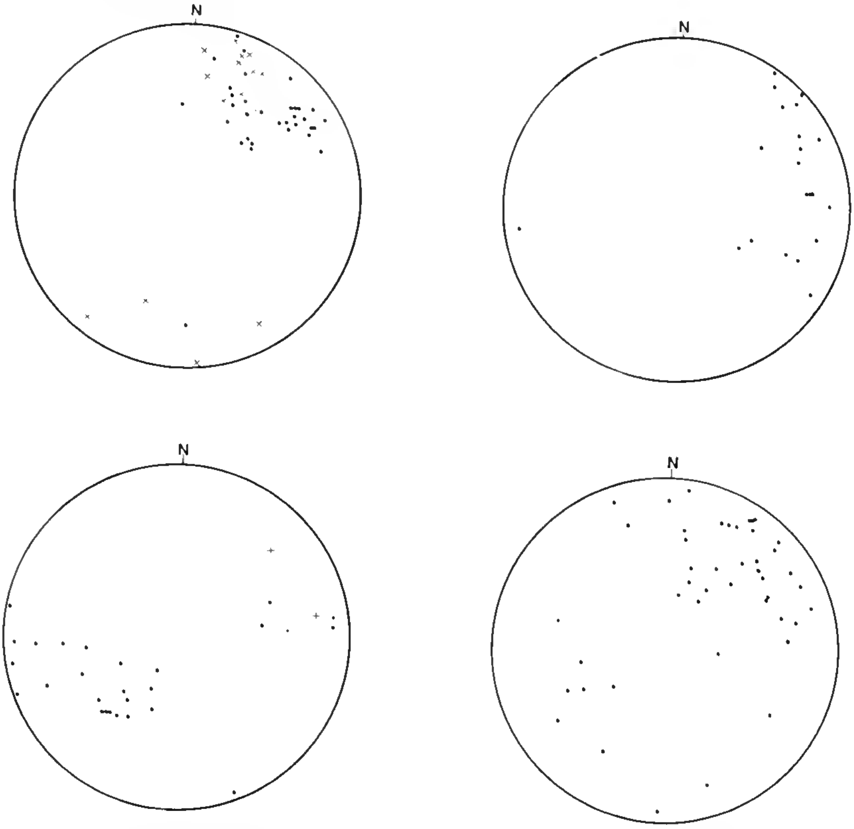
In thin section, a fissility defined by platy minerals aligned parallel to bedding can be seen to have been crenulated by the slaty cleavage. This earlier surface may be a folded slaty cleavage which is axial planar to an earlier set of folds, although no refolded folds have been observed in this area. However further north near Lockhart Gap, McKay (1969) has recorded mesoscopic folds refolded by northwest-trending regional structures. East-west trending folds which have been refolded by the northwest-southwest trending regional structures of the Omeo Metamorphic Complex have been recognized at Albury (Hellman 1976) and Tallandoon (Rogerson 1976). It thus appears that the Ordovician beds in northeastern Victoria have undergone at least two deformations.

Silurian Structures

The only prominent structural element observed throughout the Wombat Creek Group is Bedding. Beds

4a ORDOVICIAN BEDS
Junction of Razorback Spur Track and Merrimac Spur Track Junction to Limestone Gap
Poles to bedding S^O • (36 points)
Poles to cleavage S_1^O · (16 points)

4b ORDOVICIAN BEDS
Razorback Spur Track West of Merrimac Spur Track Junction
Poles to bedding S^O • (20 points)



4c ORDOVICIAN BEDS
Benambra–Corryong Road
Poles to bedding S^O • (27 points)
Poles to cleavage S_1^O · (2 points)

4d WOMBAT CREEK GROUP
Poles to bedding S^S • (43 points)

Fig. 4—Stereographic projections of bedding and cleavage surfaces.

are usually steeply dipping and sometimes overturned. No fold hinges have been observed, and the average fold trend of 150° is inferred from the direction and attitude of dips (Fig. 4d).

In contrast to the underlying Ordovician slates, strong foliation is only developed near major faults. There is a poorly defined reticulate cleavage in siltstones near the junction of the Mitta Mitta and Gibbo Rivers. Adjacent to the Wombat Creek Fault there is slaty cleavage in parts of the Gibbo River Siltstone and a prominent foliation, defined by stretched brachiopods, is parallel to bedding in a limestone lens of the Tongaro Sandstone on the east bank of the Mitta Mitta River.

Because of the near absence of bedding and the paucity of dipsin the Mitta Mitta Volcanics, the structure of this unit is not well known, but bedding trends are parallel with those of the Wombat Creek Group.

Discussion of the Benambran Deformation (or Mitta Mitta Movement)

The Benambra-Wombat Creek area is structurally significant in that it is the type area of the Benambran Orogeny (Browne 1947)—a tectonic event recorded from many localities through the Lachlan Fold Belt (e.g. Packham 1969, Crook *et al.* 1973). The deformation in the type area has been inferred from the structural differences between the Ordovician and Silurian beds (Talent 1959a). The Benambran Deformation was originally called the Mitta Mitta Movement by Andrews (1938, p. 151) but this name has failed to gain acceptance.

The contacts between the Ordovician and Silurian are always faulted and no angular unconformity has been observed. However the fold shapes and degree of deformation appear to differ between the Ordovician and Silurian in the study area. The variably plunging, tight, small scale folds in the Ordovician are not observed in the Silurian and the Ordovician probably has a refolded cleavage. In contrast, the continuity of marker beds in the Wombat Creek Group suggests tight but relatively simple folding in the Silurian rocks.

The metamorphic grade of the Ordovician in the Wombat Creek area is much higher than the Silurian, with the lowest grade (biotite zone) rocks passing westwards into the high temperature-low pressure Omeo Metamorphic Complex. Hellman (1976) has shown that the regional metamorphism at Albury post-dates early east-west trending folds but pre-dates northwest-southeast trending folds which are the prominent fold trends in the Omeo Metamorphic Complex. However, McKay (1969) and Rogerson (1976) suggested that metamorphic crystallization accompanied and post-dated the northwest-southeast folding.

The Omeo Metamorphic Complex is intruded by Early to Middle Silurian S-type granitic rocks with Rb/Sr ages of 430±8 m.y. (Brooks & Leggo 1972, recalculated by J. Richards 1980 pers. comm.) and K/Ar ages from isolated granitic intrusions of 440±9 m.y. (J. Richards pers. comm. 1980).

The Ordovician in northeastern Victoria has undergone at least two periods of folding with concomitant metamorphic and intrusive events. The folding and thermal events are here referred to as the Benambran Deformation, which has traditionally been considered to be Early Silurian in northeastern Victoria (Talent 1969, VandenBerg 1978).

In New South Wales, the Benambran Deformation is considered to range from the Early Silurian and comprise three separate tectonic events inferred from unconformities within the Silurian sequence at Orange (Packham 1969). The oldest of these, referred to as the Cobblers Creek Orogenic Phase, is of Late Ordovician to Llandovery age, while the Panuara Phase and the Quarry Creek Phase range from middle to late Llandovery and late Llandovery to Wenlock respectively. The tendency has been to correlate these events throughout the Lachlan Fold Belt (Scheibner 1973, Talent *et al.*, 1975), thereby assigning minor breaks in deposition and slight angular discordances to intense deformation events.

There is good evidence to infer that deformations took place between the Late Ordovician and Llandovery and the late Llandovery and the late Wenlock-Ludlow at a number of localities in southeastern New South Wales (Crook *et al.* 1973). The former event is referred to the Benambran Deformation and the latter to the Quidongan Deformation (Crook *et al.* 1973).

The age of the Benambran Deformation in its type area in northeastern Victoria is not closely constrained. The oldest possible age of the Toaks Creek Conglomerate, based on the occurrence of poorly preserved trimerellid brachiopods, is late Llandovery (Talent 1959a). However, tentative correlations with other areas in southeastern Australia (Table 1) suggest that the Mitta Mitta Volcanics and the Wombat Creek Group may be Middle and Late Silurian (Wenlock and Ludlow to Pridoli) respectively. If these "preferred" ages are accepted, there is a wide gap between deposition of graptolitic shales in the Late Ordovician and the extrusion of the Mitta Mitta Volcanics.

Evidence from east of the Wombat Creek Graben at Yalmy suggests that deposition was continuous during the Late Ordovician and Early Silurian (A. H. M. VandenBerg pers. comm.). It may have also extended westwards into the Wombat Creek Graben and the Indi River-Limestone Creek Graben. If so, the possibility that the Benambran Deformation is actually a late Early Silurian to Middle Silurian event cannot be precluded. The real Benambran Deformation in eastern Victoria may, in fact, be equivalent to the Wenlockian Quidongan Deformation, and events referred to the Benambran Deformation in southeastern New South Wales may be a pre-Benambran event not recognised in eastern Victoria.

SUMMARY

Turbiditic Early to Late Ordovician sandstone and shale suffered multiple deformation, high temperature-low pressure regional metamorphism and granitic intrusion during the Benambran Deformation. The resulting rocks comprise the Omeo Metamorphic complex.

The Wombat Creek Graben was initiated during or after the Benambran Deformation. In the Middle (?) to Late Silurian it was a locus for accumulation of a thick acid volcanic pile (the Mitta Mitta Volcanics) and subsequent fluvial (?) to shallow marine clastic and calcareous sediments (Toaks Creek Conglomerate and Gibbo River Siltstone) and turbiditic marine clastic sediments (Tongaro Sandstone). Clastic detritus was derived from the Mitta Mitta Volcanics extruded outside the graben, possibly from Lower Silurian clastic deposits and from the highest levels of the Omeo Metamorphic Complex. High grade rocks of the Metamorphic Complex were not exposed during the deposition of the Wombat Creek Group.

ACKNOWLEDGEMENTS

The author wishes to thank O. P. Singleton for supervision of the project during 1974 and R. A. Cas, M. J. Garratt, T. G. Russell and A. H. M. VandenBerg for critical reading of the manuscript. M. J. Garratt and A. H. M. VandenBerg assisted in identification of fossils. Limestone samples were processed through the courtesy of the Geological Survey of South Australia and conodonts recovered were examined by B. J. Cooper. H. R. Thorne and P. D. Wood of State Rivers and Water Supply Commission provided some field data and helpful discussion. The paper is published with permission of the Director of the Geological Survey Division, Department of Minerals and Energy, Victoria.

REFERENCES

Andrews, E. C., 1938. The structural history of Australia during the Palaeozoic: The stabilization of a continent. *J. Proc. R. Soc. N.S.W.* 71: 118-187.

Beavis, F. C., 1962. The geology of the Kiewa area. *Proc. R. Soc. Vict.* 75: 349-410.

Bolger, P. F., 1978. New graptolite localities from northeastern Victoria. *Rep. geol. Surv. Vict.* 1978/44. (Unpubl.).

Bouma, A. H., 1962. *Sedimentology of some flysch deposits. A graphic approach to facies interpretation.* Elsevier, Amsterdam, 168 pp.

Brooks, C. & Leggo, M. D. 1972. The local chronology and regional implications of a Rb-Sr investigation of granitic rocks from the Corryong District, southeastern Australia. *J. geol. Soc. Aust.* 19: 1-19.

Browne, W. R., 1947. A short history of the Tasman Geosyncline of Eastern Australia. *Science Progress* 35: 623-637.

Chapman, F., 1906. New or little-known Victorian fossils in the National Museum, Melbourne. Part VII—A new cephalaspid, from the Silurian of Wombat Creek. *Proc. R. Soc. Vict.* 18: 93-100.

Chapman, F., 1912. Reports on fossils. Silurian and Devonian fossils from the Mitta Mitta District, northeast Victoria. *Rec. geol. Surv. Vict.* 3: 215-217.

Chapman, F., 1917. Preliminary notes on new species of Silurian and Devonian fossils from northeast Gippsland. *Rec. geol. Surv. Vict.* 4: 103-104.

Chapman, F., 1920. Palaeozoic fossils of eastern Victoria. Part IV. *Rec. geol. Surv. Vict.* 4: 175-194.

Cooper, B. J., 1977. Preliminary report on conodonts from the Wombat Creek Group, north eastern Victoria. *S. Aust. Dept. Mines Rept.* 77/139 (Unpubl.).

Crohn, P. W., 1950. The geology, petrology and physiography of the Omeo District, north-eastern Victoria. *Proc. R. Soc. Vict.* 62: 1-70.

Crook, K. A. W., Bein, J., Hughes, R. J. & Scott, P. A., 1973. Ordovician and Silurian history of the southeastern part of the Lachlan Geosyncline. *J. geol. Soc. Aust.* 20: 113-138.

Dunn, E. J., 1907a. Geological notes on the Mitta Mitta River, north-east District. *Rec. geol. Surv. Vict.* 2: 122-123.

Dunn, E. J., 1907b. Limestone deposits at Wombat Creek and the Mitta Mitta River. *Rec. geol. Surv. Vict.* 2: 123-124.

Ferguson, W. H., 1899. Report on collection of fossils, etc., from Wombat Creek. *Mon. Progr. Rept. geol. Surv. Vict.* 3: 1-17.

Harris, W. J. & Keble, R. A., 1932. Victorian graptolite zones, with correlations and description of species. *Proc. R. Soc. Vict.* 44: 25-48.

Hellman, P. L., 1976. Structural analysis of the Albury District, N.S.W. *J. Proc. R. Soc. N.S.W.* 109: 103-113.

Hills, E. S., 1958. A brief review of Australian fossil vertebrates. In *Studies on fossil vertebrates,* T. S. Westoll, ed., Athlone Press, London, 86-107.

Kenny, J. P. L., 1937. Dam site, Mitta Mitta River, below Gibbo Junction. *Rec. geol. Surv. Vict.* 5: 469-470.

Kilpatrick, D. J. & Fleming, P. D., 1980. Lower Ordovician sediments in the Wagga Trough: discovery of early Bendigonian graptolites near Eskdale, north-east Victoria. *J. geol. Soc. Aust.* 27: 69-73.

McKay, W. J., 1969. Metamorphic and igneous rocks in the Tallangatta District, Northeast Victoria. *B.Sc. (Hons) Thesis, Aust. Nat. Univ.* (Unpubl.).

Mutti, E. & Ricci Lucchi, F., 1978. Turbidites of the Northern Apennines: introduction to facies analysis. *Int. Geol. Review* 20: 125-166.

Okada, H., 1971. Classification of sandstone: analysis and proposal. *J. Geol.* 79: 509-525.

Packham, G. H., 1969. Southern and Central Highlands Fold Belt. Tectonics and sedimentation. *J. geol. Soc. Aust.* 16: 216-226.

Pogson, D. J. & Baker, C. J., 1974. Revised stratigraphic nomenclature for the Yass 1:100 000 sheet. *Quart. Notes geol. Surv. N.S.W.* 16: 7-9.

Rogerson, R. J., 1976. Metamorphism, folding and plutonism in the Wagga Metamorphic Belt of N.E. Victoria. *Bull. Aust. Soc. Explor. Geophys.* 7: 41-43.

Scheibner, E., 1973. A plate tectonic model of the Palaeozoic tectonic history of New South Wales. *J. geol. Soc. Aust.* 20: 405-426.

Singleton, O. P., 1965. Geology and mineralization of Victoria. In *Geology of Australian Ore Deposits,* J. McAndrew, ed., AIMM, Melbourne, 1: 440-449.

Stirling, J., 1887. Second progress report on preliminary geological traverse of the western boundary of County of Benambra. *Quart. Rep. Mining & Surveyors Registrars* Dec. 1887, Appendix D: 75.

Stirling, J., 1888. Preliminary notes on the geology of the Wombat Creek Valley, its caves and silver lodes. *Quart. Rep. Mining & Surveyors Registrars* Sept. 1888: 78-80.

Stirling, J., 1889. Report on the tin lodes at Wombat Creek.

Quart. Rep. Mining & Surveyors Registrars March 1889, Appendix A: 65-67.

Talent, J. A., 1959a. Notes on Middle Palaeozoic stratigraphy and diastrophism in eastern Victoria. *Min. geol. J. Vict.* 6: 57-58.

Talent, J. A., 1959b. Subsurface Silurian sediments, Parish of Nowa Nowa South, Victoria. *Bull. geol. Surv. Vict.* 57: 45-48.

Talent, J. A., 1960. Contributions to the stratigraphy and palaeontology of the Silurian and Devonian of Gippsland. Ph.D. Thesis, Melbourne University. (Unpubl.).

Talent, J. A., 1965. The stratigraphic and diastrophic evolution of central and eastern Victoria in Middle Palaeozoic times. *Proc. R. Soc. Vict.* 79: 179-195.

Talent, J. A., 1969. The Geology of East Gippsland. *Proc. R. Soc. Vict.* 82: 37-60.

Talent, J. A., Berry, W. B. N. & Boucot, A. J., 1975. Correlation of the Silurian rocks of Australia, New Zealand and New Guinea. *Spec. Pap. geol. Soc. Amer.* 150: 1-108.

VandenBerg, A. H. M., 1976. Silurian-Middle Devonian of Eastern Victoria. *In* Geology of Victoria, J. G. Douglas & J. A. Ferguson, eds, *Spec. Publ. geol. Soc. Aust.* 5: 62-70.

VandenBerg, A. H. M., 1978. The Tasman Fold Belt System in Victoria. *Tectonophysics* 48: 267-297.

VandenBerg, A. H. M, Bolger, P. F., Carey, S. P., O'Shea, P. J. & Nott, R. J., 1979. Geology of the Limestone Creek area, northeast Victoria. In *Victoria Exploration Potential, Seminar.* Aust. Min. Found. and Dept. of Mins. & Energy, Melbourne.

VandenBerg, A. H. M., Bolger, P. F. & O'Shea, P. J. in press. Geology and mineral exploration of the Limestone Creek area of northeast Victoria. *Rept. geol. Surv. Vict.* 72.

Whitelaw, H. S., 1954. Some limestone and marble deposits in east Gippsland. *Min. geol. J. Vict.* 5(3): 23-33.

PROC. R. SOC. VICT. vol. 94, no. 1, 49-52, March 1982

OCCURRENCE OF THE TASMANIAN MUDFISH, *GALAXIAS CLEAVERI* SCOTT, ON WILSONS PROMONTORY—FIRST RECORD FROM MAINLAND AUSTRALIA

By P. D. Jackson and J. N. Davies

Fisheries and Wildlife Division, Arthur Rylah Institute for Environmental Research, P.O. Box 137,
Heidelberg, Victoria 3084

Abstract: The Tasmanian mudfish, *Galaxias cleaveri* Scott, is recorded from Wilsons Promontory, Victoria which is the first report from outside Tasmania. This occurrence is considered in the context of recent land bridges between the mainland and Tasmania.

Scott (1934) described the Tasmanian mudfish, *Galaxias cleaveri*, and later (Scott 1936) created the genus *Saxilaga* for *G. cleaveri* and another species, *S. anguilliformis*. Subsequently he (Scott 1942) described a third species of mudfish, *Galaxias upcheri*. Andrews (1976) considered the two *Saxilaga* species not generically separate from *Galaxias* and judged *S. anguilliformis* and *G. upcheri* to be synonyms of *G. cleaveri*. Recent observations by McDowall and Frankenberg (1981) support these views.

Galaxias cleaveri is one of the most specialised of the galaxiids, having adopted a benthic mode of life in swamps and drains, where it is apparently able to aestivate during periods of drought (Scott 1934). It has been recorded from low-lying coastal areas in north, west and south-western Tasmania (Fig. 1). This paper documents the occurrence of *G. cleaveri* on mainland Australia.

METHODS

Specimens of *G. cleaveri* were obtained during a survey of the fish fauna of Wilsons Promontory between 29 April and 16 December 1980. A number of sampling techniques were employed during the survey but all specimens of *G. cleaveri* were taken by electrofishing.

Fish were anaesthetised with quinaldine before being fixed in 10% neutral formalin. After about two weeks, they were transferred to 70% alcohol. Body measurements, according to Andrews (1976), were taken with vernier calipers, read to the nearest 0.1 mm. The four largest specimens were X-rayed and all vertebrae having unmodified centra at both ends counted.

On 16 December 1980, the ph, conductivity, salinity and dissolved oxygen were measured at one point in the sampling site. Depth, to the nearest 5 cm, was recorded every 5 m along a single transect across the site.

RESULTS

Locality

Specimens of *G. cleaveri* were taken from a single locality on a small, swampy tributary of Freshwater Creek, on the south-eastern side of the Promontory (Fig. 1; Lat. 39°4′S Long. 146°26′E). There was no discernible flow, mean depth was 16 cm and the substrate was mud. Conductivity was 1364Ωmhos at 25°C and pH was 5.3. There was no measurable salinity or dissolved oxygen and a 'metallic' film was present over much of the water surface, possibly due to the presence of metallic sulphides formed under anaerobic conditions (T. Pearce, pers. comm. 1981). This film was not present when the site was first visited on 29 October 1980.

Dense stands of tea-tree, *Melaleuca* sp., were present together with areas of eel grass, *Triglochan* sp. The sampling area was partially cleared to construct a walkway for hikers. Outside the area the tea-trees were only centimetres apart, making electrofishing impossible.

Specimens

Five specimens of *G. cleaveri* were captured on 29 October 1980 and ten on 16 December 1980. Ten were preserved for identification and have been deposited in the National Museum of Victoria (NMVA 2037). Other species captured were the common jollytail, *Galaxias maculatus* (Jenyns) (82 specimens, 44-95 mm total length), and the short-finned eel, *Anguilla australis* Richardson, (2 specimens, 231-235 mm total length).

The standard lengths of preserved specimens of *G. cleaveri* ranged from 37.4 to 75.4 mm with a mean of 52.5 mm. Morphometric and meristic data recorded from the 10 specimens are shown in Table 1. Also shown are the ranges of data recorded by Andrews (1976) from three separate collections, each of 10 fish, from Tasmania.

DISCUSSION

Table 1 shows that, except for the ratios of interorbital width to head length and head length to standard length, the mean body ratios for Wilsons Promontory specimens all fall within the range of data recorded by Andrews (1976). The deviant proportions are only marginally outside that range. Similarly, meristic variations agree closely.

The occurrence of *G. cleaveri* on Wilsons Promontory undoubtedly reflects the recent land connections between Victoria and Tasmania. Lying on the con-

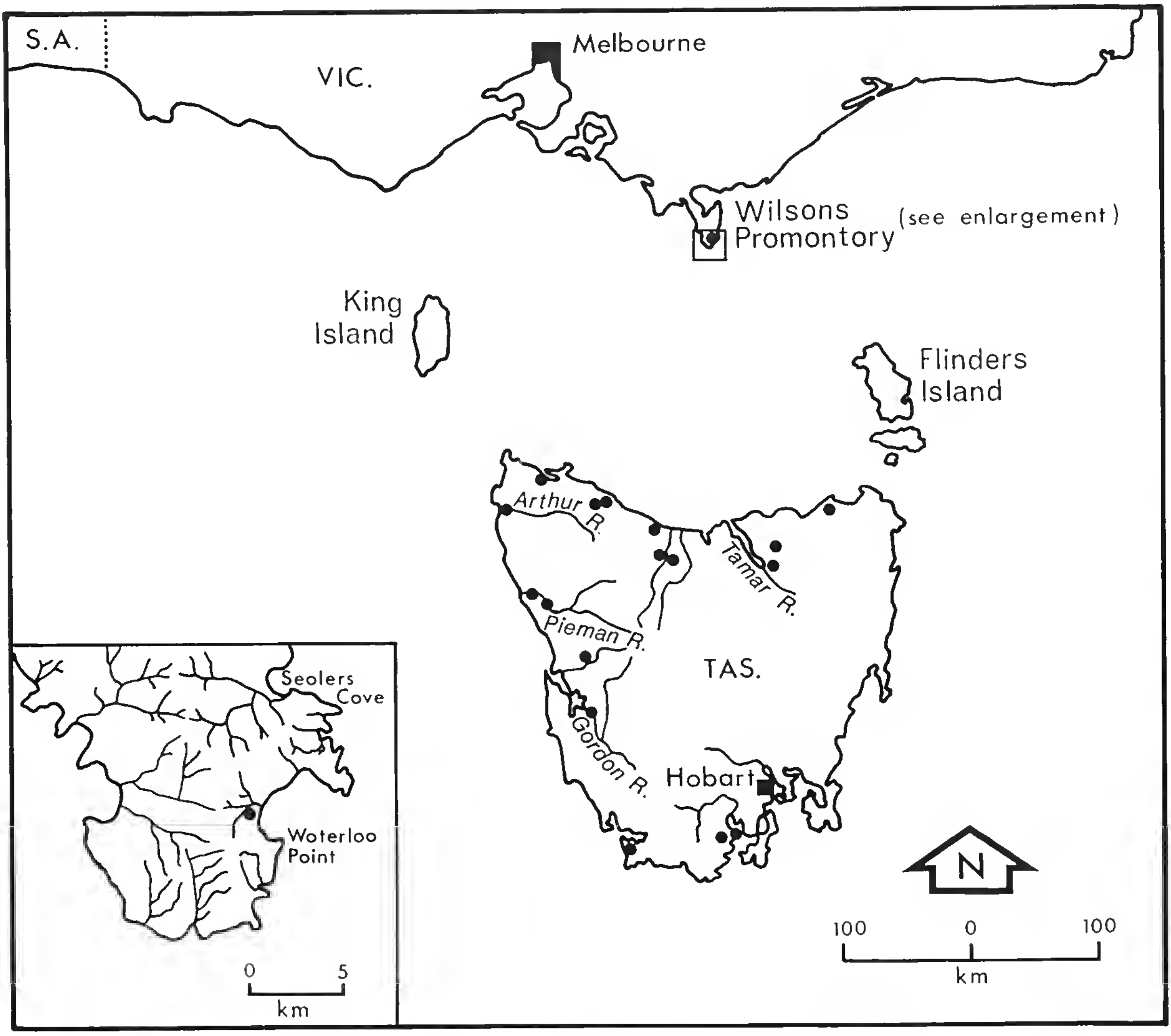


Fig. 1—Current known distribution of *Galaxias cleaveri* with Tasmanian localities taken from McDowall and Frankenberg (1981). Insert shows locality on Wilsons Promontory.

tinental shelf, Tasmania has been part of the Australian land mass throughout its history with the last severing of the land bridge apparently taking place about 12 000 to 13 500 years ago (Galloway & Kemp 1981). Opportunities have existed several times in the past for dispersal of fauna via confluent streams (Walker 1981) and McDowall (1981) has pointed out that the freshwater fishes of southern Victoria are nearly all represented by conspecific populations in Tasmania. Andrews (1976) believed that the present distribution of the Australian Galaxiidae could be explained by the hypothesis that species groups were once widely distributed over southeastern Australia and became fragmented by the formation of Bass Strait. He expressed surprise at the apparent absence of *G. cleaveri* from the Australian mainland and from the Bass Strait islands, particularly since the species appears to be tolerant of brackish water. The lack of any records of *G. cleaveri* from Victoria may, at least in part, be explained by the fact that low-lying coastal swamps have seldom been adequately sampled, often because they are relatively inaccessible. Additional sampling may extend the range of *G. cleaveri* in Victoria.

Galaxias cleaveri has undoubtedly been fragmented in its range in Tasmania by the draining and clearing of swamps (Frankenberg 1974). In New Zealand, a similarly adapted galaxiid, *Neochanna burrowsius* (Phillipps), is seriously threatened with extinction for the same reason (Cadwallader 1975). Indeed, the Nature Conservation Council of New Zealand has decided to create reserves for the preservation of *N. burrowsius* (Eldon 1979). The occurrence of a population of *G. cleaveri* on Wilsons Promontory may thus be fortuitous as the site is within the bounds of a National Park, where the habitat can be protected.

ACKNOWLEDGEMENTS

We thank the Victorian National Parks Association for permission to sample in Wilsons Promontory National Park, and the staff of the Park, particularly Peter Thomas, for their assistance with the sampling. Thanks to Martin Gomon (National Museum of Victoria) who prepared the X-rays of the specimens and reviewed the manuscript. Thanks also to Phillip Andrews (Tasmanian Museum) and Bob McDowall (Fisheries Research Division, New Zealand) for critically reading the manuscript.

REFERENCES

Andrews, A. P., 1976. A revision of the family Galaxiidae (Pisces) in Tasmania. *Aust. J. mar. Freshwater Res.* 27: 297-349.

Cadwallader, P. L., 1975. Distribution and ecology of the Canterbury mudfish, *Neochanna burrowsius* (Phillipps) (Salmoniformes: Galaxiidae), *J. Roy. Soc. N.Z.* 5: 21-30.

Eldon, G. A., 1979. Habitat and interspecific relationships of the Canterbury mudfish, *Neochanna burrowsius* (Salmoniformes: Galaxiidae), *N.Z. Jl. mar. freshw Res.* 13: 111-119.

Frankenberg, R., 1974. Native freshwater fish. In *Biogeography and Ecology in Tasmania*, W. D. Williams, ed., W. Junk, The Hague, 113-140.

Galloway, R. W. & Kemp, E. M., 1981. Late Cainozoic environments in Australia. In *Ecological Biogeography of Australia*, A. Keast, ed., W. Junk, The Hague, 53-80.

McDowall, R. M., 1981. The relationships of Australian freshwater fishes. In *Ecological Biogeography of Australia*, A. Keast, ed., W. Junk, The Hague, 1253-1273.

McDowall, R. M. & Frankenberg, R. S., 1981. The galaxiid fishes of Australia. *Rec. Aust. Mus.* 33: 443-605.

Scott, E. O. G., 1934. Observations of some Tasmanian fishes, with descriptions of new species. *Pap. Proc. R. Soc. Tasm.* 1933: 31-53.

Scott, E. O. G., 1936. Observations on fishes of the family Galaxiidae. Part 1. *Pap. Proc. R. Soc. Tasm.* 1935: 113-129.

TABLE 1

BIOMETRIC DATA FROM TEN SPECIMENS OF *GALAXIAS CLEAVERI* FROM WILSONS PROMONTORY AND THIRTY SPECIMENS FROM TASMANIA (TASMANIAN DATA FROM ANDREWS 1976)

A *Morphometric data*

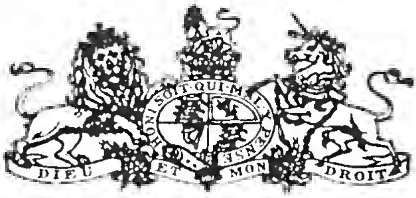
Body proportions	Wilsons Promontory		Tasmania	
	Mean	s.d.	Min.	Max
As a percentage of standard length:				
Head length	21.7	1.3	16.7	20.8
Snout tip to dorsal fin origin	71.7	1.0	65.1	77.0
Snout tip to ventral fin origin	53.1	1.8	49.7	54.7
Dorsal length of caudal peduncle	14.0	1.7	12.1	19.3
As percentage of head length:				
Eye diameter	15.2	2.2	10.4	17.7
Upper jaw length	28.1	1.6	20.8	31.4
Lower jaw length	26.5	2.1	22.7	32.0
Gape width	34.6	4.0	30.3	44.6
Interorbital width	43.3	1.2	33.9	43.0
Pectoral fin length/pectoral fin base to ventral origin	39.5	5.1	24.6	42.9
Ventral fin length/ventral fin base to anal origin	43.3	2.4	26.9	46.2
Minimum length of caudal peduncle/dorsal length of caudal peduncle	57.5	9.8	41.8	70.1

B *Meristic data*

	Variation (Number of fish in parenthesis)	
	Wilsons Promontory	Tasmania
Dorsal rays	12(7), 13(3)	11(10), 12(15), 13 (5)
Anal rays	13(7), 14(3)	12 (3), 13(13), 14(12), 15(2)
Pectoral rays	13(6), 14(4)	12 (1), 13(19), 14 (9), 15(1)
Ventral rays	6(4), 7(6)	5 (1), 6 (5), 7(21)
Vertebrae	56(2), 57(2)	56 (2), 57 (4), 58(4), 59(1)

Scott, E. O. G., 1942. Description of Tasmanian mud trout, *Galaxias* (*Galaxias*) *upcheri* sp. nov.: with a note on the genus *Brachygalaxias* Eigenmann, 1924, and its ocurrence in Australia. *Rec. Queen Vict. Mus.* 1: 51-57.

Walker, K. F., 1981. The distribution of freshwater mussels (Mollusca: Pelecypoda) in the Australian zoogeographic region. In *Ecological Biogeography of Australia*, A. Keast, ed., W. Junk, The Hague, 1231-1249.



PROCEEDINGS

OF THE

ROYAL SOCIETY OF VICTORIA

Volume 94

NUMBER 2

ROYAL SOCIETY'S HALL
9 VICTORIA STREET, MELBOURNE 3000

CONTENTS OF VOLUME 94 NUMBER 2

PROC. R. SOC. VICT. vol. 94, no. 2, 53-60, June 1982

SEALS IN TASMANIAN PREHISTORY

By Jim Stockton

Department of Prehistory, Research School of Pacific Studies, Australian National University, P.O. Box 4, Canberra, ACT 2600

Abstract: Aboriginal sealing began over 8000 years ago and continued up to the early part of the last century. Species exploited included *Arctocephalus pusillus doriferus, A. forsteri, Mirounga leonina* and *Hydruga leptonyx*. Historical information, derived from Warneke (1976), on the locations of seal colonies at the time of the arrival of European explorers is plotted as a series of maps. Archaeological data on the antiquity and distribution of seal remains are presented. Aboriginal methods of sealing are reviewed, and their possible effects on the prey species considered. It is concluded that there are insufficient data available at present to suggest a change in seal numbers through time, in spite of the long duration of the predator/prey relationship.

In prehistoric midden sites in coastal north-western Tasmania the numerous remains of seals attest to the importance of seals as a meat source to the Aborigines. In this paper I have attempted to synthesize all the available ethnographic information on Aboriginal sealing, and to look at the antiquity of seal remains in Tasmania.

The data for this paper fall into three broad classes, biological, historical, and archaeological.

SYNOPSIS OF RELEVANT BIOLOGICAL DATA

Biological data relevant to the prehistoric use of seals was taken from a variety of published and unpublished sources (Gaskin 1972, Horton 1978, Hyett & Shaw 1980, Thoughton 1965, Warneke 1975, 1976 and pers. comm., Wood Jones 1925). In the period when the colonists first entered Tasmanian waters, there appear to have been four common species of seal around Tasmania and in Bass Strait, consisting of Southern Elephant Seal, Australian Sea Lion, Australian Fur Seal, and New Zealand Fur Seal. The Leopard Seal is and was an occasional visitor, but was never abundant. Although Wood Jones (1925) referred to Australian Sea Lion remains having been found in Aboriginal middens in Tasmania, subsequently they have not in fact been identified in excavations and will not be dealt with in this section. It is quite possible that Australian Sea Lion remains will be found in future excavations.

Southern Elephant Seal, *Mirounga leonina*

At the start of the Nineteenth Century, large colonies of the Southern Elephant Seal occurred on the Hunter Islands, New Year Island, and on King Island (Micco 1971) (Fig. 1), but today the nearest breeding grounds are on Macquarie Island (Green 1973). Reproductive behaviour of this species has been summarised by Warneke (1976). Breeding sites are usually sandy beaches. Mature males are ashore from early August to early December while mature and pregnant cows start arriving in September. Groups of females form harems with large male 'beachmasters'. On average a female is on the breeding site for 28 days during which she does not eat. Lactation lasts about 23 days (Hyett & Shaw 1980). During this time pups gain about 5 kg in weight per day (Warneke 1976). The male Southern Elephant Seal is the largest seal occuring in Tasmanian waters. At maturity it may attain lengths of 6 m and weights of 3 600 kg. Females weigh about 900 kg at maturity and attain lengths of 3-4 m.

The Southern Elephant Seal also spends a period ashore during December, January and February when adults of both sexes haul out on suitable beaches to moult. This process take about 20 to 40 days, during which time the animals cease feeding and rarely go near the sea unless disturbed. When the moult is complete the animals return to the sea to feed, and large concentrations of Elephant Seals are not seen ashore until the following breeding season. However breeding sites may not be completely abandoned as there are usually some resting young present all year round (Hyett & Shaw 1980).

Australian Fur Seal, *Arctocephalus pusillus doriferus* and New Zealand Fur Seal, *Arctocephalus forsteri*

As the *Arctocephalus* remains in middens cannot usually be identified to species, the life history of both species will be considered together.

Fur seals were recorded in early accounts at numerous locations throughout Bass Strait. The highest concentrations were around King Island and the Furneaux Group (Fig. 2). The Australian Fur Seal is the only seal which is still a regular breeding species in Bass Strait (Green 1973). The distribution map of modern seals is based on Pearse (1979) (Fig. 3). The figure is somewhat misleading as the number of sites cannot be directly equated with abundance; some of the locations had very few individuals. Although there is little detail of the historic colonies of seals in the southeast and south, they were present.

Australian Fur Seal males grow to about 2.25 m long with weights of up to 360 kg, while females grow to around 1.5 m and 90 kg (Hyett & Shaw 1980). New

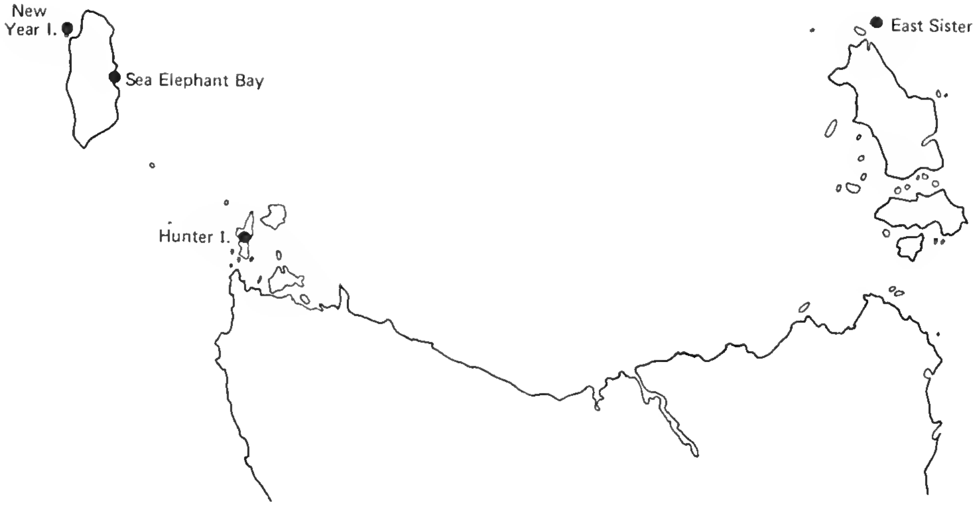


Fig. 1 — Historic locations of *Mirounga leonina* colonies (source: Warneke 1976). Scale and north marker as for Figure 2.

Zealand Fur Seal males grow up to 2 m and 110 kg, while females are up to 1.6 m and 80 kg (Hyett & Shaw 1980). Breeding locations, usually exposed rocky beaches, are occupied by males from October. Most females give birth in November (Australian Fur Seal) and January (New Zealand Fur Seal). Pups weigh around 4-5 kg. Australian Fur Seal pups congregate in groups of up to 50 while their mothers are away feeding.

Observations on the vulnerability to capture of Australian Fur Seal have been made (R. M. Warneke pers. comm.). Young pups less than eight weeks of age are almost helpless on land. If harassed they quickly take refuge in the sea, but soon tire and return to shore. If the hunter lay down and remained still the pups would approach quite closely. By three months of age they are strong active swimmers and are much more difficult to catch by pursuit; they are quite curious however, and will approach a stationary crouching person. Around 20% of pups die of natural causes in the first three months (Horton 1978).

The reconstructions of the distribution of Southern Elephant Seal and of fur seals (Figs 1, 2) are based on historic records (Warneke 1976). In spite of the limitations of the historical records, the maps show the highest density for both groups is on the inaccessible islands of Bass Strait.

Leopard Seal, *Hydruga leptonyx*

The Leopard Seal ranges widely through the Southern Ocean but is a rare visitor to Tasmania. The species is migratory, with both immature and adult seals moving northwards in the autumn and winter. The younger animals tend to wander further afield than reproductively mature adults. Fully grown a female may weigh 450 kg and attain a length of 4 m. Males weigh about 270 kg and attain lengths of about 3 m at maturity. On land Leopard Seals are quite agile (Gaskin 1972).

HISTORIC ACCOUNTS OF ABORIGINAL SEALING

Information on the hunting and use of seals is contained in the journals of Robinson (Plomley 1966) and Kelly (1920). There are two types of Aboriginal weapon for hunting seals described in the literature, a club and a spear. In his account of a voyage around Tasmania in 1815-1816, Kelly (1920) describes Aboriginal women stalking seals at George Rocks. This fascinating account describes Aboriginal women sneaking up on seals by imitating seal behaviour. After first washing their bodies to lessen the chance of the seal catching their scent, they approached slowly from the downwind side to the rocks where the seals lay sleeping. When observed by a seal the women would imitate the seals' movements by raising their heads, looking around, and scratching. The six women stayed on the rocks with the seals (where they were washed by the occasional wave) for nearly an hour before making their attack. Each then clubbed two seals. By clubbing a seal on the nose it can be stunned into unconsciousness, and then dispatched. Over the next few days the women continued to catch seals from the rocks, even though the animals were becoming increasingly shy. When Kelly's party and Aboriginal helpers returned to the mainland, the men danced around a pile of seal carcasses on the beach, sticking their spears into the dead seals as if killing them (Kelly 1920). There is an interesting problem in this northeast region in that the people did not have watercraft (Jones 1976). All the seal colonies on the islands of the Furneaux Group and George Rocks were inaccessible to them until the arrival of the colonists and their boats. Some of these islands are as little as 3 km offshore.

The reference to killing seals by spearing is contained in a hearsay account in Robinson's journal where Robinson's native companion WOORRADY describes sealing at Cox Bight by the Bruny Island and southwest

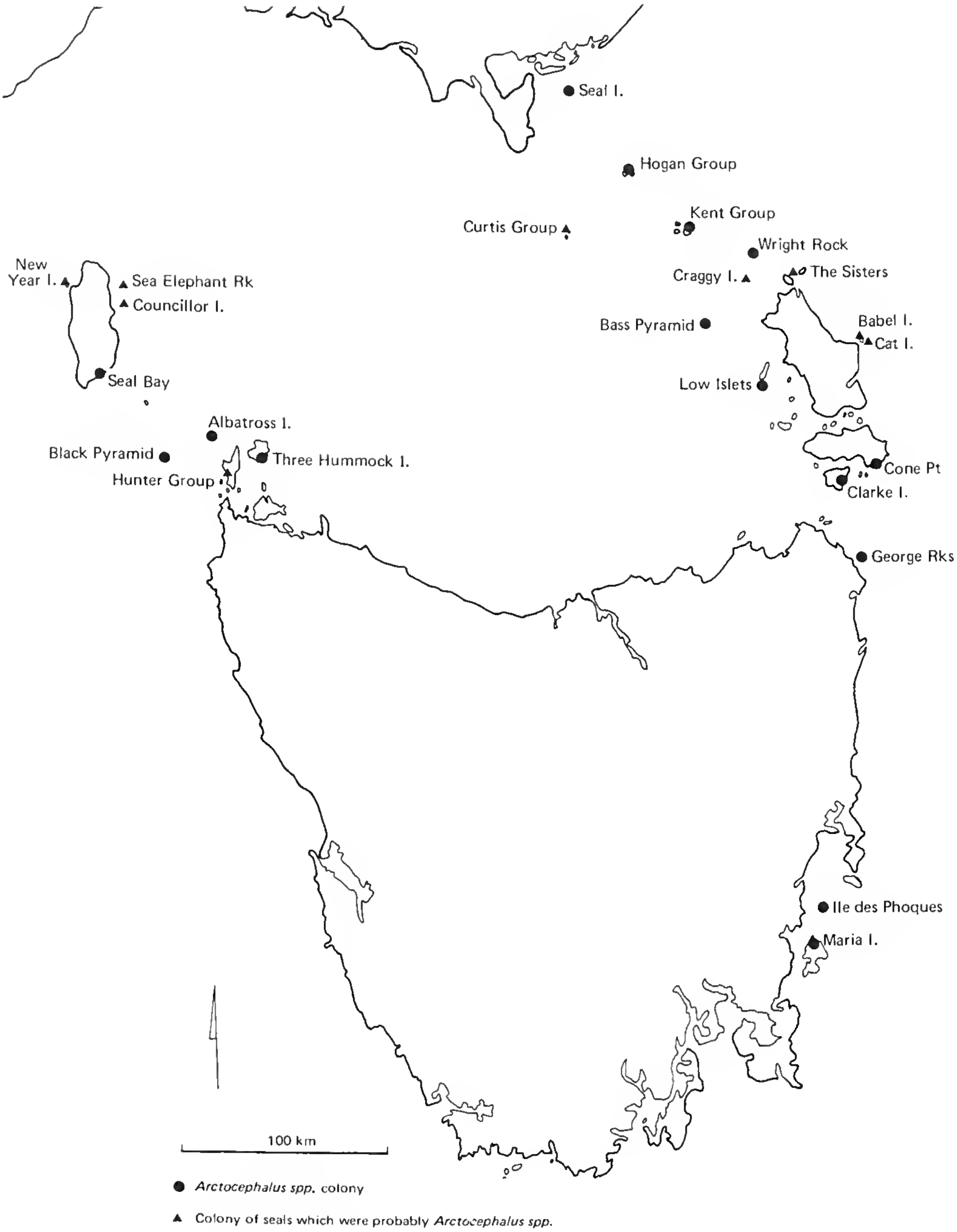


Fig. 2—Historic locations of *Arctocephalus* spp. colonies (source: Warneke 1976)

tribes who "went off in catamarans to the De Witt Islands and to the different rocks, and speared seal and brought them back to the mainland. Also went to the Eddystone and speared seal." (Plomley 1966). On one occasion Robinson observed a large seal at Cox Bight which the natives killed, but he does not say how it was dispatched (Plomley 1966). However, he does say that it was cut into flitches which were then carried to the camp. If butchering at the kill site was a common practice for large seals, then their bone remains will be under represented in middens, having been left behind at the site of the kill. Vanderwal (1978) has excavated seal remains in a midden on Maatsuyker Island and interprets the bulk of archaeological debris to suggest local consumption rather than a return to the mainland with the meat, but the reasons for this statement are not given. The seal bones recovered by Jones (1966) at West Point are all from young animals and bones from the flippers

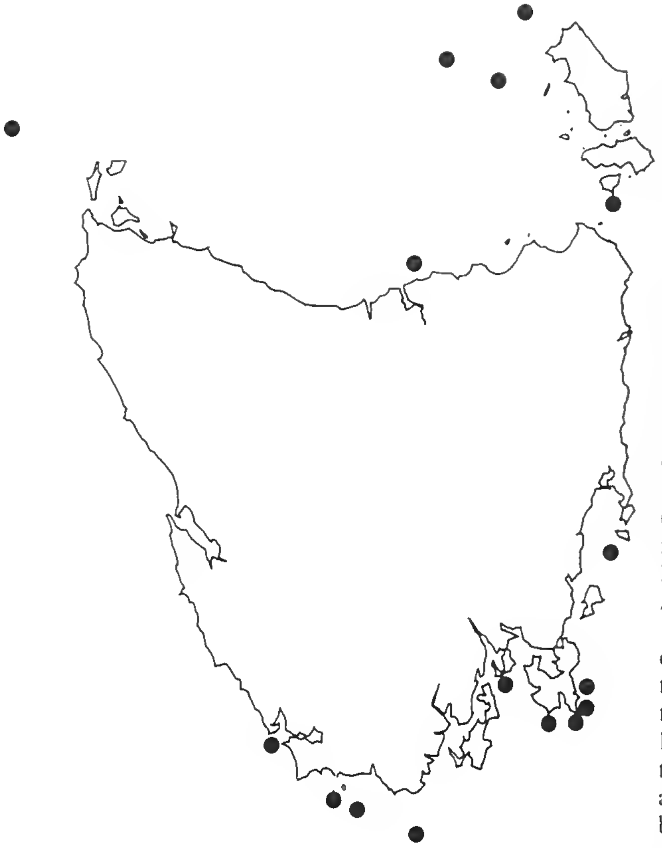


Fig. 3—Modern observations of fur seals (source: Pearse 1979)

and skull over represented (R. Jones pers. comm.).

Also of interest is Robinson's mention of Aborigines catching a Leopard Seal at Sandy Cape (Plomley 1966) and an unsuccessful attempt to catch a seal at Hunter Island (Plomley 1966). The Hunter Island seal he calls a "Leopard Oil Seal from its being spotted like a leopard", which Plomley (1966) interprets as a Leopard Seal.

Seal meat was a food which the Tasmanians were very fond of (Plomley 1966) but hunting seals was a high risk activity. Robinson records in his diary that WOORRADY had told him that many hundred natives had been lost on sealing trips to the De Witt group and Eddystone Rock (Plomley 1966). Although this is probably exaggerated, access to these islands does involve water crossings of 5 km and 27 km respectively. Further confounding this claim, a voyage of 27 km should have been beyond the capacity of Tasmanian watercraft (Jones 1976). Steep Island and Albatross Island in the northwest involve water crossings of 3.2 km and 11.3 km, and neither appear to have been visited by Aborigines in the recent prehistoric period (Bowdler 1974, R. Jones per. comm.). The reference to Eddystone Rock may be a mistake in Robinson's translation of the location. On another occasion TRUCANINI told Robinson that the seals fought with the men at Cox Bight, and that once "a seal caught a black man by the thigh and they both fell over the rocks into the water and the seal carried the man down. He however came up but was ever after lame" (Plomley 1966). WOORRADY relates at least four attacks by seals in the Cox Bight area (Plomley 1966). The risks of seal hunting fall into three categories. Seals occasionally attacked the hunters.

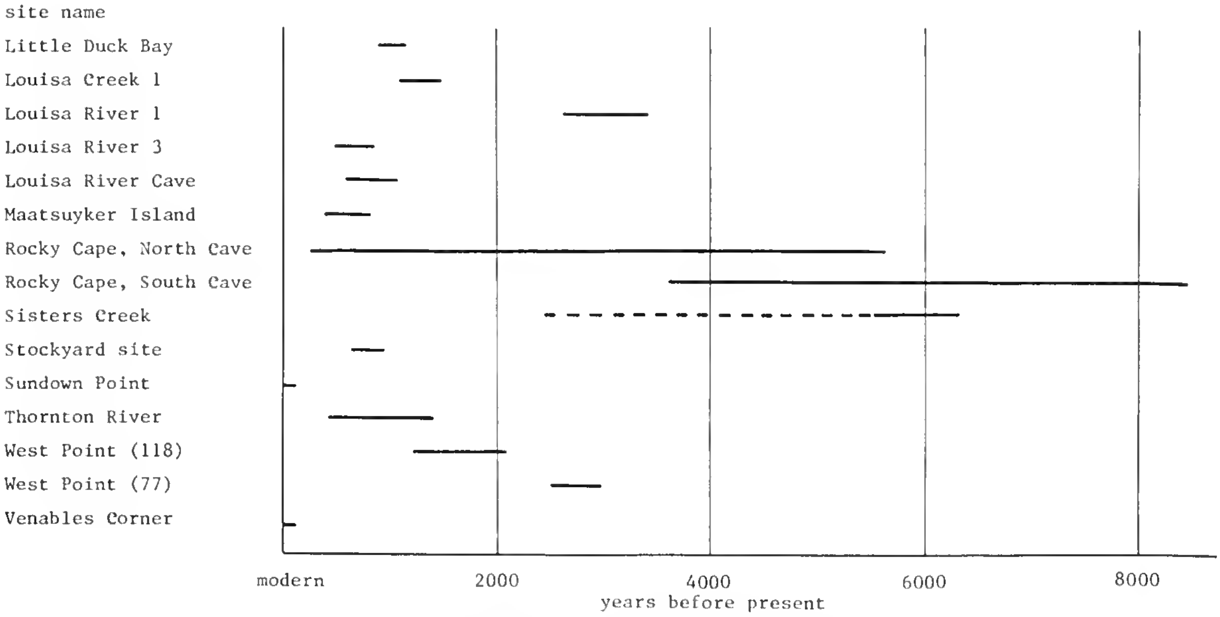


Fig. 4—Dates of seal remains in Tasmanian archaeological sites. The dotted line for Sisters Creek is based on stratigraphic correlation with Rocky Cape.

Long distance water crossings were dangerous given the inherent structural limitations of Tasmanian watercraft (Jones 1976). There was a risk of injury while landing on wave swept rocky seal islands.

ARCHAEOLOGY OF SEAL REMAINS

How long have seals formed part of the diet of the coastal people of Tasmania? I have plotted the C14 dates ± two standard deviations for all the sites where seal remains occur throughout the deposit (Fig. 4). The Rocky Cape sequence demonstrates some 8 000 years of continuous exploitation of seal. It was about this time that the rising post-glacial sea level reached the vicinity of the Cape and shows that seals (and seal hunters) came with the encroaching sea. The next dated appearance of seal bone is at Sisters Creek at around 6 000 BP. No top date is available for the Sisters Creek site, but on stratigraphic correlation with Rocky Cape its upper layers (which do not contain fish bones) are taken to be less than 3 500 years old (R. Jones pers. comm.). The remaining dates show the occurrence of seal remains from around 3 000 BP to the present for west and southwest sites. The figure shows a pattern of long-term exploitation of seals in coastal sites up to the contact period, but the pattern is not quite that simple. In the northwest, seal bones were not recorded in the excavations of the midden layers of Cave Bay Cave on Hunter Island (Bowdler 1979). Similarly in the east and southeast at Little Swanport (Lourandos 1970), Alum Cliffs (Stockton 1978), Shag Bay (Vanderwal 1977), and Jordan River (Healey & Stockton 1980, Gaffney & Stockton 1980) seal bones were not found. That so many sites do not contain seal bones cannot be dismissed as a problem of excavation sample size. This is especially true of the large excavations of the midden layers in Cave Bay Cave, which is geographically close to the northwest and covers a similar time span to sites which contain seal bones. Why do seals appear to be abundant in some locations, but absent from others?

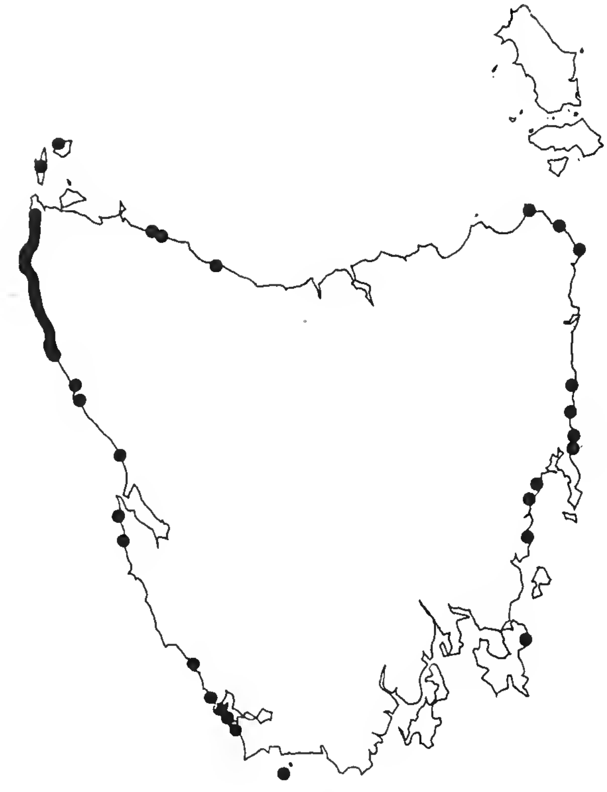


Fig. 5—Distribution of seal remains of all species

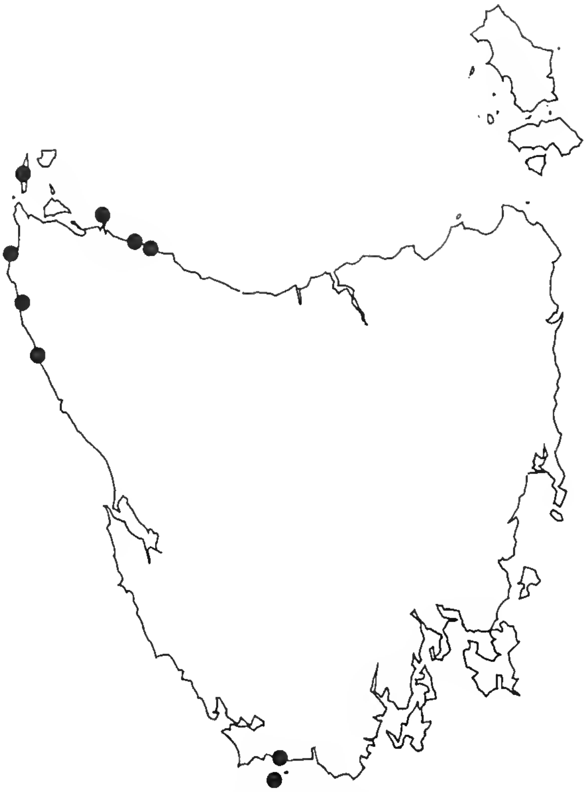


Fig. 6—distribution of *Arctocephalus* spp. remains

DISCUSSION

The distribution of archaeological seal remains was compiled from published and unpublished sources. The majority of the observations are of fragmentary remains noted during field reconnaissance. Under these conditions it is easy to distinguish seal bone from other mammals, but difficult to identify species. A number of people contributed records of their observations of seal remains in middens in response to a letter circulated in 1980. Subsequently, it was possible to check many of the observations from northwest Tasmania, but records from other areas were not checked. Identifications to generic level for *Arctocephalus* spp. and specific level for other seals were available for remains from excavated sites (Jones 1966, 1971, Bowdler 1979, Vanderwal 1978). The distribution of archaeological sites with prehistoric seal remains shows a marked concentration on the northwest coast (Figs 5-8), from Sandy Cape to Cape Grim, with a lower frequency along the remaining coast. Of lowest frequency are the Bass Strait coast east of Port Sorell, and Tasman Peninsula and Bruny Island. The patterns for *Arctocephalus* spp. (Fig. 6) and *Mirounga* (Fig. 7) remains are similar. The remains are found on the northwest, west and southwest coast. These patterns reflect the locations of analysed excavations where accurate generic identifications are available, and so the absence of records from other areas may bias the picture. This could be tested by sampling sites in other areas for seal remains. This could be done quite easily by collecting material from deflated sites around the coast. Occurrence of the Leopard Seal (Fig. 8) is less common than the other species. The species was recorded ethnographically, and an Aboriginal word, "TOPER", has been recorded for it (Plomley 1976). The present day distribution of fur seal is in contrast to the archaeological and contact period distributions. The modern pattern is strongly centered on the south and southeast coast. Several hypotheses can be advanced in an attempt to explain this.

Did Aborigines exterminate or drive away the seals of the coastal breeding populations before European arrival, as Jones (1966) speculated for the Southern Elephant Seal at West Point. There is no evidence that seals breed on "mainland" coasts, so it is extremely unlikely that *Mirounga* was breeding on the Tasmanian coast at any time. Secondly modern C14 dates have been obtained for sites containing Southern Elephant Seal at Sundown Point (Ranson pers. comm.) and at Venables Corner. Both of these sites also contain fur seal.

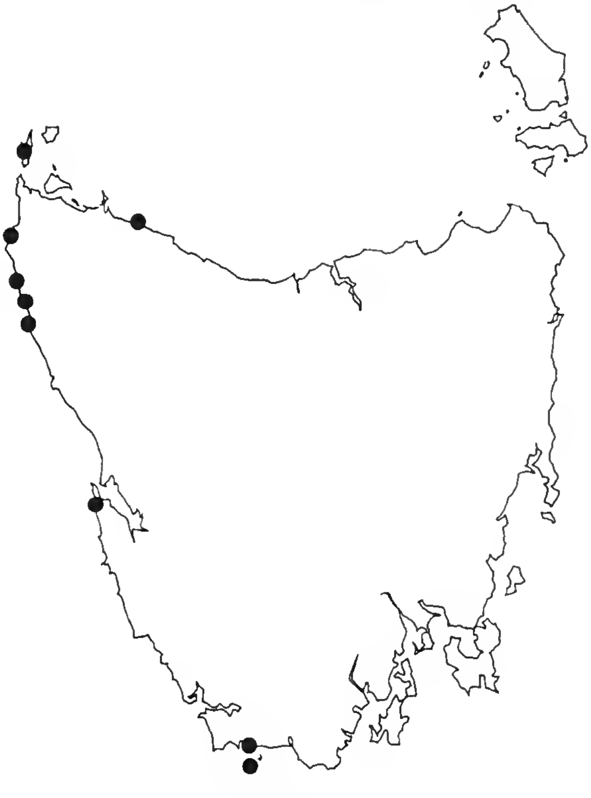


Fig. 7 — Distribution of *Mirounga leonina* remains

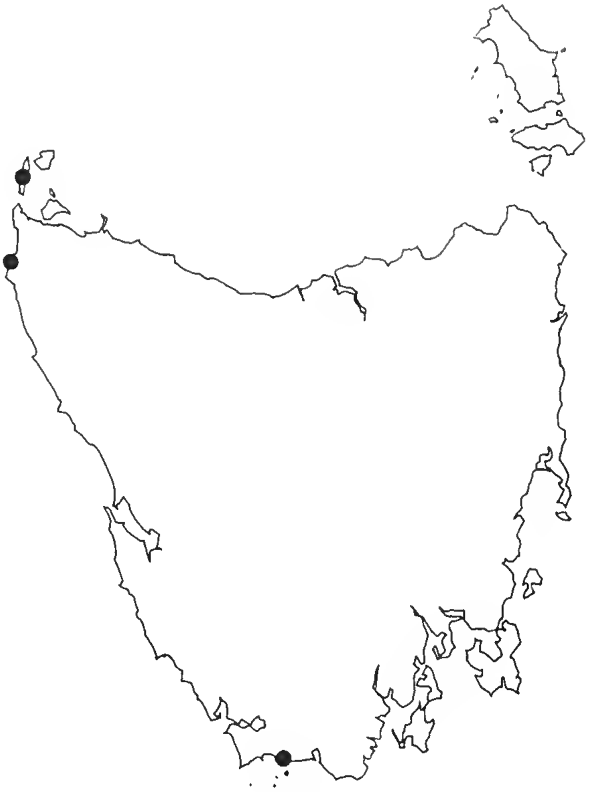


Fig. 8 — Distribution of *Hydruga leptonyx* remains

Did Aboriginal activity reach just the fringe of the range of seals? Were the main seal areas on inaccessible islands in Bass Strait or the far south? Was it just the stray wandering seal which came ashore on the mainland and fell prey to the Aborigines? Because of the extremely high density of seal remains along the northwest coast, I have plotted the distribution for the region at a larger scale (Fig. 9). The high density of site information here is partly due to the fact that the coast from Cape Grim to Macquarie Harbour has been surveyed more frequently and more intensively than any other part of Tasmania. Also, shell middens in the northwest are more numerous and larger than elsewhere in Tasmania. Consequently, in this well studied area we find an almost continuous occurrence of seal remains. This suggests a resident population of seals, or regular visitors, all along the coast. At West Point, Jones' (1966) tentative minimum numbers estimates for seals in the whole site is several thousand individuals. Supplementing this, analysis of the Southern Elephant Seal canine teeth has shown that all specimens were young animals, with some teeth belonging to seals less than three months old. All this evidence suggests a large breeding colony of Southern Elephant Seals in the immediate vicinity — but where was it located? There are no offshore islands or rocks any distance from the coast, but there are a few little islands less than 100 m away. Some of these have shell midden on their surface, and in 1980 two were rookeries for the Little Penguin, *Eudyp-*

tula minor. The simplest explanation of the evidence is to put breeding Southern Elephant Seal colonies on the shore of the Tasmanian mainland, or on these islands just off shore, where they are quite accessible to Aborigines. In fact, given the age structure of the seals found at West Point, is it possible the Aborigines are just scavenging dead juveniles? (Horton 1978). On the other hand, there is historical evidence for a concentration of *Mirounga* to the northwest of Tasmania on King Island, New Year Islands and Hunter Island (Peron in Micco 1971). The prevailing winds are southwesterly i.e. onshore. With significant seal activity in the offshore waters it is inevitable that some freshly dead, sick or tired individuals are going to end up on the coast. The presence of the remains of juveniles of less than three months of age at West Point is not surprising as the pups are weaned at about one month (Warneke 1975). This evidence does not imply that there was a breeding colony at West Point. The same argument also applies to *Arctocephalus.* During a seven year period Warneke recovered 170 tagged pups within a radius of 140 km from the Seal Rocks colony of *A. pusillus doriferus.* This is just 2% of the total sample tagged in the same period. The sealer Kelly estimated that the Albatross Island colony off Hunter Island had a population in the order of 12 000 (Plomley 1966). Reid Rocks further to the northwest probably had more than 2 000 animals and the many colonies around King Island possibly exceeded 50 000 (R. M. Warneke pers. comm.). With these population numbers, beach scavenging could account for all the fur seal remains in northwest Tasmanian coastal middens (R. M. Warneke pers. comm.). No reference to historic sealing on the northwest coast of Tasmania has been found (Warneke 1976).

CONCLUSIONS

Quantitative studies of seal remains in large sites may give clues to the times of the year when seals were killed. With an idea of what ages and sexes were killed it should be possible to describe the population structure of the seal groups that the Aborigines preferred to prey upon. Alternatively, it may suggest that the Aborigines were collecting dead animals. Work along these lines using growth rings on teeth is presently being conducted by Horton (1980) on material from Maatsuyker Island and O'Connor (1980) for West Point. Since the various species vary so widely in size and habits, any reconstruction concerned with seasonal availability or significance of seals in the diet will need to be species specific.

The distribution maps for seal remains indicate few records of seal bone in the northeast and southeast. Whether this is a reflection of the true distribution or an artefact of a lack of archaeological work in the region could be tested by systematic site survey and sampling.

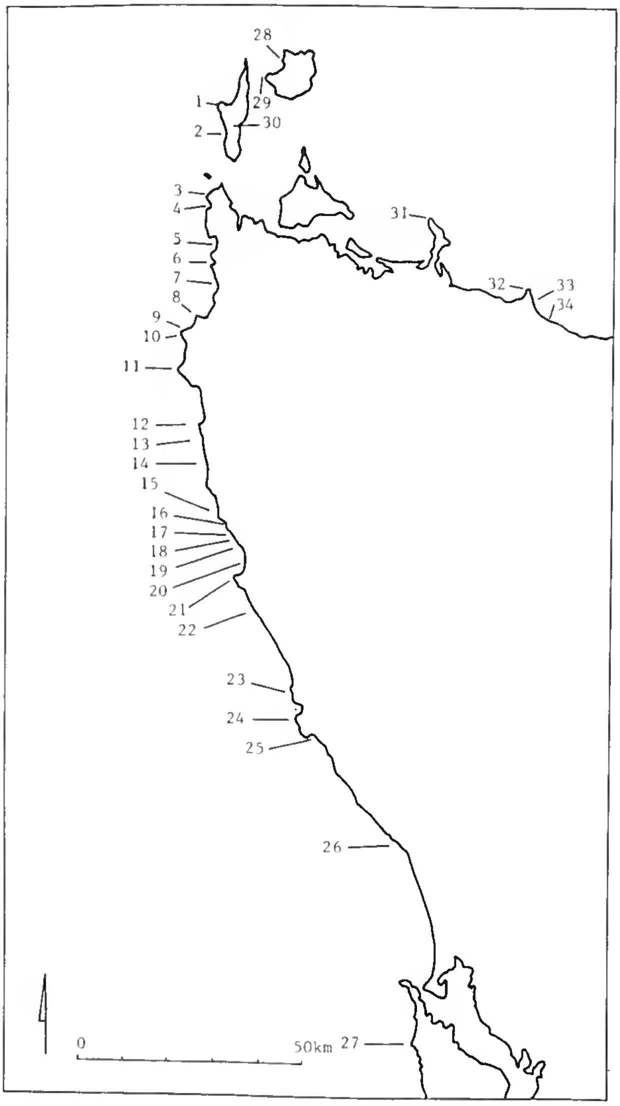


Fig. 9—Distribution of seal remains in northwest Tasmania. Location and observer of numbered sites:

1, Curvier Point—pers. obs. 2, Little Duck Bay—Bowdler (1979). 3, Suicide Bay—pers. obs. 4, Valley Bay—Jackson (pers. comm.), pers. obs. 5, Studland Bay—Lourandos (1970).6, Calm Bay—Jackson (pers. comm.). 7, Maxies Point—Lourandos (1970), Jackson (pers. comm.), 8, Green Point—Lourandos (1970), Jackson (pers. comm.). pers. obs. 9, West Point (Nettley Bay—Jones (1966), pers. obs. 10, West Point (south)—Jones (1966), Jackson (pers. comm.), pers. obs. 11, Bluff Hill Point—Jackson (pers. comm.), pers. obs. 12, Sundown Point—Ransom (pers. comm.), Jackson (pers. comm.), pers. obs. 13, Nelson Bay—pers. obs. 14, Rebecca—Jackson (pers. comm.). 15, Gannet Point Hazard Bay—Jackson (pers. comm.). 16, Ordinance Point—Pulleine (1929), Jackson (pers. comm.), pers obs. 17, Thornton River—pers. obs. 18, Daisy River—pers. obs. 19, Wild Wave River—pers. obs. 20, Sandy Cape Beach—pers. obs. 21, Sandy Cape/Venables Corner—Pulleine (1929), Legge (1929), Jackson (pers. comm.), Ranson (pers. comm.), pers. obs. 22, Johnson River—Jackson (pers. comm.). 23, Rupert Point—Jackson (pers. comm.). 24, Conical Rocks—Jackson (pers. comm.). 25, Ahrberg Bay—Jackson (pers. comm.). 26, Trial Harbour—Cane (pers. comm.). 27, Sloop Rocks—Jackson (pers. comm.). 28, Ranger Point—pers. obs. 29, Burgess Point—pers. obs. 30, Homestead Lagoon (Stockyard site)—Bowdler (1979). 31, North Point—pers. obs. 32, Rocky Cape—Jones (1966). pers. obs. 33, Lee Archer—Jones (pers. comm.). 34, Sisters Creek—Jones (1966).

The large numbers of seals in the Furneaux Group and Maria Island at contact suggests that seal remains should be common in middens on the adjacent coasts.

The overall impression of the combined archaeological and ethnographic data is a picture of long term exploitation of seals by Aborigines. An early speculation by Jones (1966) that the Aborigines had in prehistoric times caused the local abandonment of the Tasmanian mainland coast by the Southern Elephant Seal has not been resolved. Jones proposed the idea of C14 dating the latest phase of prehistoric Aboriginal sealing to see if the species continued to be found up to the contact period. This has now been done by Bowdler, Ranson, Vanderwal and the author, who have shown that the species is present up to the contact period. However, we still do not know if the seals were living on the coast in colonies, or only coming ashore occasionally. The presence of juvenile *Mirounga* teeth (less than three months old) at West Point does not resolve the problem as weaning occurs at about one month of age, after which the juveniles will be travelling widely in order to feed. There is insufficient evidence to suggest a decline or increase in seal numbers, in spite of at least 8 000 years of continuing predator/prey relationship. This relationship was to alter drastically when the arrival of European technology made it possible to exploit previously inaccessible colonies in Bass Strait.

ACKNOWLEDGEMENTS

The distribution maps which forced me to think about the problems outlined here were compiled from contributions by Scott Cane, David Horton, W. D. and L. Jackson, Rhys Jones, Don Ranson, Ron Vanderwal and the Tasmanian Aborignal Sites Index. I am deeply indebted to their willingness to share information. For comments on early drafts of this paper I am indebted to R. H. Green, John Luly, R. M. Warneke, Jeanette Hope, Rhys Jones and Phil Hughes. R. M. Warneke generously gave access to unpublished material, and discussed many of the difficult questions raised in this paper.

REFERENCES

Bowdler, S., 1974. An account of an archaeological reconnaissance of Hunter's Isles, north-west Tasmania, 1973/4. *Rec. Queen Vict. Mus.* 54: 1-22.

Bowdler, S., 1979. Hunter Hill, Hunter Island. Unpublished PhD thesis, Australian National University.

Green, R. H., 1973. *The Mammals of Tasmania.* The Author, Launceston.

Gaffney, L. & Stockton, J., 1980. Results of the Jordan River Midden Excavation. *Australian Archaeology* 10: 68-78.

Gaskin, D. E., 1972. *Wales, Dolphins and Seals.* Heinemann.

Healey, L. & Stockton, J., 1980. Problems and potentials of archaeological evidence for prehistoric biophysical description in the Derwent estuary. *The Artefact* 5: 145-154.

Horton, D. R., 1978. Preliminary notes on the analysis of Australian coastal middens. *Australian Institute of Aboriginal Studies Newsletter* 10: 30-33.

Horton, D. R., 1980. Age determination in Australian Fur Seals based on canine teeth. *Bull. Aust. Mammal Soc.* 6: 41.

Hyett, J. & Shaw, N., 1980. *Australian Mammals.* Nelson, Australia.

Jones, R., 1966. A speculative archaeological sequence for northwest Tasmania. *Rec. Queen Vict. Mus.* 25: 12.

Jones, R., 1971. Rocky Cape and the problem of the Tasmanians. Unpublished PhD thesis, ANU.

Jones, R., 1976. Tasmanian aquatic machines and off-shore islands. In *Problems in Economic and Social Archaeology*, G. de G. Sieveking, I. H. Longworth & K. E. Wilson, eds, Duckworth, London, 235-263.

Kelly, J. 1920. First discovery of Port Davey and Macquarie Harbour, by James Kelly *Pap. Proc. R. Soc. Tasm.* 1920: 160-181.

Legge, R. W., 1929. Tasmanian Aboriginal Middens of the West Coast. *Australasian Association for the Advancement of Science* 19: 323-328.

Micco, H. M., 1971. *King Island and the Sealing Trade, 1802.* Roebuck, Canberra.

Lourandos, H., 1970. Coast and hinterland: the archaeological sites of eastern Tasmania. Unpublished MA thesis, ANU.

O'Connor, S., 1980. Bringing it all back home: an analysis of the vertebrate faunal remains from the Stockyard Site, Hunter Island, north-west Tasmania. Unpublished B.A. Honours thesis, University of New England.

Pearse, R. J., 1979. Distribution and conservation of the Australian fur seal in Tasmania. *Vict. Naturalist* 96: 48-53.

Plomley, N. J. B. (ed.), 1966. *Friendly Mission. The Tasmanian Journals and Papers of George Augustus Robinson 1829-1834.* Tasmanian Historical Research Association, Hobart.

Plomley, N. J. B., 1976. *A Word-list of the Tasmanian Aboriginal Languages.* The author in association with the Government of Tasmania.

Pulleine, R., 1929. The Tasmanians and their stone culture. *Australasian Association for the Advancement of Science* 19: 296-314.

Stockton, J., 1978. Archaeological investigation of the Derwent River Estuary, south-east Tasmania: Alum Cliffs test excavation interim report. *The Tasmanian Naturalist* 53: 8-9.

Thoughton, E., 1965. *Furred Animals of Australia.* Angus and Robertson, Sydney.

Vanderwal, R. L., 1977. The Shag Bay Rockshelter, Tasmania. *The Artefact* 2: 161-170.

Vanderwal, R. L., 1978. Adaptive technology in south west Tasmania. *Australian Archaeology* 8: 107-127.

Warneke, R. M., 1975. Dispersal and mortality of juvenile fur seals *Arctocephalus pusillus doriferus* in Bass Strait, Southeast Australia. *Rapp. R.-v. Reun. Cons int. Explor. Mer* 169: 296-302.

Warneke, R. M. 1976. *Preliminary report on the distribution and abundance of seals in the Australian region.* Scientific Consultation on Marine Mammals, Food and Agriculture Organisation of the United Nations, Bergen, Norway.

Wood Jones, F., 1925. *Mammals of South Australia Part 3, The Monodelphia.* Government Printer, Adelaide.

PROC. R. SOC. VICT. vol. 94, no. 2, 61-68, June 1982

WIND-INDUCED MOVEMENTS OF BEACH SAND AT PORTSEA, VICTORIA

By C. L. So

Department of Geography and Geology, University of Hong Kong, Hong Kong

ABSTRACT: An attempt is made to monitor beach changes associated with wind-induced movements of beach sand at Portsea, Victoria. This reveals that given adequate wind strength and atmospheric aridity, a process of sand-layer levelling, arising from alternate drying of sand and activation of sand movement by wind, takes place within a favourable time span of the tidal cycle. The moving sand ending up in sinks may constitute a permanent loss unless intra-compartmental and inter-compartmental transfers of the beach sand are made good by feedbacks from the dune-dominated coastal hinterland and the swell-dominated offshore subsystem. Where recovery is not complete, the cumulative, though diminished, net loss of beach sand plays a significant role in both the spatial and the temporal distributions of sand on the beach.

Beach changes associated with wind-induced movements of beach sand have not been given the attention they deserve. Well-based observations are confined to coastal dunes and dune topography. Mobility of beach levels of aeolian origin is considered to lag behind. However, recognition of transport surfaces on the foreshore as sites of sand mobilization without significant change of sand level renders this assertion untenable. Moreover, relevance of sand movements by wind to beach sediment budget further calls for their investigation. The beach at Portsea, with ample catchment for sand and a multi-directional wind system, provides an adequate base for such study.

THE COASTAL ENVIRONMENT

The ocean coast of Portsea between Mt. Levy and Sphinx Rock (Fig. 1, Inset A), formed since the Post-glacial rise of sea level (Keble 1950), encompasses a sandy beach abutting a series of dune-capped cliffs and shore platforms cut in Pleistocene dune calcarenite (Bird 1975, 1977). Forming the coastal hinterland is an undulating terrain 30-40 m high (Fig. 1, Inset B). Its overlying Holocene dunes (Bird 1972) rest on a basement of calcarenite formed by the consolidation and cementation of older dunes (Bowler 1966). Deflation, periodically affecting the dune surface, which is now partly under scrub or grass, initiates sand migration and blowout development. The lack of spatial pattern in the asymmetry of some dune profiles points to less well-defined sand drift. Absence of surface drainage testifies to permeability of the dune sand and percolation of rainwater into the ground. This enhances backshore sand movement.

Part of the beach compartment (Fig. 1) has been chosen for monitoring wind action on sand. The beach material is calcareous sand derived from shelly organisms thriving in coastal waters to the south, and from eroded calcarenite cliffs and overlying dunes. Except where a berm develops, beach profiles rise landward at angles of 10-12° but occasionally flatten off to 6-8°. Where a hardened calcarenite layer persists seaward beyond the beach sand, remnants of dissected intertidal platforms and reefs are exposed at low water.

The coast is characterised by a microtidal swell environment (Davies 1972). Northerly and north-easterly winds are prevalent in autumn, winter and spring, while southerly and south-westerly winds are prevalent in summer. Westerly winds may blow throughout the year but easterly winds are weak and infrequent. Winds strengthen with passage of cyclonic depressions south of the Victorian coastline. Despite a high frequency of gales in spring and summer (Bowler 1966), the mean monthly velocities are the highest in winter (Maher & McRae 1964), being largely those of northerly winds. Running from west-northwest to east-southeast, the coast is affected by wave action associated with onshore southerly winds, a favourable fetch and offshore depth in excess of 18 m. The more significant impact of the wind system, in the present context, is its role in the spatial tranfser of sand particles. Thus, given sufficiently dry conditions and a widening sand surface associated with an ebb tide, the southerly winds may move sand from the foreshore to the backshore which, if not acting as a sink, may subsequently allow northerly winds to return particles to the foreshore. Some or all of these may end up in the offshore zone. The decrease in rainfall in summer favours such inducement of sand movement by the southerly winds.

MONITORING SAND MOVEMENTS

Sand-level changes were recorded simultaneously with wind data. A sector of the beach (Fig. 1), 120 m long and 40-50 m wide, was chosen that had relatively uniform internal and external parameters including sand source, beach face slope, beach materials, offshore profile, and backshore and dune hinterland configuration. Fifty-six wooden stakes, each 30 cm long and 1.25 cm in diameter, were placed in a network designed by random-stratified sampling. This design was modified to account for different zones such as lower intertidal, mid-intertidal, upper-intertidal, storm-wave and backshore, and also for variation in beach topography. The posi-

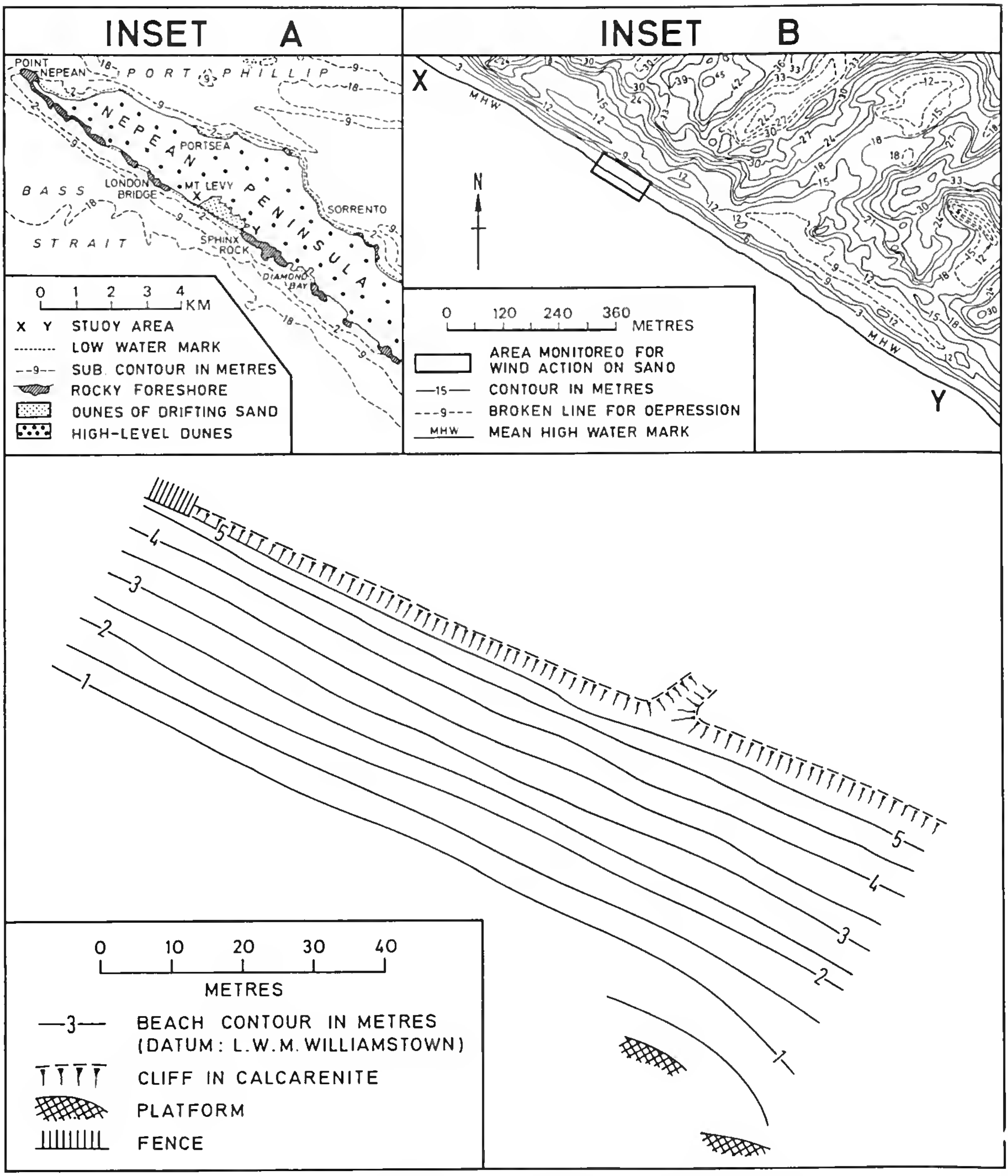


Fig. 1—Location of study area and shore-zone physiography at Portsea.

tion of the stakes was fixed by compass and tape and plotted on a base map, produced by levelling and tacheometry. Readings of sand levels were taken hourly over a six-hour period spanning where possible the second half of an ebb tide and the first half of the following flood. To collect sand moving in saltation or in creep, plastic sand traps 3.5 cm in diameter and 3.4 cm deep were used.

INTRA-COMPARTMENTAL AND INTER-COMPARTMENTAL TRANSFERS

Sand movement was found to be associated with winds above a critical force. A macroclimatic wind (Jennings 1957) of 46 km/hr with shear velocities up to 19 km/hr failed to initiate sand movement on 15 November (Table 1), but a macroclimatic wind of 44 km/hr with shear velocities of 19-22 km/hr started the process on 18

November despite the drizzle, pointing to threshold velocities of 19-22 km/hr required to move sand. With sand transport varying as the cube of excess of velocity over this threshold (Bagnold 1954), strengthening of wind offset the effect of rain as seen on 11 November. Raising the threshold velocity were salt crusts formed on the sand surface, reported on 25 November, and air dampness (Belly 1964), locally enhanced by splash and spray associated with plunging breakers.

Sand movement on 4 November 1977

Sand movement was localised in place and in time. The greater sand loss on 4 November than on 14 and 18 November (Fig. 2), taking place at low tide, was associated with strengthening of wind brought about by a passing, complex, low pressure system accompanied by a cold front. It took a subsequent drop in ground-level wind speed to below 19 km/hr, the onset of rain and increasing splash and spray with a rising tide to terminate the process. In the course of sand movement, phases of differential cut and fill were involved (Fig. 3) such that along rows EF and GH sand loss dominating the first two hours was then increasingly held up or replaced by gain. Hourly changes of beach levels (Fig. 4) revealed a change from dominantly falling sand levels, especially along profiles AB, EF and GH, to rising ones towards the backshore late in the monitoring period, pointing to intra-compartmental and inter-compartmental transfers of sand. Where the hourly sand levels merged together, transport surfaces occurred.

Nine of the ten sand traps operating at noon were filled by 1.00 p.m. More rapid infilling of those placed near the high water mark than those located down the beach pointed to sand migration from the lower-foreshore source region to the upper-foreshore receptor, overspill of which then effected inter-compartmental transfer. In size and rounding, the migrating sand in traps was comparable to those on the foreshore and in the blowouts, the only variation being its higher percentage of medium grains indicative of sorting effect. In respect of pivotability (Shepard & Young 1961) determined with a 'rock-and-roll' shape-sorter (Kuenen 1964), the sand displayed a better spread of values, and higher percentages of the more pivotable fractions, than the foreshore or the blowout sand.

Sand movement on 14 November 1977

Sand movement spanned half a spring flood tide and part of the following ebb. The reducing wind force, moist air persisting after rain, and abundant splash and spray generated by a rough sea cut down sand-level changes. Part of the upper intertidal zone and adjacent backshore became a receptor of the migrating sand (Fig. 2B). Elsewhere alternate gain and loss dominated (Fig. 3). The upper part of profile EF changed function from a transport surface to a receptor with overspill (Fig. 4) while gain in the upper part of the profile was concurrent with loss from the lower part, pointing again to intra-compartmental and inter-compartmental transfers of sand.

Sand movement on 18 November 1977

Covering the late stage of an ebb tide and almost entirely its succeeding flood counterpart, subdued movement of slightly wet sand took place under a narrow range in wind speeds and directions (Fig. 2C). This resulted in small cumulative changes (Fig. 3) and limited depth of disturbance (Fig. 4) of the foreshore. Profile EF showed limited change at the seaward end from 1.00 p.m. onwards (Fig. 4), a node of no change of the mid-tide level, and sand transfer from the lower to the upper foreshore.

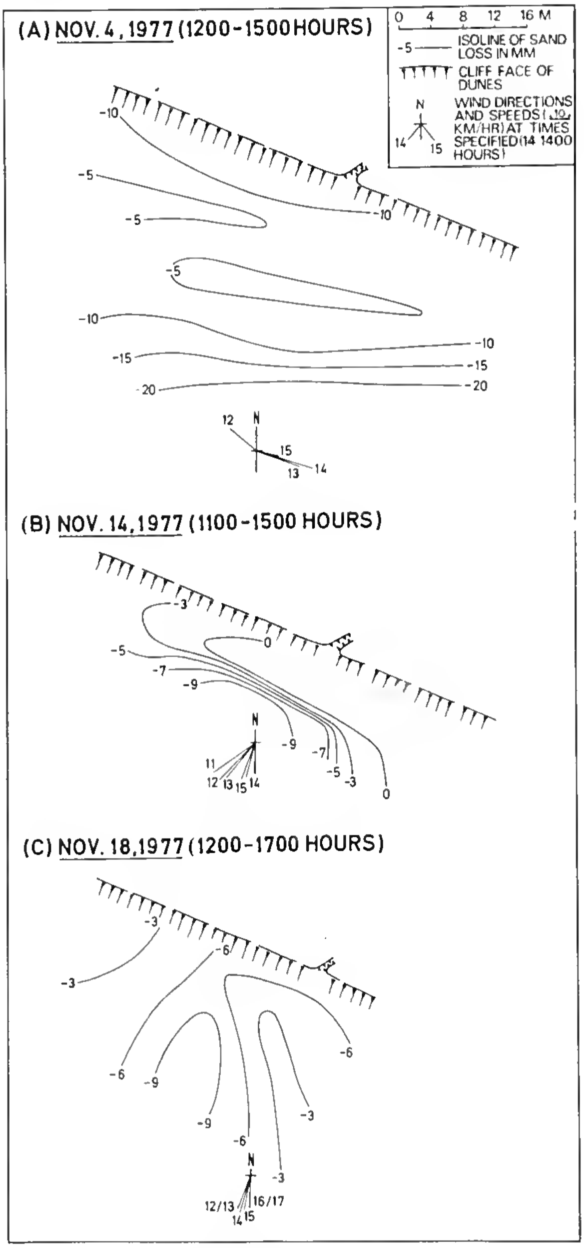


Fig. 2—Isolines of sand loss from Portsea Beach on 4, 14 and 18 November 1977.

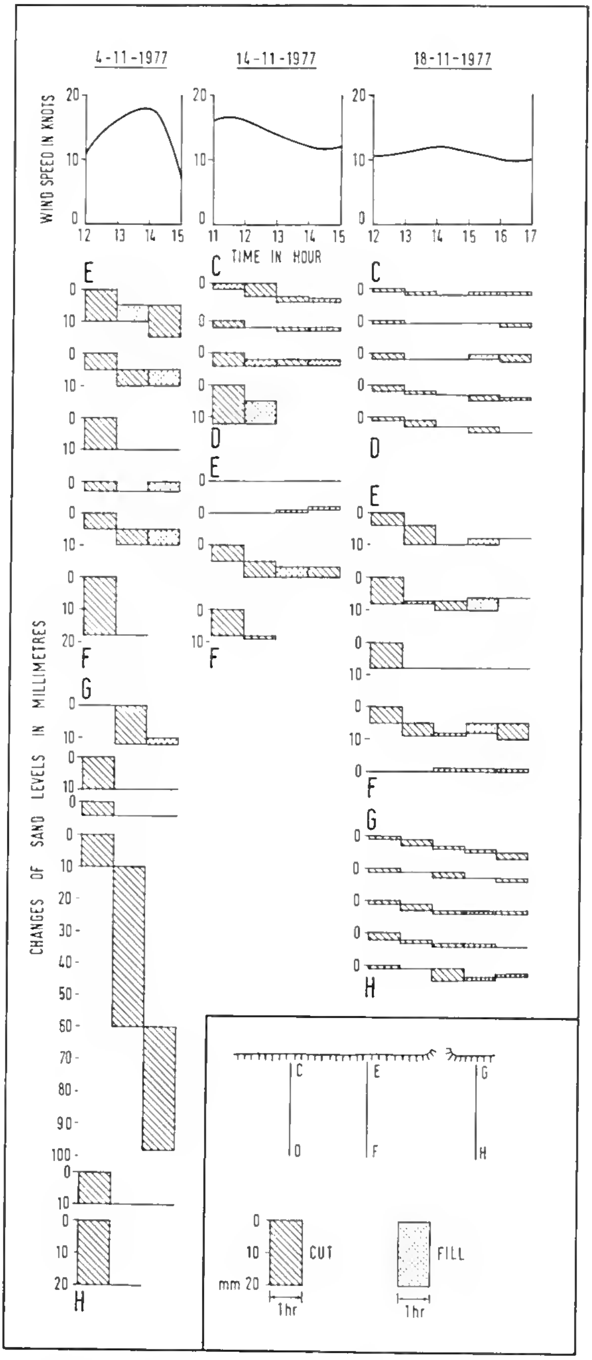


Fig. 3—Cumulative graphs showing cut and fill at selected points on Portsea Beach on 4, 14 and 18 November, 1977.

SAND MOVEMENT ON 11 NOVEMBER 1977

To depict patterns of cut and fill, more sand traps were laid out to form a close network with the stakes used. Some cut was experienced (Fig. 5A) despite the fall of 2-3 mm of rain at Point Lonsdale (Table 1). Data on fill indicated the amount of sand passing over a transport surface. Its decrease in value landward from a peak (Fig. 5B) revealed substantial sand migration from source regions. Towards the back of the beach where the fill thinned out within the zero isoline for cut, there was a gain of sand.

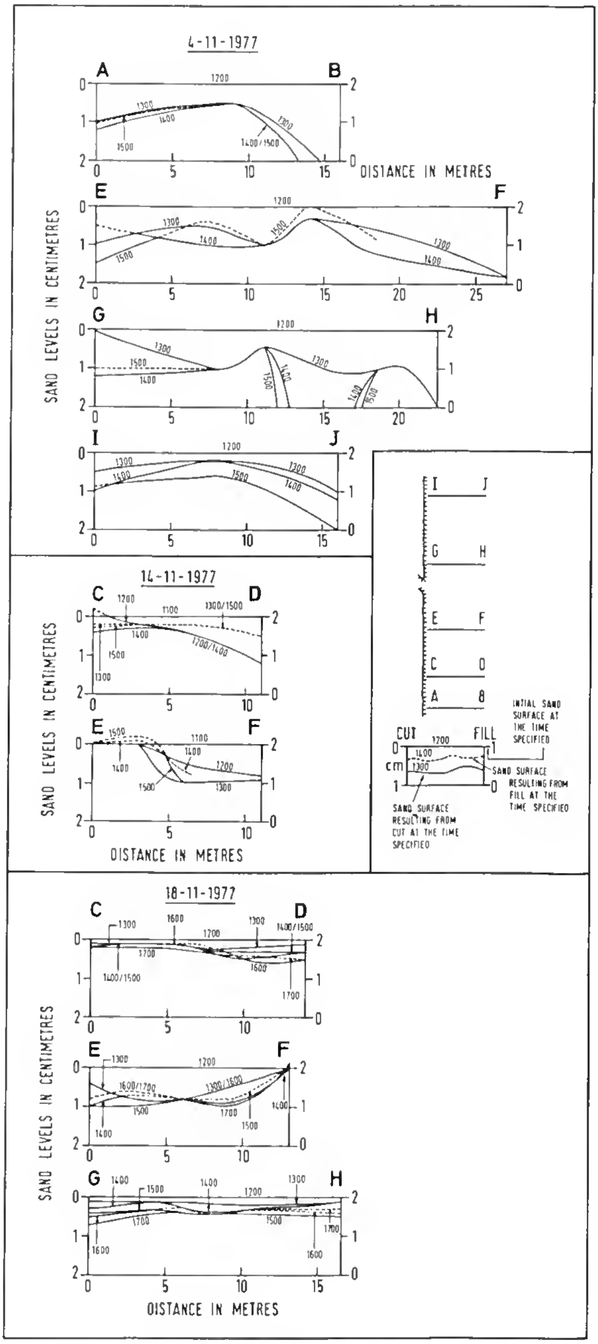


Fig. 4—Hourly sand-level changes on Portsea Beach on 4, 14 and 18 November, 1977.

TABLE 1
WIND AND RAIN CONDITIONS IN THE PERIOD OF SAND-MOVEMENT MONITORING

	Ground-level wind observations at site				Wind and rain observations at Point Lonsdale (9 km from site)					
					Wind				Rain (mm)	
	Date (1977)	Time	Direction	Speed (km/h)	0900		1500		0900	1500
					Direction	Speed (km/h)	Direction	Speed (km/h)		
With sand movement	Nov. 4	1200-1500	NW, ESE	13-30	WNW	72	N	44	Nil	0.60
	Nov. 11	1100-1330	SSW to SW	20-30	WSW	90	WSW	44	2.00	3.00
	Nov. 14	1100-1500	S to SW	22-30	SW	76	WSW	80	Nil	Nil
	Nov. 18	1200-1700	S to SSW	19-22	SSW	50	WSW	44	3.00	Nil
Without sand movement	Oct. 31	1245-1500	SSW to SW	12-19	WNW	11	SE	30	Nil	Nil
	Nov. 8	1000-1500	S, SE	5-14	ESE	12	W	14		
	Nov. 15	1000-1500	S to SW	15-19	SW	46	WNW	32		
	Nov. 17	1000-1500	SE to S	6-13	SE	30	E	16		
	Nov. 22	1200-1400	W to SW	6-9	S	12	WNW	20		
	Nov. 25	1000-1500	ESE to SE	7-11	E	36	ENE	34		

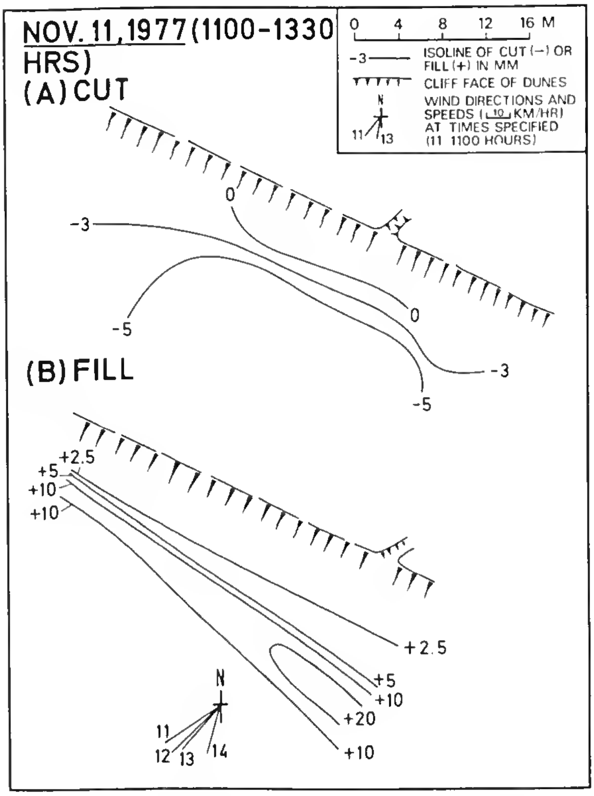


Fig. 5—Isolines of cut and fill of Portsea Beach on 11 November 1977.

SAND-LAYER LEVELLING

Such intra-compartmental and inter-compartmental transfers of sand reflect deflation by wind action. This is tantamount to a process of sand-layer levelling in which removal of dry foreshore sand by wind, halted by the increasingly moist sand at depth, renews activity once the sand exposed at that level becomes sufficiently dry to be entrained. Alternate drying of sand and activation of sand movement by wind, preferably over a wide foreshore by spanning the latter part of an ebb tide and the first part of its succeeding flood, are held responsible for some loss of foreshore sand. Despite atmospheric drying of the upper foreshore for a relatively long period, the lower foreshore on the upwind side of an onshore wind witnesses maximum sand loss. This may be made good during the next flood tide or sustained during the following ebb. Thus, mainly by saltation and surface creep, sand moves inland and onto the coastal hinterland. Unless return of sand is effected by reversals of wind directions, the resultant sand deposition, often by accretion and to some extent by encroachment, is such that to the lower foreshore sand, the upper foreshore, the backshore and to some extent the coastal hinterland act as interceptors, receptors and sinks.

A wind simulation experiment carried out on samples of foreshore and blowout sand in the laboratory reveals a threshold in the percentage of sand moved when wind speed increases from 15 km/h to 19 km/h with the blowing time kept constant at eight minutes (Table 2). Further increase in wind speed with substantial reduction in blowing time increases the percentage of moving sand.

TABLE 2
RESULTS OF LABORATORY SIMULATION OF WIND ACTION ON SAND

Simulated wind action		% of simulated moving fraction	
Wind speed (km/h)	Exposure time	Foreshore sand	Blowout sand
15	8 min.	2.88	2.59
19	8 min.	44.30	64.48
22	30 sec.	52.28	52.00
26	10 sec.	71.59	65.98
30	5 sec.	79.06	75.13

DISCUSSION

Wind-induced movements of beach sand at Portsea have to be viewed in perspective if their impact on the spatial distribution and redistribution of sand and on the long-term sand budget of the beach is to be appraised. The primary movement, intra-compartmental transfer, is influenced by numerous local factors. Lenses of moistened or compressed grains resist wind action. The size of sand particles determines the ease with which the grains can be entrained. Shell or pebble layers present impose frictional effect on creep and inhibit sand movement where they survive instabilities and turbulence they help to create in the wind. Subsurface irregularities exhumed in the course of sand movement provide local base levels for deflation. The same is true of water tables of the beach although Portsea is relatively free from the impact of a raised water table associated with excessive seepage or inability of streams to maintain open channels to the sea. Periodic splash and spray accompanying plunging breakers or strong onshore winds, and obstacles, hollows or wet surfaces created by man on the foreshore, curtail sand migration.

While ridges and swales temporarily halt sand movement or channel it into pathways through windward scour and leeside accumulation giving patterns of cut and fill not readily explained in simple spatial terms, sand transfer from the lower to the upper foreshore is largely independent of beach gradient, profile or curvature. The extent of intra-compartmental transfer of sand is determined by the net catchment made available by an expanding or contracting foreshore associated with ebb or flood. It also varies with the nature and direction of winds. Locally, conditions range between increase in catchment associated with offshore, relatively dry northerlies in an ebb tide and decrease in catchment associated with onshore, relatively moist southerlies in a flood tide. In the former case, transfer of sand from the upper to the lower foreshore covers a catchment encompassing the backshore. The resultant inter-compartmental transfer not only returns sand from backshore receptors to the foreshore compartment, but also causes much sand to be lost to the offshore zone, especially with a spring ebb tide. In the latter case, transfer of sand from the lower to the upper foreshore by onshore, moist wind lags behind, especially with a contracted catchment associated with a flood tide. Between these extremes occur many catchments of intervening sizes representing different combinations of wind directions besides north and south, varied moisture content of the wind, and tidal states other than spring tides.

In such circumstances, sand movement operates along a number of pathways. With onshore wind of adequate strength in an ebb tide and dry conditions, deflation brings about surface erosion of the beach but may be held up by a subsurface shell or pebble layer (Fig. 6). Whether beach erosion undergoes or by-passes this negative feedback loop, it reduces the amount of beach material on the foreshore and the beach gradient. This permits deposition in the following flood tide should material be made available for deposition, helping to replenish the beach materials previously lost. Surface erosion of the beach through deflation, bringing about intra-compartmental transfer of sand in the foreshore subsystem, provides a link to the backshore subsystem through its supply of sand from an enlarging catchment to the backshore, thus initiating inter-compartmental transfer of sand (Fig. 6). Increasing the sand cover of backshore dunes thickens the loose sand mantle which in turn encourages sand removal by an onshore wind. Where a sizable transgressive sand sheet under a strong onshore wind makes available to the backshore sand in quantities too large to be trapped and fixed by the limited vegetation present, conditions are especially conducive to spilling of sand inland. Removal of sand by an onshore wind thus deprives the dune cover of a sand supply and impoverishes sand deposition on the backshore, imposing on the backshore in the long run a limit to sustained deposition (Fig. 6). Sand lost by the backshore, under unidirectional transport characteristic of wind action, is then either stored up temporarily in a catchment of the coastal hinterland or permanently lost to a sink.

The development of events as shown in Fig. 6 depicts the tendency for intra-compartmental transfer of sand, and backshore deposition arising from inter-

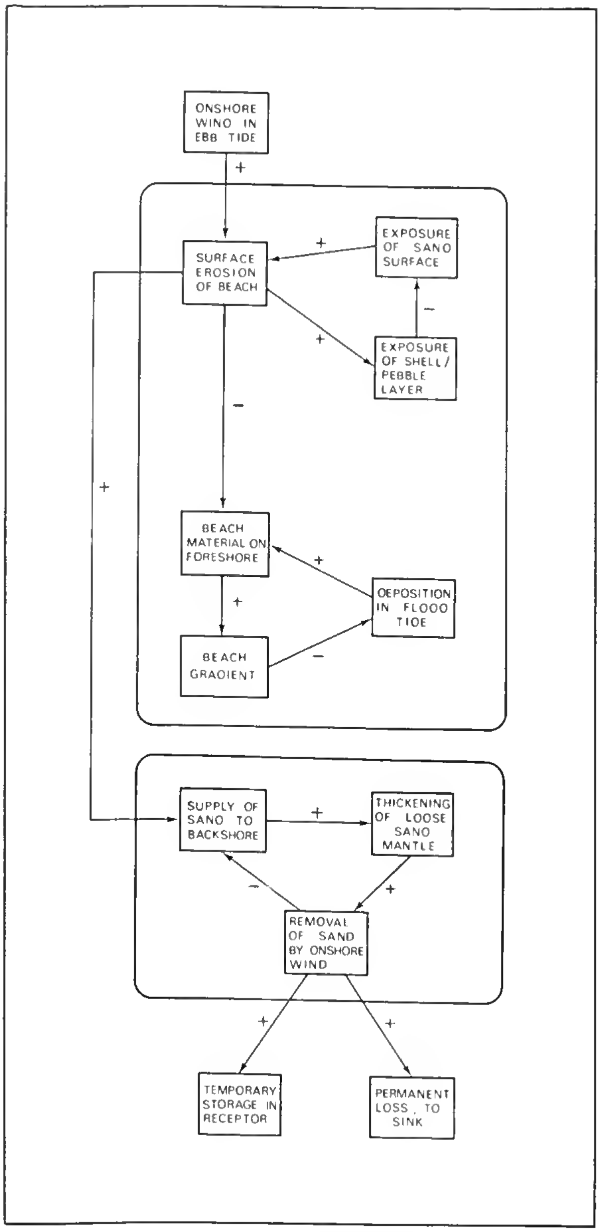


Fig. 6—Model showing the effect of onshore winds on the foreshore and the backshore in an ebb tide.

compartmental transfer of sand, to be self-arrested to some extent should conditions required for the feedback mechanism to work be made available so that the foreshore's loss is not always the backshore's gain. This confines the function of the backshore to that of a transport surface serving the coastal hinterland. The model presents the operation of processes associated with an onshore wind during an ebb tide. A flood tide imposes on the functioning of this system a contracted foreshore relative to the backshore, cutting down the catchment for sand supply and eventually reducing inter-compartmental transfer.

A change in wind direction gives the situation a face-lift. Combination of an offshore wind with an ebb tide turns the backshore, now on the upwind side, into a catchment and feeder of sand. Substantial movement of sand on the backshore, unless self-arrested to an appreciable extent through exposure of the indurated dune surface, sustains inter-compartmental transfer of sand to an expanding foreshore and receptor provided by a retreating tide, and the backshore's loss is the foreshore's gain except where the moving sand ends up in the sea. It takes the next flood tide to turn the bulk of this receptor into a sink, to cut short transfer of sand from the backshore by diminishing the foreshore, and to cause much sand gained through inter-compartmental transfer from the backshore to be moved to the offshore zone, imparting to the foreshore the mere role of a transport surface.

Broadly along these lines of action, the beach at Portsea, dominated by onshore southerlies in summer and offshore northerlies in winter, experiences differential transfer of sand in and across its compartments with every fluctuation of wind components and variation of the tide. Alternations of onshore and offshore winds over a relatively large time span are superimposed on the more regular cycles of ebb and flood of the tide occupying relatively small intervals on the time scale. Response of the beach to such external adjustment of changing process parameters is likely to find expression in a range of changes between two poles. On one hand, intra-compartmental and inter-compartmental transfers of sand, operating in association with onshore southerlies and under conditional self-regulation, make themselves felt, on a gradually diminishing scale with a change from ebb to flood tides, in the provision of fill to the backshore at the expense of cut on the foreshore. On the other hand, in another changing phase from ebb to flood, intra-compartmental transfer of sand imposing a cut on the backshore, and inter-compartmental transfer effecting a fill to the foreshore in association with the offshore northerlies hold sway. Whatever combination of process parameters prevails in association with one of these situations, the general tendency is for much moving sand entrained by wind to end up in sinks outside the foreshore subsystem and to some extent the backshore subsystem. This constitutes a permanent loss unless and until such intra-compartmental and intercompartmental transfers of the beach sand are made good. Feedbacks induced by wind action from the coastal hinterland dominated by dunes, and their counterparts induced by wave action from the offshore zone dominated by swell, may contribute towards this. Where the recovery process is not complete, the net loss of beach sand, although it is relatively diminished in amount, is cumulative. It is likely to play a significant role in the spatial distribution and redistribution of sand on the beach in general, and in the long-term sand budget of the beach in particular.

CONCLUSION

This study reveals that given the optimal wind strength and a combination of favourable circumstances, marked changes of beach levels result from wind-induced intra-compartmental and inter-compartmental transfers of sand in a shore system. Such mobility of beach levels recorded over short-term observations points to the 'catastrophic' loss of sand within short periods. Part of the significance of this lies in its bearing on how far the magnitude of a process may over-ride its frequency as so far indications are such that any interpretation of the role of aeolian agents in a beach environment solely on the principle of uniformitarianism may be taken too far. In the functioning of a process-response system, the periodic encroachment of drifting sand on the backshore, or on the offshore zone as the case may be, reinforces the assertion that the catastrophic loss of sand is spasmodic in action but cumulative in effect, and that there is the tendency for it to play such a significant role in the spatial distribution and redistribution of sand in a beach environment as not to be readily ignored.

ACKNOWLEDGEMENTS

I thank Dr E. C. F. Bird of the Department of Geography, University of Melbourne, for advice and help with the research. I am grateful to the Regional Director (Victoria) of the Bureau of Meteorology for permission to have access to meteorological records for reference. The research was carried out with the award of a Leverhulme Fellowship to the author.

REFERENCES

Bagnold, R. A., 1954. *The physics of blown sand and desert dunes.* Methuen, London.

Belly, P., 1964. *Sand movement by wind.* Tech. Memo. Coastal Eng. Res. Center U.S. No. 1.

Bird, E. C. F., 1972. Ancient soils at Diamond Bay, Victoria. *Vict. Nat.* 89: 349-353.

Bird, E. C. F., 1975. The shaping of the Nepean Peninsula, Victoria, Australia. *Vict. Nat.* 92: 132-141.

Bird, E. C. F., 1977. *Sites of special interest in the Victorian coastal region: a report on geological and geomorphological aspects.* Town and Country Planning Board, Melbourne.

Bowler, J. M., 1966. Geology and geomorphology—Port Phillip Bay. *Mem. Natn. Mus. Vict.* 27: 19-67.

Davies, J. L., 1972. *Geographical variations in coastal development.* Oliver and Boyd, Edinburgh.

Jennings, J. N., 1957. On the orientation of parabolic or U-dunes. *Geog. Journ.* 123: 474-480.

Keble, R. A., 1950. Mornington Peninsula. *Mem. Geol. Surv. Vict.* 17.

Kuenen, Ph. H., 1964. Pivotability studies of sand by a shape-sorter. 207-15. In *Deltaic and Shallow Marine Deposits*, L.M.J.U. van Straaten, ed., Elsevier, London.

Maher, J. V., & McRae, J. N., 1964: *Upper wind statistics, Australia. Surface to 55,000 feet.* Bureau of Meteorology, Melbourne.

Shepard, F. P., & Young, R., 1961. Distinguishing between beach and dune sands. *J. Sediment. Petrol.* 31: 196-214.

PROC. R. SOC. VICT. vol. 94, no. 2, 69-87, June 1982

WETLANDS OF VICTORIA III. WETLANDS AND WATERBIRDS BETWEEN PORT PHILLIP BAY AND MOUNT EMU CREEK

By A. H. Corrick

Fisheries and Wildlife Division, Arthur Rylah Institute for Environmental Research, 123 Brown Street, Heidelberg, Victoria 3084

Abstract: Wetlands in the Western District were categorized by water regime and salinity, and subcategories were based on vegetation. Waterbird distribution and numbers were recorded during ground inspection and by counts at 135 sites in March, July and October 1980.

In all 1437 wetlands totalling 72 500 ha were located. They were of 6 categories, 23 subcategories and in sewage and salt evaporation systems. Permanent saline wetland (37 200 ha) and permanent open freshwater (16 100 ha) were the most extensive categories and permanent open freshwater (397) and freshwater meadows (371) the most numerous. Since European settlement 34% of the original area of freshwater wetland has been lost; most reduced have been shallow and deep freshwater marshes, with 79% and 66% lost respectively. Little saline wetland has been lost. Three hundred and seventy four impoundments (3580 ha), 4 salt evaporation systems (2180 ha) and 11 sewage oxidation systems (1680 ha) have been created since settlement.

Eighty six of the 110 waterbird species recorded were seen during the study period. On most wetland subcategories 5 to 10 species comprised more than 90% of the waterbirds using that subcategory. Many of these most abundant species occurred on most wetland subcategories. Wetlands with shallow permanent water support the highest densities of non-breeding birds (8 to 24 birds/ha) and average the most species (4 to 7) per visit. Assessment was made of the most important species in the various categories and whether they were breeding there or not. Some comments are offered on duck distribution based on duck band returns. Factors influencing the distribution of birds are discussed and the lack of freshwater meadows and shallow freshwater marshes in reserves for conservation is highlighted.

Earlier reports in this series (Corrick & Norman 1980, Corrick 1981) document the number, area and types of wetlands lost as well as the extent and waterbird use of remaining wetlands in south-eastern Victoria; in this report I present similar information for wetlands in western Victoria.

Study Area

The boundaries of the study area (Fig. 1) are Mount Emu Creek in the west, the main divide of the western highlands in the north, the eastern watershed of the Werribee River in the east and the coastline of Port Phillip Bay and Bass Strait in the south. It is approximately 19 000 km² or 8% of the area of the state.

The population of the area is approximately 350 000 (1978 estimate from Cowie 1980). Of these 45% live in Geelong and nearby settlements on the Bellarine Peninsula, 21% live in Ballarat, 15% in Bacchus Marsh and outer suburban centres of Melton and Werribee and the remainder in the few large country towns (Colac 10 500 and Camperdown 3600), numerous smaller towns and on rural properties. During summer the population of all coastal towns is increased sharply by holiday makers.

Physical Divisions

The study area may be divided into western highlands, volcanic plains, coastal plains and Otway Ranges (Hills 1964, Cowie 1980).

The western highlands occupy the northern quarter of the area. Elevation in this division is about 400 m and relief generally low near Ballarat where areas of basalt have filled river valleys; both the ancient interfluves and eruption points extend above this general level. To the south of Ballarat the Yarrowee and Moorabool Rivers are well embedded and about Bacchus Marsh relief is more pronounced where the Werribee River and its tributaries have formed steep gorges. The Otway Ranges, which occupy the southern tenth of the area, have been created by upwarping and faulting during the Tertiary to form a broad dome which grades gradually northward to the surrounding plain but dips sharply to the coast along the southern side. Although dissection is mature the topography is rounded due to land slip. The drainage patterns mirror the basic structure with the Gellibrand and Barwon Rivers draining the northern flanks and many small streams draining the southern slopes directly to the sea. On the northern edge of the Otway Ranges the coastal plains form a narrow strip between the ranges and the volcanic plain. They extend eastward to include the Bellarine Peninsula and westward to Peterborough and Warrnambool on the coast and are a partially dissected sedimentary surface which is flat or undulating with a veneer of Quaternary dune limestones and sands in places.

The final physical division, the basalt plains, covers the remaining half of the study area. The plains have a slight southward slope and prominent eruption

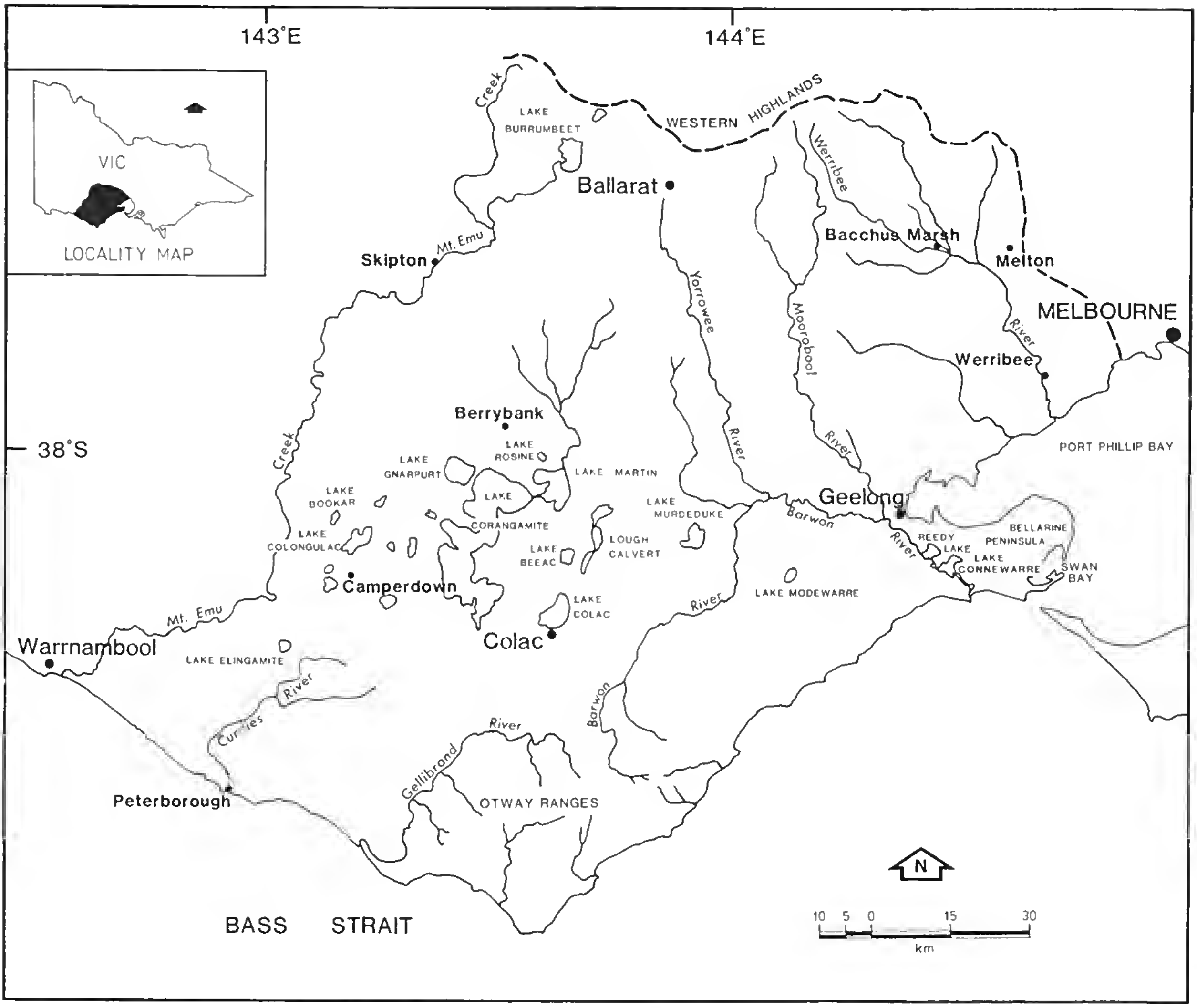


Fig. 1 – The study area.

cent flows south and east of Lake Corangamite and south of Skipton. Lakes and swamps occur in volcanic craters, in depresssions caused by lava collapse (both in stony rises and elsewhere) and where drainage patterns have been interrupted particularly along the edges of lava flows (Currey 1970). Lunettes, parna dunes and lacustrine deposits formed during the retreat of a much larger Lake Corangamite (Currey 1963) and by present lakes (Gill 1963) are common. Over much of the plains drainage is internal, either to lakes, swamps or to ground water and has been greatly modified by drainage works.

Climate

The region's climate as it affects this study including wetland maintenance is taken from Central Planning Authority (1956), Bureau of Meteorology (1959), Department of National Development (1966), Bureau of Meteorology (1968), Hounam & Powell (1964) and Cameron (1979).

Rainfall distribution is mainly influenced by orographic features, namely the western highlands and Otway Ranges where rainfall is increased; the latter cast a rain shadow over the lowlands to the west of Port Phillip Bay. Median (10 and 90 percentile) annual rainfall is 900 to 1800 mm (800 to 1800 mm and 1200 to 2400 mm) in the Otway Ranges, 700 to 900 mm (600 to 800 mm and 800 to 1200 mm) on the coastal plains, 700 to 1000 mm (400 to 600 mm and 800 to 1200 mm) in the western highlands, 500 to 700 mm (400 to 500 mm and 600 to 800 mm) throughout the western plains and is 400 to 500 mm (300 to 400 mm and 600 to 800 mm) in the rain shadow to the west of Port Phillip Bay. Annual variation in rainfall is amongst the lowest in Australia (Cameron 1979). January is the driest month throughout the area; falls in the wettest months on the eastern lowlands (September and October) and elsewhere (July, August and September) exceed January falls by 1 to 2 and 2 to 3 times respectively.

Temperatures range from January average maxima of 21 to 27°C (minima 10 to 16°C) to July average maxima of 5 to 10°C (minima 1 to 4°C inland and 4 to 10°C near the coast). Frost can be expected on fewer than 5 days per year close to the coast and on up to 15 days per year inland and on higher parts.

Evaporation decreases towards the sea and towards increasing altitude; it ranges from less than 150 mm per year in the Otway Ranges to just under 1000 mm per year on the plains where it is highest in January (110 to 150 mm) and lowest in July (25 to 40 mm). Evaporation exceeds rainfall from September until May and this is reflected in both the patterns of run-off which result in stream flows and in the occurrence of periods of non-effective rainfall (i.e. falls insufficient to start germination and maintain growth). Over most of the plains, where Berrybank (30 years of records) can be used as an example, non-effective falls have been recorded in most months in the six month period April to September; however, these events have not been consecutive. From the spring months onward periods of non-effective rainfall become both more frequent and protracted. In the six month period October to March, 2, 3 and 4 consecutive months of non-effective falls have occurred in 93%, 66% and 33% of years respectively. Close to the coast and in the ranges the frequency of non-effective falls during summer decreases e.g. at Beech Forest (51 years of records) 2 and 3 months of non-effective falls have occurred in only 15% and 2% of years respectively.

Hydrology

The Werribee (gauged mean annual discharge of 78×10^3 ML from a catchment of 1100 km^2), Moorabool (70×10^3 ML from 1100 km^2) and Yarrowee (92×10^3 ML from 870 km^2) Rivers and Mount Emu Creek (67×10^3 ML from 1240 km^2) rise in the western highlands and the Barwon (139×10^3 ML from 1040 km^2), Curdies (130×10^3 ML from 780 km^2) and Gellibrand (135×10^3 ML from 560 km^2) Rivers rise in the Otway Ranges. Smaller streams which drain the southern slopes of the Otways include the Aire (27×10^3 ML from 25 km^2) and the Carlisle Rivers (37×10^3 ML from 77 km^2) (Bibra & Riggs 1971).

Stream flows are highest in August or September and are lowest, often reaching zero, in January, February or March. Floods can occur throughout the year but are least frequent during summer. Flood frequencies and summer flows have been reduced in most rivers by the construction of dams and the subsequent diversion of irrigation and urban water.

On the plains countless minor drains have either eliminated or limited the extent of swamps and lakes. Major drains constructed in the 1950s control the levels of Lakes Colac and Corangamite, diverting excess water to the Barwon River and preventing a recurrence of the extensive expansion these lakes underwent following successive years of above average rainfall during the 1950s.

Seasonal variation (Bibra & Riggs 1971), type of basalt substrate (Maddocks 1967) and various catchment to surface area ratios and throughflows combine to produce lakes and swamps of a very wide range of salinities (e.g. Williams 1964, Bayly & Williams 1966). The geochemistry of waters in the region is discussed by Maddocks (1967) and detailed studies which include seasonal changes of individual basins have been made (e.g. Pollard 1971a, Timms & Brand 1973, Walker 1973, Geddes 1976, Timms 1976, Williams & Buckney 1976).

METHODS

Wetland Distribution

All wetlands and drained areas larger than 1.0 ha (excluding river flats inundated during floods) were located from aerial photographs (Division of National Mapping and Department of Crown Land and Survey, 1:85000 enlarged ×2, flown 1961 Ballarat and 1976 Melbourne map sheets and 1:33000 flown 1975-77 for the remainder), from topographic maps and during ground surveys between July 1978 and November 1980. Water source and regime were determined, plant communities identified and areas calculated by planimeter measurement from aerial photographs.

Wetland Classification

Water regime and salinity were used for definition of wetland categories while subcategories were based on vegetation important in determining waterbird usage. Wetlands were classified as fresh if salinity remains below 3000 parts per million (ppm) (Williams 1964) for the greater part of the period of inundation. Changes in depth and area (e.g. Lake Corangamite, Currey 1963, Parliamentary Public Works Committee 1965) resulting from long term trends in the amount of rainfall have been ignored and the areas calculated and categories assigned using conditions prevailing during this study.

Sewage oxidation basins have not been included in previous surveys (Corrick & Norman 1980, Corrick 1981); however, in the present study area, along with salt evaporation basins, their area is substantial. Individual basins in these systems are small (often < 1 ha) and collectively show a wide range of chemical compositions and limnological development and could be assigned individually to one of several wetland subcategories (e.g. salt evaporation basins range in salinity from sea water to saturation and thus cover subcategories 6.1, 6.5 and 7.1). The condition of the individual basins may also change at anytime with changes in management practices. Classification of individual basins was considered to be inappropriate; the systems were considered as single wetlands outside the category system (Tables 2 and 3) but their distribution and waterbird use have not been shown.

The diagnostic salinities, water regimes and vegetation of all wetland categories and subcategories found are summarized in Table 1. Subcategories not described by Corrick and Norman (1980) or Corrick (1981) are described below.

Red Gum-dominated (Subcategories 2.3 and 3.5)

Red Gum (*Eucalyptus camaldulensis* Dehnh.)

Table 1

Characteristic Depth, Duration of Inundation of the Wetland Categories and Typical Vegetation of Wetland Subcategories in the Study Area

Category	*Depth* (m)	*Duration of inundation*	*Subcategories*	*Typical vegetation*
FRESHWATER				
2, Meadows	<0.3	<4 months	.1 Herb-dominated	Annual moist soil species
			.3 Red Gum-dominated	*Eucalyptus camaldulensis*
			.4 Lignum-dominated	*Muehlenbeckia cunninghamii*
3, Shallow marshes	<0.5	<6 months	.1 Herb-dominated	Annual moist soil and aquatics
			.3 Cane Grass-dominated	*Eragrostis australasica*
			.4 Lignum-dominated	*M. cunninghamii*
			.5 Red Gum-dominated	*Eucalyptus camaldulensis*
4, Deep marshes	<2	12 months	.2 Reed-dominated	*Phragmites australis*, *Typha* sp. *Scirpus validus*
			.3 Sedge-dominated	*Lepidosperma longitudinale*
			.4 Rush-dominated	*Eleocharis sphacelata*
			.5 Open water	Submerged aquatics with moist soil annuals in the littoral zone.
			.6 Cane Grass-dominated	*Eragrostis australasica*
			.7 Lignum-dominated	*M. cunninghamii*
5, Permanent open water	>0	permanent	.1 Shallow (<3 m)	Submerged aquatic species, emergent species in the littoral zone.
			.2 Deep (>3 m)	Submerged aquatics[1]
			.3 Impoundment	Submerged aquatics with emergent species in the littoral zone[2]
SALTWATER				
6, Semipermanent	<2	<8 months	.1 Salt pan	*Lepilaena* spp. *Ruppia* sp[3].
			.2 Salt meadow	Halophytes with *Ruppia* sp. and *Lepilaena* spp. in shallows
			.3 Salt flats	Dense ground cover of halophytes
			.5 Hypersaline lakes	none
7, Permanent	>0	permanent	.1 Shallow (<3 m)	*Ruppia* spp. *Lepilaena* spp.
			.2 Deep (>3 m)	*Ruppia* spp. *Lepilaena* spp.
			.3 Intertidal flats	*Zostera* spp. various alga, none in places[4]

[1] Reduced by turbidity and depth. [2] Depends on grazing. [3] No vegetation when dry. [4] Sand flats are usually devoid of vegetation.

woodland up to 20 m tall occurs on both freshwater meadows and shallow freshwater marshes. Associated vegetation is similar to herb-dominated subcategories but Cane Grass (*Eragrostis australasica* (Steud.) Hubbard) and Lignum (*Muehlenbeckia cunninghamii* (Meissn.) Mueller) may also occur. Mature trees, both in wetlands and on higher ground, provide nest hollows for waterfowl; however, grazing and cultivation prevent regeneration so that mature trees are not being replaced.

Cane Grass-dominated (Subcategories 3.3 and 4.6)

Cane Grass has upright stems (<5 mm in diameter) up to 1.4 m high which range from scattered tussocks to continuous extensive stands in which the stems become progressively more tangled if flooding persists for several seasons. Grazing reduces stems to ground or water level and prevents regrowth until after flooding. In highly turbid water associated species may be absent.

Lignum-dominated (Subcategories 2.4, 3.4 and 4.7)

Lignum forms dense tangled bushes (up to 2.5 m high and 3 m in diameter) in water up to 1 m deep. Although the stems are woody, persistent grazing will eventually break these down and along with cultivation will remove bushes entirely. Both Red Gum and Cane Grass are often associated with Lignum which also occurs as scattered bushes above the shoreline of permanent open waters and persists in drained areas which have not been cultivated.

Hypersaline lakes (Subcategory 6.5)

In lakes of this category salinity only drops below 50 000 ppm in exceptionally wet seasons. The water usually reaches saturation each year as the water level recedes. Smaller basins may be 3 m deep but large areas are shallow (<0.4 m) so that summer drying occurs. Rooted aquatic plants may be present for the short period when salinity is low but growth is reduced as salinity rises. Zooplankton, particularly *Parartemia zietziana*, which will hatch in salinities to 202 000 ppm and survive almost to saturation (Geddes 1976), are abundant.

WATERBIRD DISTRIBUTION AND ABUNDANCE

When wetlands were visited throughout the study period waterbirds were either counted on the whole, or part, of each wetland; alternatively only the species present were recorded. Large wetlands were visited several times although usually only one complete count of waterbirds present was made on each. The counts, 780 in all, were used to indicate habitat preferences, provide

TABLE 2

NUMBER OF WETLANDS OF EACH CATEGORY AND NUMBER OF AREAS OF EACH WETLAND SUBCATEGORY IN EACH WETLAND SIZE RANGE

Category/subcategory	*Number of wetlands in the following size (ha) ranges*					*Total number*	
	1-5	6-10	11-25	26-100	>100	*Subcategory*	*Category*
2 Freshwater meadow							
.1 Herb-dominated	237	80	44	8	1	370	
.4 Lignum-dominated			1			1	
Number of wetlands	237	80	45	8	1		371
3 Shallow freshwater marsh							
.1 Herb-dominated	154	34	33	25	1	247	
.3 Cane Grass-dominated	1		3			4	
.4 Lignum-dominated	1		1	1		3	
.5 Red Gum-dominated			1			1	
Number of wetlands	156	34	37	26	1		254
4 Deep freshwater marsh							
.1 Shrub-dominated		1				1	
.2 Reed-dominated	1	1			2	4	
.3 Sedge-dominated	1	1	2	1	1	6	
.4 Rush-dominated	4	2		1	1	8	
.5 Open-water	47	2	14	13	5	81	
.6 Cane Grass-dominated			1	3	2	6	
.7 Lignum-dominated				1		1	
Number of wetlands	52	5	16	13	6		92
5 Permanent open freshwater							
.1 Shallow	2	2	1	8	9	22	
.2 Deep	1			1	2	4	
.3 Impoundment	318	25	13	8	10	374	
Number of wetlands	321	27	14	16	19		397
6 Semipermanent saline							
.1 Salt pan	101	41	36	32	10	220	
.2 Salt meadow	19	16	11	16	5	67	
.3 Salt flats	3	3	6	13	4	29	
.4 Hypersaline lake	1	2	6	3	3	15	
Number of wetlands	119	50	46	38	14		267
7 Permanent saline							
.1 Shallow	2	4	5	10	16	37	
.2 Deep		1			5	6	
.3 Intertidal flats			1	1	2	4	
Number of wetlands	2	4	6	11	18		41
Salt evaporation basin					4		4
Sewerage oxidation basin	6	3	1		1		11
Totals	893	203	165	112	64		1437

a species list (common names according to RAOU 1978) for each category and subcategory and enable both the frequency of occurrence of species to be compared and the regional significance of concentrations to be gauged.

During August, September and October 1978 and September 1979 records were kept of sightings of waterbirds not on wetlands included in the study. Observations aided by 10×50 binoculars were made from a vehicle over 1100 km of roads through open farmland between Geelong and Colac and near Ballarat. Approximately 0.3 km on each side of the road was covered except where hedges, trees and buildings obscured views.

So that seasonal changes in wetland area and waterbird use and populations could be monitored on a quantitative basis 135 wetlands (or parts of large wetlands) of known area between 38°00′ and 38°30′S and 143° to 144°E were selected and counts made in March, July and October 1980. Buoys, stakes and natural features were used to mark site boundaries and areas were calculated from aerial photographs, by triangulation and by rangefinder measurements. Observations were aided by 10×50 binoculars and 25×60 telescope. The area of water was estimated each month.

ANALYSIS OF WATERFOWL BANDING DATA

Ducks have been banded in Victoria since 1950, 81% at the Wildlife Research Station at Lara (38°01′S 144°25′E). The distribution of the returns of bands from ducks shot during open seasons between 1951 and 1980 has been plotted on a 10′ grid of the area and the number compared with recoveries from elsewhere in the state.

RESULTS

WETLAND DISTRIBUTION

During this study 1437 wetlands (Table 2) totalling 72 500 ha (Table 3) were located, including 1680 ha of sewage oxidation and 2180 ha of salt evaporation systems (which were not categorized). Impoundments

TABLE 3

AREA OF WETLAND CATEGORIES AND SUBCATEGORIES IN WETLANDS OF VARIOUS SIZE RANGES

Category/subcategory	*Area (ha) of wetlands in the following size (ha) ranges*					*Total area*	
	1-5	6-10	11-25	26-100	>100	*Subcategory*	*Category*
2 Freshwater meadow							2410
.1 Herb-dominated	630	620	700	323	123	2400	
.2 Lignum-dominated			16			16	
3 Shallow freshwater marsh							2540
.1 Herb-dominated	368	261	557	1060	190	2440	
.3 Cane Grass-dominated	5		30			35	
.4 Lignum-dominated	3		20	26		49	
.5 Red Gum-dominated			16			16	
4 Deep freshwater marsh							2320
.1 Shrub-dominated		9				9	
.2 Reed-dominated	1	2			365	368	
.3 Sedge-dominated	3	7	30	43	69	152	
.4 Rush-dominated	11	12		30	66	119	
.5 Open-water	75	15	213	580	540	1420	
.6 Cane Grass-dominated			8	36	148	192	
.7 Lignum-dominated				53		53	
5 Permanent open freshwater							16100
.1 Shallow	9	16	19	376	11400	11800	
.2 Deep	4			30	680	710	
.3 Impoundment	580	187	212	416	2180	3580	
6 Semipermanent saline							8080
.1 Salt pan	239	261	460	1260	1540	3760	
.2 Salt meadow	43	111	86	279	385	904	
.3 Salt flats	7	12	82	500	1220	1820	
.5 Hypersaline lake	3	15	98	117	1360	1590	
7 Permanent saline							37200
.1 Shallow	3	23	85	660	14400	15200	
.2 Deep		5			20900	20900	
.3 Intertidal flats			15	57	1020	1090	
Salt evaporation basin					2180		2180
Sewerage oxidation basin	18	27	19		1620		1680
Total	2000	1580	2670	5850	60400		72500

TABLE 4

NUMBERS AND AREA (ha) OF WETLANDS DESTROYED BY DRAINAGE WORKS AND THE AREA LOST AND THE AREA OF OTHER WETLAND CATEGORIES CREATED BY PARTIAL DRAINAGE

	Destroyed	*Reduced or altered to:*							*Total*	*net*
Category	*Area* (No)	*area lost*	*FM*	*SFM*	*DFM*	*POFW*	*SPS*	*PS*	*affected*	*lost**
Freshwater meadow	1660 (162)	67	31 (6)						1760	390
Shallow freshwater marsh	5090 (228)	3860	1020 (137)	133 (16)		4 (1)			10110	9340
Deep freshwater marsh	2280 (16)	1690	166 (9)	408 (13)	16 (1)		4 (1)		4560	4540
Permanent open freshwater	590 (2)	1100		36 (2)	13 (1)		670 (7)		2410	2410
Semipermanent saline	53 (5)	278					1100 (10)		1430	−1390
Permanent saline	0	940	153 (1)				1050 (4)	560 (1)	2890	2330
Total area (number)	9670 (413)	7940	1370 (153)	767 (31)	29 (2)	4 (1)	2820 (22)	560 (1)	23160	17610

*total affected less area of category formed by partial drainage of other categories.

(374) and herb-dominated freshwater meadows (370) are the most numerous subcategories but are on average small in area (9.6 ha and 6.5 ha respectively). Other subcategories which are numerous include herb-dominated shallow freshwater marshes (247 average 9.9 ha) and salt pans (220 average 17.1 ha). These four subcategories account for 85% of the wetlands in the region studied but only 18% of the area of wetland in it. Permanent saline wetland (37 200 ha) and shallow and deep permanent open freshwater (12 500 ha), account for 54% and 24% of the area and 3% and 2% of the number of wetlands respectively. In all categories except permanent saline the number of wetlands in the various size ranges decreases with increasing size. For freshwater meadows and shallow freshwater marshes the largest area is in the 11-25 and 26-100 ha size classes; for all other categories the >100 ha class contains the greatest area even though it contains the fewest wetlands. Overall, 62% of wetlands and 3% of the area is in wetlands 1-5 ha in area while 4% of wetlands and 82% of the area is contained in wetlands >100 ha in area.

Six wetland subcategories each occur at 4 or fewer sites and total less than 100 ha. A further 3 subcategories occur at 4 or fewer sites but their area is greater than 100 ha. These nine subcategories, together with sedge and Cane-Grass-dominated deep freshwater marshes and hypersaline lakes are restricted to 5 or fewer 10′ grids (Fig. 2). Natural freshwater wetlands (52% of the total wetland area) are found throughout the lowlands and are absent from the ranges; saline wetlands are found on the basalt plains and along the coast. The most widespread subcategories are also the most numerous (i.e. freshwater meadows, shallow freshwater marshes and impoundments).

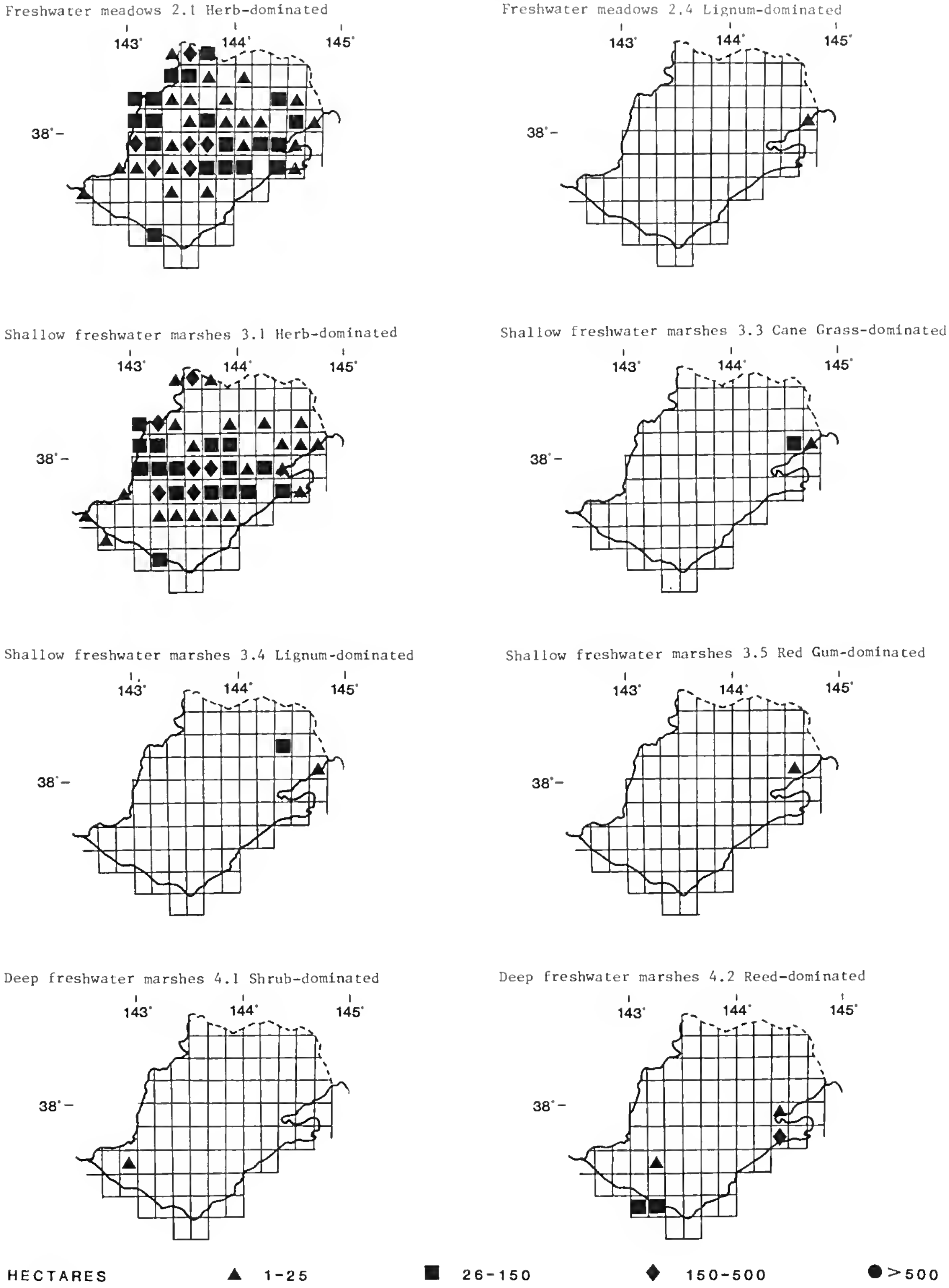
Drainage works of various forms have destroyed or altered 623 wetlands which covered 23 160 ha (Table 4); of these 413 (9670 ha) have been lost completely with freshwater meadows 162 (1660 ha), shallow freshwater marshes 228 (5090 ha) and deep freshwater marshes 16 (2280 ha) having decreased most. The net result, allowing for the area of some categories created by partial drainage of others, is that 390 ha of freshwater meadow, 9340 ha of shallow freshwater marsh, 4540 ha of deep freshwater marsh and 2410 ha of permanent open freshwater have been lost. Only the area of semipermanent saline wetland has increased since settlement (by 1390 ha). These changes, when compared to the area present before European settlement, represent a loss of 14% of the area of freshwater meadow, 79% of shallow freshwater marsh, 66% of deep freshwater marsh, 16% of permanent open freshwater, 6% of permanent saline wetland and an increase in the area of semipermanent saline wetland of 17%.

SEASONAL CHANGES IN WETLAND AREA

Changes in area of the count sites visited in March, July and October 1980 (Table 5) show that subcategories with permanent water show little seasonal change in area while salt and freshwater meadows, shallow freshwater marshes and salt pans will dry during summer and fill during winter. Drying rate depends on rainfall, temperature, catchment area, bottom type and contour. Wetland categories and subcategories not included in the count sites, particularly various subcategories of deep freshwater marshes, would show similar variation to open water areas of this category. In impoundments the seasonal fluctuations are increased by diversions of water and tidal flats vary in extent according to the lunar cycle.

WATERBIRD DISTRIBUTION AND ABUNDANCE

During the study 86 species of waterbird were recorded (Table 6, Appendices 1 & 2) and a further 24 have been recorded by other authors. The five most abundant species on each of the wetland subcategories (28 species in all) surveyed during counts in March, July and October 1980 are listed in Table 6. Wetland subcategories used by less abundant but regularly seen



Freshwater meadows 2.1 Herb-dominated

Freshwater meadows 2.4 Lignum-dominated

Shallow freshwater marshes 3.1 Herb-dominated

Shallow freshwater marshes 3.3 Cane Grass-dominated

Shallow freshwater marshes 3.4 Lignum-dominated

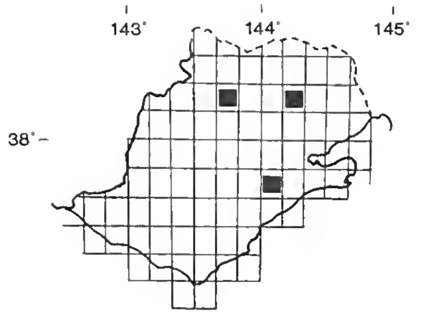
Shallow freshwater marshes 3.5 Red Gum-dominated

Deep freshwater marshes 4.1 Shrub-dominated

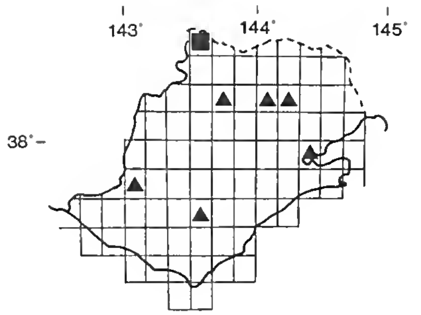
Deep freshwater marshes 4.2 Reed-dominated

Fig. 2—The distribution (plotted on a 10′ grid) of the area (ha) of each wetland subcategory of the study area.

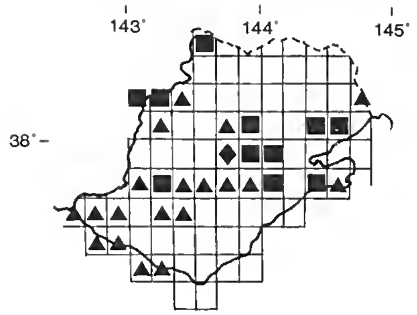
Deep freshwater marshes 4.3 Sedge-dominated



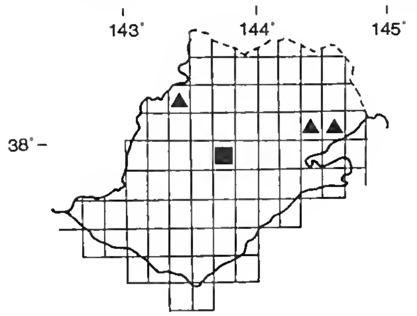
Deep freshwater marshes 4.4 Rush-dominated



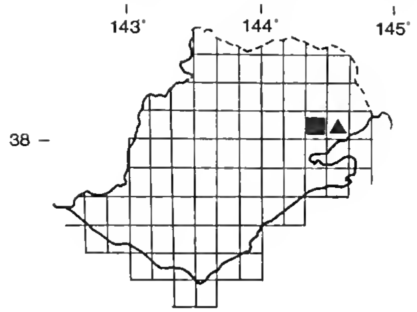
Deep freshwater marshes 4.5 Open water



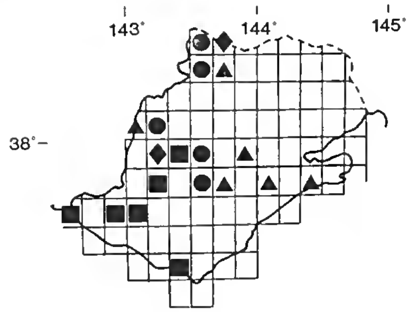
Deep freshwater marshes 4.6 Cane Grass-dominated



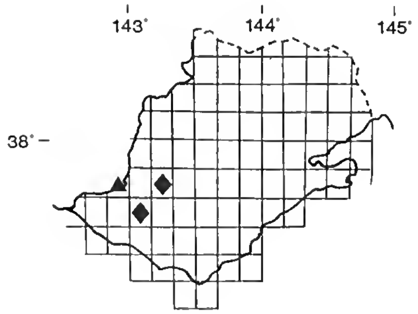
Deep freshwater marshes 4.7 Lignum-dominated



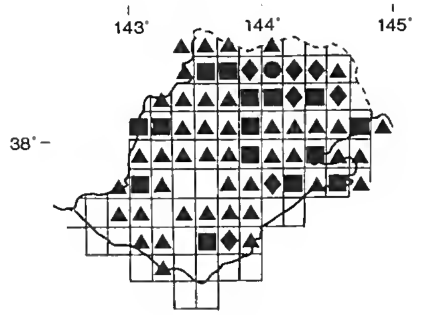
Permanent open freshwater 5.1 Shallow



Permanent open freshwater 5.2 Deep

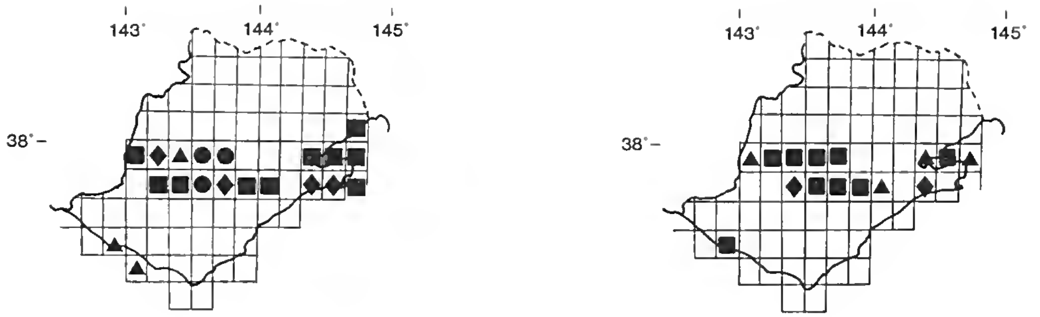


Permanent open freshwater 5.3 Impoundments

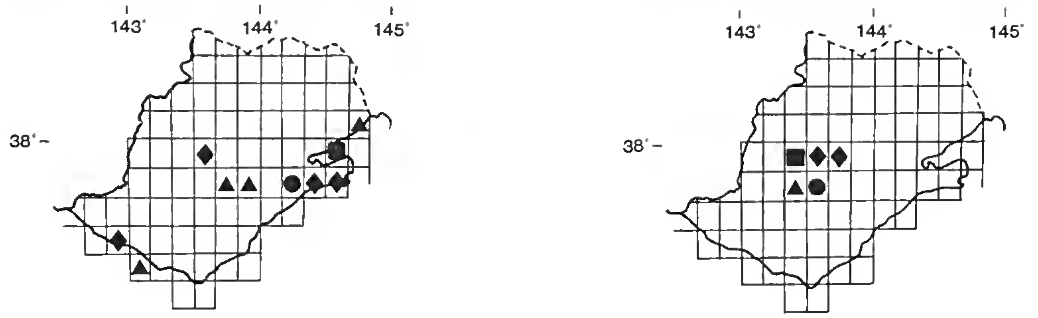


HECTARES ▲ 1-25 ■ 26-150 ◆ 150-500 ● >500

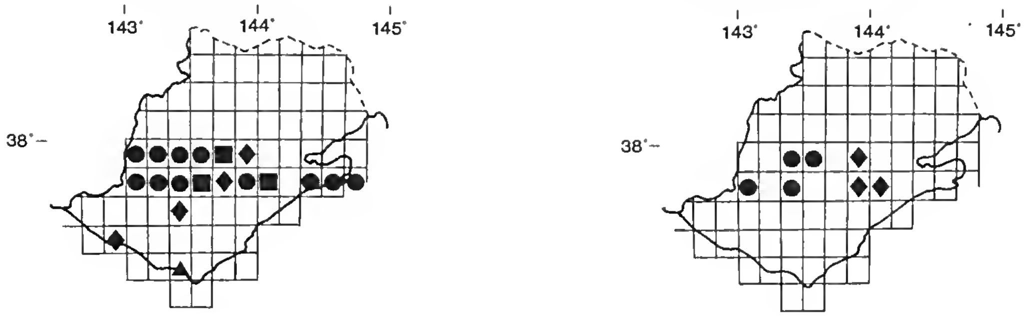
Fig. 2(*continued*)


Semipermanent saline wetlands 6.1 Salt pans

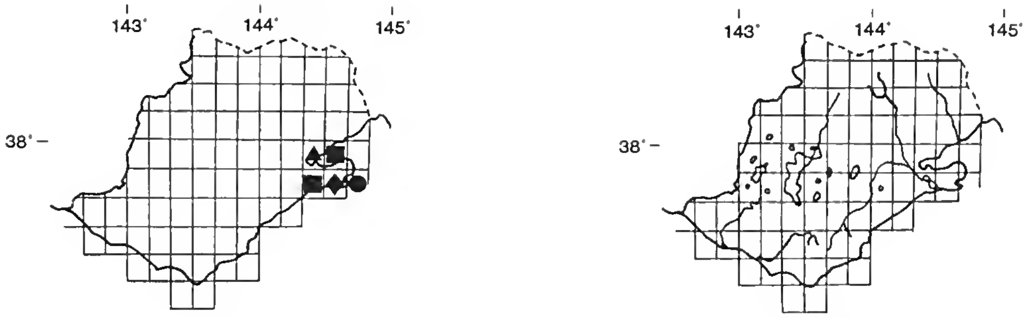
Semipermanent saline wetlands 6.2 Salt meadows


Semipermanent saline wetlands 6.3 Salt flats

Semipermanent saline wetlands 6.5 Hypersaline lakes


Permanent saline wetlands 7.1 Shallow

Permanent saline wetlands 7.2 Deep


Permanent saline wetlands 7.3 Intertidal flats

HECTARES ▲ 1-25 ■ 26-150 ◆ 150-500 ● >500

Fig. 2(*continued*)

species are presented in Appendix 1 and Appendix 2 lists the remaining rare species, which either occur regularly in very low numbers, are misplaced nomadic or migratory species (e.g. various sandpipers, Garganey Teal) or are more common on other habitats of the region (e.g. Hooded Plover—ocean beaches, Black-faced Shag—offshore waters).

The 780 counts made of waterbirds during ground surveys have been used to indicate subcategories utilized by species listed in Appendix 1. The more abundant species (Hoary-headed Grebe, Black Swan, Masked Lapwing, Australian Shelduck, Silver Gull, Table 6) were also the most frequently recorded occurring on a wide variety of wetlands. The counts also indicate species with particular habitat preferences, thus more than 50% of the records of some species came from a single wetland category, e.g. Latham's Snipe—freshwater meadow; Brolga—shallow freshwater marsh; Marsh Harrier, Dusky Moorhen and Purple Swamphen—deep freshwater marsh; Banded Stilt—hypersaline lakes and Great Crested Grebe, Pelican, Pied Cormorant, Great Egret, Chestnut Teal, Blue-billed Duck and Freckled Duck—permanent saline wetlands.

Data from counts conducted in March, July and October 1980 (Table 6) show the distribution of species and numbers amongst the subcategories studied. Hoary-headed Grebe, Black Swan, Shelduck, Grey Teal, Coot, Masked Lapwing and Silver Gull are abundant on most categories while other species, e.g. Great Crested Grebe, Blue-billed Duck, Dusky Moorhen and Purple Swamphen, are restricted to only a few; shorebirds are obviously absent from deep permenant open freshwater and cormorants from hypersaline lakes. Count sites on wetlands with shallow permanent water have the highest density of birds (means of 8-24 birds/ha) and the most species (means 4-7 species/visit) while sites on seasonal wetlands have lower population densities (means from 1.5-13.2 birds/ha) and fewer species (1.5-4 species/visit). On all subcategories the 5 most abundant species accounted for more than 70% of all birds/ha and in many cases for more than 95% of this total. Observations suggest that intertidal flats, sewage oxidation and salt evaporation systems, a subcategory and habitats not included in the 3 counts during 1980, also carry comparatively high densities of birds. The results of detailed surveys of these habitats are provided by Tarr (1952), Morgan (1954), Watson (1955), Wheeler, W. R. (1955), Barkla (1978) and personal communication from members of the Australasian Wader Studies Group in 1981.

The numerical distribution of all species across the wetlands of the area cannot be considered in detail here; however, it is clear that the shallow lakes (salinities <50 ppt), which comprise a large proportion of the total wetlands area (Table 3) support a large proportion of the populations of some non-breeding waterbirds. The seasonal and annual changes which occur in these lakes can provide conditions particularly favourable to a species and large concentrations which are not necessarily annual events can occur. Wetlands at which regionally significant concentrations of non-breeding birds were recorded include:

Lake Corangamite (southern half)—7500 Coot, 1400 Great Crested Grebe, 8200 Black Swan, 100 Chestnut Teal on 30 November 1979.

Lake Corangamite (northern half)—14 000 Hoary-headed Grebe, 1900 Musk Duck on 10 April 1979 and 650 Freckled Duck on 26 August 1980 (Corrick 1980).

Lake Rosine—6000 Pink-eared Duck, 3000 Blue-billed Duck 25 July 1979.

Lake Murdeduke—19 000 Coot on 9 April 1979.

Lake Gnarpurt—900 Musk Duck 31 April 1979.

Lake Beeac—11 000 Banded Stilt 23 February 1979, 1000 Whiskered Tern on 17 October 1979.

Lake Bookar—7000 Hoary-headed Grebe on 26 June 1979.

An unnamed shallow freshwater marsh at 38°08'S 143°45'E—300 Avocet on 18 November 1979.

Seasonal changes apparent in Table 6 may be due to changes in the area of available habitat (see Table 5), or to arrival and departure of migratory species (e.g. Sharp-tailed Sandpiper and Whiskered Tern). Nomadic species (Pink-eared Duck, Hardhead, Grey Teal and Black Swan) may also show numerical changes related to climate and wetland conditions outside the study area, which are not regular seasonal events, and finally the effect of the duck shooting season may also modify populations. The long term variability of numbers of a nomadic species, Grey Teal, is shown by Figure 3 (see also Morgan 1954). The population is generally low from July to December inclusive and high with greater variation from year to year for the remainder of the year.

During roadside counts of waterbirds (not on wetlands included in the study), 494 sightings of 31 species were made, 222 sightings of 25 species were on farm dams and ponds <1.0 ha in area. In all 953 dams were checked and of these 158 (17%) had waterbirds on or close by; Masked Lapwing (on 44 dams), Pacific Heron (on 30), White-faced Heron (on 27), Hoary-headed Grebe (on 26) and Black Duck (on 22) were seen most frequently. Of the 158 dams with waterbirds 73% had only one species present, 18% had two, 5% three, 3% four and 1% five species. Away from dams the most frequently seen species were White-faced Heron (73 sightings), Masked Lapwing (41), Straw-necked Ibis and Pacific Heron (36), Silver Gull (35) and Australian Shelduck (22). Of the common species on dams only two, Black Duck and Hoary-headed Grebe, were not seen more frequently away from dams.

The habitats used by breeding waterbirds are often entirely different and often distant from the non-breeding records given previously. Time did not permit detailed searches of each category of wetland for nests so except for colonial nesting species relatively few breeding records were obtained. However, the dependence of some species on particular conditions or vegetation for successful breeding are apparent. Some species breed throughout the area, e.g. White-faced Heron which next in trees away from water, and Masked

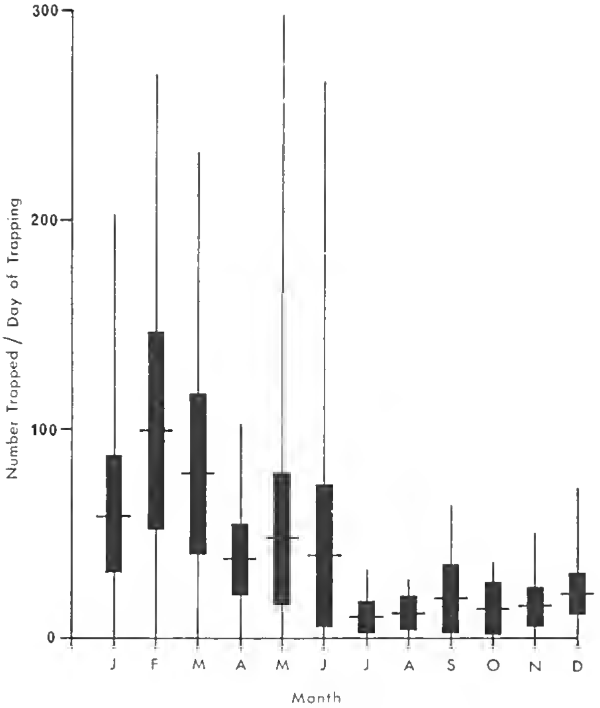


Fig. 3 – The range (vertical line), mean (horizontal line) and 95% confidence limits of the number of Grey Teal caught per day of trapping each month between 1951 and 1977 at Serendip Wildlife Research Station 38°01′S and 144°25′E.

Plover which nest on the ground around wetlands and in pasture. Some species are restricted to either particular wetland categories (e.g. Brolga to freshwater meadows and shallow freshwater marshes, Black-winged Stilt to freshwater and saltwater meadows, Blue-billed Duck to deep freshwater marshes (Wheeler, J. R. 1953) and Bittern to deep freshwater marshes); or utilize non-wetland habitats (e.g. Shelduck use tree hollows, Black Duck use long grass and dense vegetation and Pied Oystercatcher and Red-Capped Plover use beaches and adjacent dunes). Finally several species nest colonially (e.g. Straw-necked and Sacred Ibis use extensive reed beds in Reedy Lake near Geelong; these species of ibis with Pelican, Glossy Ibis, Black Swan, Pied and Great Cormorant, Silver Gull and Gull-billed Tern use islands in wetlands; Pied Cormorant use trees on an island in Swan Bay and on the Melbourne Sewage Farm at Werribee and Fairy Terns use large areas of exposed sand above high tide line). The continued success of these colonies is dependent on the continued seclusion of the sites both from predators and disturbance by man and the maintenance of appropriate nesting substrates.

Analysis of Waterfowl Banding Data

Bands have been returned from all but one (in the Otway Ranges) of the 10′ grid squares entirely within the area (Fig. 4) and all but seven partly in the area, 5 of which are mainly ocean, 1 outer suburban, and the last forested ranges along the northern boundary. Recoveries of all species are concentrated in squares about the main banding location at Serendip (Table 7), which include tidal flat, semipermanent saline wetlands, salt evaporation and sewage oxidation systems along the western shores of Port Phillip Bay and semipermanent and permanent saline wetlands and deep freshwater marshes at the mouth of the Barwon River and in the four 10′ grid squares which include Lakes Corangamite, Martin and Colac. A higher proportion of bands from Black Duck, than from other species, have come from 10′ squares without large wetlands, particularly in the northeastern part of the area. Grey Teal have come from more squares (73) and a higher proportion have come from the grid squares containing Lake Murdeduke and Modewarre than have returns of other species. Chestnut Teal have come from only 32 squares, more along the southern coast and few in the ranges, while most returns

TABLE 5

THE MEAN AND STANDARD ERROR (SE) OF THE AREA (EXPRESSED AS A % OF THE TOTAL POSSIBLE AREA) AND THE NUMBER OF SITES AT WHICH WATERBIRD COUNTS WERE MADE IN MARCH, JULY AND OCTOBER 1980

	March		*July*		*October*		
Category	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*number*
Freshwater meadow	0		44	8	63	8	27
Shallow freshwater marsh	0		58	11	69	10	19
Deep freshwater march	65	14	96	2	98	2	9
Permanent open freshwater							
Shallow	91	5	95	2	96	3	9
Deep	100	0	100	2	100	0	2
Semipermanent saline							
Salt pan	12	6	92	3	96	3	29
Salt meadow	0		71	12	71	12	9
Hypersaline lakes	43	16	99	6	100	0	8
Permanent saline wetland							
Shallow	72	7	86	5	97	2	24
Deep	0		100		100		

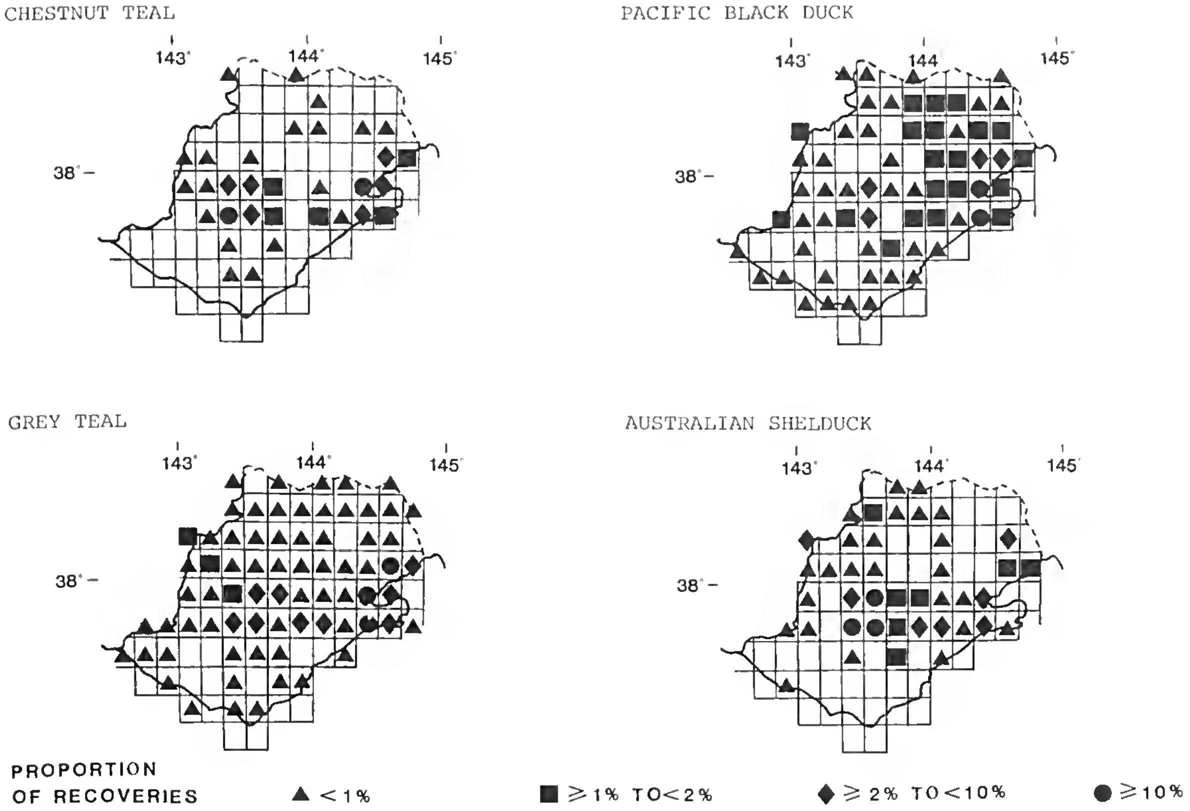


Fig. 4—The distribution of band recoveries from Australian Shelduck, Pacific Black Duck, Grey Teal and Chestnut Teal by shooting in 10′ grid squares covering the study area. Recoveries between 1951 and 1980 are included. The number recovered in each square is displayed as a proportion of the total number recovered from each species in the study area.

of Australian Shelduck, few of which were banded at Serendip, are from the western plains.

DISCUSSION

The total area of wetland including sewage oxidation and salt evaporation systems located in this study, is 72 500 ha, which compares with 72 200 ha and 75 900 ha located in similar surveys in Gippsland and South Gippsland (Corrick & Norman 1980, Corrick 1981); however, there are many more wetlands (1437 cf. 320 and 202) and the proportions of various categories are different. In South Gippsland, for example, 91% of the wetland area is intertidal flats while here only 1.6% is of that subcategory. Around the Gippsland Lakes shallow and deep permanent saline wetlands comprise respectively, 13% and 21% of the total while in this study they comprise 22% and 31%. The proportion of freshwater wetland is higher (35% of total cf. 33% and 3%) and the area of freshwater meadow and shallow freshwater marsh is some four times higher than in the previous studies.

As in the other areas studied there have been widespread changes in wetland area since European settlement. These changes include the large number of wetlands which have been drained, the 374 impoundments spread almost throughout the region and the extensive sewage (1680 ha) and salt evaporation (2180 ha) systems on Port Phillip Bay. In all 34% of the original area of freshwater wetland has been lost, 14% of freshwater meadow, 79% of shallow marshes, 66% of deep marshes and 16% of permanent open water. These changes in area include 37% of the number of wetlands. These losses are not as severe as those in South Gippsland where 95% of the area of freshwater wetlands has been lost but worse than around the Gippsland Lakes where 22% has been lost. As in other parts of the state little saline wetland has been lost.

The impact of these changes on waterbird populations is difficult to assess. Certainly the large number of impoundments and increased area of cleared land have benefited a few species (e.g. Hoary-headed Grebe, Ibis and White-faced Heron) enabling them to occur more widely. The large populations of migratory waders along the western shores of Port Phillip Bay are probably due to a combination of factors including the increased productivity of intertidal flats due to outfalls of treated sewage and the presence of adjacent sewage and salt works ponds which enable migratory waders to feed for longer periods each day than is possible on intertidal flats alone. Although the sewage ponds and impoundments are used by flocks of waterfowl it is unlikely that the populations of these species have benefited

TABLE 6

ABUNDANCE OF BIRDS ON WETLAND CATEGORIES INCLUDED IN COUNTS IN MARCH (M), JULY (J) AND OCTOBER(O) 1980. Birds are ranked in order of abundance (birds/ha) from 1 (highest) to 10 (lowest). The table includes the 5 most abundant species from each category in each month and indicates the rank (or its presence (+) at ranks over 10) on the other categories and in other months. The number of sites, the number of species and the total number of birds/ha is also given. The category and subcategories are listed in full in Table 1.

	Wetland category and subcategory																										
Species	2.1			3.1			4.5			5.1			5.2			6.1			6.2			6.5			7.1		
	M	J	O	M	J	O	M	J	O	M	J	O	M	J	O	M	J	O	M	J	O	M	J	O	M	J	O
Great Crested Grebe											+			2	1		+	+							+	+	7
Hoary-headed Grebe		9	+		+	7	3	2	3	3	2	2	1	1	2	+	7	3					4	3	2	3	4
Little Black Cormorant									8	10	10			4	4			+							8		+
Little Pied Cormorant										+	+			3			+								+	+	
White-faced Heron		3	10		9	3	9			+						5	+	+			+	5			+		
Straw-necked Ibis		+	1			6										7		+			+						
Yellow-billed S'bill											7					2	+										
Black Swan		1	2		7	4	4	7	4	2	+	5	2		6	6	3	1		1	5	6		1	10	7	3
Australian Shelduck		8	8		+	+	7			+			4	5			4	8		2		1	2	5	7		+
Pacific Black Duck		6			4		6	6		+	+		6				6										
Grey Teal			5		3		10	4	9	9	5	+				9	1	2			7				3	5	8
Australasian Shoveler			+		10	+		10	5	7	6	9						+			+				+	+	+
Pink-eared Duck										5		+				3		+							+	2	2
Hardhead			+			8		8	2	+	+	3						9							+		5
Blue-billed Duck										6	4	8					+								+	10	
Musk Duck							+			+	9			6	3										4	4	6
Dusky Moorhen							5	5	+																		
Purple Swamphen		+	+		1	2	2	3	6									+									
Eurasian Coot		+			6	+	1	1	1	1	1	1	3		5	+	2	+			6			6	1	1	1
Masked Lapwing		4	9		5	9	8	9	+		+					1	5	7		4	8	4	5		6	+	+
Red-capped Plover					8	+		+	+	+	+	+				+	8			3			6		+	+	+
Black-winged Stilt			4			5				+		+						10			4				+		
Red-necked Avocet								+		8						10	9	6			9		1		+		
Sharp-tailed Sandpiper			+			10		+	+	+		7						5			2				+	+	+
Red-necked Stint		7						+		+	+	6				8			2		3				+	6	9
Curlew Sandpiper		5						+										+			+						
Silver Gull		2	6		2	+			+	4	3	+	5				10	+	4	7	+	3	3	4	5	8	10
Whiskered Tern			3			1			10		+	4					+	4			1			2	+		+
Number of Sites	0	19	23	0	13	15	7	9	9	9	9	9	2	2	2	3	28	29	0	8	7	3	8	8	20	28	24
Total number of species	1	13	23	0	14	22	15	17	21	24	21	22	6	6	6	13	21	26	0	7	17	6	7	7	31	19	21
Mean total number/ha with 95% limits	M 0			0			11.9			22.6			0.62			2.9			0			0			9.5		
							2.9-49			7-65						0-4.8									5.3-17		
	J 4.8			1.5			13.9			14.2			0.5			0.9			3.8			0.65			7.6		
	1.6-12			0.5-3.1			4.7-40			4.5-41						0.4-1.7			1.2-9.5			0-2.5			4.6-12		
	O 4.7			3.2			12.7			21.2			0.74			3.5			13.2			1.1			11.4		
	2.4-8.7			1.5-6.1			1.1-34			7.3-58						2.1-5.6			3.7-42			0.02-3.3			6.7-19		

because these wetlands provide habitat similar to shallow and deep permanent open fresh and salt water wetlands and represent only 8% of the area of these categories already present in the study area. The large number of rare species recorded along the western shores of Port Phillip Bay reflect the very prolonged and intensive observations made in the area (Morgan 1954, Watson 1955, Smith 1962 to 1978, Barkla 1978) compared to the few studies in other parts (Binns 1953, Hirth 1976, Missen & Timms 1976), rather than some unique feature of the habitats present.

The detrimental effect of the loss of wetland on waterbird populations is more certain. Sites at which counts were made on freshwater meadows, and shallow and deep water marshes had up to 45, 21 and 117 birds/ha respectively during 1980. The 14 300 ha of these categories which have been lost would have supported substantial populations and similar habitats have not been provided by wetlands created since settlement. Species most affected would presumably be those restricted to freshwater (e.g. Latham's Snipe, Purple Swamphen, Crakes, Dusky Moorhen and Whiskered Tern) and particularly those which rely on such categories for breeding habitat (e.g. Brolga, Australasian Bittern and Black-winged Stilt).

The factors which control the number of species of waterbirds in the area at any one time are complex and depend not only on the condition and area of the wetland categories available but also on rainfall patterns in other parts of Australia which control the movement of many Australian waterfowl (Frith 1967, Cowan 1973, Braithwaite 1975) and day length which regulates the movement of migratory species. Within the area the distribution of the numbers and species present also depends on a number of interacting factors, e.g. the amount and distribution of rainfall, seasonal changes in wetland area, the potential food available and habitat condition of individual basins and the normal range of the species involved. Counts of waterbirds show the effects of these factors and also suggest the important factors acting on the distribution of some species within the area. Species such as Pied Oystercatcher, Black-faced Cormorant, Crested Tern, Fairy Tern, Pacific Gull and many migratory waders occur on marine and estuarine wetlands and do not extend to inland saline areas; Australasian Bittern, crakes and rails occur on deep freshwater marshes with Cane Grass, Lignum or reeds and Banded Stilts are found most often on hypersaline lakes. The distribution of many other species can be linked more precisely to the distribition of potential food particularly as it is influenced by salinity. The upper salinity tolerances of various species of potential food include fish (*Galaxias maculatus*) 30 parts per thousand (ppt) (Chessman & Williams 1974); Gastropoda (*Coxiella*) 100 ppt, Insecta 90 to 120 ppt and Isopoda (*Haloniscus*) 159 ppt (Bayly & Williams 1966); Ostracoda (*Platycypris*) 176 ppt and Anostraca (*Parartemia*) 298 ppt (Geddes 1976) and plants *Ruppia* 60 ppt (Yezdani in Aston 1973) and *Lepilaena* 65 ppt (this study). Thus fish eating species (grebe, cormorant, Pelican) will be confined to salinites of less than 30 ppt; grazing species (Swan and Coot) will not occur at salinities greater than 60 ppt unless they are feeding on grassland above the waterline; species (e.g. Hardhead) feeding on benthic organisms such as *Coxiella* and chironomid larvae will be excluded from waters greater than 100 ppt and the prey of birds (Banded Stilt and Avocet) feeding on highly saline waters must be restricted to only a very few species of microcrustaceans.

The few studies of primary and secondary production (Hammer 1970, Walker 1973, Paterson & Walker 1974, Marchant & Williams 1977) show that production will be highest during summer when incident radiation and water temperature are highest, provided that the water regime and salinity are suitable. Thus Marchant and Williams (1977) showed that the population of *Parartemia* in hypersaline lakes comprises cohorts which originate from hatchings which are most likely to occur following increases in water-level during winter and spring but are unlikely to occur during summer when levels are declining and Pollard (1971b) showed that the population size of *Galaxias maculatus* in Lake Modewarre depends on flood flows in the spawning areas during spring. Production of aquatic plants such as *Ruppia* and *Lepilaena* which comprise the major food of Coot and Swan has not been studied but clearly turbidity and bottom type as well as season and salinity influence their distribution and growth (e.g. Mayer & Low 1970, Congdon & McComb 1979, Verhoeven 1979). It follows that variations in the usage by birds of wetlands of the same category, or of the same wetland from year to year may result from minor seasonal differences in rainfall, turbidity and water chemistry and my observations show that concentrations of birds do occur on particular wetlands presumably when appropriate food is most abundant.

Although there are limited waterbird population data available for other areas of Victoria (e.g. Loyn 1978, Corrick & Norman 1980, Corrick 1981) and regional comparisons are complicated by the annual and seasonal variations which occur in the numbers of many species, counts made during the study indicate that the area supports important numbers of many species. Species for which the area is important include all colonially nesting species (e.g. Straw-necked Ibis, Sacred Ibis, Pied Cormorant, Fairy Tern) but particularly Pelican, the only known recently active colony in Victoria; Gull-billed Tern, the only breeding since 1971-72 (cf. Bourke *et al.* 1973) and Glossy Ibis, the first breeding attempt since 1973 (cf. Cowling & Lowe 1981) and for the non-colonially nesting species Brolga, Australasian Bittern and Chestnut Teal all of which

TABLE 7

NUMBER OF DUCKS BANDED IN VICTORIA AND RECOVERIES BY SHOOTING DURING OPEN SEASONS FROM 1951 TO 1980. The percentage of bandings within the area made at Serendip Wildlife Research Station (38°01'S 144°25'E) is shown.

	Banded			*Recovered*		
	Total	*in area*	*(% at Serendip)*	*Total*	*in area*	*(%)*
Australian Shelduck	3832	3625	(14.2)	982	338	(34)
Pacific Black Duck	7516	5848	(74.4)	2209	517	(23.4)
Grey Teal	67736	60965	(97.7)	13508	4054	(30)
Chestnut Teal	6045	5766	(87.8)	899	281	(31)

have restricted distributions in Victoria. The area is also important for non-breeding populations of many nomadic or migratory species (e.g. Great Crested Grebe, Hoary-headed Grebe, Black Swan, Grey Teal, Pink-eared Duck. Hardhead, Freckled Duck, Blue-billed Duck, Musk Duck, Banded Stilt, Avocet, Coot, Whiskered Tern and several migratory waders in particular Curlew Sandpiper, Red-necked Stint and Sharp-tailed Sandpiper.

Wetlands reserved specifically for conservation in National Parks and Wildlife Reserves include 868 ha of deep freshwater marsh (37% of the area in the region), 1000 ha of permanent open freshwater (6%), 2870 ha of semipermanent saline wetland (36%) including 960 ha or 60% of hypersaline lakes, 4650 ha of shallow and deep permanent saline wetland (13%) and 190 ha of intertidal flats (17%). Only a very small proportion of freshwater meadows (1%) and shallow freshwater marshes (5%) are included in these reserves. In addition large areas (e.g. 11 300 ha of permanent open freshwater, 2700 ha of semipermanent saline wetland and 30 100 ha of permanent saline wetland) of lakes which are on public land are Lake Reserves which recongize their value for recreation, water supply and drainage as well as for conservation. Although their future as wetland is assured, the value of some areas to waterbirds will be lowered unless the requirements of waterbirds are considered. High speed or intensive boating on shallow lakes and increased activity near breeding colonies pose particular threats. At present the large non-breeding populations of waterbirds which use the open lakes and many of the breeding colonies are well protected by reserves; however, some categories (freshwater meadow and shallow freshwater marshes) and the species which utilize them are not. Significant areas of these latter categories should be reserved to ensure that adequate and representative areas of each wetland type and its associated communities are conserved.

ACKNOWLEDGMENTS

It is a pleasure to thank Mr K. G. Bode for technical assistance throughout the project, Mr M. O'Sullivan for assistance during bird counts and Mrs L. Keetch for processing data.

REFERENCES

Abbott B. & Hughes, P., 1972. Some birds of the Bellarine Peninsula. *Geelong Nat.* 9: 47-50.

Aston, H. I., 1973. *Aquatic plants of Australia.* Melbourne University Press, Melbourne.

Barkla, J. G., 1978. Winter birding on "the farm"—1978. *Bird Observer* 563: 57-58.

Bayly, I. A. E. & Williams, W. D., 1966. Chemical and biological studies on some saline Lakes in south-east Australia. *Aust. J. mar. Freshwater Res.* 17: 177-288.

Bibra, E. E. & Riggs, H. C. W., 1971. *Victoria River Gaugings to 1969.* State Rivers and Water Supply Commission, Melbourne.

Binns, G., 1953. Birds of Terang, South-western Victoria. *Emu* 53: 211-221.

Bourke, P. R., Lowe, V. T. & Lowe, T. G., 1973. Notes on the Gull-billed Tern. *Aust. Bird Watcher* 5: 69-79.

Braithwaite, L. W. 1975. Managing waterfowl in Australia. *Proc. Ecol. Soc. Aust.* 8: 107-128.

Bureau of Meteorology, 1959. *Climatological Survey Region 4—Corangamite, Victoria.* Bureau of Meteorology, Melbourne.

Bureau of Meteorology, 1968. *Review of Australia's Water Resources. Monthly rainfall and evaporation.* Bureau of Meteorology, Melbourne.

Cameron, R. J., 1979. *Year Book Australia, No. 63.* Australian Bureau of Statistics, Canberra.

Campbell, A. J., 1924. The Garganey Teal *Querquedula querquedula. Emu* 24: 146.

Carter, M. J., 1968. A Victorian sight record of the Ruff *Rhilomachus pygnax. Aust. Bird Watcher* 3: 100-102.

Central Planning Authority, 1956. *Resources Survey: Central Highland Region.* Central Planning Authority, Melbourne.

Chessman, B. C. & Williams, W. D., 1974. The distribution of fish in inland saline waters in Victoria, Australia. *Aust. J. mar. Freshwat. Res.* 25: 167-172.

Congdon, R. A. & McComb, A. J., 1979. Productivity of *Ruppia:* Seasonal changes and dependence of light in a Australian estuary. *Aquat. Bot.* 6: 121-132.

Corrick, A. H., 1980. Freckled Duck on lakes in the Western District, Victoria. *Aust. Bird Watcher* 8: 254-255.

Corrick, A. H., 1981. Wetlands of Victoria II. Wetlands and waterbirds of South Gippsland. *Proc. R. Soc. Vict.* 92: 187-198.

Corrick, A. H. & Norman, F. I., 1980. Wetlands of Victoria I. Wetlands and waterbirds of the Snowy River and Gippsland Lakes catchment. *Proc. R. Soc. Vict.* 91: 1-15.

Cowan, I. M., 1973. *The conservation of Australian waterfowl.* A.F.A.C. Special publication No. 2. Australian Government Publishing Service Canberra.

Cowie, I. M., 1980. *Victorian Year Book 1980.* Number 100. Aust. Bureau of Statistics Melbourne.

Cowling, S. J. & Lowe, K. W., 1981. Studies of ibises in Victoria, I: records of breeding since 1955. *Emu* 81: 33-39.

Currey, D. T., 1963. The former extent of Lake Corangamite. *Proc. R. Soc. Vict.* 77: 377-386.

Currey, D. T., 1970. Lake systems. Western Victoria. *Aust. Soc. Limnol. Bull.* 3: 1-13.

Department of National Development 1966. *Atlas of Australian Resources.* Department of National Development, Canberra.

Frith, H. J., 1967. *Waterfowl in Australia.* Angus and Robertson, Sydney.

Geddes, M. C., 1976. Seasonal fauna of some ephemeral saline waters in western Victoria with particular reference to *Parartemia zietziana* Sayce (Crustacea: Anostraca). *Aust. J. mar. Freshwat. Res.* 27: 1-22.

Gill, E. D., 1963. Rocks contiguous with the basaltic cuirass of western Victoria. *Proc. R. Soc. Vict.* 77: 331-355.

Gilmore, A. M., Emison, W. B. & Wheeler, J. R. 1979. Vertebrate fauna of the Ballarat area, Victoria. *Mem. Natn. Mus. Vict.* 40: 51-103.

Goodrick, G. N., 1970. A survey of the wetlands of coastal New South Wales. *CSIRO Div. Wildl. Res. Tech. Mem.* 5.

Hammer, U. T., 1970. Primary production in saline waters. *Aust. Soc. Limnol. Bull.* 3: 20.

Hills, E. S. 1964. *The physiography of Victoria.* Whitcomb and Tombs, Melbourne. 4th ed.

Hirth, G. J., 1976. The birds of Trialla and Lake Coradgil, Lesilie Manor. Victoria. *Aust. Bird Watcher* 6: 310-317.

Hounam, C. E. & Powell, P. A., 1964. *Climate of the basalt plains of Western Victoria*. Bureau of Meteorology, Melbourne.

Land Conservation Council, 1973. *Report on the Melbourne study area*. Land Conservation Council, Melbourne.

Loyn, R. H., 1978. A survey of birds in Westernport Bay, Victoria 1973-74. *Emu* 78: 11-19.

Maddocks, G. E., 1967. The geochemistry of surface waters in the western district of Victoria. *Aust. J. mar. Freshwat. Res.* 18: 35-52.

Marchant, R. & Williams, W. D., 1977. Population dynamics and production of a brine shrimp *Parartemia zietziana* Sayce (Crustacea: Anostraca), in two salt lakes in western Victoria, Australia. *Aust. J. mar. Freshwat. Res.* 28: 417-438.

Mayer, F. L. & Low, J. B., 1970. The effect of salinity on widgeon-grass. *J. Wildl. Mgmt.* 34: 658-661.

Missen, R. & Timms, B., 1974. Seasonal fluctuations in waterbird populations on three lakes near Camperdown, Victoria. *Aust. Bird Watcher* 5: 128-135.

Morgan, D. G., 1954. Seasonal changes in populations of Anatidae at the Laverton Saltworks, Victoria, 1950-53. *Emu* 54: 263-278.

Parliamentary Public Works Committee, 1965. *Final Report. The Flooding of Lakes Corangamite, Gnarpurt and Murdeduke Inquiry*. Parliamentary Public Works Committee, Victoria.

Paterson, C. G. & Walker, K. F., 1974. Seasonal dynamics and productivity of *Tanytarsus barbitarsis* Freeman (Diptera: Chironomidae) in the benthos of a shallow, saline lake. *Aust. J. mar. Freshwat. Res.* 25: 151-165.

Pollard, D. A., 1971a. Faunistic and environmental studies on Lake Modewarree, a slightly saline athalassic lake in south-western Victoria. *Aust. Soc. Limnol. Bull.* 4: 25-42.

Pollard, D. A., 1971b. The biology of landlocked form of the normally catadromous salmoniform fish *Galaxids maculatus* (Jenyns). 1. Life cycle and origin. *Aust. J. mar. Freshwat. Res.* 22: 91-123.

RAOU, 1978. Recommended English names for Australian Birds. *Emu* 77: 245-313.

Riggert, T. L., 1966. *Wetlands of Western Australia, 1964-1966*. Department of Fisheries and Fauna, Western Australia, Perth.

Smith, F. T. H., 1962a. An Australian sight record of the Buff-breasted Sandpiper. *Aust. Bird Watcher* 1: 185-192.

Smith, F. T. H., 1962b. Some recent wader records from the vicinity of Melbourne, Victoria. *Aust. Bird Watcher* 1: 211-214.

Smith, F. H. T., 1963. An Australian sight record of the Red-necked Phalarope (*Phalaropus lobatus*). *Aust. Bird Watcher* 2: 1-4.

Smith, F. H. T., 1964. Wader observations in southern Victoria, 1962-1963. *Aust. Bird Watcher* 2: 70-84.

Smith, F. H. T., 1965. The White-winged Black Tern in Southern Victoria. *Aust. Bird Watcher* 2: 128-134.

Smith, F. H. T., 1966. Wader records and observations in mid-southern Victoria, 1963-1965. Part 1. *Aust. Bird Watcher* 2: 246-266.

Smith, F. H. T., 1967. Wader records and observations in mid-southern Victoria, 1963-1965. Part 2. *Aust. Bird Watcher* 3: 19-29.

Smith, F. H. T., 1968a. An Australian sight record of Wilson's Phalarope. *Aust. Bird Watcher* 3: 91-99.

Smith, F. H. T., 1968b. The pectoral Sandpiper in mid-southern Victoria. *Aust. Bird Watcher* 3: 122-128.

Smith, F. H. T., 1968c. The Long-toed Stint in southern Victoria. *Aust. Bird Watcher* 3: 132-140.

Smith, F. H. T., 1969a. Waders of the Geelong District. *Geelong Nat.* 6: 66-67.

Smith, F. H. T., 1969b. Field notes—a season's waders. *Bird Observer* 453: 5-7.

Smith, F. H. T., 1969c. Additional records of the Long-toed Stint. *Aust. Bird Watcher* 3: 167-168.

Smith, F. H. T., 1969d. The Dunlin near Melbourne. *Aust. Bird Watcher* 3: 193-195.

Smith, F. H. T., 1969e. Mallard records from Werribee Sewerage Farm. *Aust. Bird Watcher* 3: 195.

Smith, F. H. T., 1970. The Dunlin—a new wader for the Geelong district. *Geelong Nat.* 7:6.

Smith, F. H. T., 1974a. A Victorian record of the Asiatic Dowitcher. *Aust. Bird Watcher* 5: 111-118.

Smith, F. H. T., 1974b. A second Victorian record of the Asiatic Dowitcher. *Aust. Bird Watcher* 5: 199-200.

Smith, F. H. T., 1976. An Australian sight record of the White-rumped Sandpiper. *Aust. Bird Watcher* 6: 317-320.

Smith, F. H. T., 1977. Another Victorian record of the Buff-breasted Sandpiper. *Aust. Bird Watcher* 7: 59-60.

Smith, F. H. T., 1981. A retraction of Victorian Dunlin records. *Aust. Bird Watcher* 9: 43.

Smith, F. H. T. & Swindley, R. J., 1975. A Victorian record of Baird's Sandpiper. *Aust. Bird Watcher* 6: 35-40.

Smith, F. H. T., Swindley R. J. & Barkla, J. G., 1978. A second Australian record of the White-rumped Sandpiper. *Aust. Bird Watcher* 7: 194-197.

Sympson, R. T., 1968. The Dunlin at Altona, Victoria. *Aust. Bird Watcher* 3: 141.

Tarr, H. E., 1952. Birds of Melbourne and Metropolitan Board of Works Farm, Werribee, and Little River. *Bird Observer Club, Monthly notes* July 1952.

Timms, B. V., 1976. A comparative study of the limnology of Three Maar Lakes in Western Victoria. 1. Physiography and Physiochemical features. *Aust. J. mar. Freshwat. Res.* 27: 35-60.

Timms, B. V. & Brand, G. W., 1973. A limnological survey of the Basin Lakes, Nalangil, Western Victoria, Australia. *Aust. Soc. Limnol. Bull.* 5: 32-42.

Verhoeven, J. T. A., 1979. The ecology of *Ruppia*-dominated communities in Western Europe. 1. Distribution of *Ruppia* representatives in relation to their autecology. *Aquat. Bot.* 6: 197-268.

Walker, K. F., 1973. Studies on a saline lake ecosystem. *Aust. J. mar. Freshwat. Res.* 24: 21-27.

Watson, I. M., 1955. Some species seen at the Laverton Saltworks, Victoria, 1950-53, with notes on seasonal changes. *Emu* 55: 224-248.

Wheeler, J. R., 1953. Notes on the Blue-billed Duck at Lake Wendouree, Ballarat. *Emu* 53: 280-282.

Wheeler, J. R., 1959. Little Bitterns move south. *Aust. Bird Watcher* 1: 53.

Wheeler, J. R., 1976. A new wader for Australia. *Geelong Nat.* 13: 52-53.

Wheeler, W. R., 1955. Charadriiformes at the Laverton Saltworks, Victoria, 1950-1953. *Emu* 55: 279-295.

Wheeler, W. R., 1964. Black-faced Cormorant in Victoria. *Aust. Bird Watcher* 2: 89-90.

Wheeler, W. R., 1967. *A handlist of the birds of Victoria*. Victorian Ornithological Research Group, Melbourne.

Wheeler, W R., 1975a. The Darter in southern Victoria. *Geelong Nat.* 12: 57-62.

Wheeler, W. R., 1975b. Altona Survey Group 25th Anniversary. *Aust. Bird Watcher* 6: 134-135.

Williams, W. D., 1964. A contribution to lake typology in Victoria, Australia. *Verh. int. Ver. Limnol.* 15: 158-168.

Williams, W. D. & Buckney, R. T., 1976. Stability of ionic proportions in five salt lakes in Victoria, Australia. *Aust. J. mar. Freshwat. Res.* 27: 367-377.

Appendix 1

Wetland Subcategories used by less common, but regularly present Waterbirds. Most common species have been listed in Table 6. Only those subcategories with areas greater than 100 ha are included. x and S, frequently recorded; (x) and (S), infrequently recorded; x and (x), throughout subcategory; S and (S), shores and shallows only; B breeding. Names of categories and subcategories appear in Table 1.

Category	2	3	4			5			6				7		
Subcategory	.1	.1	.4	.5	.6	.1	.2	.3	.1	.2	.3	.5	.1	.2.	3
Australasian Grebe		x	x	x		x		x							
Australian Pelican				x		x	x	x	x				B	x	x
Great Cormorant				x		x	x	x	x				B	x	x
Pied Cormorant						x							B	x	x
Pacific Heron	x	x	(x)	x		S		S					(S)		
Catte Egret	x	x													
Great Egret	x	x	x	x	x	S		S	x				S		x
Little Egret						(S)			x				S		x
Rufous Night Heron				x											
Australasian Bittern					x										
Glossy Ibis	x	x		x									B		
Sacred Ibis	x	x		x	x	S		S					B		x
Royal Spoonbill	x	x	x	x	x	S	S	x	x				S		x
Freckled Duck	(x)						x	x	x				x		
Cape Barren Goose										x	x				
Chestnut Teal						x			x				x		x
Maned Duck								S							
Marsh Harrier			x	x	B	x				x	x				
Australian Crake		x	x	x				S			x				
Brolga	B	B		x	B	S									
Pied Oystercatcher															x
Grey Plover															x
Lesser Golden Plover									x			x	S		x
Red-kneed Dotterel	x	x		x	x	S		S							
Mongolian Plover															x
Double-banded Plover						S			x	x	x		S		x
Red-capped Plover	x	x		x	x	S	S		B	B	x	x	S		x
Black-fronted Plover	x	x		x	x	S	S								
Banded Stilt					x	(S)			x			x	(S)		
Avocet		x		x	x	(S)			x	x		x			(x)
Ruddy Turnstone									(x)						x
Eastern Curlew															x
Grey-tailed Tattler															x
Common Sandpiper															(x)
Greenshank									x				S		x
Marsh Sandpiper									x				S		x
Latham's Snipe	x	x	x		x					x					
Black-tailed Godwit				(x)											x
Bar-tailed Godwit															x
Red Knot						(S)							(S)		x
Great Knot															x
Pacific Gull															x
Gull-billed Tern	x	x	x	x	x	x	x	x	x				B		(x)
Caspian Tern				(x)		(x)							(x)		x
Fairy Tern															x
Crested Tern															x

APPENDIX 2

VAGRANT OR RARELY REPORTED SPECIES WHICH UTILIZE WETLANDS OF THE AREA

In some cases (e.g. Black-faced Shag, Hooded Plover) species are more common on other habitats in the area (e.g. rocky shores, ocean beaches or ocean waters). The references cited usually assess specific status or review past records. (* indicates the species was seen during the study).

Darter* (Wheeler, W. R. 1975a, Gilmore *et al.* 1979), Black-faced Shag* (Wheeler, W. R. 1964), Intermediate Egret* (Watson 1955, Abbot & Hughes 1972, Gilmore *et al.* 1979), Little Bittern (Wheeler, J. R. 1959, Gilmore *et al.* 1979), Wandering Whistling-Duck (Wheeler, W. R. 1967), Plumed Whistling-Duck* (Wheeler, W. R. 1967, Gilmore *et al.* 1979), Mallard* (Smith 1969e, Gilmore *et al.* 1979), Garganey Teal (Campbell 1924), Buff-banded Rail, Lewin's Rail* and Spotless Crake (Watson 1955, Wheeler, W. R. 1967, Gilmore *et al.* 1979), Black-tailed Native-hen (Watson 1955, Gilmore *et al.* 1979, LCC 1973), Painted Snipe* (Wheeler, W. R. 1967, Smith 1969a, Gilmore *et al.* 1979), Sooty Oystercatcher (Wheeler, W. R. 1967, Smith 1969a), Hooded Plover *(Wheeler, W. R. 1967), Large Sand Plover (Smith 1964, 1969a), Oriental Plover (Smith 1964, 1969a, Wheeler, W. R. 1967), Whimbrel (Smith 1969a,b), Little Curlew (Smith 1964, 1969a), Wood Sandpiper* (Smith 1964, 1969b) Terek Sandpiper* (Smith 1967, 1969a), Asian Dowitcher (Smith 1974a,b), Pectoral Sandpiper (Smith 1968a,b), Baird's Sandpiper (Smith & Swindley 1975), Long-toed Stint (Smith 1968b, 1969c), White-rumped Sandpiper (Smith 1976, Smith *et al.* 1978), Dunlin (Sympson 1968, Smith 1969d, 1970, 1981), Sanderling* (Wheeler, W. R. 1955, Smith 1969a), Buff-breasted Sandpiper (Smith 1962a, 1977, Wheeler, W. R. 1975b), Broad-billed Sandpiper (Smith 1962b, 1969b, Wheeler, W. R. 1955), Ruff (Carter & Smith 1968, Smith 1969b), Red-necked Phalarope (Smith 1963, Wheeler, J. R. 1976), Wilson's Phalarope (Wheeler, J. R. 1976, Smith 1968a, 1969b), White-winged Tern (Smith 1965, LCC 1973), Common Tern* (LCC 1973) and Little Tern (LCC 1973).

PROC. R. SOC. VICT. vol. 94, no. 2, 89-106, June 1982

STUDIES ON AUSTRALIAN MANGROVE ALGAE: II. COMPOSITION AND GEOGRAPHIC DISTRIBUTION OF COMMUNITIES IN SPENCER GULF, SOUTH AUSTRALIA

By Warwick R. Beanland and Wm. J. Woelkerling

Department of Botany, La Trobe University, Bundoora, Victoria, Australia 3083

Abstract: This study of algal communities associated with the temperate mangrove ecosystems of Spencer Gulf, South Australia documents the occurrence of 49 species including 10 Chlorophyta, 2 Cyanophyta, 9 Phaeophyta, and 28 Rhodophyta. Pertinent morphosystematic and distributional data are presented for each species. The Spencer Gulf mangrove algal flora is far more diverse than previously thought but is pedestrian and depauperate compared with the southern Australian marine algal flora as a whole. Most species are widespread on a global basis, although several typically tropical taxa also occur on Spencer Gulf mangroves and possible explanations for their occurrence are provided. Frequency data indicate that *Caloglossa leprieurii* occurs most commonly but that most species found occur only rarely or sporadically. Comparisons of the Spencer Gulf mangrove algal flora with those of mangrove ecosystems elsewhere in Australia suggest that the Spencer Gulf flora is comparatively species rich and shows distinct similarities to and differences from the mangrove algal flora in Victoria.

Data on Australian tropical and warm temperate mangrove algal communities are scant and pertain mainly to scattered floristic records (and one biomass production estimate) in Queensland and New South Wales (Cribb 1979, King 1981a, 1981b, 1981c, Saenger *et al.* 1977). Along the cool temperate southern Australian coast, mangrove ecosystems occur as geographically disjunct stands within Victoria, South Australia, and Western Australia (Fig. 1), but the only detailed account (Davey & Woelkerling 1980) of associated mangrove algae deals with community composition and geographic distribution in Victoria. Data for Western Australia are lacking entirely.

Within South Australian mangrove ecosystems, *Cladophora* sp., *Enteromorpha compressa* (Linnaeus) Greville, *Hormosira banksii* (Turner) Decaisne, *Ulva lactuca* Linnaeus and various diatoms have been regarded as common (Butler *et al.* 1977a, 1977b, Specht 1972, Womersley & Edmonds 1958, Wood 1937), whereas *Bostrychia* and *Caloglossa*, two of the most characteristic and cosmopolitan genera of mangrove algae (Post 1963), have been reported as apparently absent (Womersley & Thomas 1976, Womersley 1981a). Based on these isolated records, mangrove algal communities in South Australia would appear to differ markedly from those in Victoria where species of *Bostrychia* and *Caloglossa* are the most frequently occurring algae, species of *Enteromorpha* and *Ulva* tend to occur only sporadically, *Cladophora* occurs only rarely and *Hormosira* appears to be absent (Davey & Woelkerling 1980). The dearth of detailed data from South Australia has precluded a more thorough comparative assessment of these apparent differences.

Among those regions in South Australia where mangrove ecosystems occur (Fig. 1), Spencer Gulf has been regarded as noteworthy (Womersley 1981b) in the sense that at least three typically tropical benthic algae (*Acetabularia calyculus* Quoy et Gaimard, *Hormophysa triquetra* (Lamouroux) Kuetzing, *Sargassum decurrens* J. Agardh) are present, presumably because summer water temperatures are high enough for a sufficient period to allow survival (Womersley 1981c). Whether Spencer Gulf mangrove ecosystems also harbour typically tropical macroscopic algae has remained unknown as has the extent to which the algal communities in Spencer Gulf mangroves contrast with those in more tropical regions of Australia.

This account presents results of detailed studies on the floristic composition, frequency of species occurrence and geographic distribution of mangrove algal communities of Spencer Gulf, South Australia. It also examines the extent to which Spencer Gulf mangrove algal communities differ from those in Victoria and those in more tropical regions of Australia, and it includes comparisons of mangrove and open coast algal communities in terms of composition, diversity, and occurrences of endemic taxa.

Study Sites

The 10 mangrove algal communities (Fig. 2) selected for detailed study included the southern-most stands on both the eastern (Wallaroo) and western (Tumby Bay) shores, three stands in the far north (Blanche Harbour, Port Augusta, Red Cliff), two stands along tidal creeks (Arno Bay, Port Davis) and three other larger stands (Cowleds Landing, Franklin Harbour, Port Broughton).

In the two tidal creeks, pneumatophores occurred in permanently submerged areas only at Arno Bay (Fig. 4). Spencer Gulf mangrove ecosystems, like others in southern Australia (Macnae 1966), are based primarily in the mid to upper eulittoral zone, are dominated solely by *Avicennia marina* (Forster) Vierhapper, and usually are associated with a salt-marsh in the littoral-fringe (Butler *et al.* 1977a, 1977b). Data relating to tree height and stand size at the study sites are

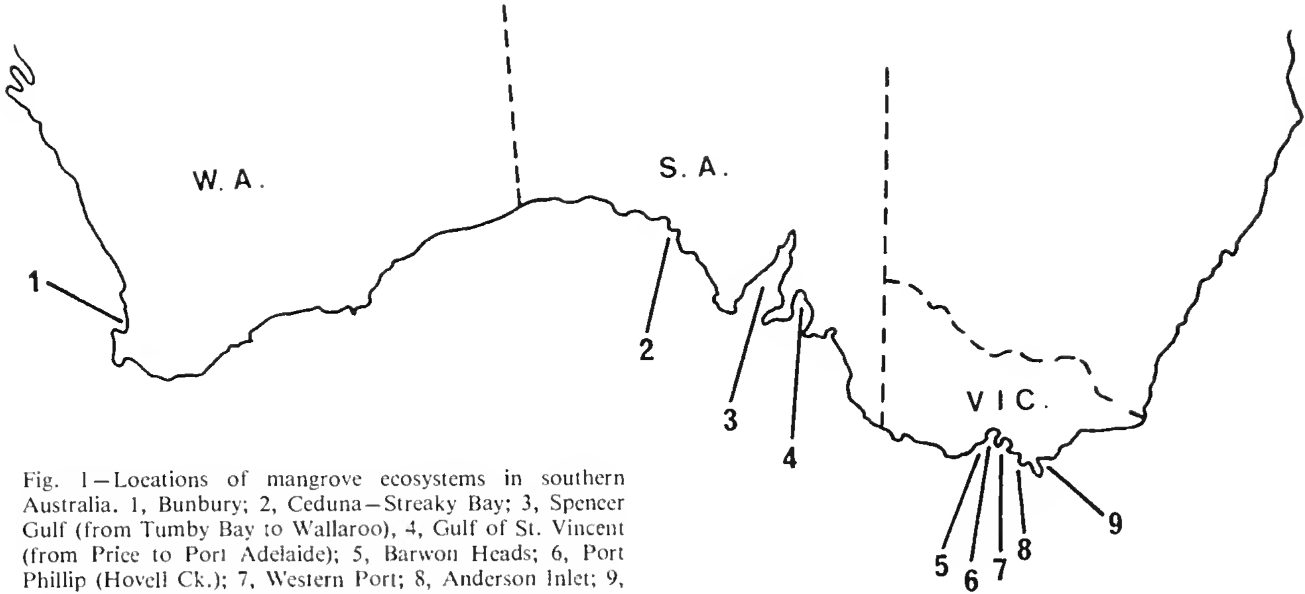


Fig. 1—Locations of mangrove ecosystems in southern Australia. 1, Bunbury; 2, Ceduna—Streaky Bay; 3, Spencer Gulf (from Tumby Bay to Wallaroo), 4, Gulf of St. Vincent (from Price to Port Adelaide); 5, Barwon Heads; 6, Port Phillip (Hovell Ck.); 7, Western Port; 8, Anderson Inlet; 9, Corner Inlet. Data from Ashton (1972), Butler *et al.* (1977a), Macnae (1966) and Saenger *et al.* (1977).

summarized in Table 1. Abundant pneumatophores (Figs 3, 4) beneath and beyond the edge of the *Avicennia* canopy are the main substrate for macroscopic algae.

Study site selection also took account of certain physical parameters which divide Spencer Gulf into two distinct regions. The tides have a phase difference between the far north (i.e. north of Port Davis) and the rest of the Gulf and change with greater amplitude in the north (Easton 1974). As a result, mean lowest tides during summer months tend to occur during the daytime in the south and at night in the north (Australian National Tide Tables 1981). Thus the mangrove algal communities south of Port Davis are emergent longer during periods of extreme salinities, air temperatures, and desiccating conditions that commonly occur at neap tide in summer.

TABLE 1
MEASUREMENTS OF *AVICENNIA* HEIGHT AND FRINGE WIDTH, AND APPROXIMATIONS OF FRINGE LENGTH, AT TEN MANGROVE COMMUNITIES IN SPENCER GULF, SOUTH AUSTRALIA

Locality	Height m	Approximate Fringe Length km	Maximum Fringe Width m
Arno Bay	5.0	2	25
Blanche Harbour	3.5	5	110
Cowleds Landing	4.0	30	100
Franklin Harbour	4.5	18	75
Port Augusta	3.0	2	200
Port Broughton	6.0	4	80
Port Davis	4.0	4	50
Red Cliff	5.0	5	320
Tumby Bay	1.5	3	75
Wallaroo	3.0	2	90

Water circulation in Spencer Gulf inhibits exchange between the northern (i.e. north of Franklin Harbour) and southern parts, and Tronson (1974) extimates that at least two years are required for a total exchange to occur. A salinity gradient ranging from 36 g/kg in the far south to 45 g/kg in the far north also occurs (Bullock 1975, Womersley 1981a: 217). While mean monthly surface water temperatures along the central South Australian open coast range from 14-19°C, the range part way up Spencer Gulf is about 12-25°C and at the head it is 13-28°C (Womersley 1981a: 216). Thus summer surface water temperatures in the central and northern parts of the gulf are 6-9°C warmer than those of the adjacent open coast. The extent to which these physical factors affect mangrove algal community composition and species distribution within the Gulf has not been examined previously, and sites for the present study were chosen partly to obtain data relevant to such an examination.

MATERIALS AND METHODS

Two procedures were employed to obtain entire *Avicennia* pneumatophores for algal community composition and frequency data from each study site during the period March to July 1981. One involved using a restricted random sampling regime (Goldsmith & Harrison 1976) to collect 50 pneumatophores from each of three 10 m wide, 50 m long belt transects. Each belt transect was bisected lengthwise into two laterally contiguous 5 m wide strips contoured so that one strip was situated just within the shaded margin of the *Avicennia* canopy while the other strip lay in the adjacent sun-exposed seaward fringe of pneumatophores beyond the canopy (Fig. 3). In the tidal creek at Arno Bay, however, one strip of each transect was situated along the creek bank at low tide while the adjacent strip lay within the permanent creek water. From each transect, 25 pairs of random co-ordinate pneumatophores were collected; one of each pair came from the strip under the shaded canopy (or in the creek) while the other came from the strip in the sun-exposed region (or along the creek bank).

The second collecting procedure involved gathering additional pneumatophores from throughout the mangrove fringe if they appeared to harbour algal species not obtained during the transect sampling. This was the only procedure used at Port Broughton, where pneumatophores bearing algae occurred so intermittently that transect sampling was not undertaken.

All pneumatophores were preserved in 1:10 commercial formalin-seawater solution and returned to the laboratory for analyses. Algal community composition data were compiled from assays of all pneumatophores collected at each locality. These data did not take account of any diatoms (Bacillariophyta) present and included only those species of blue green algae (Cyanophyta) which formed macroscopic colonies. Permanent slides, liquid preserved material, and/or dried voucher specimens have been deposited in the La Trobe University Botany Department Herbarium (LTB—see Holmgren & Keuken 1977).

Species frequency data for each locality except Port Broughton were calculated from results of a species presence/absence survey of the 150 pneumatophores collected in the three transects by using the formula:

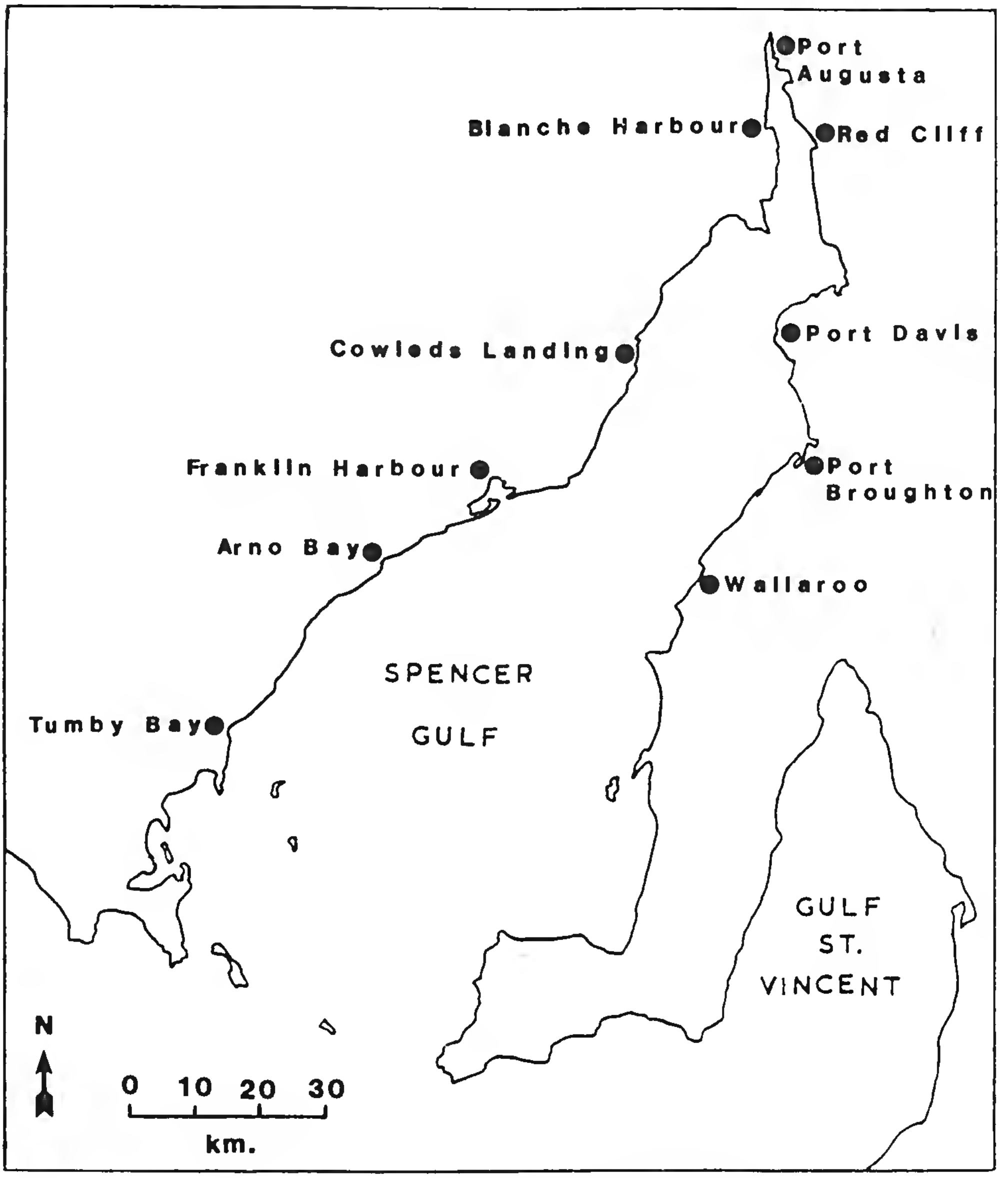


Fig. 2—Location of study sites in Spencer Gulf, S.A.

F

$F = \Sigma N/N$, where
F = the absolute frequency;
ΣN = the number of pneumatophores on which a particular alga occurred;
N = the total number of pneumatophores surveyed.

Following Davey & Woelkerling (1980), the relative profusion of taxa has been determined from absolute frequency data, and species have been assigned to one of five categories: *Rare* ($F < 0.05$); *Sporadic* ($F = 0.05$ to 0.24); *Occasional* ($F = 0.25$ to 0.49); *Common* ($F = 0.50$ to 0.75); *Abundant* ($F > 0.75$). In the text, the word 'prevalent' is used to include both common and abundant frequency classes.

COMMUNITY COMPOSITION AND SPECIES DISTRIBUTION

Forty-nine species of algae, including 10 Chlorophyta, 2 Cyanophyta, 9 Phaeophyta and 28 Rhodophyta, were recorded. At any particular locality 5-26 species were detected (Table 2), and with the exceptions of Port Augusta, Port Broughton and Port Davis, red algae predominated. Taxa from all four algal Divisions were encountered in 7 of the 10 mangrove stands; macroscopic colonies of blue green algae were not detected at Arno Bay, Port Broughton or Port Davis and brown algae were not observed at Port Broughton or Port Davis. Sixteen species were found at 5 or more localities while 15 other species were recorded from only one locality each. Relationships between distribution and frequency data are considered later.

TABLE 2
SUMMARY OF THE MANGROVE ALGAL COMMUNITY COMPOSITION AT SPENCER GULF STUDY SITES

Locality	CHLOROPHYTA	CYANOPHYTA	PHAEOPHYTA	RHODOPHYTA	TOTAL
Arno Bay	8	—	3	13	24
Blanche Harbour	5	2	1	5	13
Cowleds Landing	5	2	4	15	26
Franklin Harbour	8	2	4	9	23
Port Augusta	5	1	4	3	13
Port Broughton	3	—	—	2	5
Port Davis	4	—	—	3	7
Red Cliff	4	2	3	12	21
Tumby Bay	7	1	1	7	16
Wallaroo	7	1	1	16	25

COMMUNITY COMPOSITION LIST

Details of locality occurrences of species in the following list may be obtained from Table 4, which also summarizes frequency data.

Fig. 3 — Portion of the mangrove ecosystem at Cowleds Landing showing sun exposed and canopy shaded regions along the seaward margin at low tide.

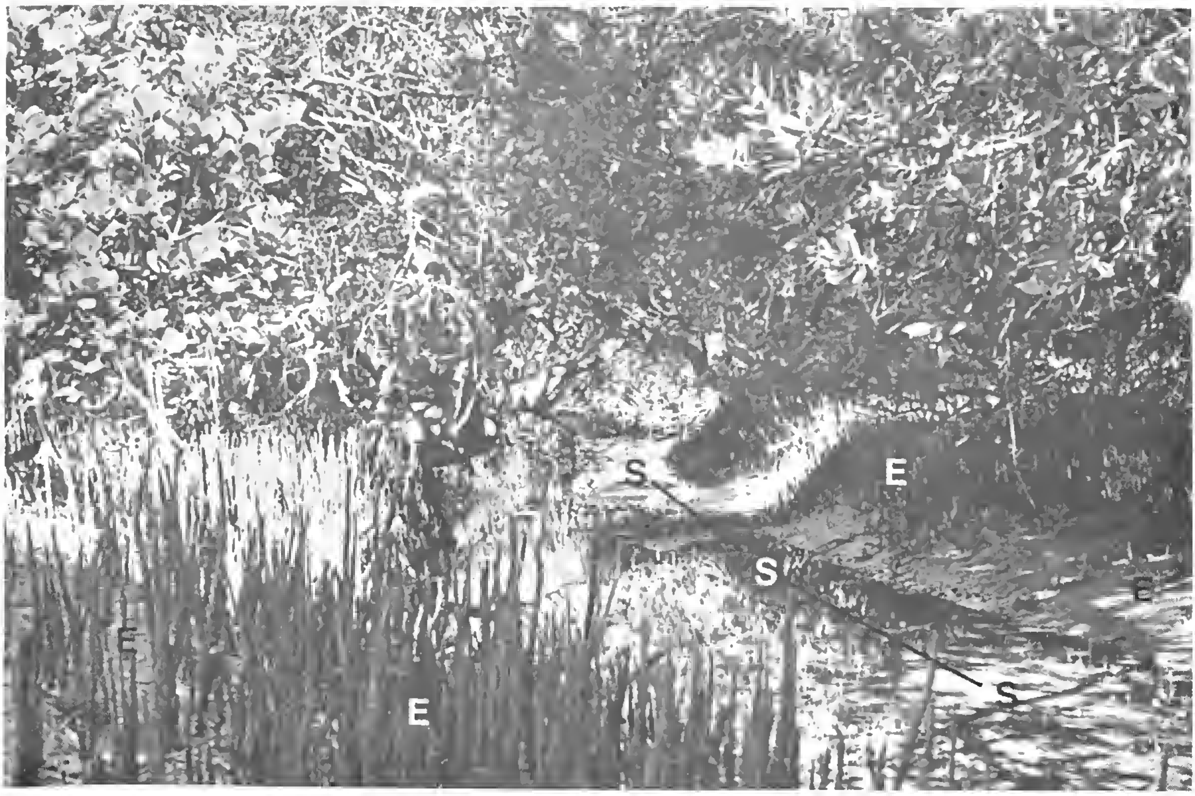


Fig. 4—Portion of the mangrove ecosystem at Arno Bay showing the eulittoral (E) and sublittoral (S) creek environment at low tide. Note emergent pneumatophores in foreground; permanently submerged pneumatophores (not visible) also occur within the creek, which is up to 1 m deep at low tide.

Division Chlorophyta
Order Ulvales
Family Ulvaceae
Genus **Enteromorpha** Link 1820

Enteromorpha sp.

Specimens Examined: LTB 12190, 12233, 12243, 12259, 12281, 12292, 12316, 12327, 12348, 12359.

Remarks: *Enteromopha* plants occurred on pneumatophores at all sites except Red Cliff and also grew loose on the sun-exposed mud flat at Tumby Bay. Most plants were less than 2 cm tall and none could be identified to species with confidence.

Genus **Percursaria** Bory 1828

P. percursa (C. Agardh) Rosevinge 1893: 963. Abbott & Hollenberg 1976: 70, fig. 23. Bliding 1963: 20, figs 5, 6.

Type Locality: Denmark.

Reported Distribution: Widespread.

Specimens Examined: LTB 12172, 12197, 12223, 12251, 12279, 12300, 12320.

Remarks: *P. percursa* occurred attached to pneumatophores under the *A. marina* canopy and in the sun-explosed seaward margin, and was encountered as an epiphyte on *Cystophyllum onustum* at Red Cliff. The only previous record of this taxon in southern Australia was on mangroves at Hovell's Creek, Victoria (Davey & Woelkerling 1980).

Genus **Ulva** Linnaeus 1753

U. lactuca (Linnaeus) C. Agardh, 1821: 409. Bliding 1968: 540, figs 3-5. Womersley 1956: 353.

Type Locality: Sweden.

Reported Distribution: Widespread.

Specimens Examined: LTB 12167, 12231, 12244, 12262, 12311.

Remarks: Plants up to 20 cm tall occurred on sun-exposed pneumatophores at Arno Bay and Wallaroo. Smaller specimens, up to 3 cm tall, were encountered at Port Davis, Port Augusta and Franklin Harbour. *U. lactuca* has been found on *Avicennia* pneumatophores in Queensland (Cribb 1979, Saenger *et al.* 1977) and Victoria (Davey & Woelkerling 1980).

Order Cladophorales
Family Cladophoraceae
Genus **Chaetomorpha** Kuetzing 1845

C. aerea (Dillwyn) Kuetzing 1849: 379. Womersley 1956: 355.

Type Locality: Cromer, Britain.

Reported Distribution: Widespread.

Specimens Examined: LTB 12181, 12360.

Remarks: Filaments 10-20 cells long, 250-350 μm broad and attached by a subclavate, lobed, basal cell occurred on pneumatophores at Arno Bay and Wallaroo.

C. capillaris (Kuetzing) Boergesen 1925: 45, fig. 13.

Feldmann 1937: 207, fig. 17. Womersley 1956: 356.
Type Locality: Nice, France.
Reported Distribution: Mediterranean and Atlantic Ocean. In Australia from Kangaroo Island, Spencer Gulf and Western Port.
Specimens Examined: LTB 12293.
Remarks: Entangled mats of *C. capillaris* occurred in patches on pneumatophores. Davey & Woelkerling (1980) found this species on mangroves throughout Western Port.

Genus **Cladophora** Kuetzing 1843

Cladophora sp.
Specimens Examined: LTB 12176, 12189, 12214, 12246, 12260, 12278, 12301, 12312, 12344, 12356, 12361.
Remarks: Plants of *Cladophora* were found attached to pneumatophores at all localities except Port Davis, and at Red Cliff and Cowleds Landing plants also grew on *Cystophyllum onustum*. Cells were mostly 40-70 μm broad and 150-230 μm long, but specimens were too small (<2 cm tall) or too young to identify to species reliably.

Genus **Cladophorella** Fritsch 1944

C. marina Chapman 1956: 442, fig. 92b, c.
Type Locality: Orongo Bay, New Zealand.
Reported Distribution: From Orongo Bay and Uruiti Bay, New Zealand; South Australia.
Specimens Examined: LTB 12178, 12210, 12261, 12275, 12295, 12313, 12343.
Remarks: The Spencer Gulf collections have been referred to *Cladophorella marina* because their morphology agreed more closely with that species than with other species assigned to the genus (Table 3). Chapman (1956) did not supply data on wall diameter or cell dimensions, but the latter have been calculated from his figure 92b. Plants commonly formed dense veneer-like mats on lower portions of pneumatophores both in the sun exposed and shaded regions of the communities. Womersley (1956, 1971) did not record this species from southern Australia but Cribb (1965, 1979) recorded the related *C. calcicola* from Queensland. The relationships of *Cladophorella* Fritsch 1944 to the genus *Wittrockiella* Wille 1909 require clarification and are under current review (Van den Hoek, H.B.S. Womersley, pers. comm.).

Genus **Rhizoclonium** Kuetzing 1843

R. implexum (Dillwyn) Kuetzing 1845: 206. Abbott & Hollenberg 1976: 92, fig 45. Newton 1931: 93. Rueness 1977: 243.
Type Locality: Ireland.
Reported Distribution: Widespread.
Specimens Examined: LTB 12185, 12234, 12252, 12294, 12310.
Remarks: Plants occurred on *Avicennia* pneumatophores at Arno Bay, Franklin Harbour, Port Davis and Tumby Bay and also occurred entangled with *Bostrychia* and *Percursaria* at Wallaroo. Most filaments were 17-22 μm broad, unbranched, and composed of cells 2-6(-9) diameters long, each containing a reticulate chloroplast mostly with 5-8 pyrenoids. The Spencer Gulf plants agreed with the concept of *R. implexum* presented by Abbott & Hollenberg (1976) and Rueness (1977). This species apparently has not been recorded previously from southern Australia (Womersley 1956, p. 361, 362).

R. riparium (Roth) Harvey 1849: pl. 239. Abbott & Hollenberg 1976: 92, fig. 46, pl. 1, fig. 9. Rueness 1977: 243. Womersley 1956: 361.
Type Locality: Northern Europe.
Reported Distribution: Widespread.
Specimens Examined: LTB 12182, 12196, 12212, 12228, 12241, 12270, 12282, 12308, 12338.
Remarks: *Rhizoclonium riparium* occurred on pneumatophores amongst other algae at all sites except Blanche Harbour and Port Broughton and was abundant at Arno Bay and Port Davis. Most filaments were 20-50 μm broad, rarely possessed rhizoidal branches, and were composed of cells 1-2.5 (-4) diameters long; each contained a reticulate chloroplast with 10 or more pyrenoids. The Spencer Gulf plants agreed most closely with the concept of *R. riparium* presented by Rueness (1977). Californian plants (Abbott & Hollenberg 1976) appear to be more robust and possess more rhizoidal branches. Davey & Woelkerling (1980) reported this species from four mangrove communities in Victoria.

Order CHAETOPHORALES
Family CHAETOPHORACEAE
Genus **Sporocladopsis** Nasr 1947

S. novaezelandiae Chapman 1949: 496, fig. 4; 1956: 433, fig. 85a-c.
Type Locality: Bay of Islands, New Zealand.
Reported Distribution: North Island of New Zealand; Queensland, southern Australia.
Specimens Examined: LTB 12288, 12319, 12336.
Remarks: Sterile plants occurred on pneumatophores as inconspicuous epiphytes. This species was not recorded from southern Australia by Womersley (1956, 1971).

Division CYANOPHYTA
Order OSCILLATORIALES
Family RIVULARIACEAE
Genus **Rivularia** Roth 1797

R. atra Roth 1806: 340. Drouet 1973: 164; 1978: 237. Umezaki 1961: 105, pl.21, fig. 2a-c. Womersley 1946: 132.
Type Locality: West Germany.
Reported Distribution: Widespread.
Specimens Examined: LTB 12187, 12202, 12269, 12276, 12296, 12314, 12333.
Remarks: *R. atra* formed solid colonies, up to 1 cm diameter on pneumatophores in the sun-exposed and shaded regions of the communities. Trichomes were 3-12 μm in diameter, sheathed in a thick hyaline coat, usually bore heterocysts of 10-12μm diameter, and tapered to a thin hair. Drouet (1973) placed this species in synonymy with *Calothrix crustacea* Schousboe & Thuret.

R. polyotis (J. Agardh) Bornet & Flahault 1886: 360. Umezaki 1961: 103. Womersley 1946: 134.
Type Locality: Mediterranean coast of France.
Reported Distribution: Widespread.
Specimens Examined: LTB 12203, 12277, 12315, 12334.
Remarks: *R. polyotis* occurred on pneumatophores; trichomes, 2-8 μm in diameter, were sheathed in a thick hyaline coat, bore basal heterocysts 6-10 μm in diameter, and usually tapered to a thin hair. Plants formed soft, hollow colonies up to 2 cm in diameter.

Division Phaeophyta
Order Ectocarpales
Family Ectocarpaceae
Genus **Ectocarpus** Lyngbye 1819

E. siliculosus (Dillwyn) Lyngbye 1819: 131. Russell 1966: 275 *et seq.*, figs. 3, 4. Womersley 1967: 190.
Type Locality: Europe.
Reported Distribution: Widespread in temperate and boreal seas.
Specimen Examined: LTB 12253.
Remarks: *E. siliculosus* occurred sporadically on continually submerged pneumatophores, grew up to 2 cm tall, and bore plurilocular sporangia. *E. siliculosus* also has been recorded from Victorian mangrove communities (Davey & Woelkerling 1980).

Ectocarpus sp.
Specimen Examined: LTB 12267.
Remarks: Two small plants with plurilocular sporangia were found in the sun-exposed seaward margin at Port Augusta. Cells were 16-20 μm broad, 20-35 μm long and plurilocular sporangia, borne terminally, were 50-80 μm long and 25-30μm broad. The plants were insufficiently developed for reliable species identification.

Genus **Giffordia** (Batters) Hamel 1939

G. sordida (Harvey) Clayton 1974: 785, fig. 12G1, G2, 15A-F, 26A-K.
Type Locality: Georgetown, Tasmania.
Reported Distribution: Southern Australia, Queensland.
Specimen Examined: LTB 12362.
Remarks: *G. sordida* was abundant at Wallaroo in June, occurring attached to pneumatophores and/or intermixed with other algae in all regions of the community. Plants up to 15 cm tall, with filaments 20-50 μm in diameter were collected. Unilocular sporangia occurred rarely.

Genus **Kuetzingiella** Kuckuck 1956

Kuetzingiella sp.
Specimens Examined: LTB 12245, 12266, 12280, 12289, 12317, 12337.
Remarks: Filaments consisted of 20-30 cells approximately 10 μm broad and 5 μm long. Plurilocular sporangia 100-200 μm long and 18-22 μm broad usually were present. According to Clayton (1974), the taxonomy of southern Australian *Kuetzingiella* species is uncertain and in need of revision.

Order Sphacelariales
Family Sphacelariaceae
Genus **Sphacelaria** Lyngbye 1819

S. furcigera Kuetzing 1855: 27, p1.90. Womersley 1967: 199.
Type Locality: Karak Is., Persian Gulf.
Reported Distribution: Widespread.
Specimens Examined: LTB 12200, 12254, 12263, 12303.
Remarks: Plants up to 1 cm tall were found on pneumatophores at Red Cliff, Port Augusta, Franklin Harbour and Arno Bay. They also grew as epiphytes on *Cystophyllum onustum* at Red Cliff and Cowleds Landing. Some plants bore plurilocular or unilocular sporangia and most produced long-armed, biradiate propagules.

S. tribuloides (Meneghini) De Toni 1895: 502. Taylor 1960: 211, p1.29 fig 6. Womersley 1967: 201.
Type Locality: Italy.
Reported Distribution: Widespread in tropical and temperate seas.
Specimens Examined: LTB 12201, 12264, 12304.
Remarks: Several plants up to 1 cm tall were found on pneumatophores at Port Augusta, Red Cliff and Franklin Harbour. Those at Red Cliff were intermixed with *S. furcigera*. Short-armed, triradiate propagules occurred on most plants.

Order Dictyotales
Family Dictyotaceae
Genus **Dictyota** Lamouroux 1809

Dictyota sp.
Specimens Examined: LTB 12214, 12351, 12363.
Remarks: Sterile plants, up to 3 cm tall, were epiphytic on *Cystophyllum onustum* at Red Cliff and Cowleds Landing, and were attached to pneumatophores in the sun-exposed seaward margin at Wallaroo in June. Plants were insufficiently developed for reliable species identification.

Order Fucales
Family Cystoseiraceae
Genus **Cystophyllum** J. Agardh 1848.

C. onustum (Mertens) J. Agardh 1848: 230. Womersley 1967: 254.
Type Locality: Western Australia.
Reported Distribution: All around Australia; Indian Ocean.
Specimens Examined: LTB 12214, 12349.
Remarks: A large, solitary plant was attached to the base of a mangrove tree at Red Cliff; a second plant was found attached to shells under the canopy at Cowleds Landing. Both plants harboured a number of epiphytes.

Family Hormosiraceae
Genus **Hormosira** (Endlicher) Meneghini 1838

H. banksii (Turner) Decaisne 1842: 331. Clarke & Womersley 1981: 497 *eq seq.* King 1981a: 325, figs 9, 12; 1981b: 107; 1981c: 569 *et seq.* Womersley 1967: 249-250.
Type Locality: 'Novae Hollandiae'.

Reported Distribution: From King George Sound, Western Australia, around southern Australia; New South Wales; Lord Howe Island; Norfolk Island; New Zealand.
Specimens Examined: LTB 12166, 12199, 12224, 12225, 12326, 12329, 12347.
Remarks: Plants up to 25 cm tall with swollen vesicles, were attached to the lower half of pneumatophores and loose lying on mud surfaces at Wallaroo, Red Cliff, Franklin Harbour, and Cowleds Landing. The loose lying form was also encountered at Tumby Bay. King (1981a, 1981b, 1981c) provided data on an extensive loose lying community of *H. banksii* within the mangroves of southern Botany Bay in New South Wales; he estimated that mean dry weight biomass ranged from 280 g m^{-2} in late winter (August) to 638 g m^{-2} in mid-summer and suggested an annual biomass production rate of approximatley 400 g m^{-2}. Clark & Womersley (1981, p. 500) reported an unattached population of plants occurring among mangroves at Port Arthur, South Australia at the north end of St. Vincent Gulf. Individuals up to 50 cm long were encountered.

Division Rhodophyta
Order Bangiales
Family Erythropeltidaceae
Genus **Asterocytis** (Hansgirg) Schmitz 1896.

A. ornata (C. Agardh) Hamel 1925: 40.
A. ramosa (Thwaites) Schmitz 1896: 314. Abbott & Hollenberg 1976: 283. Taylor 1960: 287.
Type Locality: British Isles.
Recorded Distribution: Widespread in temperate seas.
Specimens Examined: LTB 12211, 12257, 12302, 12340, 12358, 12364.
Remarks: *A. ornata* was attached to pneumatophores in the sun-exposed seaward margin at Port Broughton and Cowleds Landing and occurred at Wallaroo in June but not in March. Plants were also encountered as epiphytes on *Chondria* sp. at Arno Bay and Wallaroo, on *Polysiphonia teges* and *Sphacelaria furcigera* at Red Cliff, and on *Cystophyllum onustum* at Cowleds Landing.

Genus **Erythrotrichia** Areschoug 1850

E. carnia (Dillwyn) J. Agardh 1883: 15. Abbott & Hollenberg 1976: 286, fig. 228. Newton 1931: 242. Taylor 1960: 291.
Type Locality: Wales, Gt. Britain.
Reported Distribution: Widespread.
Specimen Examined: LTB 12247.
Remarks: *E. carnea* grew on pneumatophores, on *Ulva lactuca* and on *Chondria* sp.

Order Nemalionales
Family Acrochaetiaceae
Genus **Audouinella** Bory 1823

A. botryocarpa (Harvey) Woelkerling 1971: 37. Searles & Schneider 1978: 100.
Type Locality: King George Sound, W. Australia.
Reported Distribution: Bunbury, Western Australia to Point Lonsdale, Victoria, and Tasmania; New Zealand; North Carolina.
Specimen Examined: LTB 12248.
Remarks: Plants were attached both to continually submerged and mud-flat pneumatophores at Arno Bay, and usually bore monospores. Woelkerling (1970) provided a detailed account of this alga.

A. daviesii (Dillwyn) Woelkerling 1971: 28, figs 7A-J, 22A-B; 1973: 550, fig. 32-43.
Type Locality: Bantry Bay, Ireland.
Reported Distribution: Widespread.
Specimens Examined: LTB 12249, 12365.
Remarks: Plants of *A. daviesii* grew attached to continually submerged and mud-flat pneumatophores and also on *Ulva lactuca* at Arno Bay. Plants were encountered at Wallaroo in June but not in March.

A. savianna (Meneghini) Woelkerling 1973: 560-565, figs 56-60.
Type Locality: Genoa, Italy.
Reported Distribution: Widespread.
Specimen Examined: LTB 12250.
Remarks: Monosporangial plants were found attached to continually submerged and mud-flat pneumatophores at Arno Bay. A detailed account of this taxon in southern Australia was provided by Woelkerling (1971) using the name *A. thuretii* (Bornet) Woelk. Subsequent comparisons of the type collections of *A. savianna* and *A. thuretii* (Woelkerling 1973) indicated that the two taxa were conspecific, with *A. savianna* having priority.

Order Gelidiales
Family Gelidiaceae
Genus **Gelidiella** Feldmann & Hamel 1934

G. nigrescens (Feldmann) Feldmann & Hamel 1934: 533. Feldmann & Hamel 1937: 222, fig. 7.
Type Locality: Algeria.
Reported Distribution: Uncertain.
Specimens Examined: LTB 12175, 12323.
Remarks: Dense stands of tetrasporangial plants colonized the lower half of pneumatophores at Wallaroo. Plants were more common under the canopy than in sun-exposed regions. A single plant also was collected at Franklin Harbour. The two species of *Gelidiella* recorded in this study closely fit the reproductive and morphological descriptions in Feldmann and Hamel (1934, 1937), and apparently have not been recorded previously from southern Australia.

G. tenuissima Feldmann & Hamel 1937: 226, figs 11, 12A-F.
= *G. panosa* (Bornet) Feldmann & Hamel 1934: 534.
Type Locality: Biarritz, France.
Reported Distribution: Uncertain.
Specimens Examined: LTB 12173, 12207, 12238, 12335, 12366.
Remarks: *G. tenuissima* was common under the *Avicennia* canopy at Wallaroo and Arno Bay and occurred infrequently at Cowleds Landing, Port Augusta and Red

Cliff. Plants were usually fertile and bore either cystocarps or tetrasporangia.

Genus **Gelidium** Lamouroux 1813

G. pusillum (Stackhouse) Le Jolis 1863: 139. Chapman 1969: 89. Dixon & Irvine 1977: 129, fig. 48A-J. May 1965: 371.
TYPE LOCALITY: England.
REPORTED DISTRIBUTION: Widely distributed in tropical and temperate waters.
SPECIMEN EXAMINED: LTB 12367.
REMARKS: Sterile plants occurred infrequently on pneumatophores under the *Avicennia* canopy.

Order CRYPTONEMIALES
Family CORALLINACEAE

REMARKS: With few exceptions, southern Australian representatives of this family are poorly known and never have been the subject of monographic studies. Moreover, species concepts among nongeniculate taxa generally are rather confused and many questions concerning generic concepts also remain unanswered. Consequently the corallines found during the study have not been identified to species, and placement into genera is based on concepts presented by Johansen (1981).

Genus **Heteroderma** Foslie 1909

Heteroderma sp.
SPECIMENS EXAMINED: LTB 12368, 12369.
REMARKS: *Heteroderma* sp. was common on pneumatophores at Wallaroo, and occurred infrequently at Cowleds Landing. Many plants possessed either female or tetrasporangial conceptacles.

Genus **Jania** Lamouroux 1812

Jania sp.
SPECIMEN EXAMINED: LTB 12372.
REMARKS: One small sterile plant, 5 mm tall, was found at Wallaroo in July.

Genus **Lithothamnium** Philippi 1837

Lithothamnium sp.
SPECIMEN EXAMINED: LTB 12318.
REMARKS: Specimens occurred on the lower portion of pneumatophores under the canopy at Franklin Harbour. Most plants bore either female or tetrasporangial conceptacles. The concept of *Lithothamnium* as a genus is under review (Woelkerling 1981).

Genus **Neogoniolithon** Setchell & Mason 1943

Neogoniolithon sp.
SPECIMENS EXAMINED: LTB 12370, 12371.
REMARKS: Crusts up to 4 mm thick occurred on pneumatophores in sun-exposed and shaded regions. Most plants had male or female or tetrasporangial conceptacles.

Genus **Phymatolithon** Foslie 1898

Phymatolithon sp.
SPECIMEN EXAMINED: LTB 12373.
REMARKS: Tetrasporangial plants encrusted the lower portions of pneumatophores.

Order CERAMIALES
Family CERAMIACEAE
Genus **Centroceras** Kuetzing 1841

C. clavulatum (C. Agardh) Montagne 1846: 140. Abbott & Hollenberg 1976: 604, fig. 547. May 1965: 371. Taylor 1960: 537.
TYPE LOCALITY: Caloa, Peru.
REPORTED DISTRIBUTION: Widely distributed in tropical and temperate seas.
SPECIMENS EXAMINED: LTB 12188, 12209, 12217, 12256, 12286, 12321, 12357.
REMARKS: Sterile plants up to 3 cm tall were found entangled with other algae at Wallaroo, and attached to pneumatophores at Red Cliff, Franklin Harbour, Arno Bay and Tumby Bay. Plants were epiphytic on *Cystophyllum onustum* at Red Cliff and Cowleds Landing. No sun or shade preference was evident. Cribb (1979) recorded this species from Queensland mangroves.

Genus **Spyridia** Harvey 1833

S. filamentosa (Wulfen) Harvey 1833: 336. Womersley & Cartledge 1975: 222, fig. 1A-D.
TYPE LOCALITY: Adriatic Sea.
REPORTED DISTRIBUTION: Widespread in tropical and temperate seas.
SPECIMENS EXAMINED: LTB 12170, 12198, 12221, 12283, 12285, 12309, 12325, 12354.
REMARKS: Plants usually grew on the lower half of pneumatophores in both the sun-exposed and shaded regions of the community. *S. filamentosa* was encountered growing on mud surfaces and attached to shells at Tumby Bay and Red Cliff, and as an epiphyte on *Cystophyllum onustum* at Red Cliff and Cowleds Landing. All specimens were sterile. This species occurs on mangroves in Queensland (Cribb 1979, Saenger *et al.* 1977).

Family RHODOMELACEAE
Genus **Bostrychia** Montagne 1842

B. moritziana (Sonder in Keutzing) J. Agardh 1863: 862. Post 1963: 57; 1964: 244.
TYPE LOCALITY: French Guiana.
REPORTED DISTRIBUTION: Widespread in tropical and temperate seas.
SPECIMENS EXAMINED: LTB 12180, 12195, 12230, 12273, 12305, 12330.
REMARKS: *B. moritziana* was locally abundant at Wallaroo, Port Davis, Red Cliff, Blanche Harbour, Cowleds Landing and Franklin Harbour. Plants were most common under the *Avicennia* canopy and often were intermixed with *B. radicans*. Tetrasporangial plants were rare, and cystocarpic or male plants were not found. Davey and Woelkerling (1980) found this to be the most widely distributed species of *Bostrychia* in Victorian mangrove ecosystems, and Cribb (1979) and Saenger *et al.* (1977) recorded the species from Queensland.

B. radicans (Montagne) Montagne 1850: 286.

Type Locality: Sinnamary, French Guiana.

Reported Distribution: Widely distributed in tropical and temperate seas.

Specimens Examined: LTB 12177, 12194, 12229, 12236, 12272, 12287, 12306, 12334.

Remarks: *B. radicans* was the most abundant and widespread species of *Bostrychia* in Spencer Gulf, occurring at all sites except Port Broughton and Port Augusta. Plants often formed mats on pneumatophores under the *Avicennia* canopy and in some cases bore spermatangia, cystocarps or tetrasporangia. The only previous record of this taxon in southern Australia was from the mangrove environment in Victoria (Davey & Woelkerling 1980); Saenger *et al.* (1977) and Cribb (1979) recorded this species from Queensland.

Genus **Caloglossa** J. Agardh 1876

C. leprieurii (Montagne) J. Agardh 1876: 499.

Type Locality: Cayenne, French Guiana.

Reported Distribution: Widespread in tropical and temperate seas.

Specimens Examined: LTB 12179, 12193, 12232, 12235, 12258, 12274, 12307, 12331.

Remarks: *C. leprieurii* was often in association with species of *Bostrychia* and sometimes forming dense, pure stands on pneumatophores in both sun-exposed and shaded regions. Tetrasporangial and cystocarpic plants were found on occasions. This species occurs commonly on mangrove pneumatophores elsewhere in Australia (see Cribb 1979, Davey & Woelkerling 1980).

Genus **Chondria** C. Agardh 1817

Chondria sp.

Specimens Examined: LTB, 12204, 12240, 12291, 12374.

Remarks: *Chondria* sp. occurred infrequently at Wallaroo, Tumby Bay and Red Cliff. Plants were attached to pneumatophores in the sun-exposed seaward margin, and were epiphytic on *Cystophyllum onustum* at Cowleds Landing and on *Ulva lactuca* at Arno Bay. Plants were insufficiently developed for reliable species identification.

Genus **Diplocladia** Kylin 1956

D. patersonis (Sonder) Kylin 1956: 504. May 1965: 383.

Type Locality: Cape Paterson, Victoria.

Reported Distribution: South Australia, Tasmania, Victoria.

Specimens Examined: LTB 12171, 12290, 12324.

Remarks: *D. patersonis* plants up to 10 cm tall were collected both in sun-exposed and shaded areas at Wallaroo, Franklin Harbour and Tumby Bay. The Wallaroo samples collected during winter (June) bore tetrasporangia. Davey & Woelkerling (1980) reported this species on mangroves at two localities in Victoria.

Genus **Herposiphonia** Nageli 1846

Herposiphonia sp.

Specimens Examined: LTB 12339, 12375.

Remarks: The two collections of *Herposiphonia* obtained during this study probably are referrable to different species but both were sterile, and as noted by Abbott & Hollenberg (1976: 720) such specimens often are difficult to identify to species level with confidence. Plants (sp. "A") in the Cowleds Landing collection (LTB 12339) had determinate branches 40-60 μm in diameter, which were 7-14 segments long and had 6-7 pericentral cells. These specimens appeared to be most similar to *H. delicatula* Hollenberg (1968: 540). Plants (sp. "B") in the Wallaroo collection (LTB 12375) had determinate branches 70-80 μm in diameter which were mostly 12-18 segments long and had 8-9 pericentral cells. These specimens appeared to be most similar to *H. tenella* f. *secunda* (C. Agardh) Hollenberg (1968).

Genus **Laurencia** Lamouroux 1813

Laurencia sp.

Specimens Examined: LTB 12168, 12208, 12216, 12355.

Remarks: Sterile plants up to 3 cm tall were found on pneumatophores at Wallaroo and Red Cliff, and other plants occurred epiphytically on *Cystophyllum onustum* at Red Cliff and Cowleds Landing. Species identification could not be made with certainty but these specimens appeared to be most similar to *Laurencia shepherdii* Saito & Womersley (1974).

Genus **Lophosiphonia** Falkenberg in Schmitz & Falkenberg 1897

L. subadunca (Kuetzing) Falkenberg 1901: 496, p1.9, figs. 21-24. Cribb 1956: 139. May 1965: 380. Taylor 1960: 605.

Type Locality: Corsica.

Reported Distribution: Arabia; southern Australia; Bahamas; Mediterranean; Queensland; Texas.

Specimen Examined: LTB 12376.

Remarks: *L. subadunca* was common at Wallaroo in June, but absent in March. Plants were sterile, up to 2 cm tall, and occupied the lower portion of *A. marina* pneumatophores under the canopy. According to Cribb (1956) *L. subadunca* has not been recorded from southern Australia.

Genus **Polysiphonia** Greville 1824

P. infestans Harvey 1855: 539. Womersley 1979: 481, fig. 6A-E.

Type Locality: Princess Royal Harbour, King George Sound, W. Australia.

Reported Distribution: From North Beach Reef, Perth, southwards and along the southern Australia coast. Botany Bay, New South Wales.

Specimens Examined: LTB 12232, 12299.

Remarks: Sterile plants up to 3 cm tall, were encountered on the lower portion of pneumatophores.

P. scopulorum Harvey 1855: 540. Womersley 1979: 467, fig. 2A-E.

Type Locality: Rottnest Island, W. Australia.

Reported Distribution: From Rottnest Island, W. Australia to Lawrence Rock, Victoria.

Specimens Examined: LTB 12205, 12218.

Table 3
Morphologic Affinities of the Spencer Gulf *Cladophorella* With Other Described Species

Species of *Cladophorella*	Cell dia. range (µm)	Cell length: width ratio	Cell wall structure	Cell wall dia. (µm)	Reported habitat and references
C. calcicola	23-39	3-10	Lamellate	8	Hot house walls, Cambridge Botanical Gardens (Fritsch 1944). *A. marina* mangrove environment in Queensland (Cribb 1979). Semi-marine cavern in Queensland (Cribb 1965).
C. fritschii	55-88	1½-3½	Lamellate	3-15	Freshwater environment in East Pakistan (Islam 1964).
C. sundarbanensis	15-55	2½-6	Not Lamellate	2-4	Mangrove environment in Bangladesh (Islam 1973). Brackish water in East Pakistan (Islam 1964).
C. marina	80-240	1-5	Lamellate	Not Supplied	Marine environment, New Zealand (Chapman 1956).
Spencer Gulf *Cladophorella*	140-250	1-4	Lamellate	10-50	*Avicennia marina* mangrove environment in Spencer Gulf.

Remarks: Sterile plants, 2 cm tall, were epiphytic on *C. onustum* under the canopy, and attached to a single pneumatophore in a tidal creek, at Red Cliff. Cribb (1979) recorded this species from Queensland mangroves.

P. subtilissima Montagne 1840: 199. Womersley 1979: 469, fig. 2F-1.

Type Locality: Cayenne, French Guiana.

Reported Distribution: Tropical and sub-tropical Eastern America, French Guiana, Hawaiian Islands; in southern Australia from Coffin Bay, South Aust., to Port Phillip Bay, Victoria; Tasmania; Botany Bay, New South Wales.

Specimen Examined: LTB 12255.

Remarks: Tetrasporangial plants, up to 3 cm tall, were attached to continually submerged and mud-flat pneumatophores at Arno Bay.

P. teges Womersley 1979: 494, fig. 10A-C.

Type Locality: Frenchmans Bay, Albany, W. Australia.

Reported Distribution: Type locality and Spencer Gulf, S.A.

Specimens Examined: LTB 12174, 12265, 12284, 12352.

Remarks: Specimens occurred epiphytically on *Cystophyllum onustum* at Cowleds Landing and on the lower portions of pneumatophores at Wallaroo, Port Augusta, and Blanche Harbour. Tetrasporangial plants were collected at the latter two locations. The only previously known specimens from Spencer Gulf were epilithic (Womersley 1979, H. B. S. Womersley pers. comm.).

FREQUENCY DATA

Frequency data for the 42 species collected from the belt transects are summarized in Table 4. Seven taxa (*Bostrychia radicans*, *Caloglossa leprieurii*, *Cladophorella marina*, *Enteromorpha* sp., *Gelidiella tenuissima*, *Rhizoclonium riparium*, *Rivularia atra*) occurred commonly ($F = 0.50$ to 0.75) or abundantly ($F > 0.75$) at one or several localities, and based on mean frequency values [i.e. $\Sigma F/N$, where ΣF is the sum of all recorded frequencies >0 and N is the total number of localities at which the alga occurred; see Table 4], *Caloglossa leprieurii* is the most conspicuous alga in Spencer Gulf mangrove ecosystems. Although all seven taxa were recorded from a majority of study sites, none

TABLE 4

FREQUENCY DATA FOR ALGAE ASSOCIATED WITH SPENCER GULF MANGROVES.
Taxa found outside sampling transects are recorded as present (P).

Taxon	ARNO BAY	BLANCHE HARBOUR	COWLEDS LANDING	FRANKLIN HARBOUR	PORT AUGUSTA	PORT BROUGHTON	PORT DAVIS	RED CLIFF	TUMBY BAY	WALLAROO	MEAN FREQUENCY (F)
CHLOROPHYTA											
Chaetomorpha aerea	0.11									0.09	0.10
C. capillaris		0.05									0.05
Cladophora sp.	0.17	0.27	0.02	0.20	0.21	P		0.03	0.04	0.26	0.16
Cladophorella marina	0.31	0.02	0.75	0.17	0.06			0.01	0.18	0.48	0.25
Enteromorpha sp.	0.27	0.26	0.02	0.22	0.57	P	0.55		0.30		0.31
Percursaria percursa	0.33	0.30		0.02				0.14	0.15	0.33	0.21
Rhizoclonium implexum	0.06			0.05			0.06		0.34	0.06	0.11
R. riparium	0.52		0.06	0.44	0.37	P	0.84	0.26	0.04	0.13	0.33
Sporocladopsis novaezelandiae			0.05	0.02					0.04		0.06
Ulva lactuca	0.24			0.24	0.02		0.02			0.13	0.13
CYANOPHYTA											
Rivularia atra		0.09	0.54	0.34	0.49			0.20	0.05	0.50	0.31
R. polyotis		0.11	0.26	0.02				0.22			0.15
PHAEOPHYTA											
Cystophyllum onustum			P					P			
Dictyota sp.			P					P		P	
Ectocarpus siliculosus	0.02										0.02
Ectocarpus sp.					0.02						0.02
Giffordia sordida										P	
Hormosira banksii			0.01	0.01						0.09	0.04
Kuetzingiella sp.	0.07	0.02	0.05	0.05	0.03				0.18		0.07
Sphacelaria furcigera	0.09			0.11	0.02			0.01			0.12
S. tribuloides				0.04	0.02			0.01			0.04

was encountered at all nine transect localities. Moreover, all seven taxa also occurred only rarely (F<0.05) or sporadically (F=0.05 to 0.24) at one or more localities and except at Wallaroo, frequency values for *Gelidiella tenuissima* never exceeded 0.13.

Nine additional taxa (*Bostrychia moritziana*, *Centroceras clavulatum*, *Chondria* sp., *Cladophora* sp., *Kuetzingiella* sp., *Percursaria percursa*, *Rhizoclonium implexum*, *Spyridia filamentosa*, *Ulva lactuca*) also occurred at a majority of study sites, but with relatively few exceptions, these species occurred rarely (F<0.05) or sporadically (F=0.05 to 0.24) and none was ever common or abundant.

In addition to the above 16 taxa, 4 (*Diplocladia patersonis*, *Gelidiella nigrescens*, *Heteroderma* sp., *Neogoniolithon* sp.) occurred with occasional frequencies (F=0.25 to 0.49) at Wallaroo. Overall, however, these algae occurred at only 1-3 study sites and were rare or sporadic except at Wallaroo. The remaining 21 algae were detected only at a minority of study sites, always were rare or sporadic, and thus appear to be of relatively little significance in Spencer Gulf mangrove ecosystems.

At a particular locality, 3 to 12 species occurred with frequencies of 0.25 or more, and except for Blanche Harbour and Tumby Bay, at least one species was common (F=0.50 to 0.75) or abundant (F>0.75). Four of the 7 species found at Port Davis were common or abundant, while other localities only 1 or 2 common or abundant taxa were present. At all study sites except Port Broughton, either *Caloglossa leprieurii* or *Bostrychia radicans* or both occurred with frequencies of 0.25 or more. Frequency data were not obtained for Port Broughton, but neither *Bostrychia* nor *Caloglossa* plants were found there. At Wallaroo, eight red algae with frequencies of 0.25 or more were present; no more than 3 such red algae occurred at any other site. Similarly 5 green algae with frequencies of 0.25 or more grew at Arno Bay while at all other localities no more than 3 such species occurred. Blue green algae became occasional to abundant ($F \geq 0.25$) at Cowleds Landing, Franklin Harbour, Port Augusta, and Wallaroo but brown algae occurred only rarely or sporadically at localities where they were present.

DISCUSSION

The marine algal flora of cool temperate Australia is rich and diverse in species, often with a biomass predominance of larger brown algae (especially Fucales) and a high percentage (71%) of endemic genera (Womersley 1981b). This contrasts with the comparatively depauperate algal flora in Spencer Gulf mangrove ecosystems, mostly consisting of red algae

TABLE 4 (Continued)

Taxon	ARNO BAY	BLANCHE HARBOUR	COWLEDS LANDING	FRANKLIN HARBOUR	PORT AUGUSTA	PORT BROUGHTON	PORT DAVIS	RED CLIFF	TUMBY BAY	WALLAROO	MEAN FREQUENCY (F)
RHODOPHYTA											
Audouinella botryocarpa	0.09										0.09
A. daviesii	0.06										0.06
A. saviana	0.03										0.03
Asterocytis ornata	0.01		0.02			P		0.02	0.01		0.02
Bostrychia moritziana		0.10	0.16	0.26			0.46	0.20		0.09	0.21
B. radicans	0.44	0.15		0.12			0.50	0.30	0.43	0.36	0.33
Caloglossa leprieurii	0.72	0.25	0.45	0.56	0.60		0.77	0.58		0.08	0.50
Centroceras clavulatum	0.01			0.04				0.06	0.22	0.06	0.08
Chondria sp.	0.12			0.01				0.03	0.04	0.03	0.05
Diplocladia patersonis				0.01					0.02	0.28	0.10
Erythrotrichia carnea	0.18										0.18
Gelidiella nigrescens										0.32	0.32
G. tenuissima	0.13		0.07		0.01			0.03		0.51	0.15
Gelidium pusillum										P	
Herposiphonia sp. "A"			0.05							0.07	0.06
Herposiphonia sp. "B"										0.07	0.10
Heteroderma sp.			0.07							0.32	0.17
Jania sp.										P	
Laurencia sp.								0.04		0.08	0.06
Lithothamnium sp.				0.12							0.12
Lophosiphonia subadunca										P	
Neogoniolithon sp.			0.16							0.30	0.23
Phymatolithon sp.										0.03	0.03
Polysiphonia infestans				0.02					0.04		0.03
P. scopulorum								P			
P. subtilissima	0.05										0.05
P. teges		0.04	P		0.03					0.24	0.10
Spyridia filamentosa	0.09	0.02	0.01	0.06		P		0.17	0.23	0.25	0.12

which have wide distributions. Based on published species estimates (Womersley 1981b: 301) only 10 (9.8%) of the 97 Chlorophyta, nine (4.4%) of the 203 Phaeophyta and 28 (3.5%) of the 800 Rhodophyta species known to occur in southern Australia seas were encountered in Spencer Gulf mangrove ecosystems. Only one alga (*Diplocladia patersonis*), of the 49 reported is endemic to southern Australia; the remaining 48 taxa are more widespread and nearly all have been reported outside Australian waters. All species recorded in Spencer Gulf are known to occur on open coastlines.

Four species (*Cladophorella marina*, *Gelidiella nigrescens*, *Gelidiella tenuissima*, *Lophosiphonia subadunca*) found during this study, are generally considered tropical, and have not been reported previously from the southern coast of Australia.

The genus *Cladophorella* has not been reported from southern Australia (see Womersley 1956, 1971) and the only record of *Gelidiella* from the southern region of Australia is *G. ramellosa* which was originally described as *Acrocarpus ramellosus* by Sonder (1848) from an unspecified locality in Western Australia (see also Kuetzing 1868, Tab. 34 d-f). Three other tropical algae (*Acetabularia calyculus*, *Hormophysa triquetra*, *Sargassum decurrens*) have been recorded outside the mangrove environment in Spencer Gulf (Womersley 1981b).

Numerous hypotheses have been proposed to explain disjunct distributions of marine benthic algae. These include:

1. Spread by shipping (Farnham *et al.* 1973, Lewis & Kraft 1979, Womersley 1981b);
2. Ocean currents (Womersley, 1981b);
3. Continental drift (Chapman 1953); and
4. The possibility that they are relict populations (Womersley 1981b).

The establishment of algal species distant from their modern recorded natural distributions was tentatively attributed to transport on shipping for *Schottera nicaeensis* (Lamouroux ex Duby) Guiry and Hollenberg in Port Phillip Bay (Lewis & Kraft 1979) and for *Sargassum muticum* and other algae in Britain (Farnham 1980, Farnham *et al.* 1973). This hypothesis is based on the apparent absence of these species from previous floristic records and their recent appearance near busy shipping ports. Spread by ocean currents over long distances seems to be of rare occurrence, due to the short life of algal spores and drifting fragments (Womersley 1981b).

An alternative hypothesis is that the isolated populations in Spencer Gulf are relics of warmer climatic periods when their natural distributions may have been quite different, and that they are able to survive in Spencer Gulf because the summer water temperatures are sufficiently high for reproduction to occur (Womersley 1981b). These populations may be relict from the Cretaceous era (70-130 million years ago) when an inland sea (Brown *et al.* 1968) joined southern Australia to the tropical waters of the Arafura sea.

Continental drift has been another hypothesis used to explain the disjunct distribution of algae (Chapman 1953). Chapman (1953) used an example of three genera (*Ecklonia*, *Macrocystis*, *Splachnidium*) which occur in both South Africa and South America. This hypothesis fails to explain the occurrence of tropical species in Spencer Gulf because, prior to continental drift (Coulomb 1969), southern Australia was connected to the Antarctic.

On the available data, it seems equally possible, that the species with tropical affinities are remnants of an earlier climatic period or, since Spencer Gulf includes a number of ports, that the algae may also have been transported by shipping. The least likely hypothesis to explain the occurrence of tropical algae in Spencer Gulf is continental drift.

Of the 10 localities examined, Blanche Harbour, Port Augusta and Red Cliff were subject to the higher salinities and surface water temperatures of the far north of Spencer Gulf while the remaining seven sites were situated in areas of more moderate salinity and temperature further south. The total flora in the far northern region (30 taxa) was less diverse than in more southern sites (47 taxa), and only one taxon (*Ectocarpus* sp.) appeared to be confined to the far north. Hence, high salinity or surface water temperature may restrict mangrove algal community composition. Davey and Woelkerling (1980) also found that the estuarine (brackish water) influence adversely affects algal diversity on Victorian mangroves. Species of *Bostrychia* and *Caloglossa*, however, occur in the estuarine environment in Victoria, the high salinity region of northern Spencer Gulf, and are widespread in tropical Queensland (Cribb 1979) and outside of Australian waters (Post 1963). Their widespread distributions may be attributed to their high resistance to osmotic shock, desiccation or temperature extremes and/or salinity extremes (e.g. Biebl 1962, Davis & Dawes 1981, Yarish *et al.* 1979, Yarish *et al.* 1981). Further studies would be required to determine whether the more characteristic mangrove algae have a relatively higher tolerance to stressed conditions than other species with more limited distributions.

The total number of species (Chlorophyta, Phaeophyta, Rhodophyta) in Spencer Gulf mangrove algal communities is far more diverse than heretofore realised; 43 (88%) of the species found during this study were not recorded previously from South Australian mangrove ecosystems. The total number of mangrove algae in Spencer Gulf (Table 5) is comparable to that reported (Cribb 1979, Saenger *et al.* 1977) from *Avicennia* pneumatophores in tropical Queensland (47 taxa), but more diverse than reported (Davey & Woelkerling 1980) from Victorian mangroves (23 taxa). It was thought previously (Davey & Woelkerling 1980) that the species richness of temperate Victorian mangrove communities was comparable to that reported by Saenger *et al.* (1977) from tropical Queensland (23 taxa). The recent floristic contribution of Cribb (1979), however, has indicated that the Queensland communities are more species rich (Table 5).

Species composition differs substantially between these three regions of Australia. Of the 10 recorded species of Chlorophyta in Spencer Gulf, two occurred in Queensland and three in Victoria; of the 28 recorded Rhodophyta, six occurred in Queensland and four in Victoria; of the nine Phaeophyta, none have been reported in Queensland or in Victoria. Thus, only 20% of the total eucaryotic macroscopic algal flora in Spencer Gulf has been reported from Queensland and only 17% from Victoria. *Percursaria percursa* and *Diplocladia patersonis* are common to Spencer Gulf and Victorian mangrove communities and do not occur on tropical Queensland mangroves. Because no distinction has been made in most cases between those taxa present in mangrove ecosystems and those taxa present in salt marsh ecosystems in New South Wales (King 1981a: 323-324, Saenger *et al.* 1977), only a few algal taxa (Table 5) are recorded unequivocally from New South Wales mangroves and meaningful comparisons with the Spencer Gulf flora are not possible. Absence of detailed data prevents biogeographic comparisons of the Spencer Gulf algal flora with those of Northern Territory, Western Australia, and other parts of South Australia (Gulf St. Vincent, Streaky Bay—Ceduna region).

Bostrychia and *Caloglossa* were thought not to occur on South Australian mangroves (Womersley 1981a), but this study has revealed that they are two of the most widespread and common algae in Spencer Gulf communities. All species of these two genera, also have been found on mangroves in Queensland and Victoria. Eight additional species of *Bostrychia* and two additional species of *Caloglossa* occur on Queensland mangroves, and two additional species of *Bostrychia* occur on Victorian mangroves. Species of *Catenella*, widespread in other mangrove ecosystems, were not found in Spencer Gulf.

Frequency data from Spencer Gulf (Table 4) and Victoria (Davey & Woelkerling 1980) suggest that the mangrove algal communities of the two regions are similar in some respects but differ in others. In both regions, *Caloglossa leprieurii* is the most conspicuous taxon. *Bostrychia radicans* was occasional, common, or abundant at many localities in both areas, while species of *Enteromorpha* and *Ulva* appear to occur with a similar range of frequencies in Spencer Gulf and Victoria.

TABLE 5

BIOGEOGRAPHIC COMPARISONS OF THE ALGAL FLORA RECORDED FROM MANGROVE ECOSYSTEMS IN SOUTH AUSTRALIA, NEW SOUTH WALES, QUEENSLAND AND VICTORIA, WITH THOSE OF SPENCER GULF (Reference sources are numerically coded)

	Spencer Gulf, S.A. (Present Study)	South Australia (1,7,8,9)	N.S.W. (4,5,6)	QLD. (2,6)	VIC. (3)	Reported Australian Mangrove Algae (Present Study + 1 − 9)
Chlorophyta	10	3	—	14	6	22
Chrysophyta	—	—	—	—	1	1
Phaeophyta	9	1	1	3	3	13
Rhodophyta	28	—	6	30	13	53
Total	47	4	7	47	23	89
Bostrychia	3	—	3	10	4	12
Caloglossa	1	—	1	3	1	3
Catenella	—	—	1	2	1	2
Total	4	—	5	15	6	17

References

1, Butler *et al.* (1977b); 2, Cribb (1979); 3, Davey & Woelkerling (1980); 4, King (1981a); 5, King (1981b); 6, Saenger (1977); 7, Specht (1972); 8, Womersley & Edmonds (1958); 9, Wood (1937).

In contrast, *Cladophorella marina* and *Rivularia atra*, fairly conspicuous components of Spencer Gulf mangrove ecosystems, were not found in Victoria, and conversely *Bostrychia intricata* and *Catenella nipae* were widespread and often prevalent in Victoria but were not found in Spencer Gulf mangroves. *Hormosira banksii*, not recorded by Davey & Woelkerling (1980) from Victorian mangroves, occurs only rarely or sporadically in Spencer Gulf mangroves studied. This contrasts with the reports of Butler *et al.* (1977a, 1977b) who regard *H. banksii* as common in South Australian mangroves and with the record of Clarke and Womersley (1981: 500) from St. Vincent Gulf.

In Victoria, 3-5 prevalent ($F \geq 0.50$) species occurred at half of the 16 study sites and at least 1 prevalent species was present at every locality. In Spencer Gulf, however, only one site (Port Davis, 4 prevalent species) harboured more than 2 prevalent species and at two localities (Blanche Harbour, Tumby Bay) no prevalent species occurred at all. Reasons for the generally lower number of prevalent species at Spencer Gulf study sites remain unclear, and whether a reduction in the number of prevalent species occurs as the overall diversity increases is also uncertain.

Both in Spencer Gulf and in Victoria, a majority of algal taxa found in mangrove ecosystems always appear to be rare ($F < 0.05$) or sporadic ($F = 0.05$ to 0.24). In Victoria, only 10 of the 23 (43%) taxa found registered frequencies greater than 0.24. In Spencer Gulf 16 of 41 (39%) similar taxa occurred. Thus in both regions, only a minority of mangrove algae appear to be potentially well adapted to the environmental stresses present.

ACKNOWLEDGEMENTS

Sincere thanks are due to Dr. Ian Price for identifying taxa of the Gelideaceae, Professor H. B. S. Womersley for confirming identifications of taxa of *Rhizoclonium*, Dr. Michael Wynne for examining some collections of Rhodomelaceae and Mr. Doug Reilley of the Red Cliff environmental research station for hospitality during field trips.

REFERENCES

ABBOTT, I. A. & HOLLENBERG, G. J., 1976. *Marine Algae of California.* Stanford University Press, Stanford, California.

AGARDH, C. A., 1817. *Synopsis Algarum Scandinaviae, Adjecta Dispositione Universali Algarum.* Berling, Lund.

AGARDH, C. A., 1821. *Species Algarum.* Vol 1. Berling, Lund.

AGARDH, J. G., 1848. *Species, Genera et Ordines Algarum. Vol. 1. Species genera et ordines fucoidearum.* T. O. Weigel, Leipzig.

AGARDH, J. G., 1863. *Species, Genera et Ordines Algarum. Vol. 2, Pt. 3, Fasc. 3. Species genera et ordines floridearum.* T. O. Weigel, Leipzig.

AGARDH, J. G. 1876. *Species, Genera et Ordines Algarum. Vol. 3, Pt. 1. Epicrisis systematis floridearum.* T. O. Weigel, Leipzig.

AGARDH, J. G., 1883. Till algernes systematik. Nya bidrag. *Lunds Univ. Arsskr.* 19(2): 1-182.

ARESCHOUG, J. E., 1850. Enumeratio phycearum in maribus Scandinaviae crescentium. Sectio posterior, Ulvaceas continens. *Nova Acta R. Soc. Scient. upsal.* Ser. 2, 14: 385-454.

AUSTRALIAN NATIONAL TIDE TABLES, 1981. Australian Government Publishing Service, Canberra.

Biebl, R., 1962. Protoplasmatische-okologische Untersuchungen an Mangrovalgen von Puerto Rico. *Protoplasma* 55: 572-606.

Bliding, C., 1963. A critical survey of european taxa in Ulvales. Pt. I. *Capsosiphon, Percursaria, Blidingia, Enteromorpha. Op. bot. Soc. bot. Lund.* 8(3): 1-160.

Bliding, C., 1968. A critical survey of european taxa in Ulvales. Pt. II. *Ulva, Ulvaria, Monostroma, Kornmannia. Bot. Notiser* 121: 535-629.

Boergesen, F., 1925. Marine algae from the Canary Islands. I. Chlorophyceae. *Kgl. Danske Vidensk. Selsk. Biol. Medd.* 5(3): 1-123.

Bornet, E. & Flahault, C., 1886. Revision des Notocacées Hétérocystées. *Annls. Sci. nat.* Ser. 7, 4: 343-373.

Bory de Saint-Vincent, J. B., 1823. *Audninella. In: Dictionnaire Classique d'Histoire Naturelle*, Vol. 3. CAD-CHI, pp. 340-341, Ray et Gravier, Paris.

Bory De Saint-Vincent, J. B., 1828. *Percursaria. In: Dictionnaire Classique d'Histoire Naturelle*. Vol. 13. PAN-PIV. p. 206, Ray et Gravier, Paris.

Brown, D. A., Campbell, K. S. W. & Crook, K. A. W., 1968. The Geological Evolution of Australia and New Zealand. Pergamon Press, London.

Bullock, D. A., 1975. The general water circulation of Spencer Gulf, South Australia, in the period February to May. *Trans. R. Soc. S. Aust*, 99: 43-53.

Butler, A. J., Depers, A. M., McKillup, S. C. & Thomas, D. P., 1977a. Distribution and sediments of mangrove forests in South Australia. *Trans. R. Soc. S. Aust.* 101: 35-44.

Butler, A. J., Depers, A. M., McKillup, S. C. & Thomas, D. P., 1977b. A survey of mangrove forests in South Australia. *S. Aust. Nat.* 51: 39-49.

Chapman, V. J., 1949. Some new species and forms of marine algae from New Zealand. *Farlowia* 3: 495-498.

Chapman, V. J., 1953. Distribution of marine algae in relation to continental drift. *Proc. VII. Pacif. Sci. Congr.* 5: 40-43.

Chapman, V. J., 1956. The marine algae of New Zealand. Pt. I. Myxophyceae and Chlorophyceae. *J. Linn. Soc. Bot. Lond.* 55: 333-501.

Chapman, V. J., 1969. *The Marine Algae of New Zealand. Pt. III. Rhodophyceae, issue I: Bangiophycidae and Florideophycidae (Nemanionales, Bonnemaisoniales, Gelidiales).* J. Cramer, Lehre.

Clarke, S. M. & Womersley, H. B. S., 1981. Cross fertilization and hybrid development of forms of the brown alga *Hormosira banksii* (Turner) Decaisne. *Aust. J. Bot.* 29: 497-505.

Clayton, M. N., 1974. Studies on the development, life history and taxonomy of the Ectocarpales (Phaeophyta) in southern Australia. *Aust. J. Bot.* 22: 743-813.

Coulomb, J., 1969. *Sea floor spreading and continental drift.* D. Riedel, Holland.

Cribb, A. B., 1956. Records of marine algae from southeastern Queensland. II, *Polysiphonia* and *Lophosiphonia. Pap. Dep. Bot. Univ. Qd* 3: 131-147.

Cribb, A. B., 1965. An ecological and taxonomic account of the algae of a semi-marine cavern Paradise Cave, Queensland. *Pap. Dep. Bot. Univ. Qd* 4: 259-282.

Cribb, A. B., 1979. Algae associated with mangroves in Moreton Bay, Queensland. In *Northern Moreton Bay Symposium*, A. Bailey & N. C. Stevens, eds, Royal Society of Queensland, Brisbane, 63-69.

Davey, A. & Woelkerling, W. J., 1980. Studies on Australian mangrove algae. I. Victorian communities: Composition and geographic distribution. *Proc. R. Soc. Vict.* 91: 53-66.

Davis, M. A. & Dawes, C. J., 1981. Seasonal photosynthetic and respiratory responses of the intertidal red algae, *Bostrychia binderi* Harvey (Rhodophyta, Ceramiales) from a mangrove swamp and a salt marsh. *Phycologia* 20: 165-173.

Decaisne, J., 1842. Essais sur une classification sès algues et des polypiers calcifers de Lamouroux. *Annls. Sci. nat. Bot.* Ser. 2, 17: 297-380.

De Toni, J. B., 1895. *Sylloge Algarum* Vol. 3. De Toni, Padova.

Dixon, P. S. & Irvine, L. M., 1977. *Seaweeds of the British Isles. Vol. I. Rhodophyta. Pt. I. Introduction, Nemaliales, Gigartinales.* British Museum (Natural History), London.

Drouet, F., 1973. *Revision of the Nostocaceae with Cylindrical Trichomes.* Hafner Press, New York.

Drouet, F., 1978. *Revision of the Nostocaceae with constricted trichomes.* J. Cramer, Lehre.

Easton, A. K., 1974. A reappraisal of the tides in Spencer Gulf, South Australia. *Aust. J. mar. Freshwat. Res*, 29: 247-277.

Falkenberg, P., 1901, Die Rhodomelaceen des Golfes von Neapel und der angrenzenden Meers-abschnitte. *Fauna Flora Golf. Neapel* 26: i-xvi, 1-754.

Farnham, W. F., 1980. Studies on aliens in the marine flora of southern England. In *The Shore Environment, Vol. 2: Ecosystems*, J. H. Price, D. E. G. Irvine, & W. F. Farnham, eds. Academic Press, London, 875-914.

Farnham, W. F., Fletcher, R. L. & Irvine, L. M., 1973. Attached *Sargassum* found in Britain. *Nature, Lond.* 243: 231-232.

Feldmann, J., 1937. Recherches sur la végétation marine de la Mediterranée. La côte des Albères. *Revue algol.* 10: 1-339.

Feldmann, J. & Hamel, G., 1934. Observations sur quelques Geldiacées. *Revue gen. Bot.* 46: 529-549.

Feldmann, J. & Hamel, G., 1937. Les algues marines de la côte des Albères. II. Chlorophycées. *Revue algol.* 9: 141-329.

Foslie, M. H., 1898. List of species of the Lithothamnia. *Kgl. Norske Vidensk. Selsk. Skr*, 1898(3): 1-11.

Foslie, M. H., 1909. Algologiske notiser. VI. *Kgl. Norske Vidensk. Selsk. Skr.* 1909(2): 1-63.

Fritsch, F. E., 1944. *Cladophorella calcicola* nov. gen. et sp., a terrestrial member of the Cladophorales. *Annls. Bot.* N.S. 8: 157-171.

Goldsmith, F. B. & Harrison, C. M., 1976. Description and analysis of vegetation. In *Methods in Plant Ecology*, S. B. Chapman, ed., Blackwell Scientific, Oxford, 85-155.

Greville, R. K., 1824. *Flora Edinensis.* William Blackwood, Edinburgh.

Hamel, G., 1925. Floridées de France III. *Revue algol.* 2: 39-67.

Hamel, G., 1939. *Phaeophycees de France.* Fasc 5. *Paris.*

Harvey, W. H., 1833. Algae. In *The English Flora of Sir James Edward Smith. Class XXIV. Cryptogamia. Vol. 5, Pt. I*, W. J. Hooker, ed., Longman, Rees, Orme, Brown, and Green, London, 248-415.

Harvey, W. H., 1849. *Phycologia Britanica* Fasc. 40, pls. 235-240, L. Reeve, London.

Harvey, W. H., 1855. Some account of the marine botany of the colony of Western Australia. *Trans. R. Ir. Acad.* 22: 525-566.

Holmgren, P. K. & Kueken, W., 1977. Additions to 'The Herbaria of the World', ed. 6(11). *Taxon* 26: 483-491.

Hollenberg, G. J., 1968. An account of the species of the red alga *Herposiphonia* occurring in the central and western tropical Pacific Ocean. *Pacif. Sci.* 22: 536-559.

Islam, A. K. M., 1964. The genus *Cladophorella* newly found in East Pakistan. *Revue algol.* 7: 276-289.

Islam, A. K. M., 1973. The flora of Sundarbans mangrove forest, Bangladesh. *Bangladesh J. Bot.* 2: 11-36.

Johansen, H. W., 1981. *Coralline Algae, a first synthesis.* CRC Press: Boca Raton, Florida.

King, R. J., 1981a. Mangrove and saltmarsh plants. In *Marine Botany: An Australasian Perspective*, M. N. Clayton & R. J. King, eds., Longman Cheshire, Melbourne, 309-328.

King, R. J., 1981b. The macroalgae of mangrove communities in eastern Australia. *Phycologia* 20: 107-108.

King, R. J., 1981c. The free-living *Hormosira banksii* (Turner) Decaisne associated with mangroves in temperate eastern Australia. *Bot. mar.* 24: 569-576.

Kuckuck, P., 1956. Ectocarpaceen-studien. IV. *Herponema, Kuetzingiella* nov. gen., *Farlowiella* nov. gen. *Helgolander wiss. meeresunters* 5: 361-382.

Kuetzing, F. T., 1841. Ueber *Ceramium* Ag. *Linnaea* 16: 727-746.

Kuetzing, F. T., 1843. *Phycologia Generalis*. F. A. Brockhaus, Leipzig.

Kuetzing, F. T., 1845. *Phycologia Germanica*. W. Kohne, Nordhausen.

Kuetzing, F. T., 1849. *Species Algarum*. F. A. Brockhaus, Leipzig.

Kuetzing, F. T., 1855. *Tabulae Phycologicae*. Vol. 5. Kuetzing, Nordhausen.

Kuetzing, F. T., 1868. *Tabulae Phycologicae*. Vol. 18. Kuetzing, Nordhausen.

Kylin, 1956. *Die Gattungen der Rhodophyceen*. Gleerups, Lund.

Lamouroux, J. V. F., 1809. Exposition des characteres du genre *Dictyota*, et tableau des especes qu'il renferme. *J. Bot.*, Paris 2: 38-44.

Lamouroux, J. V. F., 1812. Extrait d'un memoire sur la classification des polypiers coralligenes non entierement pierreux. *Nouv. Bull. Sc. Soc. Philomat. Ser. 2*, 3: 181-188.

Lamouroux, J. V. F., 1813. Essai sur les genres de la famille des Thalissiophytes non articulees. *Ann. Mus. Hist. nat.*, Paris 20: 21-47, 115-139, 267-293.

Le Jolis, A., 1863. Liste des algues marines de Cherbourg. *Mem. Imp. Soc. Sci. nat. Cherbourg* 10: 1-168.

Lewis, J. A. & Kraft, G. T., 1979. Occurrence of a European red alga (*Schottera nicaeensis*) in southern Australian waters. *J. Phycol.* 15: 226-230.

Link, H. F., 1820. Epistola de algis aquaticus in genera disponendis. In *Novae Physicae Berolineses*, C. G. D. Nees, ed., Marcus, Bon, 1-8.

Linnaeus, C., 1753. *Species Plantarum*. 1 Ed., L. Salvii: Stockholm.

Lyngbye, H. C., 1819. *Tentamen Hydrophytologiae Danicae*. Schultzianis, Copenhagen.

Macnae, W., 1966. Mangroves in eastern and southern Australia. *Aust. J. Bot.* 14: 67-103.

May, V., 1965. A census and key to the species of Rhodophyceae (red algae) recorded from Australia. *Contr. N.S.W. natn. Herb.* 3: 349-429.

Meneghini, G., 1838. Cenni sulla organografia e fisiologia delle alghe. *Accad. Sci. Padova* 4: 325-88.

Montagne, J. F. C., 1840. Seconde centurie de plantes cellularies exotiques nouvelles, decades I et II. *Annls, Sci. nat. Bot.* Ser. 2, 13, 193-207, pl. 5, 6.

Montagne, J. F. C., 1842. Algae. In *R. de la Sagra, Histoire Physique Politique et Naturelle de L'Ile de Cuba. Botanique-Plantes Cellulares*, 1-104, A. Bertrand, Paris.

Montagne, J. F. C., 1846. Phyceae. In *Exploration Scientifique de l'Algerie Flore d'Algerie Cryptogamie Paris*, M. C. Durieu de Maisonneuve, ed., Impreimerie Royale, Paris, 1-197.

Montagne, J. F. C., 1850. Cryptogamia guaynensis, sue plantarum cellularium in Guayana Gallica annls. 1835-1849 el. Leprieur collectarum enumeratio universalis. *Annls Sci. nat. Bot.* Ser. 3: 14, 283-309.

Nageli, C., 1846. *Herposiphonia Z.wiss.Bot.* 1:238-256.

Nasr, A. H., 1947. Synopsis of the marine algae of the Egyptian Red Sea coast. *Bull. Fac. Sci. Fouad I Univ.* 26: 1-155.

Newton, L., 1931. *A Handbook of the British Seaweeds.* British Museum (Natural History), London.

Philippi, P., 1837. Beweis dass die Nulliporen Pflanzen sind. *Arch. Naturgesch.* 3: 387-393, pl. 9, fig. 2-6.

Post, E., 1963. Zur Verbrietung und Oekologie der *Bostrychia-Caloglossa*-Assoziation. *Int. Revue ges. Hydrobiol. Hydrogr.* 48: 47-152.

Post, E., 1964. Bostrychietum aus dem National park von Melbourne. *Revue algol* N.S. 7(3): 242-255.

Rosenvinge, L. K, 1893. Grønlands halvager. *Meddr. Groenland* 3, 795-981, 2 pl.

Roth, A. W., 1797. *Catalecta Botanica.* Vol. 1. J. G. Mueller, Leipzig.

Roth, A. G., 1806. *Catalecta Botanica.* Vol. 3. J. G. Mueller. Leipzig.

Russell, G., 1966. The genus *Ectocarpus* in Britain I. The attached forms. *J. mar. biol. Ass. U.K.* 46: 267-294.

Rueness, J., 1977. *Norsk Algenflora.* Universitetsforlaget, Oslo.

Saenger, P., Specht, M. M. Specht, R. L. & Chapman, V. J., 1977. Mangal and coastal salt-marsh communities in Australasia. In *Ecosystems of the World I. Wet Coastal Ecosystems*, V. J. Chapman, ed., Elsevier Scientific Publishing Company, New York, 293-345.

Saito, Y. & Womersley, H. B. S., 1974. The southern Australian species of *Laurencia* (Ceramiales: Rhodophyta). *Aust. J. Bot.* 22: 815-874.

Schmitz, F., 1896. Bangiaceae. In *Die Naturlichen Pflanzenfamilien* Vol. 1., Part 2, A. Engler & K. Prantl, eds., Wilhelm Engelmann, Leipzig, 307-316.

Schmitz, F. & Falkenberg, P., 1897. Rhodomelaceae. In *Die Naturlichen Pflanzenfamilien*, Vol. 1, Part 2, A. Engler & K. Prantl, eds., Wilhelm Engelmann, Leipzig, 421-480.

Searles, R. B. & Schneider, C. W., 1978. A checklist and bibliography of North Carolina seaweeds. *Botanica marina* 21: 99-108.

Setchell, W. A. & Mason, L. R., 1943. *Goniolithon* and *Neogoniolithon*: Two genera of crustaceous coralline algae. *Proc. Nat. Acad. Sci.* 29: 87-92.

Sonder, O. G., 1848. Algae. In *Plantae Preissianae sive Enumeratio Plantarum quas in Australasia Occidentali et meridionali Occidentali anis,* Vol. 2, C. Lehmann, ed., Sumptibus, Hamburg, 148-195.

Specht, R. L., 1972. *The Vegetation of South Australia.* 2nd Ed., Government Printer, Adelaide.

Taylor, W. R., 1960. *Marine algae of the Eastern Tropical and Subtropical Coasts of the Americas.* University of Michigan Press, Ann Arbor.

Tronson, K., 1974. The hydraulics of the South Australian gulf system I. Circulation. *Aust. J. mar. Freshwat. Res.* 25: 413-26.

Umezaki, I., 1961. The marine blue-green algae of Japan. *Mem. Coll. Agr. Kyoto Univ.* 83: 1-148, pl. 1-21.

Wille N., 1909. Algologische Notizen. XV. Ueber *Wittrockiella* nov. gen *Nytt. Mag. Naturvid.* 47: 209-225.

Woelkerling, W. J., 1970. *Acrochaetium botryocarpum* (Harv.) J. Ag. (*Rhodophyta*) in southern Australia. *Br. phycol. J.* 5: 159-171.

Woelkerling, W. J., 1971. Morphology and taxonomy of the *Audouinella* complex (Rhodophyta) in southern Australia. *Aust. J. Bot., Suppl. Ser.* 1: 1-91.

Woelkerling, W. J., 1973. The morphology and systematics of the *Audouinella* complex (Acrochaetiaceae, Rhodophyta) in northeastern United States. *Rhodora* 75: 529-621.

Woelkerling, W. J., 1981. New insights into the systematics of the Corallinaceae (Rhodophyta). In *XIII International Botanical Congress. Abstracts,* Australian Academy of Science, Canberra, 161.

Womersley, H. B. S., 1946. Studies on the marine algae of southern Australia. Introduction and No. 1. The genera *Isactis* and *Rivularia* (Myxophyceae). *Trans. R. Soc. S. Aust.* 70: 127-136.

Womersley, H. B. S., 1956. A critical survey of the marine algae of southern Australia I. Chlorophyta. *Aust. J. mar. Freshwat. Res.* 7: 343-383.

Womersley, H. B. S., 1967. A critical survey of the marine algae of southern Australia II. Phaeophyta. *Aust. J. Bot.* 15: 189-270.

Womersley, H. B. S., 1971. New records of taxa of marine Chlorophyta in southern Australia. *Trans. R. Soc. S. Aust.* 95: 113-120.

Womersley, H. B. S., 1979. Southern Austalian species of *Polysiphonia* Greville (Rhodophyta). *Aust. J. Bot* 27: 459-528.

Womersley, H. B. S. 1981a. Marine ecology and zonation of temperate coasts. In *Marine Botany: An Australasian Perspective*, M. N. Clayton & R. J. King, eds., Longman Cheshire, Melbourne, 211-240.

Womersley, H. B. S., 1981b. Biogeography of Australasian marine macroalgae. In *Marine Botany: An Australasian Perspective*, M. N. Clayton & R. J. King, eds., Longman Cheshire, Melbourne, 292-307.

Womersley, H. B. S., 1981c. Aspects of the distribution and biology of Australian marine macro-algae. In *The Biology of Australian Plants*, J. S. Pate & A. J. McComb, eds., Univ. W. Australia Press, Nedlands, W.A., 294-306.

Womersley, H. B. S. & Cartledge, S. A., 1975. The southern Australian species of *Spyridia* (Ceramiaceae: Rhodophyta). *Trans. R. Soc. S. Aust.* 99: 221-234.

Womersley, H. B. S. & Edmonds, S. J., 1958. A general account of the intertidal ecology of South Australian coasts. *Aust. J. mar. Freshwat. Res.* 9: 217-260.

Womersley, H. B. S. & Thomas, I. M., 1976. Intertidal ecology. In *Natural History of the Adelaide Region*, C. R. Twidale, M. J. Tyler & B. P. Webb, eds., Royal Society of South Australia, Adelaide, 175-185.

Wood, J. G. 1937. *The Vegetation of South Australia.* 1st ed. Government Printer, Adelaide.

Yarish, C., Casey, S. & Edwards, P., 1981. The effects of salinity, and calcium and potassium variations on the growth of two estuarine red algae. *Phycologia* 20: 118-119.

Yarish, C., Edwards, P. & Casey S., 1979. A culture study of salinity responses in ecotypes of two estuarine red algae. *J. Phycol.* 15: 341-346.

PROC. R. SOC. VICT. vol. 94, no. 3, 107-120, September 1982

DISCOVERY OF *CHEIROCRATUS* (CRUSTACEA: AMPHIPODA) ON AUSTRALIAN SHORES

By J. LAURENS BARNARD* AND MARGARET M. DRUMMOND†

* Smithsonian Institution, Washington, D.C. 20560, USA
† National Museum of Victoria, 285-321 Russell Street, Melbourne, Victoria 3000

ABSTRACT: Two new species of the gammaroid amphipod genus *Cheirocratus*, *C. bassi* and *C. praedens*, and a new genus and species, *Prosocratus butcheri* with close affinities to *Cheirocratus*, all from Australian waters, are described. A new genus, *Incratella*, is erected to accommodate *C. inermis* Ledoyer, 1967. A revised diagnosis of *Cheirocratus* and a key to all known species in the genera *Cheirocratus*, *Incratella* and *Prosocratus* are presented.

For more than fourteen decades the marine amphipod genus *Cheirocratus* has been well known in Arctic, North Atlantic and Mediterranean seas. Recently a species of the genus was described from Madagascar (Ledoyer 1967) which we propose should be transferred to a new genus *Incratella*.

We have discovered in southern Australia, and here report on two new species of *Cheirocratus* both of which show close ties to Mediterranean species; we report a third new taxon which we consider to be generically distinct from, though very closely allied to *Cheirocratus*. We assume the flow of evolutionary deployment proceeds from Australia towards the North Atlantic as it does in so many other groups of Amphipoda (see Barnard 1972, 1974, Barnard & Drummond 1978).

Most of the materials examined came from the two benthic surveys conducted in Western Port, Victoria, sponsored by the Victorian Government and supported by industrial organizations: Crib Point Benthic Survey, 1964-5 (CPBS) and Westernport Bay Environmental Study 1973-4 (WPBES). Acknowledgements to those concerned in these undertakings, as well as station data, have been detailed in a previous publication (Barnard & Drummond 1978). Additional material came from plankton samples collected in Western Port by R. H. Miller, University of Melbourne (RHM); from Tasmania (collected by T. Walker); from the Bass Strait survey at present being conducted by the Victorian Institute of Marine Science (VIMS); from the Queensland University Survey of Middle Banks, Moreton Bay, Queensland, from Port Phillip (PPBES) and from the N.S.W. Fisheries Estuarine Benthic Survey (EBS).

LEGENDS

Capital letters and numbers on the figures denote parts, as follows: A, antenna; B, body or carcass; C, coxa; D, dactyl; E, epistome, left view; F. accessory flagellum; G, gnathopod; H, head; I, inner plate; J, ramus; K, variable, see legend; L, lower lip = labium; M, mandible; N, molar; O, palp; P, pereopod; Q, pleopod; R, uropod; S, maxilliped; T, telson; U, upper lip = labium; V, brood plate; W, pleon; X, maxilla; Y, gill; Z, gland.

The figures each contain illustrations from a master specimen listed first in the caption of each figure and no lower case letters are placed on these figures; subsidiary specimens on each figure are denoted by lower case letters to left of capitals as specified in the caption for each figure. Lower case to the right of capitals indicate: m, medial; r, right; s, setae removed.

SYSTEMATICS

Genus **Cheirocratus** Norman 1867

TYPE SPECIES (by monotypy): *Cheirocratus mantis* Norman 1867, (= *Gammarus assimilis* Liljeborg 1852 according to Stebbing 1906: 417).

DIAGNOSIS: Body ordinary, urosomites free, dorsally denticulate and spinosetose transversely. Rostrum obsolescent, lateral cephalic lobes mamiliform, sinus present. Eyes present. Antenna 1 much shorter than antenna 2, ratio of peduncular articles = 16:16:5 (in type species), primary flagellum as long as peduncle, accessory flagellum 2+ articulate. Antenna 2 large and elongate, flagellum scarcely shorter than peduncle. Labrum as broad as long, weakly notched apically. Mandibular incisor toothed, molar triturative, ratio of palp articles = 10:18:11 (in type species), article 3 weakly falcate or strongly sickle-shaped, setae = (A)DE. Inner lobes of labium well developed. Maxillae medially setose, inner plate of maxilla 1 ovatotriangular, fully setose medially, outer plate with 11 (rarely 9) spines, palps [?symmetrical]. Inner plate of maxilla 2 with oblique facial row of setae or strongly setose medially. Outer plate of maxilliped medially spinose, palp article 3 unlobed, dactyl shorter than article 3, unguiform, [?without nail). Coxae of ordinary length, poorly setose, coxa 1 slightly to strongly expanded apically, coxa 4 scarcely or not, lobate. Gnathopods diverse; female gnathopods simple, feeble, wrists elongate, not lobate, hands thin, lacking palms; male gnathopod 1 like female, gnathopod 2 greatly enlarged, wrist short, not lobate, hand large, elongate, ovate, rectangular or trapezoidal, palm oblique, elongate, smooth or sculptured. Pereopods 3-4 ordinary. Article 2 of pereopods 5-7 scarcely expanded or not, almost linear, scarcely lobate or not, posterior margins weakly serratosetulate. Pleopods ordinary. Rami of uropods 1-2 marginally spinose, evenly extended, peduncle or uropod 1 [?without basofacial armaments]. Uropod 3

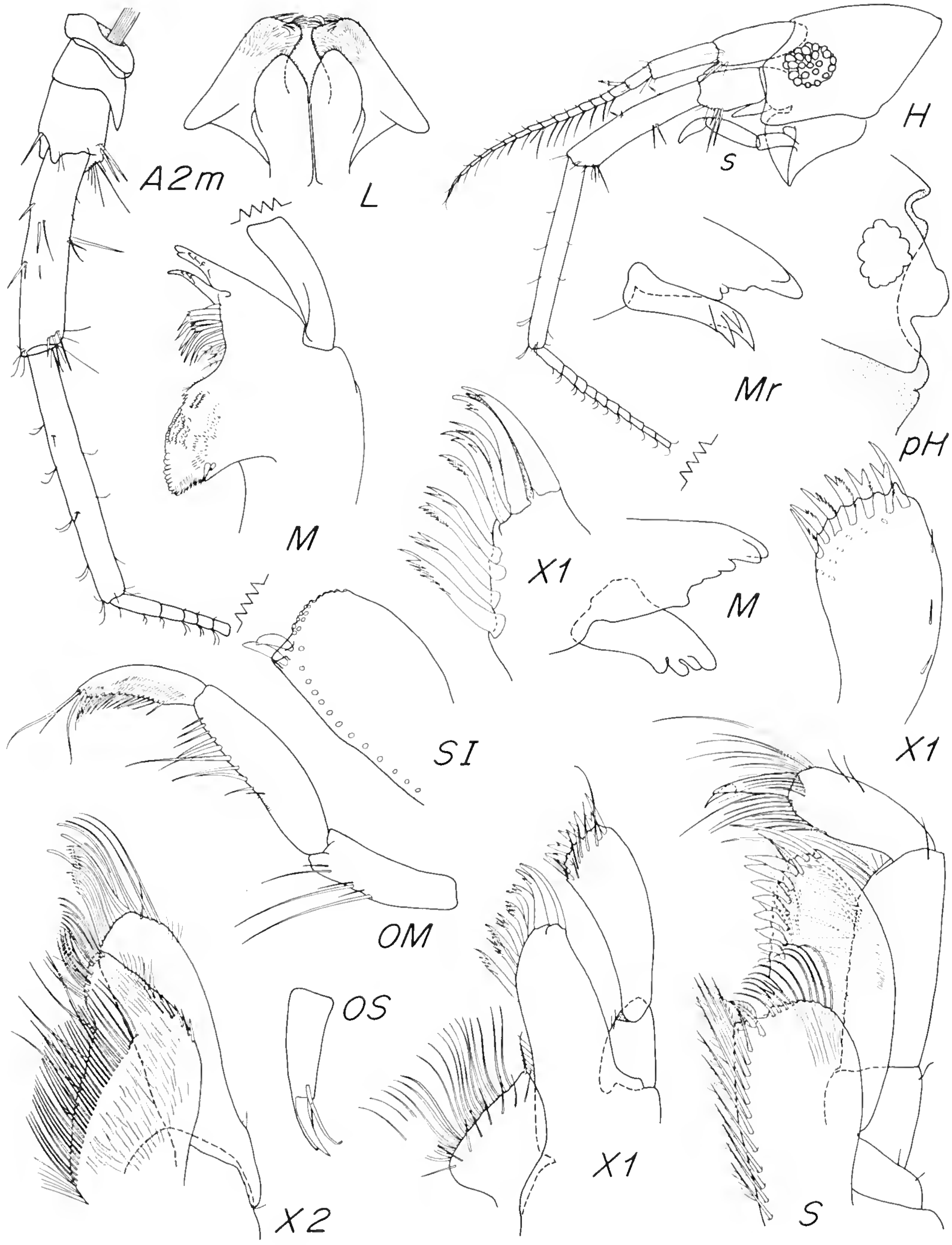


Fig. 1—*Cheirocratus bassi* sp. nov. Unattributed figures = holotype male "h" 5.80 mm; p = female "p" 4.41 mm.

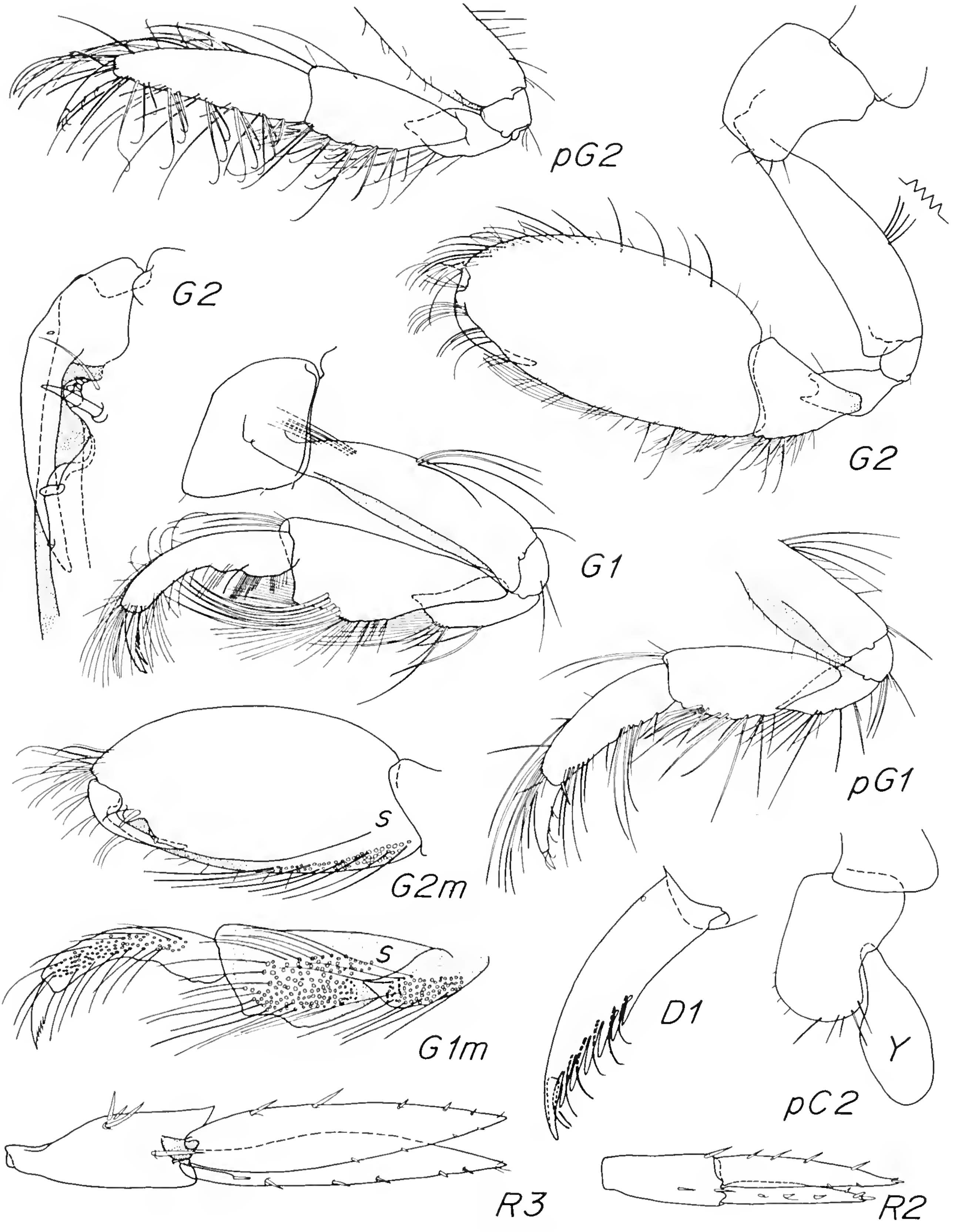


Fig. 2 — *Cheirocratus bassi* sp. nov. Unattributed figures = holotype male "h" 5.80 mm; p = female "p" 4.41 mm.

extended, magniramous, almost aequiramous, peduncle elongate, rami 1-articulate, lanceolate. Telson short, deeply cleft, gaping, lobes tapering, well spinose apically. Coxal gills [?2-6], ovate, occasionally pediculate. Oostegites narrow.

Variants: Telson poorly armed (*C. bassi, C. praedens*); male gnathopod 2 like *zeylanca melitas*, hand ovate, palm undefined and heavily setose, dactyl riding onto medial face of hand (*C. sundevalli*); mouthparts in diagnosis based on *C. sundevalli* of Sars (1895).

Relationship: Like *Cheirocratella* but female gnathopod 2 simple.

Species: See Chevreux & Fage (1925); *armatus* G. S. Karaman 1977a; *assimilis* (Liljeborg 1852) (Sars 1895) (Chevreux & Page 1925); *bassi* Barnard & Drummond herein; *intermedius* Sars 1895; *monodontus* G. S. Karaman 1977b; *praedens* Barnard & Drummond herein; *robustus* Sars 1895 (Stephensen 1928, 1929, 1940); *sundevalli* (Rathke 1843) (Sars 1895).

Key to *Cheirocratus, Incratella* and *Prosocratus* (modified after Karaman 1977)

(Note: *C. bassi* is placed twice in key, second time ignoring telson to show position near species from Europe)

1. Male gnathopod 2 simple .... *Prosocratus butcheri* gen. et sp. nov.
   Male gnathopod 2 subchelate 2
2. Telson with thin setae but no spines 3
   Telson with both setae and spines 5
3. Urosomites untoothed, article 1 of mandibular palp as long as article 3, article 2 of pereopod 7 lobate .... *Incratella inermis*
   Some urosomites toothed, article 1 of mandibular palp longer than article 3, article 2 of pereopod 7 not lobate 4
4. Urosomite 2 untoothed .... *C. armatus*
   Urosomite 2 with 2 dorsal teeth ... *C. bassi* sp. nov.
5. Dactyl of male gnathopod 2 closing on toothed posterior palm, hinge part of palm with crenellate tooth or teeth 6
   Dactyl of male gnathopod 2 overriding palm onto face of hand, hinge part of palm smooth or with smooth hump 7
6. Palm of male gnathopod 2 with 4 major teeth spread throughout palm, palm poorly setose .... *C. assimilis*
   Palm of male gnathopod 2 with 2 major teeth or tooth groups, one at hinge, one at defining corner, middle of palm lacking teeth but heavily setose .... *C. intermedius*
7. Dorsomedial peduncular spination of uropod 3 concentrated into group, adult male without cephalic notch, telson with only small apical flexible setules .... *C. bassi* sp. nov.
   Dorsomedial peduncular spination of uropod 3 widespread, adult male retaining cephalic notch, telson with one or more stout and stiff apical spines 8
8. Articles 4-6 of pereopod 7 stout, medial face of hand on male gnathopod 2 with humped setae, no spines or ridges .... *C. robustus*
   Articles 4-6 of pereopod 7 slender, medial face of hand on gnathopod 2 with setae, ridge and spines 9
9. Urosomite 2 with 4 dorsal teeth, epimeron 3 with straight posterior margin 10
   Urosomite 2 with 2 dorsal teeth, epimeron 3 with convex posterior margin ... *C. praedens* sp. nov.
10. Urosomite 1 with one large dorsal tooth .... *C. monodontus*
    Urosomite 1 with several small dorsal teeth (at least 3) .... *C. sundevalli*

Cheirocratus bassi sp. nov.

Figs 1-3

Diagnosis: Cephalic notch lost in adult male; male gnathopod 2 without major palmar teeth, palm formed by inner facial ridge near posterior margin, this ridge with teeth and spines near apex, medial face with setae only near posterior margin, dactyl overriding posterior margin; articles 4-6 of pereopod 7 slender; urosomite 1 with 3 closely contiguous dorsal teeth; urosomite 2 with 2 widely spaced dorsal teeth; spines on peduncle of uropod 3 forming one group only, not queued; apices of telsonic lobes with minor armaments only.

Description of Male Holotype "h": Rostrum minute, lateral cephalic lobe weakly excavate anteriorly but notch found in juvenile obliterated in adult, anteroventral corner weakly produced; eyes round, pigment widely spread but ommatidia sparse.

Antenna 1 of medium extension, ratio of peduncular articles = 16:12:5, article 1 with 2 apical sharp teeth near spines, one above and one below, primary flagellum longer than peduncle, with thick but sparse aesthetascs, accessory flagellum 2-articulate. Antenna 2 elongate, much longer than antenna 1, gland cone large, extending 50% or more along article 3, article 5 of peduncle longer than 4, flagellum elongate.

Upper lip broad, entire, rounded.

Mandibular incisors weakly toothed, right lacinia mobilis thin, narrow, left broad, flat, each 4-toothed; raker spines main row with 7, accompanied by 7 vestigial fern-like setae near molar, left rakers like right but subsidiary row with only 2 rakers; molars large, poorly triturative; tiny setule on the left, longer weak seta on the right; mandibular palp large, ratio of articles = 11:14:9, articles 1 and 2 with inner setae, article 3 weakly falcate, setae of article 3 = DE.

Inner lobes of lower lip large and fleshy, outer lobes with medial gape. Inner plate of maxilla 1 broadly pyriform, leaf-like, fully setose medially, also with facial setae, outer plate slender, with 11 spines; palps 2-articulate, symmetrical, apices truncate, with simple, bifid pectinate spines and facial setae, and outer marginal row of 3 facial setal-spines. Inner plate of maxilla 2 broader and shorter than outer, somewhat geniculate, with fully developed oblique facial row of setae, some outer marginal setal-spines, sparse medial

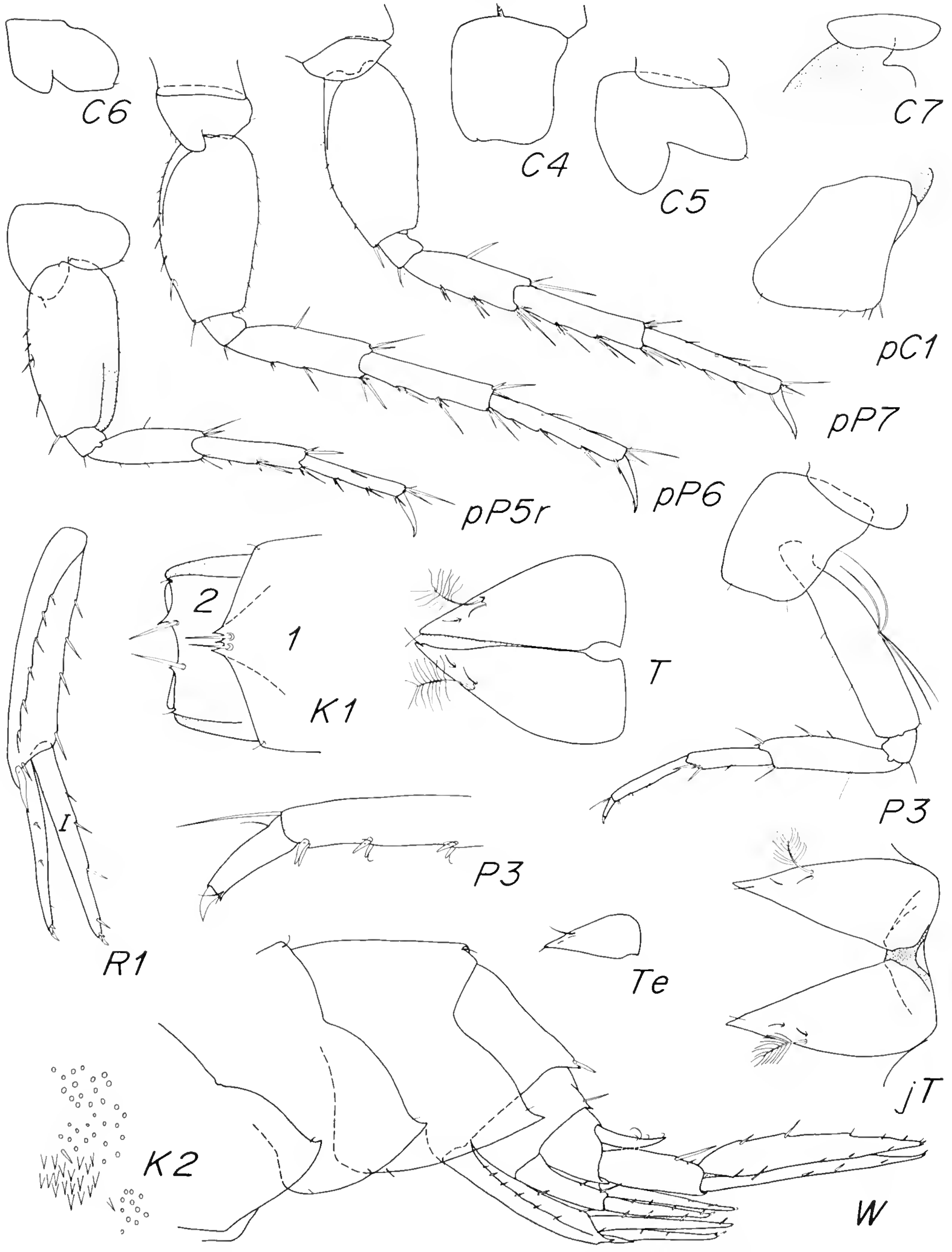


Fig. 3 – *Cheirocratus bassi* sp. nov. Unattributed figures = holotype male "h" 5.80 mm; j = male "j" 5.34 mm; p = female "p" 4.41 mm; e marks figure drawn to same size as uropod 3 on Fig. 2; K1, dorsal urosome; K2, cuticle of pereopod 5.

and dense apical setae; outer plate almost evenly rectangular, with 3-4 apicolateral setae and dense apical setae. Inner plate of maxilliped broad, truncate, with 2 inner apical spines, medially and apicolaterally setose; outer plate ovate, medially and apically spinose; palp article 2 elongate, article 3 shorter, unlobate, dactyl shorter, uniform, with partly immersed nail and accessory setule; palp poorly setose laterally.

Coxae 1-5 of medium length, extending almost equally, only coxa 2 with long setal-spines; coxa 1 expanded apically and with short armaments, other coxae poorly armed; coxa 2 constricted midposteriorly; coxae 3-4 subrectangular, 4 not significantly excavate, 3 slightly longer than 4; coxa 5 bilobed; coxae 6-7 shorter than 5.

Gnathopod 1 slender, small, simple; wrist elongate, weakly but broadly lobate posteriorly; hand very slender, weakly bent, irregularly tapering, posterior margin at base sinuous, palm absent, dactyl short, curved, serrate. Wrist of gnathopod 2 short, not lobate, posterior margin with moderately developed setal clumps; hand very large, elongate, ovate, anterior margin setose, posterior margin smooth, convex, with dense inner facial setae near base, medial face with heavy ridge near posterior margin, broken into 2 processes near hinge, distal process with long spine, long seta, 4-5 small jewel-like spines, proximal process with one medium spine; dactyl fitting into slot formed by ridge and palmar margin, strongly bent, short; dactyl interpreted to be overriding margin onto face of palm; longer setae on wrist of gnathopod 1 and hands of both gnathopods extremely thick and with basal bulbs.

Pereopod 4 smaller than pereopod 3.

Article 2 of pereopods 5-7 scarcely expanded, not lobate, posterior margins weakly serratosetulate; legs slender; pereopods 6 and 7 subequal in length.

Pleopods ordinary. Pleonites 1-5 each with dorsal posterolateral setule in weak notch; epimera 1-3 with sinuous posterior margin and sharp medium posteroventral tooth marked with weak setule; ventral margin of epimeron 2 with one weak spinule, of epimeron 3 with 2 weak anteroventral spinules.

Urosomites 1-2 dorsally toothed, urosomite 1 with 3 dorsal teeth in tight group, this complex armed with 2 setal spines; urosomite 2 with 2 widely spread dorsal teeth each armed with setal-spine.

Uropods 1-2 extending equally, outer rami scarcely shortened, all rami with marginal spines and weakly spinose apices; peduncle of uropod 1 with both margins spinose, no basofacial spine, apicolateral margin with small sharp cusp, large spine and small spine. Uropod 2 peduncle with 2 lateral spines and one medial. Uropod 3 strongly extended, peduncle slightly elongate, apicodorsal margin with 2 spines in tandem, midmedial margin with cluster of 3 spines, apicomedial margin with cusp; rami elongate, lanceolate, weakly spinose along margins. Telson very short, cleft to base, lobes slightly separate at base, each lobe tapering to sharp point and bearing weak subapical setule, one dorsal setule, pair of dorsolateral setules greatly distad.

Coxal gills on pereonites 2-6, sausage-shaped.

Cuticle under medium power appearing to be pebbled, under oil-immersion pebbles seen to be poorly developed (only well refractive on low power), composed of complex concentric interrupted line-pairs, in places yielding to or basally underfounded by sharp scales; cuticle also with occasional spikes or studs and fine bulbar setules.

Description of Female "p": Lateral cephalic lobe with deep notch like juvenile. Antenna 1 like male; flagellum of antenna 2 only as long as articles 4-5 of peduncle combined.

Gnathopod 1 generally like that of male but hand less grotesque, tapering evenly, wrist more softly rounder posteriorly. Gnathopod 2 feeble, simple, wrist and hand both elongate, dactyl with 2 inner spinules each with partner setule, palm and posterior margin confluent and bearing several groups of apically curled setae.

Both epimera 2-3 with 2 strong anteroventral spine-setae, much stronger than in male holotype. Brood plates very slender.

Description of Male "g": Right maxilla 1 with 9 spines on outer plate.

Illustrations: Mandibular incisors and laciniae mobiles when shown together spread apart; main spines of mandibular raker row with bases heavily broadened and from side view appearing to form secondary spine row; maxillae 1-2 equally magnified. Small version of one telsonic lobe magnified equally to uropod 3. Larger telsonic versions greatly enlarged.

Holotype: NMV J1631 male "h" 5.80 mm.

Type Locality: WPBES 1749/1, Australia, Victoria, Western Port, 25 November 1974, 14 m, sand with mud, silt, clay.

Paratypes: NMV J1632-1636. The type-locality, 6 other specimens, including male "j" 5.34 mm; CPBS Al/1, female "p" 4.41 mm; RHM, male "g", 5.86 mm; 21 (2) dredged WP, 20/2/78, female "q".

Relationship: *Cheirocratus bassi* resembles *C. armatus* particularly in the lack of thick spines on the telson and the lack of significant incision in the cephalic lobe. The other known species of *Cheirocratus* have apically spined telsons and markedly incised cephalic lobes in addition to individual gnathopodal distinctions. *C. bassi* differs from *C. armatus* in the presence of teeth on the second urosomite. *C. monodontus* and *C. praedens* sp. nov. each have only one tooth on urosomite 1 instead of the 3 in *C. bassi*; *C. sundevalli* has 4 (instead of 2) on urosomite 2; and in both *C. robustus* and *C. assimilis* pereopod 7 is unequal in length to pereopod 6 and stouter, in contrast to *C. bassi* in which pereopods 6 and 7 are slender and subequal.

Material: CPBS, 77 samples from 33 stations (258 specimens); WPBES, 8 samples from 5 stations (23 specimens); RHM 27/10/71 (1 specimen); PPBES, 4 samples from 2 stations (4 specimens).

Distribution: Australia, Victoria, Western Port, Port Phillip and Bass Strait, 0-36 m, fine to coarse sand, muddy sand, gravelly sand, sand and shell.

Etymology: The species is named for George Bass, physician, who discovered and named Western Port in 1797.

Cheirocratus praedens sp. nov.

Figs 4, 5 (upper)

Diagnosis: Cephalic notch persistent in adult male; male gnathopod 2 without major palmar teeth, palm formed by inner facial ridge near posterior margin, this ridge with teeth and spines near apex, apical process very broad with about 6 spines, medial face with setae in middle stripe and near posterior margin, dactyl overriding posterior margin; articles 4-6 of pereopod 7 slender; urosomite 1 with one medium sized dorsal tooth, urosomite 2 with 2 widely spaced dorsal teech; spines on peduncle or uropod 3 widely spread; apices of telsonic lobes with at least one thick spine each.

Description of Male Holotype "k": Rostrum minute, lateral cephalic lobe strongly notched anteriorly, anteroventral corner rounded; eyes round, pigment fully covered by morula of ommatidia.

Antenna 1 short, reaching about half way along peduncular article 5 of antenna 2, ratio of peduncular articles is 16:14:5, article 1 with 2 apical sharp teeth near apex, one medial and one lateral; primary flagellum longer than peduncle, with thick but sparse aesthetases; accessory flagellum 2 articulate. Antenna 2 elongate, much longer than antenna 1, gland cone large, article 5 of peduncle longer than 4, flagellum elongate.

Upper lip broad, entire, almost truncate below.

Mandibular incisors weakly toothed, right lacinia mobilis thin, left flat broad each 4 toothed; raker spines main row with 9, accompanied by 3-4 vestigial fern-like setae near molar, left and right sides similar; molars large, poorly triturative, with conspicuous medium-sized seta each; mandibular palp large, ratio of articles is 9:11:8, article 3 weakly falcate, articles 1 and 2 with inner setae (article 1 = medial, 3 large; apicomedial, 1 medium 1 setule; apicolateral, 1 setule; article 2 = medial, 15 mixed setae), setae of article 3 = DE (medial = 17, apical = 3 large and 1 small). Inner lobes of lower lip large and fleshy, outer lobes with medial gape. Inner plate of maxilla 1 broadly pyriform, leaf-like, fully setose medially, also with facial setae; outer plate slender, with 11 spines, palps 2-articulate, symmetrical, apices truncate, with simple, bifid and pectinate spines and facial setae, also with outer marginal row of 3 setules (widespread). Inner plate of maxilla 2 broader but scarcely shorter than outer, somewhat geniculate, with fully developed oblique facial row of setae, some outer marginal setal spines, sparse medial and dense apical setae, outer plate almost evenly rectangular, with 2 apicolateral setae and dense apical setae.

Inner plate of maxilliped broad, truncate, with 2 inner apical spines, medially and apicolaterally setose, outer plate ovate, medially and apically spinose, palp article 2 elongate, article 3 shorter, unlobate, dactyl shorter, unguiform, with partly immersed nail and accessory setule; palp poorly setose laterally.

Coxae 1-5 of medium length, extending equally, only coxa 2 with long setal spines but some on coxa 1 short and thick, other coxae poorly armed; coxa 1 expanded apically, coxa 2 weakly constricted midposteriorly, coxae 3-4 subrectangular, 4 not significantly excavate, 3 and 4 equally extended, coxa 5 bilobed, coxae 6-7 shorter than 5.

Gnathopod 1 slender, small, simple, wrist elongate, broadly rounded but not lobate posteriorly, hand very slender, almost straight, tapering, sinuosity very minor, palm absent, dactyl short, curved, serrate. Wrist of gnathopod 2 short, not lobate, posterior margin with moderately developed setal clump, hand very large, elongate, ovate, posterior margin smooth, convex, with dense inner facial setae on posterior margin and stripe down middle of face, medial face with heavy ridge near posterior margin. Ridge broken into broad process near hinge, armed with 6 small, jewel-like spines, plus proximal process with one spine; dactyl wiping ridge between both processes, strongly bent, short, dactyl interpreted to be overriding palm onto face of hand; anterior margin of hand setose, longer setae on wrist of gnathopod 1 and hands of both gnathopods extremely thick and with basal bulbs.

Pereopod 4 scarcely smaller then pereopod 3.

Article 2 of pereopods 5-7 scarcely expanded, not lobate, posterior margins weakly serratosetulate, legs slender.

Pleopods ordinary. Pleonites 1-2 each with dorsolateral setule, epimera 1-3 with sinuous posterior margin and sharp posteroventral tooth marked with weak setule. Ventral margin of epimeron 2 with 4 strong setal spines, of epimeron 3 with 5 similar armaments.

Urosomite 1 with strong dorsomedial tooth, urosomite 2 with pair of small dorsal teeth. Uropods 1-2 extending equally, outer rami scarcely shortened, all rami marginally and apically weakly spinose; peduncle of uropod 1 with both margins spinose, without basofacial spine, apicolateral margin with small sharp cusp, large spine and small spine; peduncle of uropod 2 with 3 lateral and 2 medial spines. Uropod 3 strongly extended, peduncle scarcely elongate, apicodorsal margin with 2 spines in tandem, medial margin with 2 spines in group and 2 spines in tandem, apicomedial margin with cusp; rami elongate, lanceolate, weakly spinose along margins.

Telson very short, cleft to base, lobes slightly separate at base, each tapering to sharp point with weak subapical inner notch armed with small stout spine (one side with second spinule) and one setule; dorsolateral surface with setule and partner (variable, either spine or long plusetule).

Coxal gills on pereonites 2-6, sausage-shaped.

Cuticle under medium power appearing to be pebbled, under oil-immersion pebbles seen to be poorly developed (only well refractive on low power), composed of complex concentric interrupted line-pairs, in places yielding to or basally underfounded by sharp scales; cuticle also with occasional spikes or studs and fine bulbous setules.

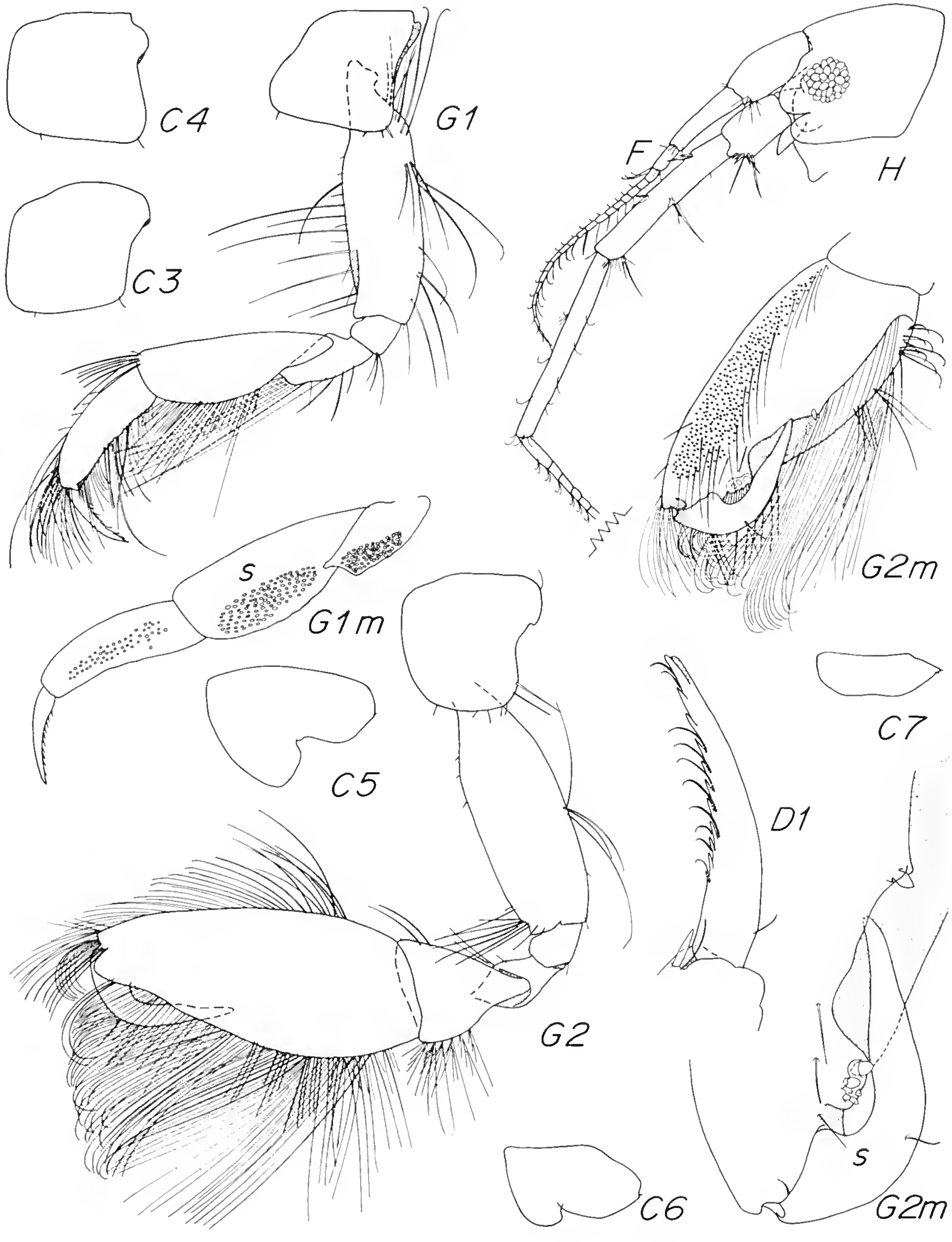


Fig. 4 – *Cheirocratus praedens* sp. nov. Holotype male "k" 12.10 mm.

Illustrations: Many parts similar to those of *C. bassi* and not repeated for this species: upper lip, epistome, mandibles, lower lip, cuticle; maxilla 2 figured in outline only. Minor distinctions from illustrations of *C. bassi*, noted but not illustrated separately: inner plate of maxilla 1 with 26 medial, 11 facial and 3 apical setae, palp apex with 10 spines (2 more thin medials and one extra bifurcate) in pattern similar to *C. bassi*; inner plate of maxilliped with 15 medial setae, outer with 2 thin apical spines and 11 thick medials, article 3 of palp with 4 lateral setae in groups of 3 and 1; pereopods 3 and 4 slightly better armed; pereopod 5 with 3 posteroventral cusps and 2 setules on article 2 and pair of small posteroventral spines on article 5; pereopods 6 and 7 with 2 posteroventral cusps and one setule on article 2 and article 4 more elongate (see formulae below); peduncle of uropod 1 with 5 lateral and 6 medial spines, of uropod 2 with 3 lateral and 2 medial; outer ramus of uropod 1 with 4 small lateral spines and 3 small medials, apex with 2 spines, one large, one small, and 2 cusps; outer ramus of uropod 2 with 4 large lateral and 4-5 small medial spines, apex with one large and one small spine, and 2 cusps; inner ramus of uropod 1 with 3 small lateral and 5 large medial spines, apex with one medium spine and 2 cusps; inner ramus of uropod 2 with 3 small lateral and 6 large medial spines, apex with one large spine, one small spine and 2 cusps. Length ratio of articles 2, 4, 5 of pereopod 6 = 65:53:48 and of pereopod 7 = 61:50:51. (For *Cheirocratus bassi* these ratios are 65:47:50 and 62:42:51.)

Holotype: NMV J1637 male "k" 12.10 mm.

Type Locality: Tasmania, 400-600 m east of Middleton, BBN/T.L., weed bottom, 5 October 1973, collected by Terry Walker.

Relationship: *Cheirocratus praedens* differs from *C. monodontus*, from the Mediterranean Sea, in the presence of only 2 (not 4) dorsal teeth on urosomite 2, the bulging posterior margin of epimeron 3, the lack of ventral armament on epimeron 1, the very sparse armament of the telson and the produced midfacial ridge on the hand of male gnathopod 2. It differs from *C. bassi*, its Australian compatriot, in the presence of only one tooth (not 3) on urosomite 1, the absence of spines on urosomites 1 and 2, the presence of a cephalic notch in fully adult male, the stronger medial cavity and more heavily armed hand of male gnathopod 2, the weaker development of gnathopod 1 in the adult male, in which article 5 is narrower and article 6 less sculptured, and the narrower hand of male gnathopod 2 relative to coxa 2, with larger dactyl.

This species shows many similarities to *C. sundevalli* (Rathke) from Europe, but differs from that species in having fewer dorsal teeth on the urosomites (1 and 2 contrasted with 3 and 4), in the convex posterior margin of epimeron 3, the more pointed telsonic lobes with fewer spines (1-2 as against 3), the larger apical process on the inner palmar face of gnathopod 2 with more spines (6 as contrasted with 2), and the shorter peduncle of uropod 3.

The holotype of this species also differs from *C. bassi* in various characters assumed to reflect its large adult size: the ventral spines on urosomites 1 and 2 (absent in *bassi*), thicker armaments on the telsonic apices, stronger or denser spination on peduncle of uropod 3 and epimera 2-3, broader, coxa 3 and the longer reach on the inner plate of maxilla 2.

Material: A second specimen of *Cheirocratus praedens* was taken in a lately-sorted sample from Bass Strait (VIMS station 110, 16m, fine, shelly sand, 3/11/80). This female, 11.2 mm in length with setose brood plates, has simple gnathopods closely resembling those of females figured for *C. bassi* and *Prosocratus butcheri*. From these two species, however, it is readily distinguished by the single, very large tooth on the first urosomite. In other respects the female conforms closely to the description of the male holotype.

Distribution: Tasmania, intertidal.

Etymology: From the Latin *prae* meaning "in front" and *dens* meaning "a tooth"—refers to the single tooth on the first urosome.

Genus **Incratella** nov.

Diagnosis: body unornamented, urosome not dorsally setose. Rostrum [?small, lateral cephalic lobes deeply notched, ? sinus present]. Antenna 2 elongate, antenna 1 much shorter than 2, ratio of peduncular articles = 35:21:10, primary flagellum as long as peduncle, accessory flagellum 2-articulate. Articles 4-5 of peduncle on antenna 2 thin, elongate, flagellum longer than article 5.

Labrum about as long as broad. Mandibular molar large but poorly triturative, ratio of palp articles = 11:15:13, article 3 slightly curved, blunt, setae = DE. Inner lobes of labium large. Maxillae medially setose; inner plate of maxilla 1 broadly ovate, fully setose medially, outer plate with [?5] spines, palps [?symmetrical with elongate article 1]. Inner plate of maxilla 2 with oblique facial row of setae. Coxae of ordinary length to slightly shortened, almost glabrous, coxa 1 strongly expanded, coxa 4 quadrate, unexcavate. Female gnathopods simple, feeble, wrists elongate, unlobate, hands thin, lacking palms; male gnathopods unknown.

Article 2 of pereopods 5-7 moderately expanded, weakly (5) to moderately (7) lobate, posterior margins lacking large setae.

Rami of uropods 1-2 marginally but poorly spinose, evenly extended, peduncle of uropod 1 [?without basofacial armaments.] Uropod 3 extended, magniramous, almost aequiramous, peduncle slightly elongate, rami 1-articulate, lanceolate. Telson short, cleft, gaping, lobes weakly tapering, not spinose apically.

Coxal gills [?2-6] ovate. Oostegites [?narrow].

Type Species: *Cheirocratus inermis* Ledoyer 1967.

Relationship: Like *Cheirocratus* but urosomites untoothed. Male unknown.

Species: *Incratella inermis* (Ledoyer 1967) Griffiths, 1975; Madagascar and southern Africa, sublittoral, 1.

Etymology: The generic name *Incratella* is contrived from word fragments.

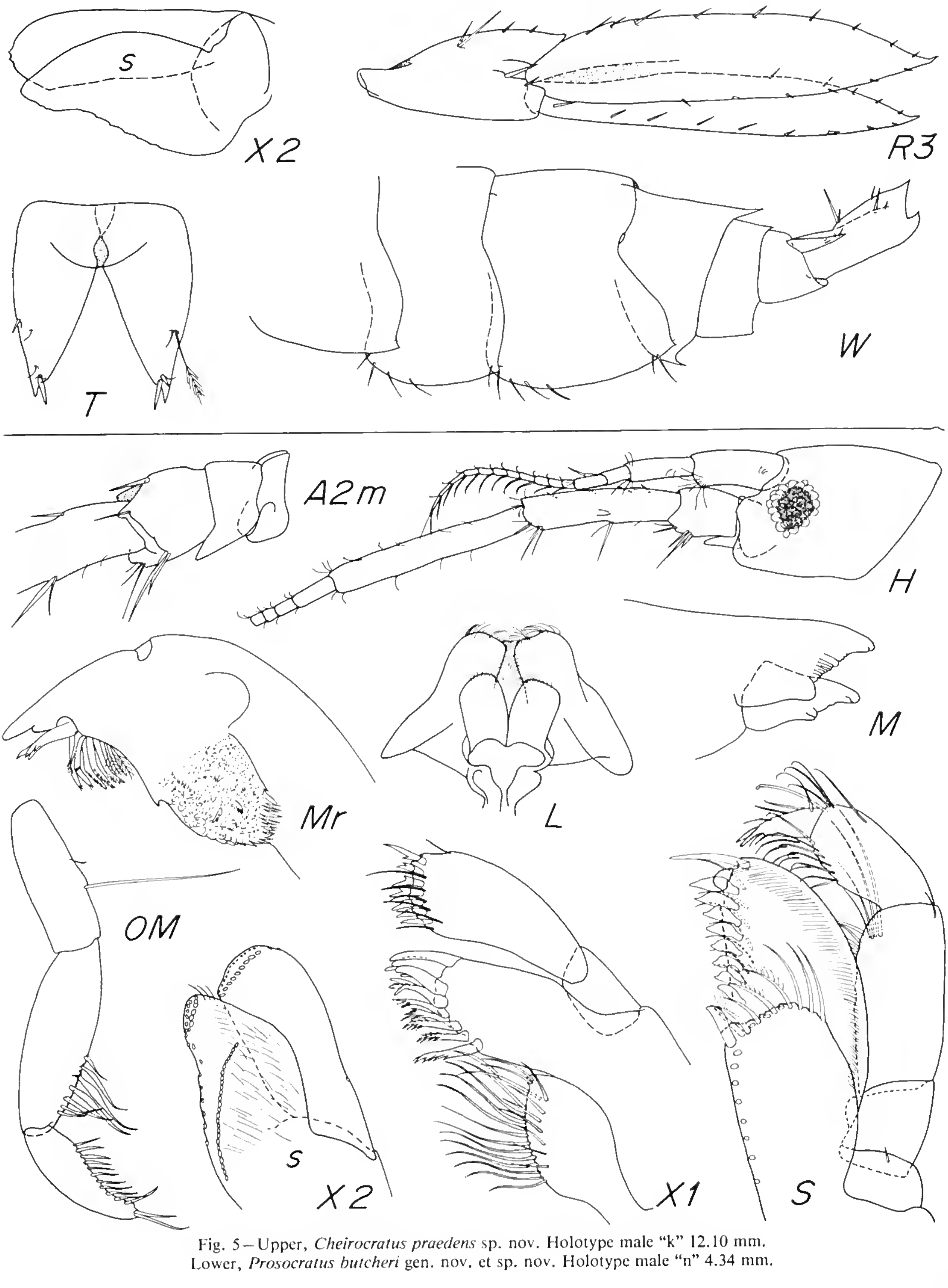


Fig. 5 – Upper, *Cheirocratus praedens* sp. nov. Holotype male "k" 12.10 mm. Lower, *Prosocratus butcheri* gen. nov. et sp. nov. Holotype male "n" 4.34 mm.

Genus **Prosocratus** nov.

Diagnosis: Body ordinary, urosomites free, dorsally denticulate and spinosetose transversely. Rostrum obsolescent, lateral cephalic lobes subtruncate, sinus absent. Eyes present. Antenna 2 elongate, antenna 1 much shorter than antenna 2, ratio of peduncular articles is 16:11:5 (in type-species), primary flagellum as long as peduncle, accessory flagellum 2-articulate. Antenna 2 large and elongate, scarcely shorter than peduncle. Labrum as broad as long, weakly notched apically. Mandibular incisors scarcely toothed, molar triturative, ratio of palp articles = 11:13:9 (in type-species), article 3 weakly sickle-shaped, setae = DE. Inner lobes of labium well developed. Maxillae medially setose, inner plate of maxilla 1 ovatotriangular, fully setose medially outer plate with 11 spines, palps symmetrical. Inner plate of maxilla 2 with oblique facial row of setae, strongly setose medially. Outer plate of maxilliped medially spinose, palp article 3 unlobed, dactyl shorter than 3, unguiform, nail almost fused, with secondary scale. Coxae of ordinary length, poorly setose, coxa 1 weakly expanded, coxa 4 scarcely lobate. Gnathopods diverse; female gnathopods simple, feeble, wrists elongate, not lobate, hands thin, lacking palms; male gnathopod 2 like female but article 2 very broad, gnathopod 1 enlarged, strongly subchelate, wrist elongate, hand broad, dactyl very long and strongly overlapping transverse sculptured palm. Pereopods 3-4 ordinary. Article 2 of pereopods 5-7 weakly expanded, not lobate, posterior margins weakly setulate. Pleopods ordinary. Rami of uropods 1-2 marginally spinose, evenly extended or outer ramus of uropod 2 shortened, peduncle of uropod 1 without basofacial armament. Uropod 3 extended, magniramous, almost aequiramous, peduncle elongate, rami 1-articulate, lanceolate. Telson short, fully cleft, gaping, lobes tapering, poorly spinose apically. Coxal gills 2-6 ovate, occasionally pediculate. Oostegites narrow.

Type Species: *Prosocratus butcheri* sp. nov.

Relationship: Differing from *Cheirocratus* in the axial reversal of male gnathopodal dominance, gnathopod 1 dominating instead of gnathopod 2.

Etymology: From the Greek *proso*, "in advance of" and *kratos* "power", refers to the dominance of the first gnathopod.

Prosocratus butcheri sp. nov.

Figs 5 (lower), 6, 7

Diagnosis: With the generic characters, thus male gnathopod 1 dominant; female with articles 4-6 of pereopod 7 slender; urosomite 1 with 3 closely contiguous dorsal teeth; spines on peduncle of uropod 2 in 2 groups of 2 each; apices of telsonic lobes with minor armaments only.

Description of Holotype Male "n": Rostrum minute, lateral cephalic lobe scarcely emarginate anteriorly, anteroventral corner rounded; eyes round, pigment not fully covered by morula of ommatidia.

Antenna 1 of medium extension, ratio of peduncular articles = 16:12:5 article 1 without teeth, primary flagellum scarcely longer than peduncle, with thick but sparse aesthetases, accessory flagellum 2-articulate. Antenna 2 elongate, longer than antenna 1, gland cone large, article 5 of peduncle longer than 4, flagellum elongate.

Upper lip broad, entire, almost truncate below.

Mandibular incisors scarcely toothed; right lacinia mobilis thin, left flat, right 4-toothed, left with 2 pairs of teeth weakly divided at extremities; raker spines main row with 5, accompanied by 4 vestigial fern-like setae near molar, left and right sides similar; molars large, poorly triturative, each with weak seta; mandibular palp large, ratio of articles = 11:13:9, article 3 weakly falcate, articles 1 and 2 with inner setae (article 1 with 1 long, 1 small; article 2 with 7 irregular weakly hooked, of various sizes), setae of article 3 = DE (medial with 11, apical with 2). Inner lobes of lower lip large and fleshy, outer lobes with medial gape. Inner plate of maxilla 1 broadly pyriform, leaf-like, fully setose medially, and with facial setae; outer plate slender, with 11 spines; palps 2-articulate, symmetrical, apices truncate, with simple, bifid and pectinate spines, facial setae, and an outer marginal setule. Inner plate of maxilla 2 slightly broader but scarcely shorter than outer, somewhat geniculate, with fully developed oblique facial row of setae, some outer marginal setal spines, sparse medial and dense apical setae; outer plate almost evenly rectangular, with 2 apicolateral setae, and dense apical setae. Inner plate of maxilliped broad, truncate, with 2 inner apical spines, medially and apicolaterally setose; outer plate ovate, medially and apically spinose; palp poorly setose laterally, article 2 elongate, article 3 shorter, not lobate, dactyl shorter than article 3, unguiform, with partly immersed nail, accessory setule and scale-flake.

Coxae 1-5 of medium length, extending equally, only coxa 2 with long setae, one on coxa 1 short and thick, other coxae poorly armed; coxa 1 expanded apically, coxa 2 weakly constricted midposteriorly, coxae 3-4 subrectangular, 4 not significantly excavate, 3 and 4 equally extended, coxa 5 bilobed, coxae 6-7 shorter than 5.

Gnathopod 1 stout, wrist elongate, with moderately dense setal clumps posteriorly; hand short, broad, medial face weakly setose, posterior margin with notch bearing 2 spines (as if situated on false palm), palm almost transverse, weakly sculptured, dactyl very long and overlapping palm. Gnathopod 2 with strongly broadened article 2 and sharp anterior tooth plus accessory tooth; remainder of appendage slender and like that of female, wrist of medium length, hand much longer, thin, tapering, without palm, dactyl short and not folding back far, posterior margins of wrist and hand with groups of apically bent setae.

Pereopods 3 and 4 subequal.

Article 2 of pereopods 5-7 weakly expanded, not lobate, posterior margins weakly setulate, legs slender.

Pleopods ordinary. Pleonites 1-2 each with dorsolateral setule; epimera 1-3 with sinuous posterior

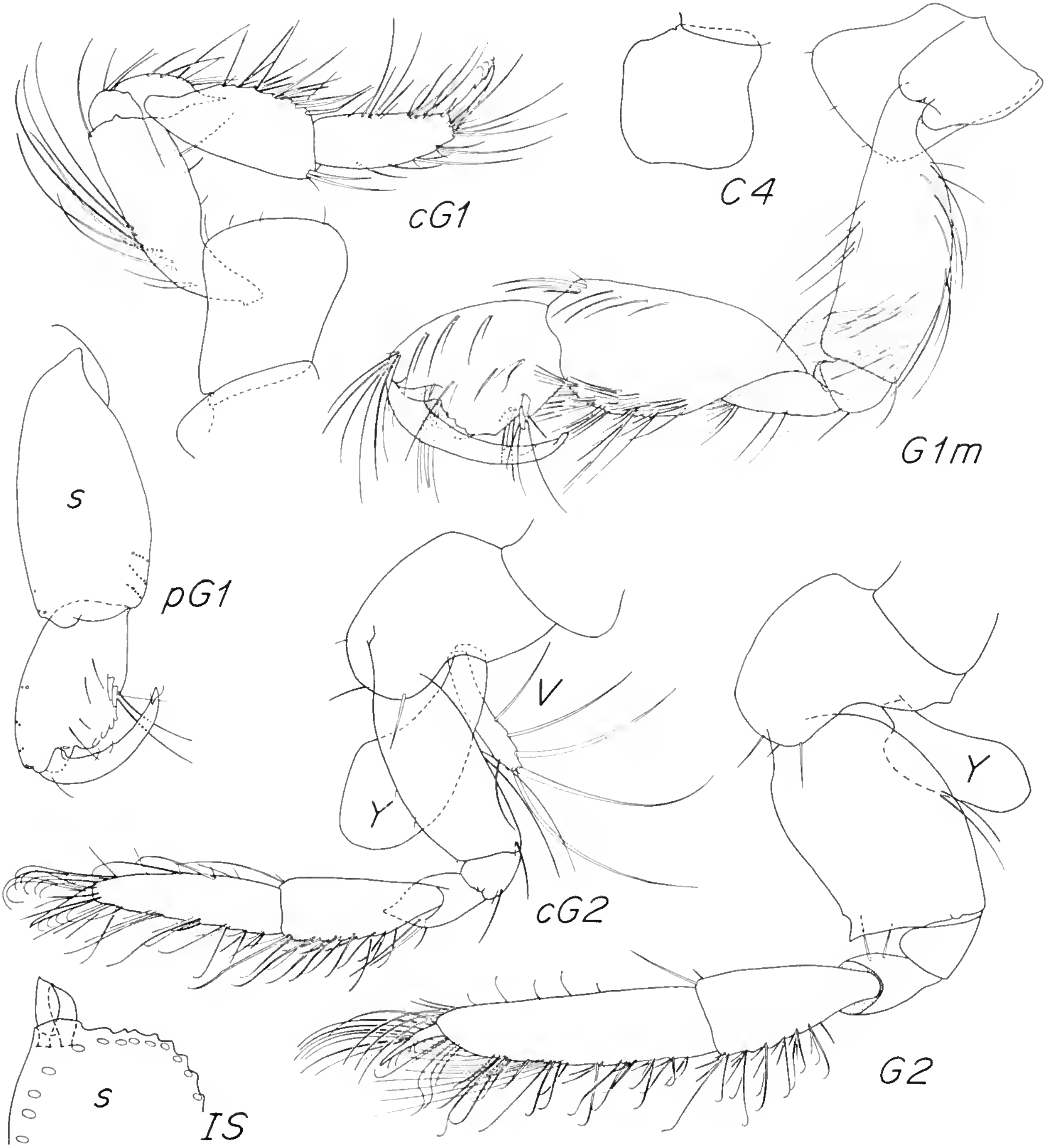


Fig. 6 – *Prosocratus butcheri* gen. nov. et sp. nov. Unattributed figures = holotype male "n" 4.34 mm; c = female "c" 3.41 mm; p = male "p" 4.18 mm.

margin and sharp posteroventral tooth marked with weak setule, ventral margin of epimeron 3 with weak spinule. Urosomite 1 with pair of medium teeth embracing third small tooth enfolding 2 spine setae; urosomite 2 with pair of more widely spaced small teeth each embracing spineseta. Uropods 1-2 extending equally, outer ramus of uropod 2 shortened, all rami weakly spinose marginally and apically; peduncle of uropod 1 with both margins spinose, without basofacial spine, apicolateral margin with small sharp cusp, large spine and small spine; uropod 2 peduncle with 1 lateral and 1 medial spine at apex. Uropod 3 strongly extended, peduncle scarcely elongate, apicodorsal margin with 2 spines in tandem, medial margin with 2 spines in basal group;

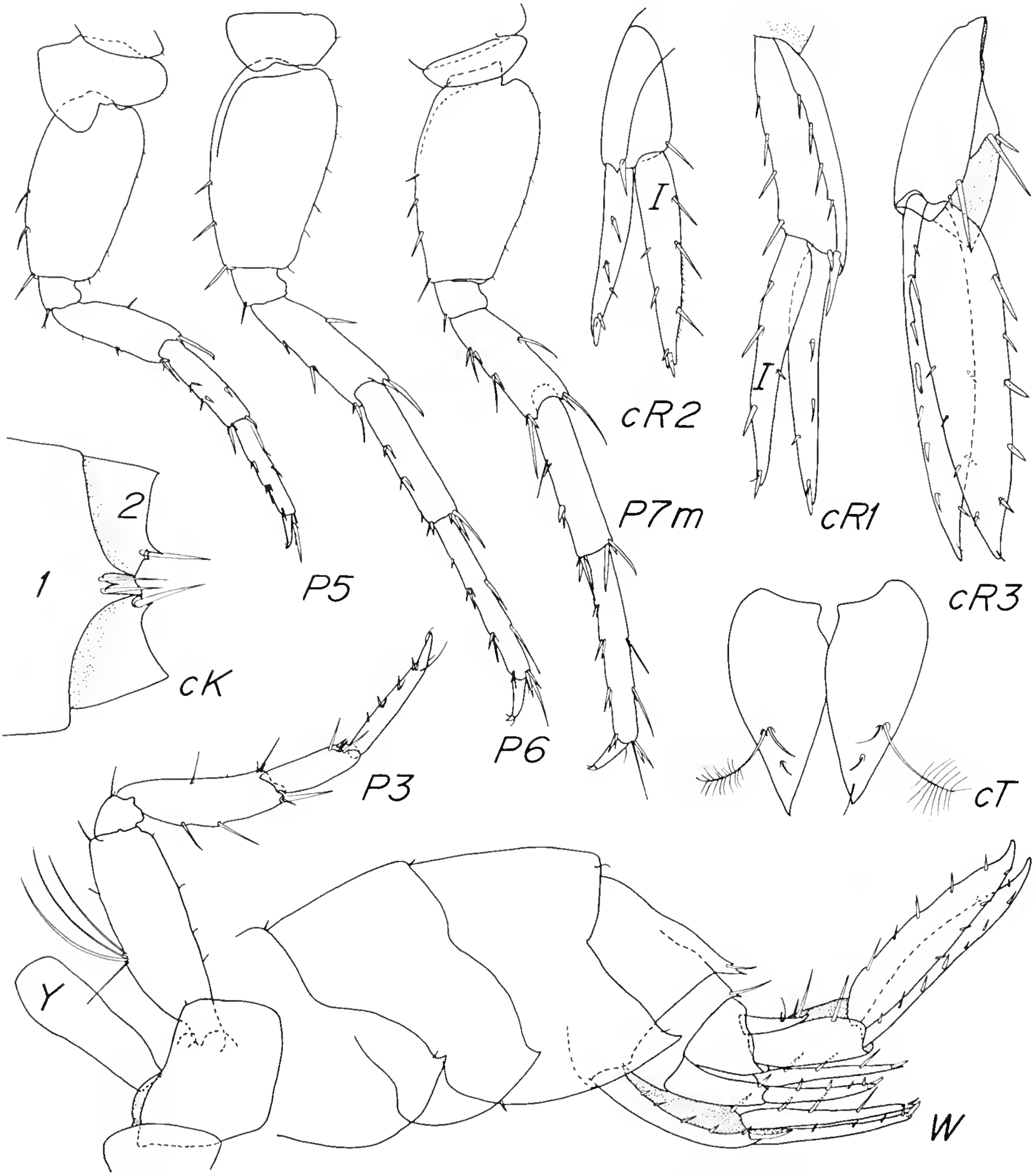


Fig. 7 — *Prosocratus butcheri* gen. nov. et sp. nov. Unattributed figures = holotype male "n" 4.34 mm; c = female "c" 3.41 mm; K = dorsal urosome.

rami elongate, lanceolate, weakly spinose along margins. Telson short, cleft to base, lobes slightly separate at base, lobes tapering to sharp point, each apex normally with setule (on holotype missing on one side), then another setule more basally, then pair of long plumose setules about M60.

Coxal gills on pereonites 2-6, ovate, sausage-shaped or adz-shaped.

Cuticle under medium power not textured, under oil immersion showing very faint tiny surficial thorn-scales and possible granules.

FEMALE: Like male but gnathopods 1-2 simple like male gnathopod 2, and article 2 slender; gnathopod 1 actually shorter than 2, with wrist longer than hand; brood plates slender, with few setae.

Young Male "p": Hand narrower than in adult (Fig. 6).

Holotype: NMV J1639 male "n" 4.34 mm.

Type Locality: WPBES 1707, Australia, Victoria. Western Port, 7 January 1974, intertidal, sand.

Paratypes: NMV J1640-1642.

Paratype Locality: Female "c", 3.41 mm; QUBS Moreton Bay Q., male "p" 4.18 mm; 1 male and 1 female from type locality.

Relationship: Although we have placed this species in a genus of its own because of the axial reversal of gnathopodal dominance in the male and the quite distinctive structure of that dominant gnathopod compared to the dominant gnathopod of other Australian taxa in this family group, we must note the very strong resemblance between this species and *Cheirocratus bassi* in dozens of small characters. Most of the morphology of this species could have been illustrated simply by reference to the drawings for *C. bassi.* This is somewhat unnerving as it means there may be very few increments of evolution between this taxon and its ancestors which may lie near *C. bassi* and that the attribution of generic importance we give it may be exaggerated.

Smaller differences between *P. butcheri* and *C. bassi* are to be found in (1) shape of the lateral cephalic lobes of which the anteroventral corner is rounded in *P. butcheri,* weakly produced in *C. bassi* (2) peduncle of antenna 2 which is rather stouter in *P. butcheri*, particularly articles 3 and 4; (3) the shorter and stouter gland cone in *P. butcheri* which reaches barely to M50 on articles 3 whereas in *C. bassi* it extends more than halfway; (4) the left lacinia mobilis, which has really only 2 branches in *P. butcheri*, 4 in *C. bassi*; (5) the stronger molar seta and (6) the broader plates of maxilla 2 in *P. butcheri*; (7) subequal and stouter pereopods 3 and 4 in *P. butcheri*; (8) longer dorsal teeth on urosome 1 and shorter urosome 2 in *P. butcheri.*

The females of these two species are not easy to distinguish at a glance, but may be separated by the first gnathopod which in *P. butcheri* has article 6 distinctly shorter than article 5, whereas in *C. bassi* the articles are subequal.

Placed side by side ovigerous females of these species of similar length reveal comparative differences; urosomite 2 is longer in *C. bassi* and the teeth on urosomite 1 are shorter. The gland cone in *P. butcheri* is stouter and shorter. *Prosocratus* appears heavier, due to slightly stouter second antennae, second articles of pereopods, subequal and stouter pereopods 3 and 4.

Material: CPBS, 1 sample (1 specimen); WPBES 9 samples from 6 stations (32 specimens); WP dredged 1 sample (1 specimen); EBS 1 sample (3 specimens); QUBS 3 samples from 3 stations (20 specimens).

Distribution: Western Port, Victoria, to Moreton Bay, Queensland, intertidal, sand, muddy sand, weed (*Posidonia*).

Etymology: This species is named for A. Dunbavin Butcher, former Deputy Director of Conservation in Victoria, in recognition of his major role in the benthic survey programmes in Victoria 1964-74 which have proved so vastly productive of new amphipod taxa.

ACKNOWLEDGEMENTS

We are grateful to Dr Alistair Gilmour formerly Officer-in-Charge, and Dr Leon Collett, of the Marine Studies Group, Ministry for Conservation, Victoria, and to Dr Barry Wilson, Director National Museum of Victoria, for their support of this study. At Smithsonian Institution we are indebted to Roland M. Brown, Janice Clark and Deborah Feher for their assistance. The Secretary of Smithsonian Institution Dr S. Dillon Ripley made it possible for J. L. Barnard to visit Australia in pursuit of this study. This publication is No. 380 in the Ministry for Conservation Environmental Study Series.

REFERENCES

Barnard, J. L., 1972. Gammaridean Amphipoda of Australia, Part I. *Smithson. Contr. Zool.* 103: 1-333.

Barnard, J. L., 1974. Gammaridean Amphipoda of Australia, Part II. *Smithson. Contr. Zool.* 139: 1-148.

Barnard, J. L. & Drummond, M. M., 1978. Gammaridean Amphipoda of Australia, part III: The Phoxocephalidae. *Smithson Contr. Zool.* 245: 1-551.

Chevreux, E. & Fage, L., 1925. Amphipodes. *Faune de France.* 9: 1-448.

Griffiths, C. L., 1975. The Amphipoda of South Africa. Part 5, The Gammaridae and Caprellidae of the Cape Provinee west of Cape Agulhas. *Ann. S. Afr. Mus.* 67: 91-181.

Karaman, G. S., 1977a. *Cheirocratus armatus* n. sp. from Suez Region with some remarks to some other members of this genus (Fam. Gammaridae). *Poljopr. Sum.* 23: 43-52.

Karaman, G. S., 1977b. New member of the genus *Cheirocratus* Nor. from Mediterranean Sea, *C. monodontus* n. sp. (Fam. Gammaridae), Glasn. *Rep. Zav. Zast. Prir. Zbirke Titogradu.* 10: 59-68.

Ledoyer, M., 1967. Amphipodes gammariens de quelques biotopes de substrat meuble de la région de Tulear (Republique Malgaehe [sic]). Etude systematique et ecologique. *Ann. Univ. Madagascar* 6: 17-62.

Liljeborg, W., 1852. Norges Crustaceer. *Ofversigt Konglelige Vetenskaps-Akademiens Förhandlinger, Attonde Argangen* 8: 19-25.

Norman, A. M., 1867. Report on the Crustacea. *Nat. Hist. Trans. Northumb.* 1: 12-29.

Rathke, H., 1843. Beïtrage zur Fauna Norwegens. *Verhandl. Kaiserl. Leopoldinisch-Carolinischen Akad. Naturforscher. Breslau* 20 (1): pp. 1-264.

Sars, G. O., 1895. *Amphipoda. An account of the Crustacea of Norway with short descriptions and figures of all the species.* Christiana, Alb. Cammermeyers Forlag.

Stebbing, T. R. R., 1906. Amphipoda I. Gammaridea. *Das Tierreich* 21: 806.

Stephensen, K., 1928. Storkrebs II. Ringkrebs I. Tanglopper (Amfipoder). *Danm. Fauna* 399.

Stephensen, K., 1929. *Amphipoda.* Tierwelt N.-u Ostsee, Leipzig.

Stephensen, K., 1940. The Amphipoda of northern Norway and Spitsbergen with adjacent waters. Fase 3. *Tromsφ Mus. Skr.* 3: 279-362.

PROC. R. SOC. VICT. vol. 94, no. 3, 121-132, September 1982

A PRELIMINARY STUDY OF MOVEMENT OF FISHES THROUGH A VICTORIAN (LERDERDERG RIVER) FISH-LADDER

By J. P. Beumer and D. J. Harrington

Arthur Rylah Institute for Environmental Research, Fisheries and Wildlife Division, 123 Brown Street, Heidelberg, Victoria 3084

Abstract: The fish community below the spillway of a diversion weir on the Lerderderg River, Victoria and the upstream and downstream movements of fishes through a fish-ladder on the weir were studied over a seven-month period from June to December 1980. Representatives of all five species of fish recorded below the weir spillway were taken in a two-way trap installed in the fish-ladder. River blackfish (*Gadopsis marmoratus* Richardson) and brown trout (*Salmo trutta* Linnaeus) were taken most frequently. The other species taken were short-finned eel (*Anguilla australis* Richardson), Australian smelt (*Retropinna semoni* (Weber)) and roach (*Rutilus rutilus* (Linnaeus)). Mean velocity at the centre of the outflowing weir orifice was 103.9 ± 30.9 cm/sec. Although mean water velocities within steps, 18.9-49.3 cm/sec, in the fish-ladder were not considered high, larger river blackfish and brown trout, longer than 180 mm in length, were the major users of the fish-ladder. Two alterations to existing tunnel off-take and downstream water diversion operations are suggested to increase access-time for fishes to the entrances of the fish-ladder.

Although dams are continually being constructed in Australia to provide water for domestic, industrial or irrigation purposes, relatively few of the existing barriers have fish-ways or fish-ladders incorporated (Harris 1980). Even for those barriers with some form of fish-way, little attention has been paid to monitoring the effectiveness of their design (Beumer 1980, Harris 1981). The study of Kowarsky & Ross (1981) on the Fitzroy River (Queensland) fish-ladder is the most recent and comprehensive in Australia.

The first fish-ladder to be incorporated on a barrier in Victoria forms part of the Lerderderg River Diversion Weir, approximately 45 km north-west of Melbourne. Pre-impoundment distribution studies on the fishes in the Lerderderg River suggested that at least two native species, the short-finned eel, *Anguilla australis* Richardson 1841 and the river blackfish, *Gadopsis marmoratus* Richardson 1848 and one exotic species, brown trout, *Salmo trutta* Linnaeus 1758 would be affected by construction of the weir (Beumer & Harrington 1980a).

In this paper, we report on a seven-month (June to December 1980) monitoring of the fish movement through the Lerderderg River fish-ladder and the fish community immediately downstream of the spillway and entrance of the fish-ladder.

STUDY AREA

The Lerderderg River is a 60 km long tributary of the Werribee River which flows into Port Phillip Bay (Maver & Farmar-Bowers 1979). The diversion weir is located at the lower end of a gorge section on the river. The storage area is approximately 2 ha with a capacity of about 65 ML. A series of tunnels of more than 6 km in length and a further weir on Goodmans Creek carry water from the weir into Coimadai Creek where it is stored in Merrimu Reservoir (Fig. 1). The catchment lies within a forestry reserve, the only other activity in the area being gold-prospecting.

The fish-ladder is a pool-type with full weirs and submerged alternate orifices (Fig. 2a). This design was chosen to provide a choice of passage for the different species of fish, either by migrating through an orifice or over a weir (Clay 1961). A total of 36 vertical and 6 horizontal steps form the ladder, each step being 90 cm long. A two-way trap to monitor fish movement was located at Step 36. Steps above the trap-bay are 107 cm wide while those below the bay are 102 cm wide. The weirs are 10 cm thick and each step drops 10 cm to the next. The orifices are 20 x 20 cm² in area and located 15 cm above the level of each pool base. Resting pools with a minimum depth of 20 cm are located at the right-angle bends at steps 21, 30 and 31 (Fig. 2b). All pools were normally operated at full depth with 2-5 cm of water spilling over the weirs. Discharge from the fish-ladder is at right angles to the direction of normal flow at a point level with the edge of the spillway. A compensation flow pipe, carrying water for agricultural requirements, discharges at a point level with but to the east of the fish-ladder entrance. The fish-ladder has a 1:10 slope up to and including the trap-bay and is then at a constant level to the reservoir proper.

METHODS

Weekly maximum and minimum water temperatures (°C) were recorded at three locations: (1) in the trap-bay for the entire monitoring period (24 June to 2 December); (2) above the main body of the reservoir for inflowing water and (3) 100 m downstream of the spillway for outflowing water from 7 October onwards. The height (cm) of water in the trap-bay was read from a metal rule attached to the upstream wall of the bay. Discharge figures were recorded by the State Rivers and Water Supply Commission of Victoria (S.R.W.S.C.) at O'Brien's Crossing, approximately 9 km upstream of the diversion weir.

The fish-ladder trap and the area immediately

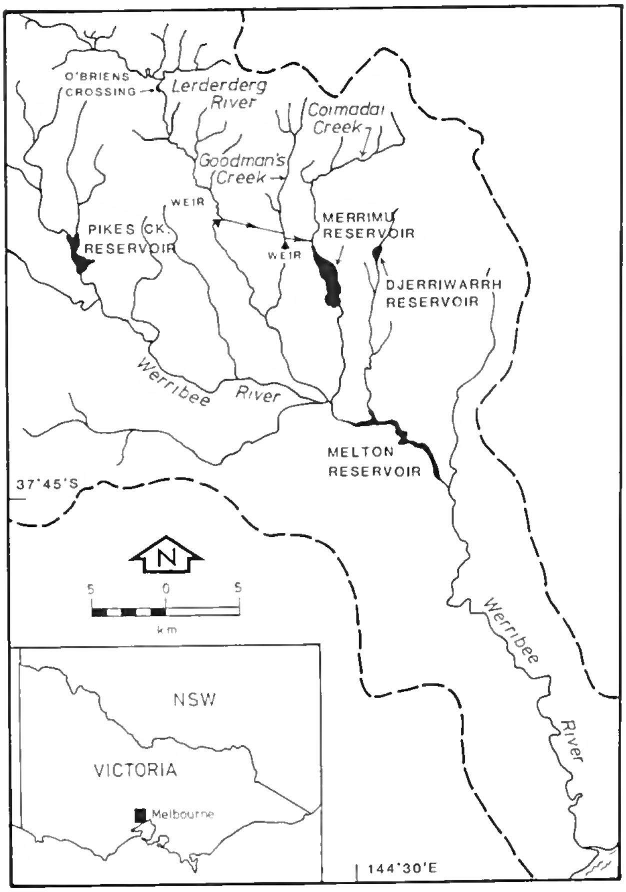


Fig. 1—Catchment area (— —) showing diversion weirs and tunnels on Lerderderg River and Goodmans Creek.

downstream of the spillway were monitored every 7 days for the occurrence and movement of fishes from 24 June to 2 December 1980, inclusive. After this date, the reservoir was drained to allow maintenance of the radial gates' control mechanism.

Two dead brown trout on the bank near the fish-ladder soon after the commencement of the monitoring led to covering the fish-ladder with a "Nylex" plastic screen of 12 mm diagonal mesh to prevent further losses. This screen was attached at a number of points in such a manner that access to steps 14, 28 and 33 could be gained readily to allow water velocities to be measured with a Teledyne Gurley flow-meter at 9 standard locations (Fig. 2a): eight within each of these steps and one in the centre of the outflowing orifice. The velocities recorded within the steps at the 8 positions were subjected to a two-way analysis of variance, using a randomised complete block design (Sokal & Rohlf 1969) where dates are blocks and step and position are factors, to test for the effects of date, step and position on the velocity. The position, open or closed, of the middle radial gate and side valves (Fig. 2b) was recorded and periods of tunnel operation were supplied by S.R.W.S.C.

The area immediately downstream of the fish-ladder entrance and below the weir spillway was electrofished with a 240 v. d.c. unit (Moore 1968) at each visit. The area, approximately 240 m^2, consisted of large boulders and a gravel substrate and had a maximum depth of 90 cm. All fishes were anaesthetised with Quinaldine, identified and measured (total length (TL) to the nearest mm). Fishes longer than 100 mm were marked below the 1st dorsal fin with small blue fingerling tags (Floy FTF-69), serially numbered with a black legend, to determine movement of individual fishes. Eels larger than 340 mm were tagged with anchor tags (Floy FD-68A). Fishes were released in the area of capture.

Movement of fishes through the ladder was monitored by a trap covered with galvanised mesh (4 mm diagonal) and installed in the trap-bay. Funnels extended from the trap into the upstream and downstream orifices of the trap-bay (Figs. 3, 4) so that all fishes would be captured. A section, 9 cm wide, was removed from the bottom of the cone of each funnel to facilitate fish entry. Guide rails were added later to facilitate movement of the funnels. Upstream and downstream catches were separated by a median division in the trap. Lids with an overhanging lip of 25 mm covered each trap section. Weights were placed on each lid to ensure a complete seal. The trap was checked every 7 days. The trap-bay was covered by a hinged steel grate and locked. All fishes were removed from the trap, handled as above, then released into the reservoir or below the spillway depending on whether these were taken in the lower or upper section of the trap respectively. For individual species, the Student's 't' test was used to determine the significance of differences between the respective mean TL of catches from below the spillway and lower trap section.

RESULTS

Both maximum and minimum water temperatures in the trap-bay were lowest during the first half of the monitoring period after which they rose to the highest values in late November (Fig. 5). Maximum and minimum temperatures in the trap-bay were significantly correlated with those recorded upstream ($P<0.01$) and downstream ($P<0.05$). Water height in the trap-bay was relatively constant except on 7 October and 2 December (Fig. 5) when the side-valves and the middle radial gate respectively were open. Discharge figures at O'Brien's crossing show peaks during early July, late August and mid-September. The middle radial gate and the side-valves were open on 13 and 3 sampling occasions respectively, while the diversion tunnel operated for a total period of approximately 20 days during late June to late September. The monthly minimum flow regime below the diversion weir instituted by S.R.W.S.C. is: 120 ML/day (May-October); 24 ML/day (November) and 60 ML/day (December-April). Of this flow, the fish-ladder carries 4 ML/day, the compensation flow pipe may release a maximum of 24 ML/day with any necessary additional flow from the side-valves and/or the middle radial gate.

Significant differences exist between velocities recorded at different positions within the steps

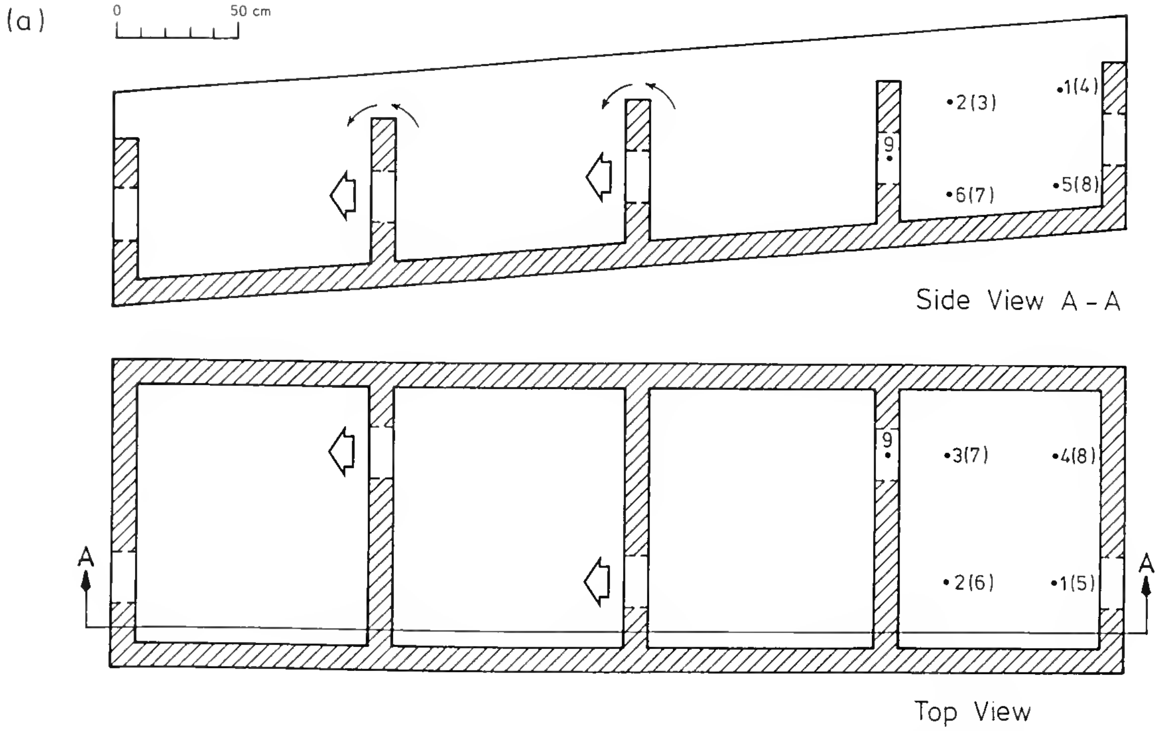


Fig. 2—a. Top and side view of four steps in fish-ladder showing positions 1-9 at which velocities measured, direction of water over weirs and through alternate orifices.

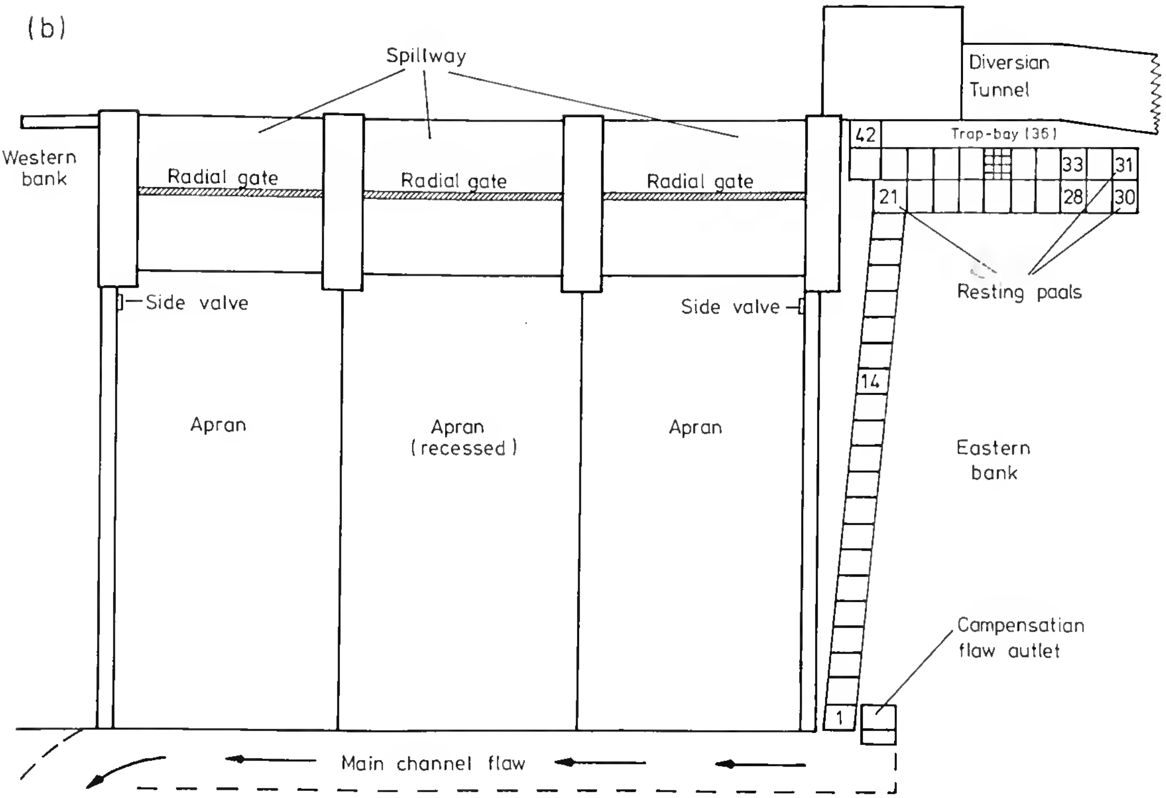


Fig. 2—b. Diagram of fish-ladder relative to diversion weir and tunnel.

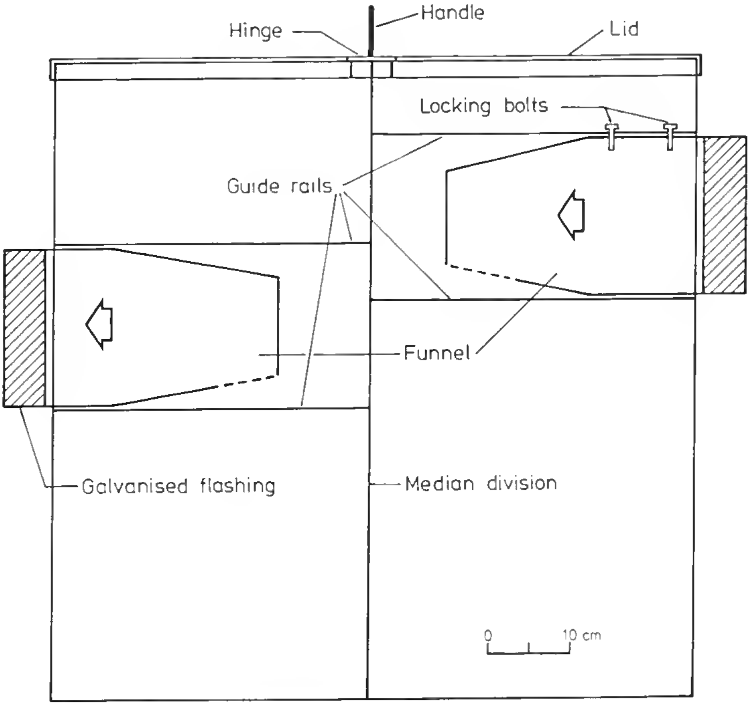


Fig. 3—Section through two-way fish-trap used for monitoring movement in fish-ladder. Arrows show direction of flow. Lower section (– –) of cone of each funnel removed.

Fig. 4—Two-way fish-trap, with upstream funnel on right-hand side, *in situ* in step 36 of the fish-ladder.

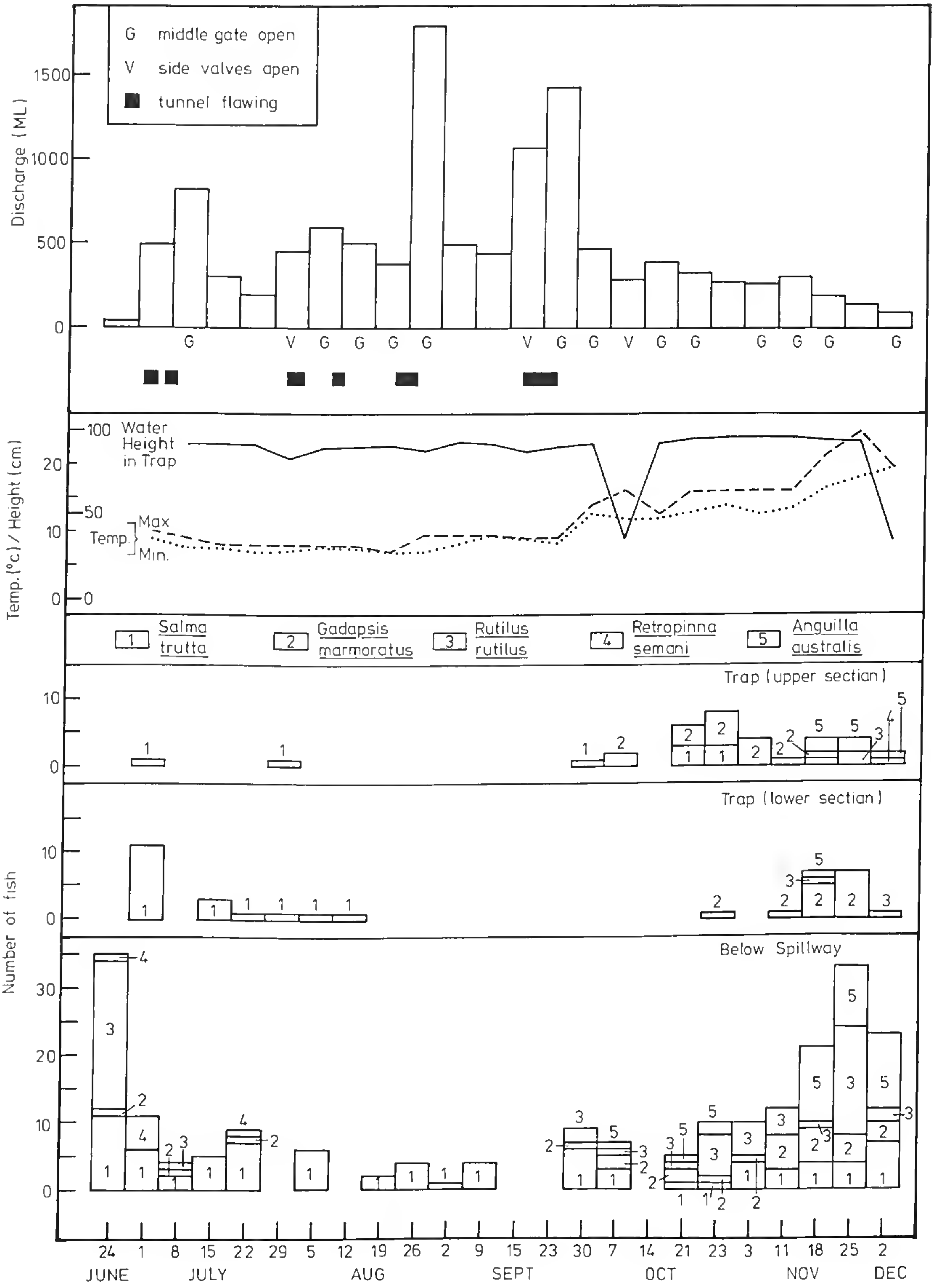


Fig. 5 — Physical parameters and abundance of fishes of the weir. Discharge recorded at O'Briens Crossing.

TABLE 1

MEAN VELOCITY ± s.d. FOR EACH POSITION AND ANALYSIS OF VARIANCE FOR EFFECTS OF DATE, STEP AND POSITION ON VELOCITY

Position	1	2	3	4	5	6	7	8
Mean Velocity (cm/sec ± s.d.)	49.3 24.1	20.9 10.4	18.9 9.9	39.1 19.5	43.5 35.3	29.4 15.3	28.2 12.4	25.2 6.4

Source of variation	d.f.	SS	MS	F
Date	16	18279.3	1142.46	3.63*
Step	2	2367.8	1183.89	3.77†
Position	7	54913.2	7844.74	24.96*
Step × Position	14	5891.0	420.79	1.34
Residual	368	115670.7	314.32	
Total	407	197122.0	484.33	

*P<0.01
†P<0.05

($P<0.01$), on different dates ($P<0.01$) and to a lesser extent at which step ($P<0.05$) (Table 1). The two highest mean velocities within the steps were at the surface (position 1) and bottom (position 5) proximal to the inflowing orifice (Table 1) while the mean velocity (103.9 ± 30.9 cm/sec) at the centre of the outflowing orifice (position 9) was more than twice any recorded within the steps.

Almost equal numbers of fishes were taken in the upper (34 specimens) and lower (35) sections of the trap during the monitoring period. Of the fishes in the trap not one was damaged. Brown trout eggs were found in the lower trap section on several occasions. Brown trout and river blackfish were the major species taken in each section of the trap, with the former species being the only one taken in the trap from June until early October (Fig. 5). In the upper section of the trap the majority of the catches was taken from mid-October onwards, with numbers of river blackfish and eels increasing as maximum temperatures rose above 15°C. In the lower section, brown trout were taken only during June to mid-August, with blackfish, roach and an eel taken from late October to early December. Below the spillway, roach, smelt and brown trout were the major species present from June to the end of September, after which river blackfish and eels became more abundant in the catches. No fishes were found in the trap-bay outside the trap.

All the brown trout taken in the upper section of the trap were longer than 210 mm TL (Fig. 6). One spent female was recorded at the end of July. None of the river blackfish, all greater than 180 mm TL, was ripe (eggs or milt freely expressed by slight pressure on the abdomen) but all were larger than the minimum spawning size of 120 mm TL (Jackson 1978). The short-finned eels, from 330 to 570 mm TL, were all immature adults with the yellow feeding body colouration. The roach taken was a juvenile.

Brown trout captured in the lower trap section (Fig. 7) were larger than those taken below the spillway on all corresponding sampling occasions. Comparison of the mean total length between below spillway and lower trap section catches for this species showed significant differences ($P<0.01$) (Table 2) for particular dates and

TABLE 2

COMPARISON OF SIZE BETWEEN BELOW-SPILLWAY AND LOWER TRAP SECTION CATCHES

Date	Below Spillway No.	Below Spillway TL ± s.d.	Lower Trap Section No.	Lower Trap Section TL ± s.d.
Salmo trutta				
1 July	6	129.5 ± 27.4	11	293.0 ± 31.0*
15 July	5	151.0 ± 70.2	3	369.0 ± 53.4*
1 July-12 Aug.	26	148.0 ± 46.3	18	313.3 ± 42.6*
Gadopsis marmoratus				
18 Nov.	5	210.6 ± 47.6	5	212.2 ± 26.1
25 Nov.	4	157.5 ± 64.4	7	215.7 ± 46.3
28 Oct.-25 Nov.	16	185.1 ± 48.3	14	222.4 ± 42.9†

* P<0.01
† P<0.05

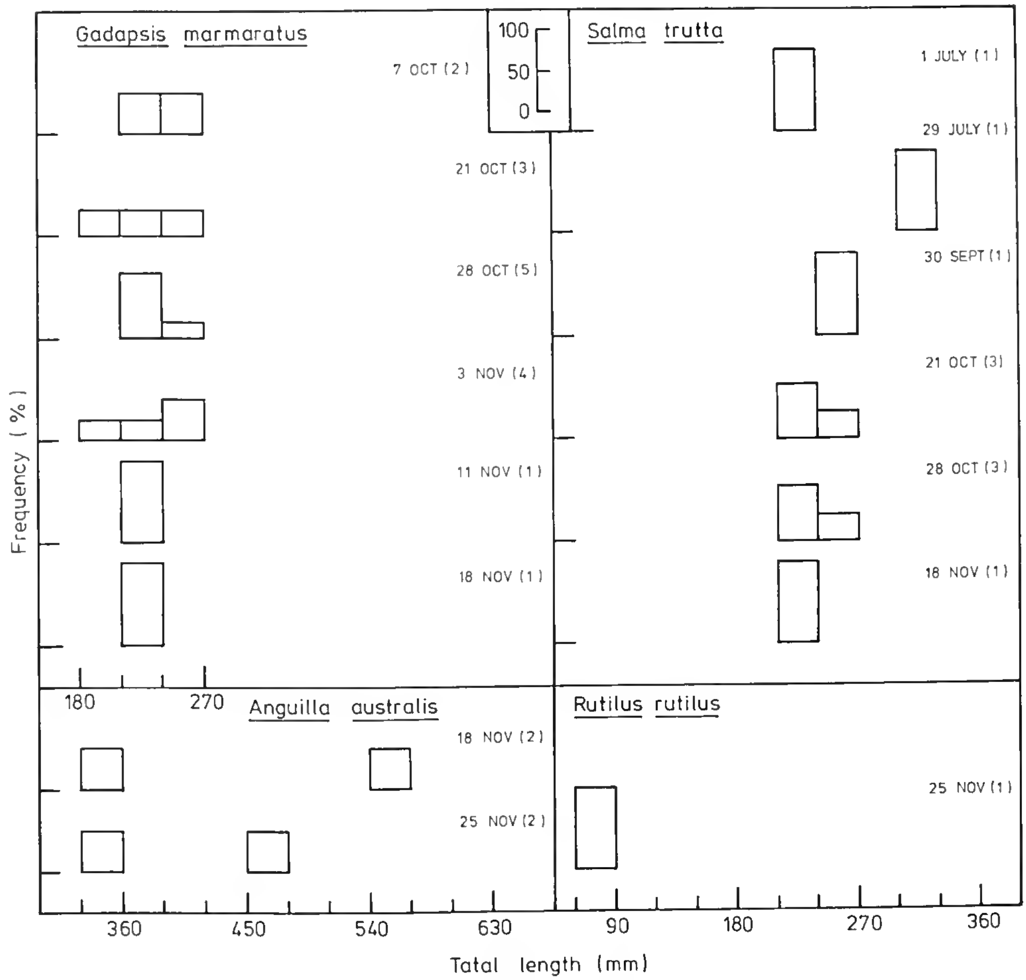


Fig. 6—Length-frequency distribution of fishes taken in the upper trap section.

for the period 1 July to 12 August. In the lower trap section, ripe males and females were present on 1 July with ripe females present during mid-July to mid-August. Brown trout taken below the spillway were juveniles or immature adults except for one ripe female taken on 15 July.

River blackfish taken in the lower trap section were greater than or equal in total length to those captured below the spillway (Fig. 8). Statistical comparison of the mean total lengths showed no significant differences for particular dates (Table 2) between the lower trap section and below-spillway samples although a significant difference ($P<0.05$) existed when the period 28 October to 25 November was considered. In the lower trap section not one of the river blackfish was ripe although all were of spawning size. Those taken below the spillway were either immature and mature adults or juveniles.

Roach larger than 90 mm were not taken in the lower section of the trap (Fig. 8) although these occurred frequently in samples from below the spillway. These samples included juveniles, immature and mature adults, and one ripe male taken on 7 October. Only one short-finned eel, a small brown elver, was taken in the lower trap section (Fig. 9). Eels taken below the spillway were brown elvers (mean $TL = 153.0 \pm 11.6$ mm; range 129-175 mm) and immature adults, again with the yellow feeding body colouration.

A total of 78 fishes was marked with fingerling tags: 39 river blackfish, 33 brown trout, 4 roach and 2 short-finned eels. A further six eels were marked with anchor tags. Of the 84 tagged fishes, 21 were recaptured once (Table 3), and three, all brown trout, were multiple recaptures. Five of the nine river blackfish recaptured were taken in the lower trap section, indicating upstream movement between 7 and 28 days after release. Four of these five fish originated from the reservoir, as these were captured initially in the upper section of the trap.

DISCUSSION

While both the number of species and specimens captured increased with elevated water temperatures during the monitoring period, the correlation between inflowing water temperatures and fish-ladder temperatures and also between fish-ladder temperatures and outflowing water temperatures suggest that the shallow

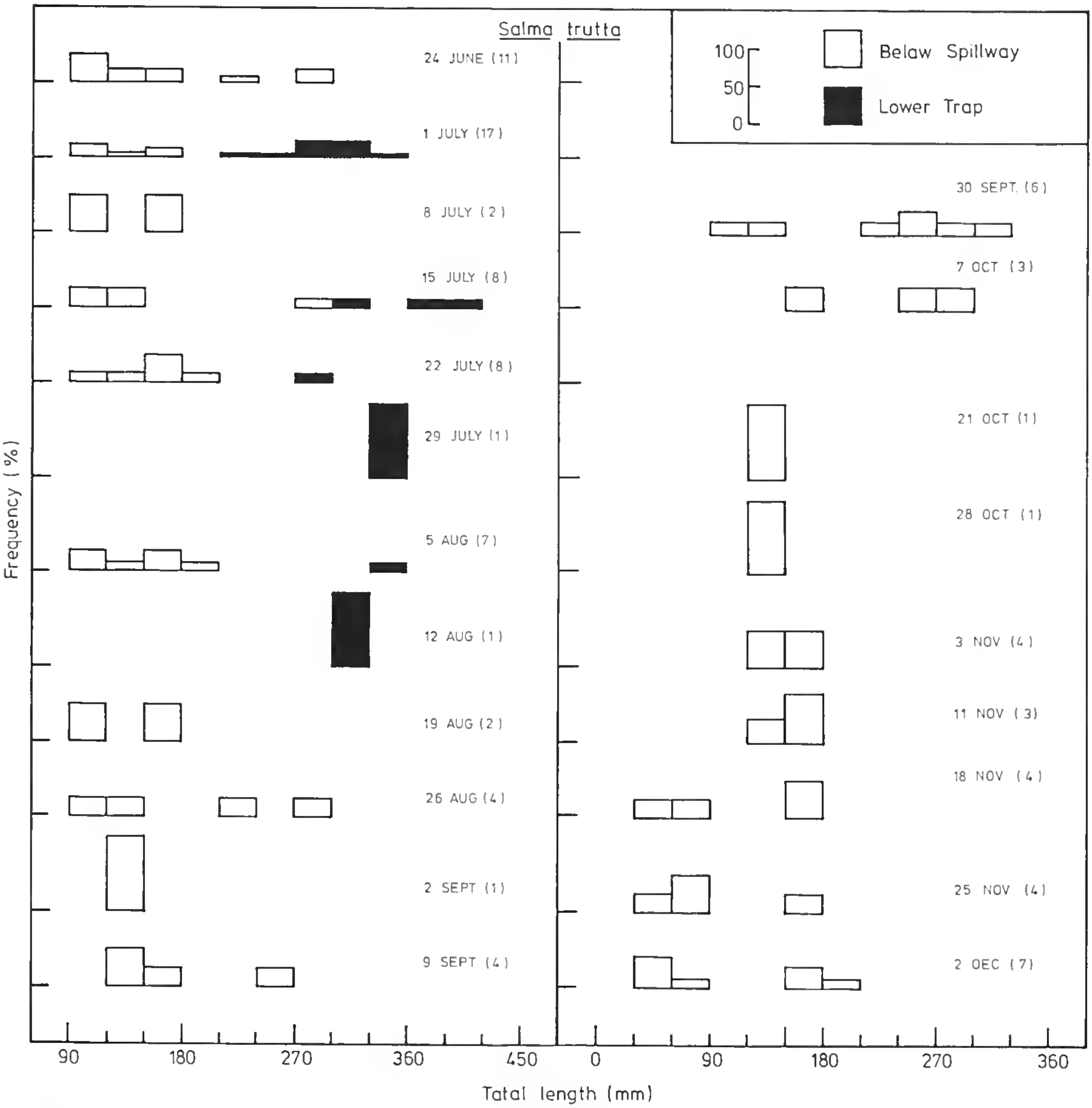


Fig. 7—Length-frequency distribution of brown trout, *Salmo trutta*, in the lower trap section and below the spillway.

reservoir does not alter the normal temperature regime of the Lerderderg River. Furthermore, fish behaviour within the river is not disrupted by fluctuations in temperature which are often associated with deeper and larger reservoirs, e.g. Dartmouth Dam (Blyth 1980) or with diversion operations. Fishes were affected by fluctuations in discharge with reduced catches related to peaks of discharge. This is due to a combination of decreased density of fishes and their displacement at times of increased water volume and to a lesser extent to the reduced visibility and consequent lower efficiency of electrofishing operations in rapidly flowing turbid waters.

The fish-ladder design permits larger brown trout and river blackfish to migrate upstream and downstream. Movement through the fish-ladder may be random, as suggested by some of the recapture data for river blackfish, or be specific as recorded for brown trout captured on upstream spawning migrations. Short-finned eels, roach and smelt did not utilise the fish ladder to the same extent. This may reflect the unsuitable velocity or the time of sampling. However, Davidson (1949) found an average swimming speed of 60.8 cm/sec for specimens of *Anguilla rostrata* Lesueur of a size similar to that of the brown elvers recorded here. This speed is higher than that recorded in any of the eight positions within a step. Sorensen (1951) found eels, *A. anguilla* Linneaus, 100-150 mm TL, capable of migrating upstream at water temperatures of 20°C against currents of between 90 and 130 cm/sec, speeds

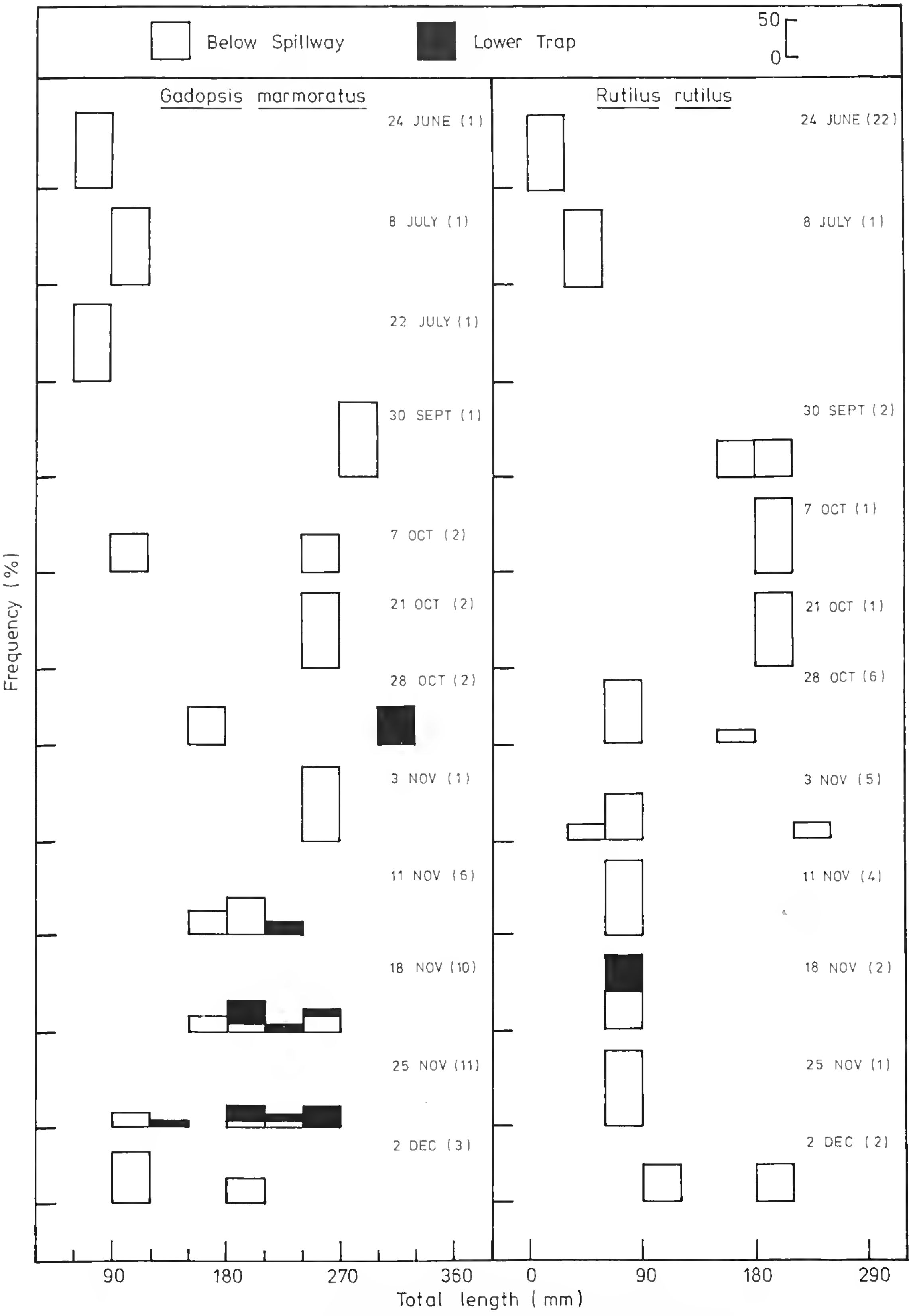


Fig. 8—Length-frequency distribution of river blackfish, *Gadopsis marmoratus*, and roach, *Rutilus rutilus*, in the lower trap section and below the spillway.

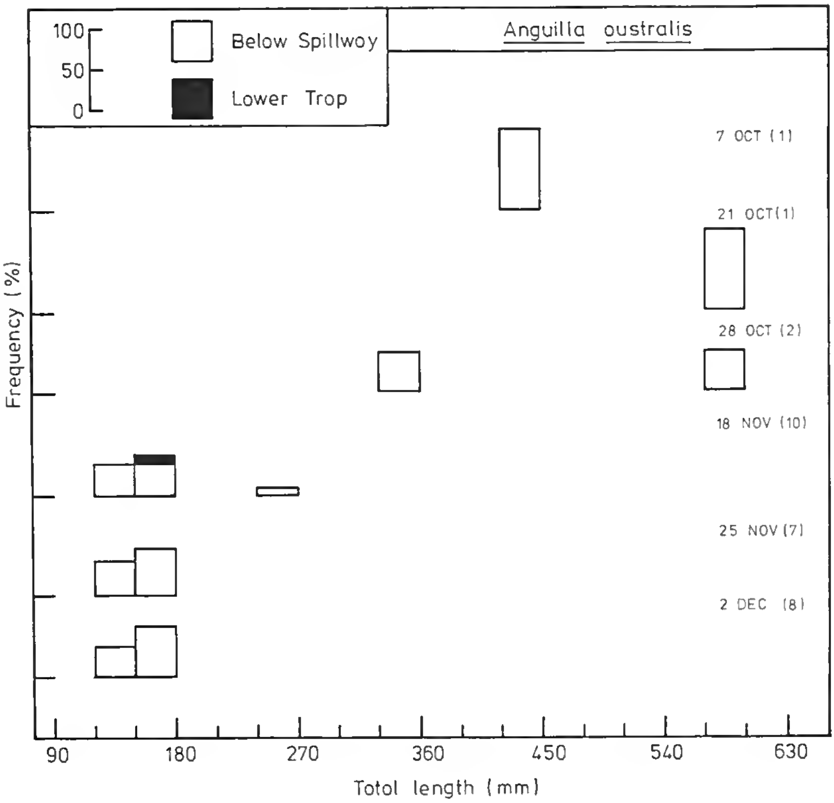


Fig. 9—Length-frequency distribution of short-finned eel, *Anguilla australis*, in the lower trap section and below the spillway.

within the range recorded in this study. The migration of short-finned eels, *A. australis*, is temperature dependent and follows a period of dormancy in winter (Beumer 1979). The upstream movement of the brown elvers follows a spring-summer pattern (Beumer & Harrington 1980b) and the results suggest this movement was just commencing when the monitoring period ended.

Although apparently suitable for larger brown trout and river blackfish, the fish ladder was not shown to be utilised by small individuals of either species. Studies of other fish species have shown that larger individuals are capable of swimming against velocities equivalent to those recorded here, especially when in peak condition (Farlinger & Beamish 1978). Even though these velocities may be high in certain sections of the fish-ladder, e.g. greater than 100 cm/sec through the outflowing orifice of a step, several factors, including the size of the brown trout and river blackfish, the relatively short distance over which these velocities extend and the presence of significantly lower velocity backwater regions in the steps, reduce the energy expenditure of fishes migrating upstream. The mean velocities recorded at all eight positions within the steps are below the threshold value of 60 cm/sec above which rheotactic coastal off-shore fishes (mean length range 30-60 mm) are displaced downstream (Schuler & Larson 1975). Furthermore, studies on marine fishes have shown burst swimming speeds of more than 100 cm/sec for one second (Dorn *et al.* 1979) and, assuming that the fishes in this study have similar swimming capabilities, the velocities recorded within the study may be within their capacity and allow upstream migration if made over an extended period. Successful swimming performances of fishes require high ambient oxygen levels (Kutty & Saunders 1973) and are temperature-dependent (Otto & Rice 1974). The oxygen levels, although not measured in this study, are assumed to be non-limiting as a result of high mixing and turbulence of the water while passing down through the orifices and over the weirs of the fish-ladder. An increase in swimming performance with increasing temperature has been recorded for certain species of freshwater fish (Otto & Rice 1974). The increase in numbers of fishes, both below the spillway and in the trap in the latter half of the monitoring period, as a result of increasing activity may in part reflect a similar performance for fish species in the Lerderderg River.

Reasons for the limited use of the fish-ladder by smaller fishes are uncertain. While the possibility of escape by returning upstream or downstream from the trap or by escape through the mesh (4 mm diagonal, 2.83 mm square) should not be discounted, several factors suggest that this would be minimal. Fishes actively migrating upstream do so in response to and by orientating into the downstream-flowing current. The absence of fishes in the trap-bay outside the trap and the body-depth (≥ 5 mm) of brown elvers (≥ 100 mm TL) suggested that there was no escape from the trap through the mesh. While the extent of escape was not evaluated, it is assumed that the opportunity to escape through the funnels would be equal for all species and

TABLE 3

RECAPTURE DATA FOR EACH SPECIES OF FISH IN 1980

Unless indicated, release and recapture sites are below diversion weir spillway.

Species	TL (mm)	Release Date	Recapture Date(s)
Gadopsis marmoratus	185[a]	3 Nov.	25 Nov.[b]
	202[a]	28 Oct.	25 Nov.[b]
	239[a]	11 Nov.	25 Nov.
	250[a]	3 Nov.	25 Nov.[b]
	262[a]	28 Oct.	18 Nov.[b]
	165	28 Oct.	18 Nov.
	252	7 Oct.	21 Oct.
	254	3 Nov.	18 Nov.
	266	18 Nov.	25 Nov.[b]
Anguilla australis	585	21 Oct.	28 Oct.
Rutilus rutilus	165	30 Sept.	28 Oct.
	196	30 Sept.	21 Oct.
Salmo trutta	103	5 Aug.	19 Aug.
	118	26 Aug.	3 Nov./18 Nov./25 Nov./2 Dec.
	125	9 Sept.	30 Sept.
	134	2 Sept.	9 Sept./21 Oct./28 Oct.
	145	3 Nov.	18 Nov.
	157	19 Aug.	9 Sept.
	158	3 Nov.	11 Nov.
	247	30 Sept.	7 Oct.
	275	26 Aug.	30 Sept./7 Oct.

[a] initially captured in upper trap section.
[b] recaptured in lower trap section.

the recorded catches in the trap still reflect the migrating trends and fish-ladder usage. Some fishes 100 mm TL or smaller are able to attain speeds of 25 body lengths/sec (Wardle 1975) and the recorded water velocities of this study are within this limit. Smaller brown trout, river blackfish, roach and smelt may not make upstream migrations similar to those of larger, more mature individuals but rather utilise the area below the spillway as a suitable habitat. Alternatively, smaller individuals of these four species may be incapable of attaining the required speeds or be inhibited from entering the fish-way by the presence of larger individuals.

As with other fish-ladders (Sakowicz & Zarnecki 1962, Dominy 1973, Kowarsky & Ross 1981) and their capability to allow fishes to pass, a number of problem areas exist with the Lerderderg River ladder. Possible modifications to the design of the fish-ladder to improve its effectiveness by reducing velocities and turbulence include bevelling each orifice on both sides (top and bottom only) or, at least, on the entry side, and the inclusion of a slot in each weir in such a manner that the flow passing through the fish-ladder forms two intersecting sinusoidal lines (Sakowicz & Zarnecki 1962). The capacity of the fish-ladder and compensation pipe combined provide the required downstream flow for only one month (November) each year. For the rest of the year, the middle radial gate and/or the side-valves must be opened and this may divert the upstream migrating fishes away from the fish-ladder entrance. A possible solution is the controlled release from the three radial gates in such a manner as to extend the area and intensity of the velocity of release water from the fish-ladder entrance outwards. However, the current operating mechanism for these gates allows only for releases from the middle gate (to an initial maximum opening of 45 cm) before the two outer gates may be opened. It is unlikely that species other than short-finned eels would make their way upstream over the spillway. A screen placed along the lower spillway margin to guide fishes to the fish-ladder entrance may partly resolve this situation. Fishes, originating from the reservoir, have also been caught between the bottom of the middle gate and the spillway (K. Long, S.R.W.S.C. pers. comm.) when water was released from the reservoir. No further fish were found outside the fish-ladder after its covering with the Nylex screen. The screen also prevented leaf-litter and other extraneous material from entering the fish-ladder, thereby reducing maintenance.

Operational procedures for the diversion of water through the tunnel may also result in physical displacement of reservoir and migrating fishes to Goodmans Creek partly because of the proximity of the fish-ladder intake to the tunnel entrance. The present procedure of diverting the entire volume of the reservior above the fish-ladder intake level when full results in extreme fluctuations of reservoir level over a relatively brief period. A gradual continual removal of excess water above the intake level of the fish-ladder would allow more stable reservoir water levels and a standard head of water acting on the upstream entrance of the fish-ladder. In addition this would allow the maintenance of flows through the fish-ladder in summer and autumn when fishes with temperature-dependent swimming performances and behaviour patterns may by-pass the diversion weir. Further monitoring with the trap at these times would provide evidence of seasonal movements by fishes and may also be of use in controlling the invasion of the reservoir and upper reaches of the catchment by undesirable species of fish, e.g. common carp, *Cyprinus carpio* Linnaeus 1758, already established in the Melton reservoir.

ACKNOWLEDGEMENTS

We thank Mark Nelson and other staff from the Arthur Rylah Institute for assistance with field work; the State Rivers and Water Supply Commission for discharge figures; Kevin Long, S.R.W.S.C., for cooperation and assistance with access to the diversion weir; Brian Barry of Bacchus March for construction of the fish-ladder trap; Alicia McShane for drafting support and David Powell for biometrical support and advice. Drs. Peter Jackson and Phillip Cadwallader and Mr. Jim Pribble read the manuscript and made many constructive comments.

REFERENCES

BEUMER, J. P., 1979. Feeding and movement of *Anguilla australis* & *A. reinhardtii* in Macleods Morass, Victoria, Australia. *J. Fish Biol.* 14: 573-592.

BEUMER, J. P., 1980. Fish ladders—steps in the right direction? *Wildl. Aust.* 17: 38-39.

BEUMER, J. P. & HARRINGTON, D. J., 1980a. Pre-impoundment distribution of fishes in the Lerderderg River, Victoria. *Victorian Nat.* 97: 68-72.

BEUMER, J. P. & HARRINGTON, D. J., 1980b. Techniques for collecting glass-eels and brown elvers. *Aust. Fish.* 39: 16-22.

BLYTH, J. D., 1980. Environmental impact of reservoir construction: the Dartmouth Dam invertebrate survey: a case history. In *An Ecological Basis for Water Resources* Management. W. D. Williams, ed., Aust. Nat. Univ. Press. Canberra, 174-181.

CLAY, C. H., 1961. *Design of Fishways and Other Fish Facilities.* Dept. of Fisheries of Canada, Ottawa. 301 pp.

DAVIDSON, V. M., 1949. Salmon and eel movement in constant circular current. *J. Fish. Res. Bd. Can.* 7: 432-448.

DOMINY, C. L., 1973. Effect of entrance-pool weir elevation and fish density on passage of alewives (*Alosa pseudoharengus*) in a pool and weir fishway. *Trans. Am. Fish. Soc.* 102: 398-404.

DORN, P., JOHNSON, L. & DARBY, C., 1979. The swimming performance of nine species of common California inshore fishes. *Trans. Am. Fish. Soc.* 108: 366-372.

FARLINGER, S. & BEAMISH, F. W. H., 1978. Changes in blood chemistry and critical swimming speed of largemouth bass, *Micropterus salmoides*, with physical conditioning. *Trans. Am. Fish. Soc.* 107: 523-527.

HARRIS, J. H., 1980. Structures affecting fish migration in streams draining the south eastern coastal region of Australia. *Ecol. Select. Est. Organ. Proj. (12-045-16), Uni. of N.S.W. Data List.* 4: 1-42.

HARRIS, J. H., 1981. Fishways and fish passage problems in Australia. *Proc. 16th Assembly Aust. Fresh Wat. Fish.* 9-20.

JACKSON, P. D., 1978. Spawning and early development of the river blackfish, *Gadopsis marmoratus* Richardson (Gadopsiformes: Gadopsidae), in the Mackenzie River, Victoria. *Aust. J. mar. Freshwat. Res.* 29: 293-298.

KOWARSKY, J. & ROSS, A. H., 1981. Fish movement upstream through a central Queensland (Fitzroy River) coastal fishway. *Aust. J. mar. Freshwat. Res.* 32: 93-109.

KUTTY, M. N. & SAUNDERS, R. L., 1973. Swimming performance of young Atlantic salmon (*Salmo solar*) as affected by reduced ambient oxygen concentration. *J. Fish. Res. Bd. Can.* 30: 223-227.

MAVER, J. L. & FARMAR-BOWERS, Q. G., 1979. Environmental studies and effects of Dartmouth and Lerderderg Dam projects, Victoria. *Gen. Eng. Trans.* 3: 41-48.

MOORE, W. H., 1968. A light-weight pulsed D.C. fish shocker. *J. Anim. Ecol.* 5: 205-208.

OTTO, R. G. & RICE, J. O., 1974. Swimming speeds of yellow perch (*Perca flavescens*) following an abrupt change in environmental temperature. *J. Fish. Res. Bd. Can.* 31: 1731-1734.

SAKOWICZ, S. & ZARNECKI, S., 1962. Pool passes—biological aspects in their construction (Engl. trans.). *Rocz. Nauk Roln. Ser. D.* 66: 5-171.

SCHULER, V. J. & LARSON, L. E., 1975. Improved fish protection at intake systems. *Proc. Am. Soc. Civil Eng.* 101EE6: 897-910.

SOKAL, R. R. & ROHLF, F. J., 1969. *Biometry—the principles and practice of statistics in biological research.* W. H. Freeman & Co., San Francisco. 776 pp.

SORENSEN, I., 1951. An investigation of some factors affecting the upstream migration of the eel. *Rep. Inst. Freshw. Res., Drottningholm.* 32: 126-132.

WARDLE, C. S., 1975. Limit of fish swimming speed. *Nature (Lond.).* 255: 725-727.

PROC. R. SOC. VICT. vol. 94, no. 3, 133-154, September 1982

TRILOBITES FROM THE MOUNT IDA FORMATION (LATE SILURIAN-EARLY DEVONIAN), VICTORIA

By David J. Holloway* and John V. Neil†

* National Museum of Victoria, 285-321 Russell Street, Melbourne, Victoria 3000
† 23 Michael Street, Bendigo, Victoria 3550

Abstract: A poorly preserved fauna of sixteen trilobite species is described from coarse quartzose sandstones of the Mount Ida Formation in the Heathcote district of central Victoria. Most of the taxa are described under open nomenclature but two new species are named, *Scutellum droseron* and *Cheirurus (Crotalocephalina) oxina*. The trilobites support the view of Philip (1967), based on brachiopods, that Unit 3 of the Mount Ida Formation is of early Gedinnian age, whereas stratigraphic relations indicate that the lower part of the formation is of Pridolian age.

The stratigraphy of the Silurian-Lower Devonian sedimentary sequence in the Heathcote district of central Victoria was originally described by Thomas (1937) and has been summarised recently by VandenBerg & Garratt (1976) (Fig. 1). The Mount Ida Formation, the uppermost unit in the sequence, consists of approximately 2100 m of sandstones with interbedded mudstones, shales and conglomerates that were interpreted by Talent (1965a) as having been deposited in a shallow-water environment close to the western margin of the Melbourne Trough. The formation was subdivided by Thomas (1937) into four units, apparently largely on the basis of the poorly preserved shelly fauna which is dominated by brachiopods but also includes molluscs, trilobites, corals, bryozoans, and rare sponges, ostracodes and echinoderms. The faunas of Units 1 and 2 are small and characterized by the abundance of the brachiopods *Molongia* cf. *elegans* Mitchell and *Notoconchidium thomasi* Gill respectively; Unit 3 contains the most abundant and diverse faunas in the Heathcote sequence. No fossils have been found in Unit 4, which contains conglomerates.

With the exception of a short paper on two species of brachiopods (Gill, 1951), the only descriptions of the fauna of the Mount Ida Formation are in a monograph by Talent (1965b) on the faunas of the whole sequence. Since that work was published large collections of fossils have been made from the Mount Ida and these contain numerous trilobites, including several forms not previously recorded. Most of the trilobites described in the present study were obtained from Unit 3 of the formation; Units 1 and 2 have yielded only a few species (Table 1). The trilobites occur as internal and external moulds in hard, grey to brown or red quartzose sandstones that are so coarse-grained that fine morphological features of the exoskeleton have not been preserved. In addition, the surfaces of the moulds are commonly encrusted with a layer of iron minerals that further obscures detail. Partially or completely articulated specimens are very rare, and furthermore the isolated parts of the exoskeleton have commonly been broken prior to preservation. This, together with the fact that the associated brachiopods are all preserved with their valves separated, is indicative of transport and deposition in a turbulent environment.

AGE AND CORRELATION

Unit 3 of the Mount Ida Formation has always been considered to be of Early Devonian age but there has been disagreement about its precise correlation with standard European sequences. Owing to the scarcity of stratigraphically useful fossils in Units 1 and 2 and in the underlying McIvor Sandstone, there has also been considerable uncertainty as to whether the Silurian-Devonian boundary should be placed within the lower part of the formation, at its base, or even below it. Talent (1965a, b) considered the fossil assemblage of Unit 3 to be indicative of a broad Gedinnian-Siegenian age and placed the Silurian-Devonian boundary (Skalian-Gedinnian boundary in his 1965a correlation chart, although at that time he included the Skalian within the Devonian) somewhere within the McIvor Sandstone. Philip (1967) placed the boundary much higher, at the base of Unit 3 of the Mount Ida, which he considered to be of early Gedinnian age on the basis of the brachiopod fauna. A similar brachiopod fauna occurs in the upper part of the Boola Beds in the Tyers area (see Philip 1962, pp. 244-6) and also in the Maradana Shale in the Manildra district of New South Wales; the latter was considered to be of early Gedinnian age by Savage (1974). Unit 2 of the Mount Ida Formation was correlated by Philip (1967) with the upper part of the Florence Quartzite of Tasmania, which he regarded as pre-Gedinnian because of the presence of encrinurid trilobites (but see discussion below on the upper range of encrinurids). Strusz *et al.* (1972) equated the upper part of the Mount Ida Formation with strata in the Yea and Seymour districts containing *Monograptus thomasi* and *M. aequabilis notoaequabilis*, and from this concluded that Unit 3 is late Lochkovian (approximately late early to middle Siegenian). They placed the Silurian-Devonian boundary in the Heathcote sequence at the top of the McIvor Sandstone which was considered to be of Pridolian age because of the entry in that unit of the brachiopod *Notoconchidium*.

VandenBerg & Garratt (1976) stated that the upper part of the McIvor Sandstone laterally becomes the Clonbinane Sandstone Member of the Humevale Formation and that this unit contains *M. thomasi* and *M. aequabilis aequabilis* at the top. Consequently they regarded the upper part of the McIvor as Early Devo-

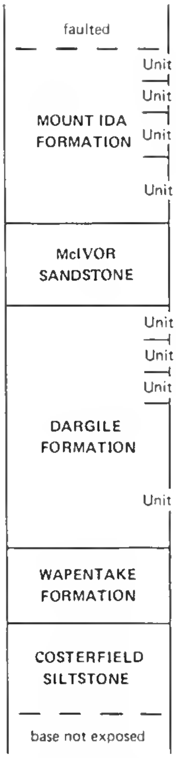


Fig. 1 — Silurian-Early Devonian stratigraphic succession in the Heathcote district.

nian. Talent *et al.* (1975) also reported the occurrence of graptolites of the *M. hercynicus* type in the Clonbinane Sandstone Member, which they considered to be a lateral equivalent of the basal part of the McIvor Sandstone. However the identification of Devonian graptolites from this horizon cannot be confirmed and appears to be incorrect as the Ludlovian species *Bohemograptus bohemicus* has been recorded well above the Clonbinane Sandstone Member at Strath Creek (Garratt 1978) and has also been identified by Dr. R. B. Rickards (pers. comm.) from an horizon in the Yea district just below the Rice's Hill Sandstone Member, which Garratt (1978) equated with the Clonbinane Sandstone Member. Assuming that the reported equivalence of all these units is correct, the McIvor Sandstone must be of Ludlovian age and is probably middle to late Ludlovian in view of the occurrence of early Ludlovian graptolites in Unit 2 of the Dargile Formation, much lower in the Heathcote sequence (Jaeger 1966).

The few species of trilobites found in Units 1 and 2 of the Mount Ida Formation are of no value for correlation, but it is of interest to note the presence of encrinurids near the base of Unit 2. The highest occurrence of encrinurids previously recorded in the Heathcote sequence was in Unit 4 of the Dargile Formation (the report by Strusz (1980) of encrinurids occurring in Unit 3 of the Mount Ida Formation was based on incorrect locality information provided by us). Encrinurids were long thought to have died out in the Pridolian and their highest occurrences in certain sequences have been used to suggest the position of the Silurian-Devonian boundary. Recently, however, they have been recorded from strata of Lochkovian age in the Tajna and Mitkov Beds in Podolia (Mozdalevskaya *et al.* 1968, Nikiforova 1977), the Kokbaital horizon in central Kazakhstan (Maksimova 1975), the Kunjak horizon in Tien-Shan (Biske *et al.* 1977), and the West Point Formation in Quebec (Bourque & Lespérance 1977). It is not known whether encrinurids persisted into the Devonian in eastern Australia. Excluding the Mount Ida Formation, the youngest occurrences are in the Florence Quartzite of Tasmania (Gill 1948a), the Derriwong Beds, Trundle Beds and Wallace Shale of New South Wales (Landrum & Sherwin 1976, Talent *et al.* 1975, Strusz 1980), and in limestone lenses outcropping in the Rockhampton district of Queensland (McKellar 1969). The ages of these units lie within the range Pridolian-Lochkovian but are not known with greater certainty.

Several trilobites from Unit 3 of the Mount Ida Formation provide evidence on the age of the fauna. *Ananaspis serrata* (Foerste 1888) was originally described from the Yass Basin of New South Wales, from beds now considered to lie within the upper part of the Elmside Formation, which contains conodonts indicative of the earliest Gedinnian *woschmidti* Zone (Link & Druce 1972). *Scutellum droseron* sp. nov. and *Cheirurus (Crotalocephalina) oxina* sp. nov. are very close morphologically to species occurring in the early Gedinnian Kokbaital horizon of central Kazakhstan. *Proetus (Coniproetus)* sp. nov. resembles *P. (C.) affinis* Boucek 1933 from the Lochkovian of Czechoslovakia. A slightly younger age than that suggested by the preceding species is suggested by *Sthenarocalymene* sp. A (Chatterton, Johnson & Campbell 1979). This species occurs also in the Garra Formation of New South

Table 1

Stratigraphic Distribution of Trilobites within the Mount Ida Formation

	Unit 1	Unit 2	Unit 3
Scutellum droseron sp. nov.			X
Proetus (Coniproetus) sp.			X
Tropidocoryphinae gen. et sp. indet.		X	X
Harpidella sp. 1			X
Harpidella sp. 2			X
Cheirurus (Crotalocephalina) oxina sp. nov.			X
Encrinurinae gen. et sp. indet.		X	
Sthenarocalymene sp. A. (Chatterton, Johnson & Campbell 1979)			X
Homalonotinae gen. et sp. indet. 1		X	X
Homalonotinae gen. et sp. indet. 2	X		
Homalonotinae gen. et sp. indet. 3			X
Ananaspis serrata (Foerste 1888)			X
Odontochile cf. *formosa* Gill 1948		X	X
Acastella sp.			X
Acanthopyge (Lobopyge) sp.			X
Leonaspis sp.			X

Wales, which has yielded late Lochkovian-Pragian conodonts (Chatterton, Johnson & Campbell 1979).

In summary, the trilobite fauna of Unit 3 of the Mount Ida Formation tends to support the early Gedinnian age suggested by Philip (1967) on the basis of the brachiopods, although as only a few trilobite species have been found to be useful for correlation the evidence cannot be considered to be sufficient by itself to give such a precise age. If the middle to late Ludlovian age suggested above for the McIvor Sandstone is correct, Units 1 and 2 of the Mount Ida Formation must be at least in part of Pridolian age.

LOCALITIES AND REPOSITORY

The localities referred to in the text are those shown on the locality map given by Talent (1965b, fig. 1) and also on the 1:31,680 geological parish maps published by the Geological Survey of Victoria (Thomas 1940 a, b, 1941). On these maps there is considerable duplication of locality numbers in different parishes and in order to avoid ambiguity the numbers are prefixed here by the initial letter of the parish, as follows: D, Parish of Dargile; H, Parish of Heathcote; R, Parish of Redcastle. Some of these localities do not represent actual outcrops but only loose boulders scattered over the ground; it is unlikely, however, that these boulders were moved an appreciable distance from where they were originally exposed. Locality R25 proved to be much more productive than any of the others and the greater part of the material collected came from here. The described specimens are housed in the palaeontological collections of the National Museum of Victoria (catalogue numbers prefixed NMVP).

SYSTEMATIC PALAEONTOLOGY

Family Scutelluidae R. & E. Richter 1955

Genus **Scutellum** Pusch 1833

Type Species (by original designation): *Scutellum costatum* Pusch 1833 from the Frasnian of Poland (not the Givetian of Germany as stated by Chatterton, Johnson & Campbell 1979; see R. & E. Richter 1926).

Scutellum droseron sp. nov.

Fig. 2P-V

Name: Greek *droseros* meaning dewy, referring to the tuberculate surface sculpture.

Type Material: Holotype, NMV P75100, internal mould of cranidium and counterpart external mould, from locality R25; Fig. 2P,R,U. Paratypes, NMV P75101-4 (cranidia), NMV P75105-6 (librigenae), from locality R25; NMV P75107 (incomplete thorax and pygidium), from 100 m south of locality R31.

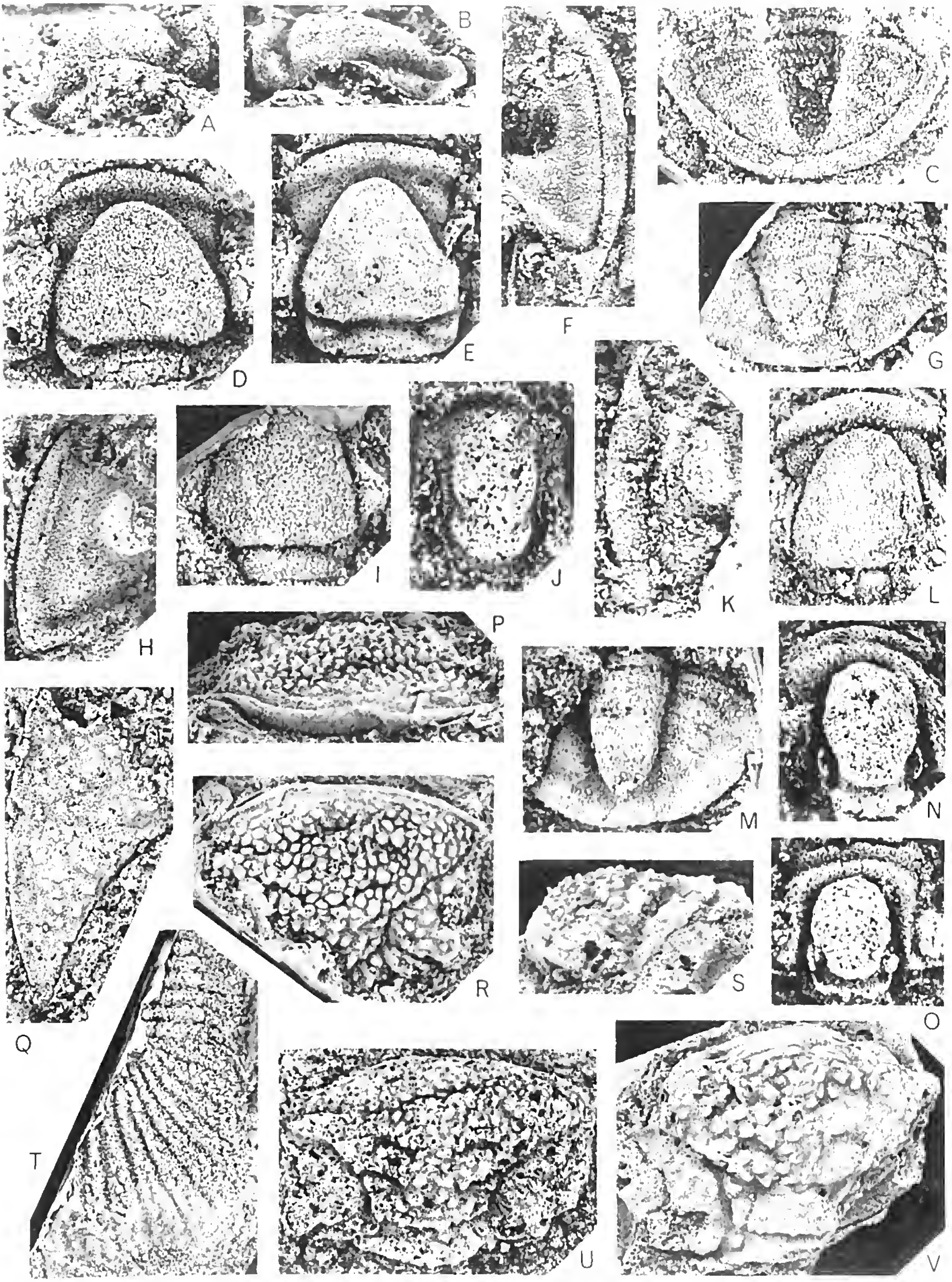
Diagnosis: Dorsal surface of exoskeleton covered with coarse tubercles that are contiguous on glabella and become scale-like on outer part of librigena. Glabella increases in width only slightly between occipital furrow and front of 1p impression but anterior two-thirds is strongly expanded so that width at frontal lobe is 2.5 times that at occipital furrow. Occipital ring short for genus, with large median tubercle or small spine on its posterior margin and large tubercle situated at outer extremity of occipital muscle impression. Glabellar muscle impressions deep but partly obscured by surface tuberculation; anterior limb of 1p deeper than posterior limb; 2p gently convex forwards and slightly oblique; 3p poorly defined, transverse. Outline of palpebral lobe more than a semi-circle; anterior branch of facial suture almost straight, diverging at 25° to sagittal axis, lying just outside axial furrow at frontal glabellar lobe. Genal angle elongate, approximately 35°.

Description: Palpebral width of cranidium almost equal to width at α-α and approximately 1.4 times the length (sag.). Occipital ring convex backwards in dorsal view (with palpebral lobe horizontal), flattened (sag., exsag.) and merging anteriorly with occipital furrow, which is bounded in front by a short, abrupt slope. Occipital muscle impression subrectangular, extending inwards about two-thirds the distance to the sagittal axis. 1p impression parabolic, somewhat expanded (tr.) proximally, enclosing a small inflated lobe; inner end of 2p impression level with glabellar midlength; 3p impression wider and shallower than 2p, lying opposite widest part of frontal lobe. Axial furrow narrow, shallowest adjacent to occipital ring and deepest at lateral muscle impression, diverging at 55°-60° to sagittal axis in front of 1p impression. Preglabellar furrow is gently impressed abaxially and anterior border is short (exsag.) with a rounded crest; furrow and border both fade adaxially and become almost obsolete medially; outer face of anterior border slightly convex (sag., exsag.) and subvertical, decreasing in height abaxially. Anterior border and tubercles on front of glabella bear terrace lines; tubercles immediately behind preglabellar furrow merge into one or more low, transverse ridges.

Palpebral lobe almost equal in height to glabella; steeply inclined portion of fixigena medial to palpebral lobe separated from subhorizontal posterior portion by a furrow directed slightly obliquely forwards from ϵ towards lateral muscle impression; in front of palpebral lobe fixigena slopes anterolaterally. Lateral muscle impression depressed. Lateral border forms a narrow, rather sharp, upturned rim inside which the librigena is flattened or slightly concave, except towards base of eye (not preserved) where is rises slightly. Posterior border furrow on librigena shallow and poorly defined proximally and fading abaxially; posterior border weakly convex, increasing in length (exsag.) abaxially.

Thorax and pygidium poorly preserved, covered with coarse tubercles. Pygidial pleural ribs decreasing in convexity abaxially; median rib (assuming there are seven pleural ribs) not appreciably wider than pleural ribs and non-bifurcate distally.

Remarks: *S. droseron* is closest morphologically to *S. michnevitchi* Maksimova 1968 from the Kokbaital horizon (Early Devonian) of central Kazakhstan. Both species differ from characteristic members of the genus in having a sculpture of coarser tubercles that are con-


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V

tiguous on the glabella; a very strongly expanded anterior part of the glabella; a relatively short (sag., exsag.) occipital ring that lacks a depressed anterior band medial to the occipital muscle impression; deep glabellar impressions; and a tubercle situated at the distal edge of the occipital muscle impression (present in at least some specimens of *S. michnevitchi*; see Maksimova 1968, pl. 4, fig. 4). As compared with *S. michnevitchi, S. droseron* has somewhat smaller tubercles on the glabella; an axial furrow that diverges more gradually in front of the 1p impression; and a less divergent anterior branch of the facial suture.

The only Australian species with which worthwhile comparisons may be made is *S. calvum* Chatterton 1971 from the *Receptaculites* Limestone (late Emsian-early Eifelian) near Yass, New South Wales. *S. calvum* is a characteristic representative of *Scutellum* and so *S. droseron* differs from it in the features listed above. In addition, *S. droseron* has a deeper occipital furrow, a more strongly curved outline of the palpebral lobe, a more divergent anterior branch of the facial suture, a relatively narrower anterior part of the fixigena and shorter (exsag.) abaxial part of the anterior border, and a longer, more acute genal angle. *S. calvum* has gently arcuate, transverse ridges on the front of the glabella as does *S. droseron* but they were described by Chatterton (1971) as terrace lines. The ridges in *S. droseron* are relatively longer (sag., exsag.) and lower than terrace lines, and have terrace lines developed on them.

Family PROETIDAE Salter 1864

Subfamily PROETINAE Salter 1864

Genus **Proetus** Steininger 1831
Subgenus **Proetus (Coniproetus)** Alberti 1966

TYPE SPECIES (by original designation): *Proetus condensus* Pribyl 1965 from the Koneprusy Limestone (Pragian), Menany, Prague district, Czechoslovakia.

Proetus (Coniproetus) sp. nov.

Fig. 2A-M

MATERIAL: At least 20 cranidia, 6 librigenae, 1 hypostome and 40 pygidia from localities R25, R31, approximately 100 m south of R31, and various places between R25 and R30.

DESCRIPTION: Glabella almost as wide as long (sag.), expanding forwards across occipital ring, subparallel-sided between occipital furrow and δ-δ, and thereafter decreasing in width (weakly constricted opposite γ in some specimens) and curving steeply downwards. Occipital ring with median tubercle and prominent lateral lobes; occipital furrow deep, medial portion convex forwards and outer portion deflected anterolaterally. Glabellar furrows 1p and 2p faintly visible abaxially but 3p furrow indistinguishable. Preglabellar field absent, glabella slightly overhanging anterior border furrow. Margin of palpebral lobe strongly flexed at δ but γ-δ and δ-ϵ only weakly curved. Between γ and β anterior branch of suture diverges at about 13° to sagittal axis; posterior branch of suture parallel to axial furrow from ϵ to ζ (the latter lying opposite midlength of occipital lobe) and thereafter turning sharply outwards.

Librigena gently convex inside border furrows, rising beneath eye to become vertical; faint ridge subparallel to outer margin runs midway between lateral border furrow and base of eye, curving backwards and inwards posteriorly. Lateral border flattened; posterior border narrower than lateral border and convex (exsag.); posterior border furrow sharply impressed. Genal angle pointed or extended into short spine. Doublure on librigena convex (tr.) anteriorly, becoming flattened opposite front of eye and narrowing towards posterior extremity; inner edge broadly rounded beneath genal angle, with no sign of panderian notch. Traces of terrace lines preserved towards outside of lateral border and doublure.

Pygidium 1.75 times as wide as long, weakly segmented on axis and pleurae. Axis strongly arched (tr.), 0.3 times as wide anteriorly as maximum width of pygidium, narrowing strongly to bluntly rounded terminus. First ring furrow weaker than articulating furrow and remainder successively fainter, defining 3-5 or possibly 6 axial rings. Pleurae curve gently downwards abaxially and bear 4-5 pleural furrows, of which only the first is sharp; first interpleural furrow faintly distinguishable; broad, weakly convex border defined by slight change of slope.

REMARKS: Specimens assigned to this species show varia-

Fig. 2—A-M, *Proetus (Coniproetus)* sp. nov.; A, C, D, H, I, K, L from locality R31; B, E, F, G, M from locality R25; J from 100 m south of locality R31. A, D, cranidium NMV P75109; lateral and dorsal views, ×5. B, E, cranidium NMV P75108; lateral and dorsal views, ×4. C, latex cast of pygidial mould NMV P75117; ventral view, ×3.5. F, latex cast of librigenal mould NMV P75113; ventral view, ×3.5. G, latex cast of external mould of pygidium NMV P75115; dorsal view, ×3.5. H, librigena NMV P78290; dorsal view, ×3.5. I, latex cast of incomplete external mould of cranidium NMV P75111; dorsal view, ×4.5. J, hypostome NMV P75112; ventral view, ×5.5. K, latex cast of external mould of librigena NMV P75114; dorsal view, ×4. L, latex cast of external mould of cranidium NMV P75110; dorsal view, ×3.5. M, latex cast of external mould of pygidium NMV P75116; dorsal view, ×3.5. N, O, *Harpidella* sp. 1, from locality R25. N, cranidium NMV P78291; dorsal view, ×6.5. O, cranidium NMV P48746; dorsal view, ×8. P-V, *Scutellum droseron* sp. nov.; T from 100 m south of locality R31, remainder from locality R25. P, R, U, holotype cranidium NMV P75100; ×2; P, R, latex cast of external mould in anterior and dorsal views; U, counterpart internal mould in dorsal view. Q, librigena NMV P75105; dorsal view, ×2. S, V, cranidium NMV P75101; lateral and dorsal views, ×1.5. T, incomplete thorax and pygidium NMV P75107; dorsal view, ×0.9. Except where otherwise stated, specimens are internal moulds.

tion in the convexity (sag.) of the glabella, the weak constriction of the glabella opposite γ in some individuals, the degree of taper of the pygidial axis, and possibly the length of the genal spine (compare Fig. 2A, D with 2B, E). Some of the observed differences may be due to tectonic distortion.

P. (C.) affinis Boucek 1933 from the Lochkovian of Czechoslovakia is similar to this species but in the former the eye is situated further from the lateral border, the hypostome is wider, the pygidial axis is more strongly segmented, and the pygidial border is better defined. Only a cranidium of the type species, *P. (C.) condensus*, has been illustrated (Pribyl 1965, pl. 1, fig. 1), but Owens (1973, text-fig. 3C, D) figured a cephalon and a pygidium of *P. (C.) glandiferus* Novák 1890, which he considered to be a synonym of *P. (C.) condensus*. These specimens differ from the present species in that the occipital ring is wider (tr.) than the basal part of the glabella; the palpebral lobes are situated slightly further forward; the pygidium is more strongly segmented and more transverse; there is a greater number (7-8) of axial rings and they are more convex (sag., exsag.) and have muscle scars impressed abaxially; and the pygidial border is better defined.

The only previously described species of the subgenus from Australia is *P. (C.) irroratus* Chatterton, Johnson & Campbell 1979 from the Garra Formation (Early Devonian) of central New South Wales. It is not very close to the present species, which has a relatively shorter glabella, more posteriorly placed palpebral lobes, more weakly divergent section γ-β of the facial suture, no eye socle, and a more weakly segmented pygidium. There are similarities with the fragmentary cranidium figured by Chatterton, Johnson & Campbell (1979, pl. 104, fig. 23) as *P. (Coniproetus)?* sp., but cranidia from the Mount Ida Formation have a more conical glabella, and no preglabellar field.

The present species appears to occur also in the Humevale Formation near Lilydale, Victoria. Formal naming of the species will be deferred until work in progress on the Lilydale faunas is complete.

Subfamily Tropidocoryphinae Pribyl, 1946

Tropidocoryphinae gen. et sp. indet.

Fig. 4S-V

1965b Proetidae indet. gen. and sp. B. Talent, p. 48, pl. 25, figs. 4, 5.

Material: A cephalon NMV P59652, and pygidium NMV P59653 (formerly 46739 and 46740 respectively in the Geological Survey of Victoria collections), from locality R26; also a cranidium and 4 pygidia from approximately 300 m east of locality R25.

Remarks: The cephalon and pygidium from locality R26 were figured by Talent (1965b). The cephalon is a badly crushed internal mould with parts of the exoskeleton adhering. The glabella is gently convex, subparabolic in outline, and lacks lateral furrows. The occipital furrow is firmly impressed, transverse or slightly convex forwards medially and deflected forwards distally. The axial furrow is shallow but distinct and merges with the anterior border furrow in front of the glabella. The anterior and lateral borders are flattened and bear fine terrace lines around their outer margins; the border furrows are broad, shallow and poorly defined. Talent (1965b) could find no trace of eyes and concluded that this species was blind but it seems more likely that the eyes were obliterated during crushing of the specimen because the palpebral lobe, outlined by the facial suture, is visible on the left cheek. The pygidium is wider than long, with a relatively narrow, strongly arched axis and weakly convex pleurae having a slightly raised rim around the outside. The axial rings and pleural ribs are flattened (sag., exsag.). The pleural furrows are very shallow and the interpleural furrows even fainter. There are traces of very fine terrace lines on the pleurae, expecially around the margins.

This species appears to be closely related to *'Proteus' bowningensis* Mitchell 1887 from the upper Ludlovian to lower Gedinnian of the Yass Basin, New South Wales. *'P.' bowningensis* was assigned by Owens (1973) to *Latiproetus* Lu 1962 but Holloway (1980) considered that until the type species was better known, that genus should not be used. Talent (1965b) considered the present material to bear some resemblance to *Lepidoproetus* Erben 1951 but members of that genus differ in the structure of the anterior and lateral cephalic borders (see Alberti 1969, Holloway 1980) and in addition have a glabella that is subquadrate instead of narrowing anteriorly, a more transverse pygidium with a broader, more conical axis, and pygidial axial rings that stand higher at the posterior edge than the ring behind.

The specimens from 300 m east of locality R25 are much smaller and more poorly preserved than those from R26 but appear to belong to the same species.

Family Aulacopleuridae Angelin 1854
Subfamily Aulacopleurinae Angelin 1854

Genus **Harpidella** McCoy 1849

Type Species (by monotypy): *Harpes? megalops* McCoy 1846 from the upper Llandoverian at Boocaun, Cong, County Galway, Ireland.

Harpidella sp. 1

Fig. 2N, O

Material: Five cranidia from locality R25.

Remarks: These cranidia are assigned to *Harpidella* because of the very large, posteriorly placed palpebral lobe; the presence of an eye ridge; and the distinct glabellar furrow 2p (opposite the front of the palpebral lobe in Fig. 2O). In having an elongated glabella that does not narrow strongly in front of the 1p lobe, very small 1p lobes, and weakly curved 1p furrows, they resemble most closely the species *H. distincta, H. tantula* and *H. kobayashii* described by Pribyl & Vanek (1981) from the Pragian to Zlichovian of Czechoslovakia.

A species of *Harpidella* from the underlying McIvor

Sandstone was described and figured by Talent (1965b, pl. 24, figs. 7, 8) as Proetidae indet. gen. and sp. A. It is not very similar to the present material, having a relatively shorter, anteriorly narrowing glabella and larger 1p lobes.

Harpidella sp. 2

1965b *Otarion?* n. sp. Talent, p. 48, pl. 25, fig. 6.

MATERIAL: A cranidium NMV P59654 (formerly 37979 in the Geological Survey of Victoria collections), from locality R9.

REMARKS: This cranidium which was figured by Talent (1965b) is very similar to *Harpidella* sp. 1 but the 1p lobes are slightly larger and more triangular in shape, the preglabellar field is longer and more convex (sag.), and the anterior border is not evenly curved in dorsal view but is strongly flexed medially.

Family CHEIRURIDAE Salter 1864
Subfamily CHEIRURINAE Salter 1864

REMARKS: The presence of continuous glabellar furrows 2p and 3p is a feature of most Devonian cheirurinids. All such species were formerly assigned to *Crotalocephalus* Salter 1853, which was generally considered to be a subgenus of *Cheirurus* Beyrich 1845, but in recent years some of them have been included in four new taxa: *Crotalocephalina* Pribyl & Vanek 1964; *Crotalocephalides* Alberti 1967; *Pilletopeltis* Pribyl *in* Pillet 1973; and *Geracephalina* Kobayashi & Hamada 1977. This has led to confusion about the identity of *Crotalocephalus* itself because there seems to be no valid designation of a type species, a problem that has been discussed by Lane (1971). For present purposes it will be assumed, in accordance with traditional usage, that *Crotalocephalus* includes species such as *Cheirurus (Crotalocephalus) sternbergii* (Boeck 1827) and *C. (C.) pengellii* (Whidborne 1889). Thus *Pilletopeltis* Pribyl *in* Pillet 1973 *(nomen novum* for *Boeckia* Pillet 1965 *non* Malm 1870, and a senior synonym of *Pilletopeltis* Pribyl & Vanek 1973), which has *C. (C.) sternbergii* as type species, is here considered to be a synonym of *Crotalocephalus*. *Geracephalina* is also considered to be a synonym of *Crotalocephalus* because the feature on which it is based—the presence of a sagittal furrow on the 3p and occasionally the 2p lobe—seems to be of no more than specific importance, and in at least some cases is teratological (Prantl 1947).

Genus **Cheirurus** Beyrich 1845
Subgenus **Cheirurus (Crotalocephalina)** Pribyl & Vanek 1964

TYPE SPECIES (by original designation): *Cheirurus gibbus* Beyrich 1845 from the Dvorce-Prokop Limestone (Pragian), Podolí (Dvorce), Prague, Czechoslovakia.

DIAGNOSIS: Subgenus of *Cheirurus* having continuous glabellar furrows 2p and 3p, and a pygidium with short, broad marginal spines.

REMARKS: In addition to the shape of the marginal spines on the pygidium Pribyl & Vanek (1964, 1973) considered *C. (Crotalocephalina)* to be characterised especially by a "transversely arched and longitudinally elliptical, somewhat laterally compressed exoskeleton" (our translation). This is certainly true of species such as *C. (Crotalocephalina) gibbus* and *C. (Crotalocephalina) globifrons* Hawle & Corda 1847, in which the pleural regions on the cephalon, thorax and pygidium are markedly reduced in width (tr.) relative to the axis. Thus in *C. (Crotalocephalina) gibbus* the cheeks and the thoracic pleurae are only about one half the width (tr.) of the occipital ring and the thoracic axial rings respectively, whereas in *C. (Crotalocephalus) sternbergii* and related species they are almost equal in width to the axis, or even wider than it. There are, however, a number of species that resemble *C. (Crotalocephalina) gibbus* in the shape of the pygidial spines and yet their pleural regions are no more reduced in width than those of *C. (Crotalocephalus) sternbergii*. These species, which include *C. (Crotalocephalina) chlupaci* Pribyl & Vanek 1962, *C. (C.) expansus* Balashova 1965, *C. (C.) hexaspinus* (Maksimova 1960), and *C. (C.) oxina* sp. nov., also appear to us to show no significant difference from *C. (Crotalocephalus) sternbergii* in the degree of transverse arching of the exoskeleton.

In our opinion, most of the other characters listed by Pribyl & Vanek in their diagnosis of *C. (Crotalocephalina)* cannot be used to distinguish this taxon from *C. (Crotalocephalus)* either. The rate of expansion of the glabella is variable in both subgenera but the amount of variation is only slight. Glabellae with inflated frontal lobes and 2p and 3p furrows that are almost straight are found also in some species of *C. (Crotalocephalus)*, such as *C. (C.) pengellii* (see Lütke 1965, pl. 20, figs. 13, 14) and *C. (C.) copiosus* Haas 1968, but these features are not present in *C. (Crotalocephalina) oxina* sp. nov. The genal spines in *C. (Crotalocephalina) hexaspinus* (Maksimova 1960) are no shorter than those in most species of *C. (Crotalocephalus)*. From published illustrations we are unable to confirm the lack of a preannulus on the thoracic segments of *C. (Crotalocephalina) gibbus* or *C. (C.) globifrons*, but one is present on the thoracic segment of *C. (C.) oxina* described below. At any rate, a preannulus is present in some species of *C. (Cheirurus)* but is poorly developed or absent in others. Finally, although we can find no published photographs of *C. (Crotalocephalus)* showing the ventral surface of the pygidium, the reconstruction given by Pribyl & Vanek (1973, text-fig. 3) shows no apparent differences from *C. (Crotalocephalina)* in the width of the pygidial doublure.

There is even some difficulty in separating *C. (Crotalocephalus)* and *C. (Crotalocephalina)* on the basis of the length and thickness of the pygidial spines because there is almost continuous variation between the extremes. In this respect, species such as *C. (Crotalocephalus) pauper* Barrande 1852, *C. (Crotalocephalus) maurus* Alberti 1966, and *C. (Crotalocephalus) africanus* Alberti 1967 lie almost midway between *C. (Crotalocephalus) sternbergii* and *C. (Crotalocephalina)* *gibbus* and in fact bear a closer resemblance to species of *C. (Cheirurus)*. It seems, therefore, that *C. (Crotalocephalus)* and *C. (Crotalocephalina)* intergrade morphologically and we consider it inappropriate to recognise them as independent genera, as advocated by Lane (1971). He proposed that they belong to separate evolutionary lineages but we can see no evidence to support this.

Cheirurus (Crotalocephalina) oxina sp. nov.

Fig. 3M-U

NAME: Greek *oxina* meaning a harrow or rake, referring to the appearance of the pygidium.

TYPE MATERIAL: Holotype, NMV P75137, internal mould of pygidium and counterpart external mould, Fig. 3P, R, S; paratypes, NMV P75138-9, P75143, P75149 (cranidia), NMV P75140 (hypostome), NMV P75141-2 (thoracic segments), NMV P75144, P75147-8 (pygidia); all from locality R25.

DIAGNOSIS: Glabella subparallel-sided; furrows 2p and 3p almost as oblique as 1p, so that 2p lobe is only slightly longer sagittally than distally. Fixigena broad, palpebral lobe lying distant from lateral border furrow; genal spine very short and strongly divergent. Thoracic pleurae slightly wider (tr.) than axial rings. Marginal spines on pygidium subtriangular, flattened in cross-section; first and second spines deflected backwards half way along their length so that tips of first pair are level with posterior end of axis; third pair much shorter than others and directed straight backwards. Posteromedian projection absent, notch between third pair of spines narrowing to an acute angle.

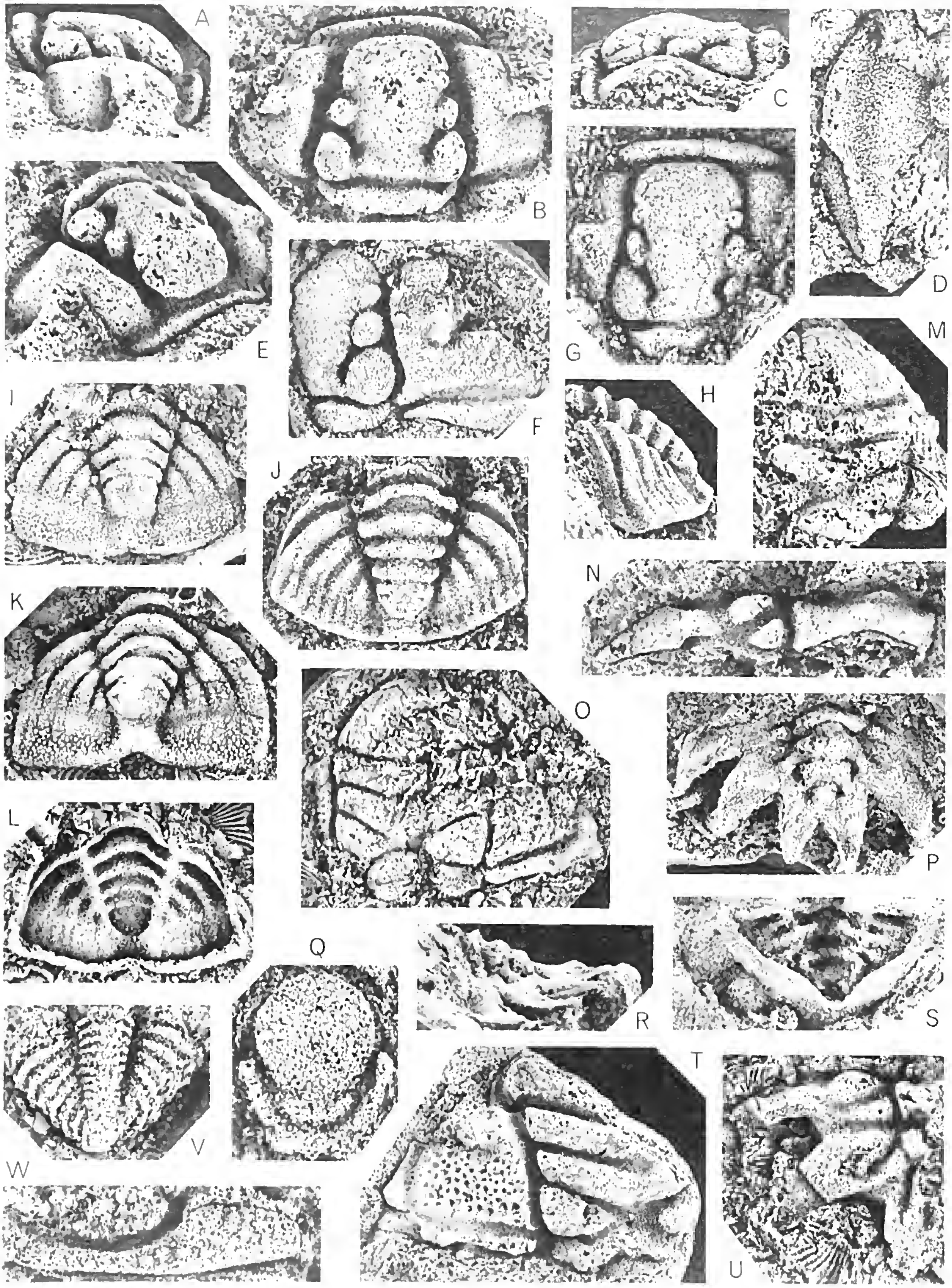
DESCRIPTION: Occipital ring twice as long sagittally as distally and gently convex (sag.); outermost two-fifths of occipital furrow occupied by slit-like apodemal pit, medial portion of furrow clearly distinguishable at posterior of depressed area between 1p lobes (Fig. 3O). 1p furrow directed obliquely backwards from axial furrow at approximately 65° to sagittal line, 1p apodeme 1.5 times as wide as occipital apodeme. 2p and 3p furrows shallow slightly adaxially, outer end of 2p opposite glabellar midlength (sag.). Frontal glabella lobe 0.4 times length (sag.) of glabella. Posterior border strongly rounded (exsag.) adaxially but decreasing in convexity beyond fulcrum; lateral border with slightly angular outward projection in line with posterior border furrow, and a similar but smaller projection immediately behind ω. Palpebral lobe situated with anterior edge opposite front of 3p lobe and posterior edge opposite outer end of 2p furrow. Anterior branch of facial suture falls steeply in front of γ, becomes horizontal opposite anterior pit in axial furrow, and curves inwards opposite widest part of frontal lobe; posterior branch of suture runs parallel to posterior border to meet lateral margin of cheek at 90°. Regularly spaced tubercles present on glabella, excluding occipital ring; inner part of fixigena coarsely pitted.

Middle body of hypostome divided into subcircular anterior lobe and subcrescentic posterior lobe by middle furrow that is well defined laterally but obsolete medially. Lateral margins of hypostome converge behind shoulder at 50°; posterior margin transverse.

Axial ring of thoracic segment strongly arched (tr.), approximately equal in length sagittally and distally but contracting to two-thirds this length half way between. Medial portion of ring divided by weak transverse change of slope into small, flattened (sag.), lenticular anterior band and convex posterior band bearing a pair of large tubercles. Pleura of usual form for subfamily, articulated portion comprising half the width; pleural band increases in height near fulcrum where it merges with a flattened, lanceolate spine that is sharply downturned at approximately 45° to the horizontal and curves backwards slightly distally.

Ratio of pygidial widths across tips of marginal spines approximately 1.5:1.0:0.3. First axial ring more prominent than remainder, inclined slightly forwards, and contracted medially; second and third rings (excluding well developed pseudo-articulating half ring on second) of constant length (sag., exsag.); posterior terminus a small subcircular swelling. Axial furrow distinct at first axial ring, poorly defined adjacent to rings 2 and 3 and axial terminus, except at the distal ends of each of the ring furrows where it contains a deep pit; on internal moulds axial furrow deeper than on external surface. First pleural furrow deep, curving outwards abaxially; first interpleural furrow sharply impressed proximally but fading towards the margin and gently curving backwards. Second pleural furrow also deep, narrower

Fig. 3—A-L, *Sthenarocalymene* sp. A (Chatterton, Johnson & Campbell 1979); D from locality R54, remainder from locality R25. A, B, E, cranidium NMV P47977; lateral, dorsal and oblique views, ×2.5. C, latex cast of external mould of cranidium NMV P75130; lateral view, ×2. D, librigena NMV P75136; dorsal view, ×2.75. F, latex cast of external mould of cranidium NMV P75133; dorsolateral view, ×2. G, latex cast of external mould of cranidium NMV P75131; dorsal view, ×2.5. H, J, pydigium NMV P47980; lateral and dorsal views, ×2. I, latex cast of external mould of pygidium NMV P47961; dorsal view, ×2. K, latex cast of external mould of pygidium NMV P75134; dorsal view, ×2. L, latex cast of pygidial mould NMV P75135; ventral view, ×2.5. M-U, *Cheirurus (Crotalocephalina) oxina* sp. nov., from locality R25. M, incomplete cranidium NMV P75138; dorsal view, ×1.5. N, thoracic segment NMV P75141; dorsolateral view, ×2.75. O, latex cast of external mould of cranidium NMV P75139; dorsal view, ×1.5. P, R, S, holotype pygidium NMV P75137, ×2.5: P, R, latex cast of external mould in dorsal and lateral views; S, latex cast of counterpart in ventral view. Q, hypostome NMV P75140; ventral view, ×3.75. T, cranidium NMV P75143; dorsal view, ×1.25. U, incomplete pygidium NMV P75144; dorsal view, ×1.75. V, W, Encrinurinae gen. et sp. indet., from locality R52. V, pygidium NMV P75146; dorsal view, ×3.5. W, librigena NMV P75145; oblique view, ×3. Except where stated otherwise, specimens are internal moulds.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W

(tr.) than first and directed more strongly backwards; anterior pleural band on second segment much lower than posterior band; second interpleural furrow faint. Third pleural furrow absent on smaller pygidium but deep on larger one, which is an internal mould (Fig. 3P, U). Pygidial doublure deeply notched posteromedially and narrowing gradually towards anterolateral extremities; it slopes gently inwards over most of its extent, but around posteromedian notch is flexed sharply upwards to stand almost vertically. Ventral surface of marginal spines separated from doublure by short, abrupt slope.

REMARKS: In the width of the fixigenae, the very short and subtriangular pygidial spines, and the lack of a posteromedian projection on the pygidium, *C. (C.) oxina* resembles *C. (Crotalocephalina) expansus* Balashova 1965 from the Early Devonian Kokbaital horizon of Kazakhstan (see Maksimova 1968, pl. 33, figs. 1-4). *C. (C.) expansus* differs from *C. (C.) oxina* in that the glabella expands more strongly forwards; there is a weak sagittal furrow on the 3p lobe; the frontal glabellar lobe is relatively larger and more inflated; the first pygidial axial ring does not appear to be contracted medially and a pseudo-articulating half ring is not developed on the second axial ring; the axial terminus is better defined and more transverse; the anteriormost pygidial spines are not directed as strongly backwards; and the notch between the third pair of spines is broader and more rounded in outline. *C. (Crotalocephalina) hexaspinus* (Maksimova 1960) also has a pygidium with very short marginal spines and no posteromedian projection, but the spines differ in shape from those of *C. (C.) oxina*, and the cranidium bears little resemblance to that of the Australian species (see Maksimova 1968, pl. 34).

Two cheirurinid species have previously been named from the Early Devonian of southeastern Australia and each is known only from a single incomplete cranidium, so that there is some doubt about their subgeneric assignment. *C. (Crotalocephalus) regius* Foldvary 1970 from the Trundle district of New South Wales differs from *C. (C.) oxina* in having a relatively longer frontal glabellar lobe, more oblique 3p furrow, relatively narrower cheeks, and more prominent tuberculation. *C. (Crotalocephalus) packhami* Strusz 1964 from the Garra Beds near Wellington, New South Wales, has a frontal glabellar lobe that is more subquadrate in dorsal view and a 2p lobe that is significantly longer sagittally than distally.

Etheridge & Mitchell (1917) described two Silurian cheirurinid species from the Yass Basin of southern New South Wales as *Crotalocephalus silverdalensis* and *C. sculptus*. Both of these are from beds now assigned to the Yarwood Siltstone Member of the Black Bog Shale, which is of late Ludlovian age (Link 1970). *C. sculptus* was said to differ from *C. silverdalensis* in having a proportionally longer and narrower glabella, a larger frontal lobe, furrows 2p and 3p that are more acutely flexed medially, and thoracic segments with a more convex (tr.) axis and relatively longer pleural spines. On examining casts of the type specimens of both species, we can see no significant differences in the proportions of the glabella or the length of the pleural spines, and we attribute the other differences to tectonic distortion. *C. silverdalensis* and *C. sculptus* are alike in all other observable characters and we consider them to be synonymous. They are not very similar to *C. (C.) oxina*, and in fact their generic or subgeneric assignment is uncertain. In the length and thickness of the pygidial spines they are closer to *C. (Crotalocephalina)* than to *C. (Crotalocephalus)*, but they differ from species normally assigned to either of these taxa in the form of the occipital and 1p furrows. These furrows do not merge medially but are separated by a very short (sag.), slightly depressed portion of the 1p lobe bearing subdued tubercles. The occipital and 1p furrows do merge medially, however, in the specimens from the Boola Beds (Early Devonian) of eastern Victoria that Philip (1962) referred to as *C. (Crotalocephalus) silverdalensis*. These specimens also differ from the Yass species in the shape of the glabella, the inflation of the frontal glabellar lobe, the form of the 2p and 3p furrows, the thickness and disposition of the pygidial spines, and the lack of a posteromedian projection on the pygidium.

Family ENCRINURIDAE Angelin, 1854
Subfamily ENCRINURINAE Angelin, 1854

Encrinurinae gen. et sp. indet.

Fig. 3V, W

MATERIAL: A librigena and 7 pygidia from locality R52.

DESCRIPTION: Lateral border on librigena relatively narrow, covered with closely spaced tubercles; lateral border furrow deep and U-shaped in cross section. Shallow vincular furrow present on lower edge of border posteriorly but dying out before reaching pseudoglabellar region.

Pygidium approximately 1.3 times as wide as long, lateral margins converging at about 100° towards rounded posterior extremity. Axis strongly arched (tr.) anteriorly but decreasing in height posteriorly and merging with postaxial region; 10-15 axial rings are distinguishable but there is no evidence of median tubercles on any of them. Pleurae curve steeply downwards abaxially, composed of 7?-10 pleural ribs which near back of pygidium are deflected slightly inwards abaxially, posterior pair tending to fuse distally behind axis. On external moulds pleural ribs are flat-topped and pleural furrows are short (exsag.) and sharply incised.

REMARKS: In the number of axial rings and pleural ribs and the apparent lack of median tubercles on the axis, these pygidia resemble the species from the Dargile Formation (Ludlovian) described by Talent (1965b) as *Encrinurus simpliciculus*, which we consider to be a junior synonym of *Cronus spryi* (Chapman 1912). The type locality of *C. spryi* is in the South Yarra area of Melbourne and was said by Strusz (1980) to lie within the Anderson Creek Formation of Wenlockian age, but the strata in this area were assigned to the Dargile Formation by VandenBerg (1974). Strusz (1980) noted that *E. simpliciculus* resembles species of *Cromus* in the glabellar tuberculation but stated that it differs from them in the more posterior position of the eye, the preglabellar furrow that is incomplete medially, the lack of a median longitudinal furrow on the cranidial portion of the pseudoglabellar region, and the form of the pygidium. We can see no significant difference between. *E. simpliciculus* and *C. spryi* in any of these features. Although the specimens of *C. spryi* figured by Strusz (1980, pl. 1, figs. 1-3) appear to have wider pygidial pleurae than the types of *E. simpliciculus*, we attribute this to tectonic flattening.

Family CALYMENIDAE Milne Edwards 1840
Subfamily FLEXICALYMENINAE Siveter 1976

Genus **Sthenarocalymene** Siveter 1976

TYPE SPECIES (by original designation): *Sthenarocalymene lirella* Siveter 1976 from the *Ampyx* Limestone (Llandeilo to lowermost Caradoc), Oslo-Asker district, Norway.

REMARKS: This genus has recently been discussed by Holloway (1980) who gave reasons for considering it to be a senior synonym of *Apocalymene* Chatterton & Campbell 1980.

Sthenarocalymene sp. A

Fig. 3A-L

1965b *Gravicalymene* cf. *angustior* (Chapman); Talent, p. 49, pl. 26, figs. 3, 4, ?5.

1979 *Apocalymene* sp. A. Chatterton, Johnson & Campbell, p. 813, pl. 104, figs. 28, 29; pl. 106, figs 10, 16-27.

MATERIAL: At least 15 cranidia, 4 librigenae and 20 pygidia from localities R25 and R54.

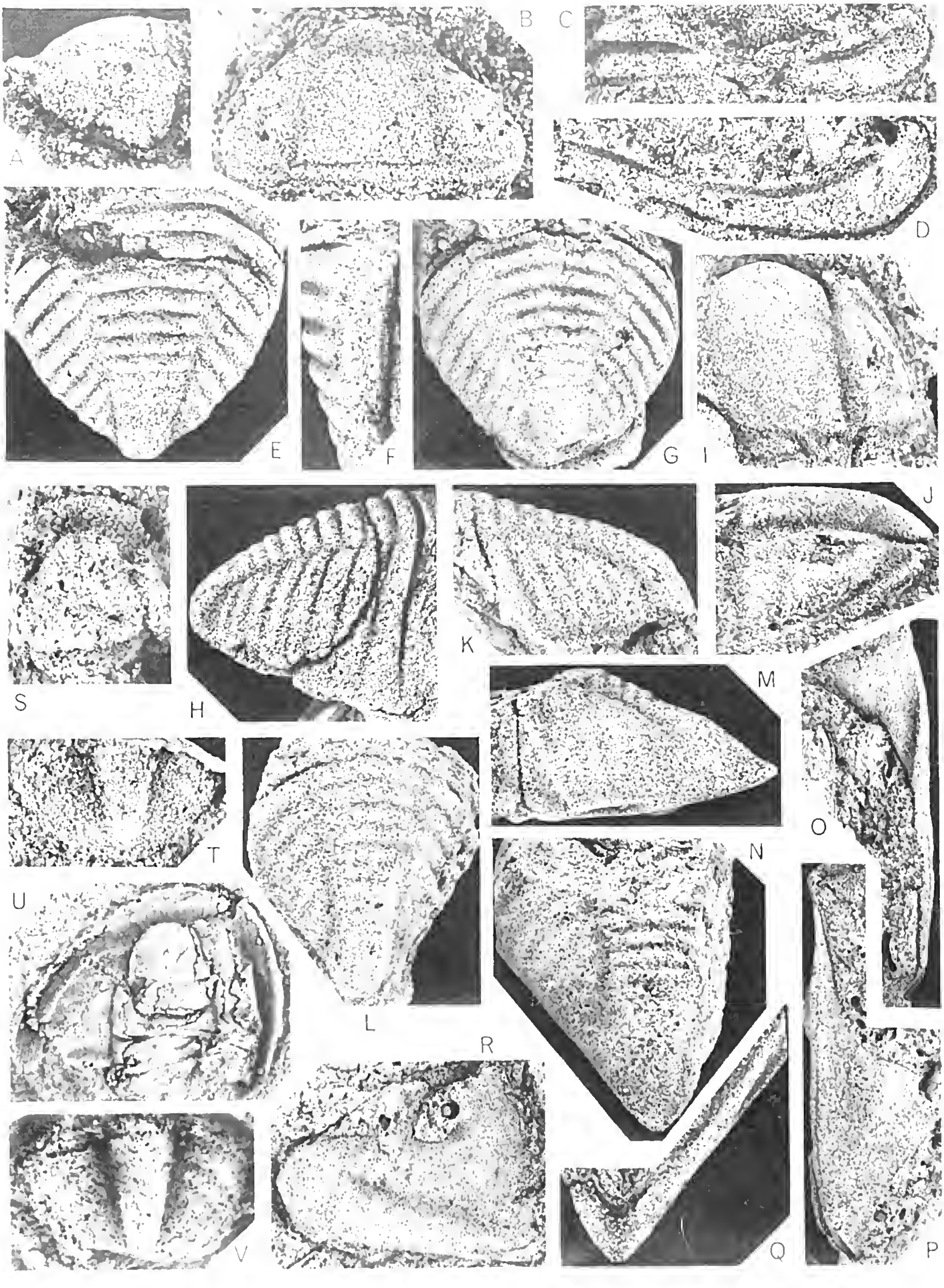
REMARKS: Our material differs only in a few details from the description and photographs given by Chatterton, Johnson & Campbell (1979). They stated that the palpebral lobes are situated so that δ-δ passes through the 2p furrow, but in our material they are slightly further back. In addition, the fifth pygidial axial ring is possibly not as well defined in the Mount Ida specimens, the axis is more distinctly separated from the postaxial ridge, and the exoskeletal granules tend to increase in size and become stronger towards the margin of the pygidium. Some of these differences may be due to the larger size of the Mount Ida specimens.

The approximately contemporaneous species *S. angustior* (Chapman 1915) from the Humevale Formation at Lilydale, Victoria has not been well illustrated, but examination of type and topotype specimens in the National Museum of Victoria shows that they differ from *Sthenarocalymene* sp. A in having a glabella that narrows forwards more strongly and is more rounded anteriorly; a palpebral lobe that is situated slightly further forward (with δ opposite the 2p furrow); a higher anterior border; a narrower pygidial axis that is indistinctly separated from the postaxial ridge; no cincture on the pygidium; and pleural and interpleural furrows that are deeper abaxially. *S. hetera* (Gill 1945) and *S. kilmorensis* (Gill 1945), which were stated to be of Gedinnian-Siegenian age by Chatterton, Johnson & Campbell (1979), are in fact from the Dargile Formation (Ludlovian) at Kilmore East, Victoria. They are probably synonymous, the differences in the shape of the glabellae evident in the figures given by Gill (1945, pl. 7, figs. 9, 12) being due almost certainly to tectonic distortion. These species differ from *Sthenarocalymene* sp. A in having much higher anterior borders, glabellae that narrow more strongly anteriorly and do not project as far forward with respect to the central part of the cheek, and relatively longer 1p lobes.

Family HOMALONOTIDAE Chapman 1890
Subfamily HOMALONOTINAE Chapman 1890

REMARKS: The classification of Silurian and Devonian homalonotinids is in a confused state because the majority of described species are in need of revision or are known only from fragmentary material. Tomczykowa (1975) recently reviewed all of the established genera and subgenera (elevating the latter to generic rank) and reassigned some of the species, but did not undertake a revision of any of the type species. She suggested that less weight in classification should be given to the form of the rostral plate, as the presence or absence of a rostral process was in her view largely of adaptive significance. In diagnosing the genera she therefore employed only features of the dorsal exoskeleton, some of which appear to us to be of doubtful taxonomic value at this level. There are no distinctive differences between any of the genera in the shape of the glabella and the strength of the thoracic segmentation, and the degree of glabellar lobation is variable even within individual species (see Clarke 1913, pl. 2). Of the other features listed by Tomczykowa in her Table 5, the shape of the pygidium and its degree of trilobation and segmentation are extremely variable within the generic groupings she has made. It is difficult to believe that there are significant differences in any of these features between her species *Trimerus novus* and the specimens she has illustrated as *Digonus vialai* (Gosselet) and *Parahomalonotus forbesi* (Rouault) (see Tomczykowa 1975, pl. 3, figs 5-7, pl. 4, figs 10, 11, pl. 6, figs 1, 3), or between her species *Trimerus lobatus* and *Dipleura praecox* (Tomczykowa 1975, pl. 2, figs 7, 11). Furthermore the species *Homalonotus clarkei* Kozlowski which has a pygidium with an acutely pointed posterior termination is assigned by her to *Dipleura*, the type species of which has a pygidium that is broadly rounded posteriorly.

The ventral morphology of the exoskeleton is known in only a few homalonotinid species at present but we believe that consideration of the structures on the cephalic and pygidial doublures may help in the elucidation of relationships within the subfamily. For example, it is apparent that some species possess different styles of vincular furrows on their pygidial doublures (compare Salter 1865, pl. 12, fig. 9a with Fig. 4Q herein), whereas others have none at all (Wolfart 1968, pl. 3, figs 1b, 2d)


A
B
C
D
E
F
G
I
S
H
K
J
M
O
T
N
U
L
R
V
Q
P

and our investigations have shown that a vincular furrow is present on the cephalic doublure in some species. These differences presumably reflect differences in enrollment patterns. We also believe that insufficient evidence exists at present to dismiss the form of the rostral plate as a taxonomically useful character.

Homalonotinae gen. et sp. indet. 1

Fig. 4A-H

1965b *Trimerus (Dipleura?)* sp. Talent, p. 49-50 (in part), pl. 26, figs 1, 2 (not text-fig 6).

MATERIAL: A cephalon, a cranidium, 3 thoracic segments and 7 pygidia from localities D2, D3 and D4.

DESCRIPTION: Cephalon subtriangular, posterior margin deflected forwards distally to well-rounded genal angle, anterior outline weakly curved laterally and interrupted medially by forwardly projecting anterior border (edge of border broken off on specimen). Glabella wider posteriorly than long, narrowing uniformly forwards; anterior outline transverse; no trace of glabellar furrows. Axial and preglabellar furrows broad, shallow and poorly defined; occipital furrow more sharply impressed than posterior border furrow. Cheek gently convex (exsag., tr.), sloping anteriorly and laterally from distal end of occipital ring. Palpebral lobe situated opposite glabellar midlength; anterior branch of facial suture converges parallel to axial furrow as far as front of glabella, thereafter becoming indistinct; posterior branch directed laterally from ε but not distinguishable distally.

Pleurae of thoracic segments have large articulating facets and broadly rounded tips. Medial to fulcrum, pleural furrow deep with steep anterior slope and more gently inclined posterior slope; beyond fulcrum it shallows and gradually curves forwards in a broad arc.

Pygidium approximately as wide as long, posterolateral margins gently convex. In transverse profile pleurae slope steeply downwards from axial furrow in a gentle curve; axis lacks independent convexity anteriorly but becomes slightly inflated posteriorly. In lateral profile crest of axis inclined at 50° to plane of lateral margin. Axis composed of strongly tapering segmented portion of 10 axial rings and a subparallel-sided terminus extending to posterior extremity of pygidium; ring furrows distinctly flexed medially in dorsal view. Anterior width of axis almost two-thirds maximum pygidial width. Axial furrow weaker than ring furrows anteriorly but increasing in depth slightly posteriorly. Pleura on anteriormost segment divided into short (exsag.) anterior band and gently convex (exsag.) posterior band by deep, sharp pleural furrow that is continuous with articulating furrow proximally and runs onto articulating facet distally; anterior band expands abaxially as far as inner edge of facet, posterior band expands slightly beyond fulcrum. Remainder of pleurae composed of 7 ribs defined by shallow rib furrows that fade towards lateral margin; between posteriormost rib and terminal piece of axis is a gently concave, subtriangular region formed in part of axial furrow and eighth rib furrow. Doublure narrow and semitubular; flattened and steeply inclined portion of border roll immediately behind articulating facet bounded below by slight vincular furrow (Fig. 4F).

REMARKS: This material is very close to the species from the Humevale Formation described by Gill (1949) as *Trimerus lilydalensis*, and may actually belong to it. The collections of the National Museum of Victoria contain several topotype and other specimens of *T. lilydalensis* that are better preserved than the types, but in the present state of knowledge of Silurian and Devonian homalonotinids they cannot be assigned with certainty to any established genus. The closest similarity seems to be with certain species presently referred to *Burmeisteria (Digonus)*, such as *B. (D.) noticus* (Clarke 1913) and *B. (D.) accraensis* Saul 1967. *T. lilydalensis* differs from these species, however, in that the rostral suture does not run along the margin of the anterior border, so that the rostral plate has a small, subtriangular dorsal portion; the rostral plate lacks a medial process; and there is a well-developed vincular furrow on the cephalic doublure, directed anteromedially from the outer end of the hypostomal suture. There are also similarities with *Trimerus (Dipleura)*, especially in the form of the rostral plate and in the fact that the anterior branch of the facial suture joins in a smooth curve in front of the glabella (Wolfart 1968, pls 1-3; note that the appearance of a transverse rostral suture in some of the illustrations by Hall & Clarke 1888, pls 2-5, is due to breakage of the specimens, and the diagnosis and reconstruction given

Fig. 4—A-H, Homalonotinae gen. et sp. indet. 1; A, B, from locality D4; C, D from locality D2; E-H from locality D3. A, B, cephalon NMV P78292; lateral and dorsal views, ×1.5. C, fragmentary thoracic segment NMV P78293; dorsolateral view (anterior at top of photograph), ×2. D, fragmentary thoracic segment NMV P78294; dorsolateral view (anterior at top of photograph), ×2. E, H, pygidium NMV P78295; dorsal and lateral views, ×1.75. F, G, pygidium NMV P59656, figured by Talent (1965b, pl. 26, fig. 2); F, anterior part of border roll in right ventrolateral view, showing slight vincular furrow, ×2.5; G, dorsal view, ×1.5. I-L, Homalonotinae gen. et sp. indet. 2, from locality H25. I, J, incomplete cephalon NMV P78296; dorsal and lateral views, ×1.5. K, L, pygidium NMV P78297; lateral and dorsal views, ×2. M-R, Homalonotinae gen. et sp. indet. 3; O, P, from locality R25, remainder from locality R55. M, N, Q, pygidium NMV P78298; lateral, dorsal and ventral views, ×1.25. O, P, librigena NMV P78299; ventral and dorsal views (anterior at top of photographs), ×1.5. R, fixigena NMV P78300; dorsal view, ×1.25. S-V, Tropidocoryphinae gen. et sp. indet.; U from locality R26, remainder from approximately 300 m east of locality R25. S, cranidium NMV P78301; dorsal view, ×6. T, latex cast of external mould of pygidium NMV P78302; dorsal view, ×5. U, partly exfoliated cephalon NMV P59652, figured by Talent (1965b, pl. 25, fig. 4); dorsal view, ×3. V, pygidium NMV P78303; dorsal view, ×5.25. Except where otherwise stated, specimens are internal moulds.

by Sdzuy, in Moore 1959 are incorrect in this respect). Species of *T. (Dipleura)* differ from *T. lilydalensis* in lacking a vincular furrow on the cephalic doublure, and in having a more weakly segmented pygidium that is rounded posteriorly instead of pointed.

The cranidium from the underlying McIvor Sandstone described and figured by Talent (1965b, text-fig. 6) as belonging to the same species as pygidia from the Mount Ida Formation differs from the cephalon described above in the shape and convexity of the glabella and in the presence of indistinct 1p lobes.

Homalonotinae gen. et sp. indet. 2

Fig. 4I-L

MATERIAL: A cephalon and a pygidium from locality H25.

DESCRIPTION: Glabella narrows forwards at a constant rate and bears faint traces of 1p and 2p furrows; at the front it curves abruptly downwards into what appears to be a deep and sharply recessed preglabellar furrow. Axial furrow broad and shallow, except near front of glabella; paraglabellar area elliptical and extending forwards almost to point opposite middle of palpebral lobe. Anterior branch of facial suture converges gently and passes close to anterolateral extremity of glabella; lateral to eye, librigena descends vertically to lateral border, or is even inclined slightly inwards.

Pygidium longer than wide. Axis approximately one-half width of pygidium anteriorly; posteriorly it narrows, increases in convexity, and merges with strongly projecting post-axial region. There are at least 10 axial rings. Pleurae composed of 7 pleural ribs, anteriormost one divided into anterior and posterior bands by deep pleural furrow.

REMARKS: Amongst established Silurian and Devonian homalonotinid genera, the only one with a deep, sharply recessed preglabellar furrow seems to be *Homalonotus* itself (see Salter 1865, pl. 12, fig. 2; McLearn 1924, pl. 27, fig. 14). The present species is also not unlike *Homalonotus* in the shape of the glabella, the indistinct glabellar lobation, and the relatively well-defined paraglabellar areas. The pygidium is not as strongly segmented as in described species of *Homalonotus*, but is more like that of species such as *Burmeisteria (Digonus) clarkei* (Kozlowski 1923, pl. 1, figs. 14, 15).

Homalonotinae gen. et sp. indet. 3

Fig. 4M-R

MATERIAL: A librigena, a fixigena, a fragmentary thoracic segment, and 2 pygidia from localities R25 and R55.

REMARKS: The librigena has a gently convex central region separated from the less steeply inclined lateral border by a broad flexure that dies out posteriorly. The anterior branch of the facial suture curves in a broad arc to converge gradually with the outer margin of the cheek, so as to isolate an acute anterior projection on the librigena. The posterior portion on the librigenal doublure is narrow and steeply inclined; the anterior portion expands strongly forwards and near its outer edge bears a vincular furrow that dies out anteriorly. The pygidia differ from those of Homalonotinae gen. et sp. indet. 1 in that the posterior extremity is more acute and is slightly upturned; the axis is more convex (tr.) and does not appear to taper as strongly; the pleural rib furrows are weaker; and the vincular furrow is much stronger.

Family PHACOPIDAE Hawle & Corda 1847
Subfamily PHACOPINAE Hawle & Corda 1847

Genus **Ananaspis** Campbell 1967

TYPE SPECIES (by original designation): *Phacops fecundus* Barrande 1846 from the Kopanina Formation (Ludlovian), Koledník near Beroun, Czechoslovakia.

Ananaspis serrata (Foerste 1888)

Fig. 5A-P

1965b *Phacops* sp. cf. *P. serratus* Foerste; Talent, p. 50, pl. 26, figs 6-8.

1971 *"Phacops" serratus* Foerste; Sherwin, p. 83, pl. 1, figs 1-10, pl. 2, figs 1-5 (with full synonymy).

1977 *Paciphacops (Paciphacops) serratus* (Foerste); Campbell, p. 32.

TYPE MATERIAL: The neotype, selected by Sherwin (1971) is Australian Museum F27132, a partly exfoliated thorax and pygidium with disarticulated and inverted cephalon, figured by Sherwin (1971, pl. 1, figs 1, 5-7, 10), from the Upper Trilobite Bed (=Elmside Formation, early Gedinnian), near Bowning, New South Wales. The specimen on which Foerste based his species—an internal mould of the dorsal exoskeleton with disarticulated cephalon—is apparently lost.

OTHER MATERIAL: At least 50 cephala, 20 pygidia and an incomplete dorsal exoskeleton from localities R9, R24, R25, R30, R31, R54, approximately 300 m east of R25, and approximately 100 m south of R31.

REMARKS: The taxonomic importance of *Paciphacops (Paciphacops)* Maksimova 1972 to which the present species was assigned by Campbell (1977), has been questioned by Holloway (1980) who considered it to be at most a subgenus of *Ananaspis*. *Paciphacops* is apparently distinguished from *Ananaspis* (s.s.) only in the presence of perforate glabellar tubercles in large-eyed morphs and thickened sclera between the lenses in all small-eyed and most large-eyed morphs. Perforations in the glabellar tubercles have not been observed in the present material or in the topotypes, although the quality of the preservation is such that they would probably have been obliterated even if they were originally present. Eye dimorphism does not appear to be present in *A. serrata* but none of the specimens has thickened sclera. Thus we can see no morphological grounds for separating *A. serrata* at the subgeneric level from other members of *Ananaspis* (s.s.)

The most distinctive feature of *A. serrata* is the presence of axial spines on the occipital ring, thorax and pygidium. Similar spines (but not on the pygidium) are also developed in *A. claviger* (Haas 1969) from the Siegenian of Nevada and in some members of *Viaphacops* Maksimova 1972, although in the latter their presence on the thorax is extremely variable even amongst individuals from the same population, and this has led to the suggestion that they are a sexually dimorphic character (Eldredge 1973, Campbell 1977). There is some evidence that the axial spines in *A. serrata* are also dimorphic as they are present in only one of the pygidia from the Mount Ida Formation (Fig. 5N), and their absence in the other pygidia cannot in all cases be explained by breakage. The only thorax of *A. serrata* available to us from the Mount Ida is too poorly preserved to retain traces of axial spines (Fig. 5K). It is not possible to argue a strong case for dimorphism on the basis of the present material, but it is of interest to note that Etheridge & Mitchell (1895) suggested that *A. serrata* may be a sexual dimorph of their species *A. crossleii* which occurs in the same beds in the Yass Basin and lacks axial spines.

Our specimens of *A. serrata* are mostly larger than those figured by Sherwin (1971) but they are alike in the majority of characters. The main points of difference are as follows.

1. The only eye in which Sherwin was able to count the lenses had 14 dorsoventral lens files of up to five lenses each. The most complete lens count obtained for our material is from the specimen in Fig. 5F in which the eye contains 17 files with a maximum of five lenses per file, although the posteriormost file seems to contain only a single lens. In another specimen, however, the eyes contain at least six lenses in the longest file. There is also evidence of some variation in the overall size of the eye but the information is inadequate to determine if dimorphism is present.
2. The genal angle in at least some of the Mount Ida specimens is more pointed than it is in the topotypes (see Fig. 5H).
3. Most of the pygidia in our collection contain 7 axial rings and 5-6 pleural furrows, the same numbers given by Sherwin, but one of the largest (the only one with medial spines on the axial rings) has 9 axial rings and 7 or possibly 8 pleural furrows.

Sherwin (1971) stated that the cephalon of *A. serrata* from the Mount Ida Formation figured by Talent (1965b, pl. 26, figs 6, 8) differs from topotype cephala in that the glabella more strongly overhangs the anterior border and the medial portion of the vincular furrow is deeper, but we are unable to confirm this. Although Sherwin describes the medial portion of the vincular furrow as "very shallow", it is in fact moderately deep in the neotype, which retains the exoskeleton on the doublure (Sherwin 1971, pl. 1, fig. 10). Any slight difference in the depth of the furrow in Talent's specimen can be adequately accounted for by the fact that it is an internal mould.

The species *A. claviger* (Haas) referred to above has been compared with *A. serrata* by Sherwin (1971). In addition to the differences noted by him, *A. claviger* has eyes that are relatively larger than those of *A. serrata* and extend closer posteriorly to the axial furrow and the posterior border furrow; the sclera is thickened between the lenses; the intercalating ring is more distinctly separated medially from the remainder of the glabella; and the pygidium has a coarser tuberculate ornament and better defined pseudo-articulating half rings on segments 2 to 5 at least.

Several specimens of aphacopid have been obtained from mudstones within the Mount Ida Formation at locality R56. The cephalon bears genal spines and there are very long axial spines on the occipital ring and thorax but apparently not on the pygidium. The material is inadequate for meaningful comparison with *A. serrata*.

Family Dalmanitidae Vogdes 1890
Subfamily Dalmanitinae Vogdes 1890

Genus **Odontochile** Hawle & Corda 1847

Type Species (ICZN Opinion 537 (1959)): *Asaphus hausmanni* Brongniart 1822 from the Dvorce-Prokop Limestone (Pragian), Prague district, Czechoslovakia.

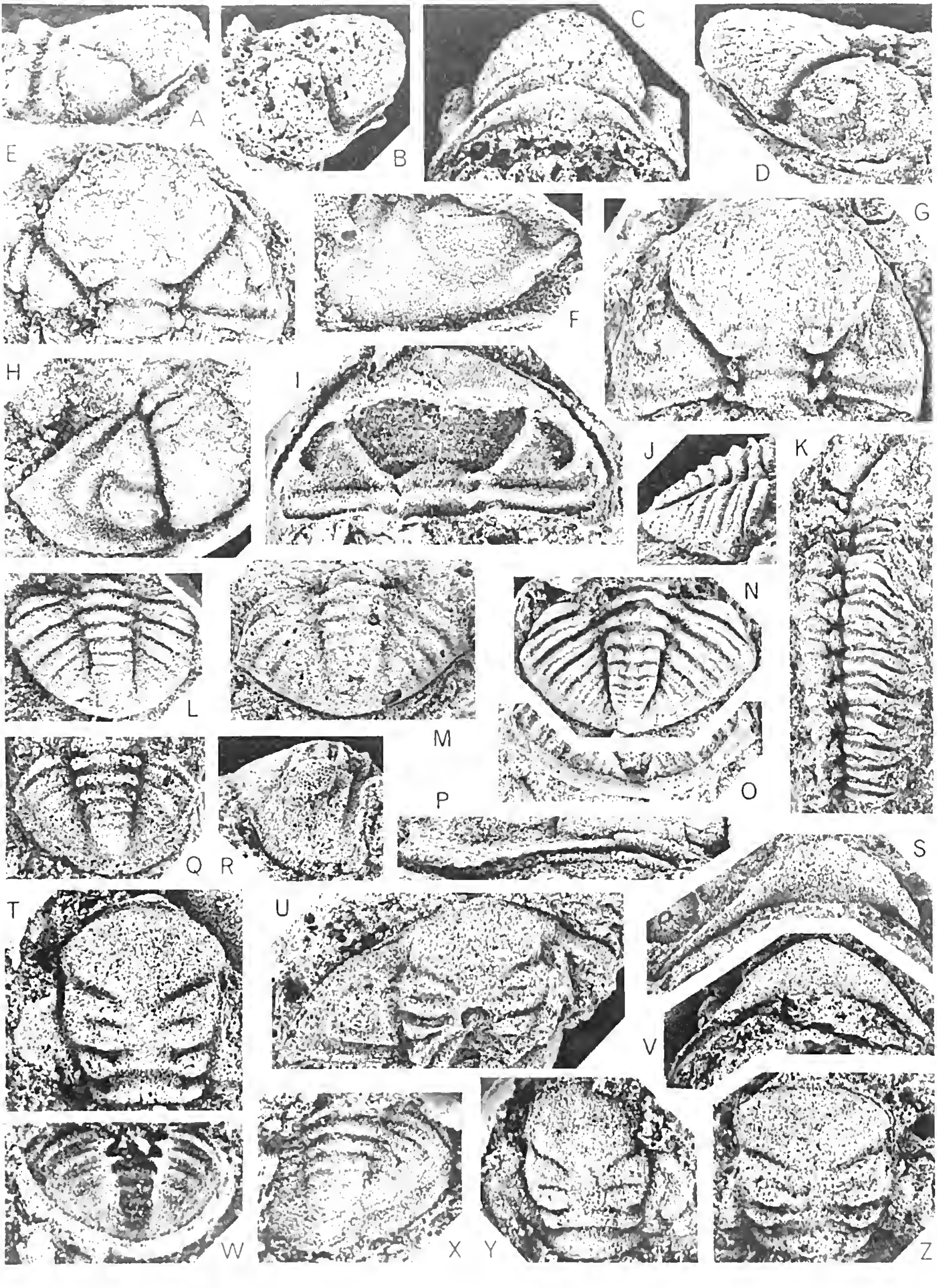
Odontochile cf. **formosa** Gill 1948

Fig. 6M-U

cf. 1948b *Odontochile formosa* Gill; p. 20, figs 1, 2.
1965b Dalmanitidae gen. indet. B Talent, p. 51, pl. 27, fig. 1.
1965b Dalmanitidae gen. indet. C Talent, p. 51, pl. 27, figs 6, 8 (not pl. 27, fig. 7 = *Acastella?* sp.)

Material: At least 18 cephala, 35 pygidia, several fragmentary fixigenae and thoracic segments, and a detached visual surface from localities R20, R25, R31, between localities R25 and R30, approximately 300 m east of locality R25, and approximately 100 m south of locality R31.

Remarks: *Odontochile formosa* was erected by Gill (1948b) for specimens from the Humevale Formation (Early Devonian) at Kinglake West, Victoria, and has been redescribed and discussed by Jell & Holloway (in press) on the basis of material from a different stratigraphic horizon and locality. The present material is too fragmentary for a confident assignment to *O. formosa* but closely resembles that species in features such as the shape of the glabella and the proportions of the frontal lobe; the anterior border that is well-rounded in outline and lacks a medial process (see Fig. 6S); the number of lenses (14) in the longest dorsoventral file of the eye; the convex (tr.) eye platform that closely abuts the lateral border furrow (Fig. 6S); and the lack of a distinct inner flange on the pygidial doublure. The pygidia show considerable variation in the number of segments, smaller specimens having 10-12 axial rings and 11-12 or possibly 13 pleural furrows, whereas the largest has 17 axial rings and 15 pleural furrows. We have therefore been in some doubt as to whether more than one species is represented, although the difference in the size of the pygidia suggests that the variation is


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z

due to ontogenetic changes. Specimens of *O. formosa* from the same area as the types show much less variation in the pygidial segmentation, even small specimens having 16-17 axial rings and 12-13 pleural furrows, whereas the largest have one or two more of each.

The presumed ontogenetic changes would account for the differences between the pygidia described by Talent (1965b) as Dalmanitidae gen. indet. B and Dalmanitidae gen. indet. C. It has already been pointed out by Shergold (1968) that the cranidium figured by Talent (1965b, pl. 27, fig. 7) as Dalmanitidae gen. indet. C. in fact belongs to an acastid.

Family Calmoniidae Delo 1935

Subfamily Acastinae Delo 1935

Remarks: We agree with Eldredge (1971) that Acastavinae Struve 1958 is a synonym of Acastinae.

Genus **Acastella** Reed 1925

Type Species (by original designation): *Phacops (Acaste) Downingiae* var. δ, *spinosus* Salter 1864 from the Upper Whitecliffe Beds (latest Ludlovian), Ludlow, Shropshire, England.

Acastella sp.

Fig. 5Q-Z

1965b Dalmanitidae gen. indet. C Talent, p. 51, pl. 27, fig. 7 (not pl. 27, figs. 6, 8 = *Odontochile* cf. *formosa* Gill 1948).

Material: At least 3 cephala, 15 cranidia and 13 pygidia from localities R25, R31, and approximately 100 m south of R31.

Description: Anterior margin of cephalon deflected gently forwards medially around front of glabella; maximum curvature at mid line. Glabella subquadrate, increasing in width anteriorly as far as 2p furrow, narrowing slightly to 3p furrow and thereafter expanding so that width at frontal lobe is almost equal to length (sag.). Occipital ring more strongly arched transversely than remainder of glabella, well rounded sagittally and exsagittally but with highest point close to posterior margin; occipital furrow deflected slightly backwards abaxially towards apodemal pit. 1p furrow directed obliquely backwards from axial furrow, becoming transverse adaxially and deflected slightly forwards proximally; 1p apodemal pit isolated from axial furrow and distinctly expanded at its inner end. 2p furrow shallower than 1p, transverse or slightly oblique, terminating relatively far from axial furrow distally. 3p furrow lying at about 60° to sagittal axis, expanding abaxially and abruptly shallowing just medial to axial furrow. Axial furrow rises gently between occipital ring and a point level with 2p furrow, thereafter falls steeply to outer end of 3p furrow and is very deep, but flattens out adjacent to frontal lobe and becomes indistinct (Fig. 5U). Palpebral lobe situated with δ opposite 2p furrow and ϵ close to posterior border furrow; anterior branch of facial suture converges slightly between γ and β. Incomplete eye preserved on specimen in Fig. 5R has at least 6 lenses in the longest dorsoventral file. Lateral border indistinctly separated from central part of cheek, which rises steeply adaxially so that recessed region below eye is vertical. Posterior border short (exsag.) but prominent, expanding slightly abaxially; posterior border furrow deep proximally but abruptly dying out distally. Posterior edge of cephalon curves backwards distally, indicating that a genal spine was probably present although it is not preserved (Fig. 5R, U). Medial part of cephalic doublure convex (sag.) anteriorly and concave behind; hypostomal suture transverse or gently convex forwards. Lateral part of doublure narrows towards genal angle and curves sharply upwards and outwards towards inner margin which is almost in contact with inner surface of cheek.

Posterior margin of pygidium of almost uniform curvature in dorsal view, deflected slightly upwards medially in posterior view. Axis composed of 6-7 axial rings; posterior to third ring, rate of taper of axis decreases slightly, apodemes abruptly decrease in size, and axial rings are more flattened (sag., exsag.). Pleurae curve steeply downwards abaxially to a gently inclined border. There are 3-4 successively shallower pleural furrows and 2-3 weak interpleural furrows. Doublure with a narrow, subhorizontal outer part and an almost

Fig. 5—A-P *Ananaspis serrata* (Foerste 1888); B, C, from locality R24; K from 100 m south of locality R31; M from locality R25; remainder from 300 m east of locality R25. A, E, latex cast of external mould of cephalon NMV P78304; lateral and dorsal views, ×2. B, C, cephalon NMV P78305; lateral and anteroventral views, ×2.5. D, G, cephalon NMV P78306; lateral and dorsal views, ×2. F, latex cast of external mould of cheek NMV P78307; dorsolateral view, ×2.5. H, latex cast of external mould of cephalon NMV P78308; oblique view, ×2.25. I, latex cast of cephalic mould NMV P78309; ventral view, ×2. J, N, O, pygidium NMV P78310, ×2; J, N, latex cast of external mould in lateral and dorsal views; O, latex cast of counterpart mould in ventral view. K, incomplete cephalon and thorax NMV P78311; dorsolateral view, ×1.75. L, latex cast of external mould of pygidium NMV P78312; dorsal view, ×3. M, pygidium NMV P78313; dorsal view, ×1.75. P, latex cast of external mould of cephalon NMV P78314; anterior border and doublure in anterolateral view showing vincular furrow, ×3. Q-Z, *Acastella* sp; Q from locality R31; T from 100 m south of locality R31; remainder from locality R25. Q, pygidium NMV P78315; dorsal view, ×3.75. R, U, cephalon NMV P78316; lateral and dorsal views, ×2.25. S, cephalic doublure NMV P78317; ventral view, ×2.75. T, cranidium NMV P78318; dorsal view, ×3. V, cephalic doublure NMV P78319; ventral view, ×2.25. W, latex cast of pygidial mould NMV P78320; ventral view, ×2.75. X, latex cast of external mould of pygidium NMV P78321; dorsal view, ×3.5. Y, latex cast of external mould of cranidium NMV P78322; dorsal view, ×3.5. Z, cranidium NMV P78323; dorsal view, ×3.75. Unless otherwise stated, specimens are internal moulds.

vertical inner flange, the junction between the two being subangular.

Remarks: There is some variation between specimens in the width of the glabella at the frontal lobe relative to that at the 2p furrow, the width (tr.) of the glabellar furrows, and the width of the pygidial pleurae as compared with that of the axis. However, in the lack of convincing evidence to the contrary, we assume that only a single species is represented.

Shergold (1968, p. 21) suggested that the incomplete cranidium from the Mount Ida Formation figured by Talent (1965b, pl. 27, fig. 7) belongs to *Acaste*. We prefer to assign the present material (as well as that of Talent) to *Acastella* because of the rather pointed anterior cephalic outline (as shown by the shape of the front of the doublure; Fig. 5S, V); because genal spines were probably present; and because in some of the cranidia (Fig. 5T, Z) it can be seen that the anterior branch of the facial suture diverges from the preglabellar furrow medially and joins at an obtuse angle, isolating a small, triangular portion of the cranidium in front of the glabella. This last feature is present in most previously described species of *Acastella* and is particularly well develolped in *A. tiro* R. & E. Richter (1954, pl. 5, fig. 73d).

The only other acastids recorded from Australia are the species *Acastella frontosa* and *Acaste longisulcata* described by Shergold (1968) from the Early Devonian Humevale Formation near Lilydale, Victoria. *A. frontosa* differs from the present material in having a larger subtriangular portion of the cranidium enclosed by the facial suture in front of the glabella, a relatively longer glabella, and a more strongly segmented pygidium with relatively broader pleural regions. The holotype of *A. longisulcata* is an internal mould of a pygidium figured by Chapman (1915, pl. 15, fig. 15) as *Phacops crossleii* Etheridge & Mitchell 1896. This pygidium does in fact belong to a phacopid, as indicated by the form of the articulating facets and the slight forward deflection of the axial rings towards their distal ends. This deflection of the axial rings is caused by the pattern of insertion of the appendage muscles (see Campbell 1975, fig. 1, pl. A, fig. 6). The other specimens figured by Shergold as *A. longisulcata* are acastid.

Family Lichidae Hawle & Corda 1847
Subfamily Ceratarginae Tripp 1957

Genus **Acanthopyge** Hawle & Corda 1847
Subgenus **Acanthopyge (Lobopyge)** Pribyl & Erben 1952

Type Species (by original designation): *Lichas Branikensis* Barrande 1872 from the Dvorce-Prokop Limestone (Pragian) at Prague, Czechoslovakia.

Remarks: This taxon was considered by Tripp (*in* Moore 1959) to be a synonym of *Acanthopyge* (s.s.) but we accept the arguments of Chatterton, Johnson & Campbell (1979) for regarding it as a separate subgenus.

Acanthopyge (Lobopyge) sp.

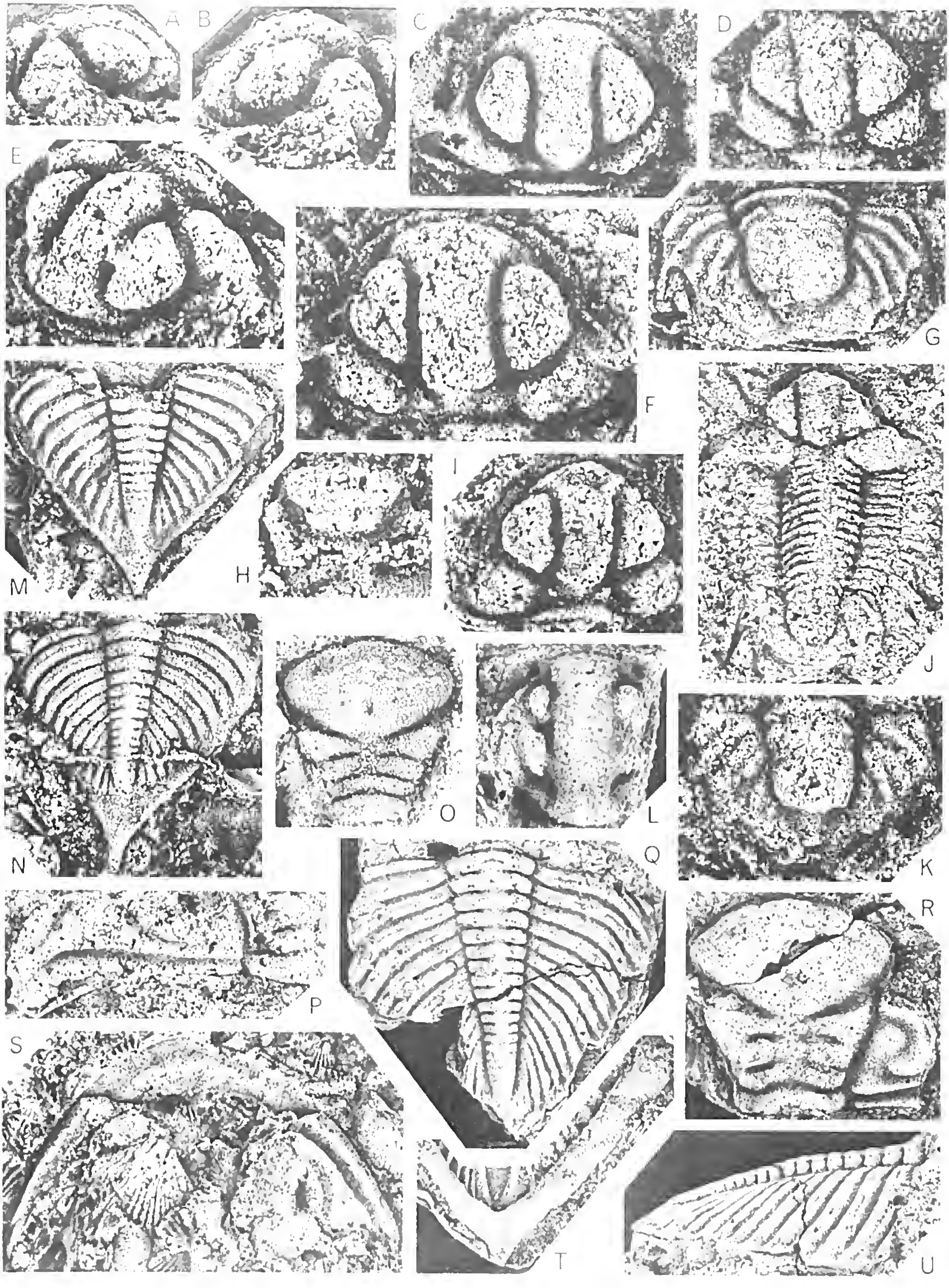
Fig. 6A-K

Material: At least 20 cranidia, a hypostome, 3 pygidia and an almost complete dorsal exoskeleton from locality R25.

Description: A pair of large tubercles is present on the depressed median part of the 1p lobe but there appears to be no definite arrangement of tubercles on other parts of the cranidium. Posterolateral cranidial lobe separated from median part of 1p lobe by broad longitudinal furrow, not separated from remainder of fixigena abaxially, or else bounded only by a faint vestige of a furrow. Median glabellar lobe rises steeply from median part of 1p lobe to reach a maximum height opposite front of palpebral lobe, subparallel-sided or even narrowing slightly forwards before expanding around front of anterolateral cranidial lobe; anterolateral extremities of median lobe acute and depressed. Pit-like depressions present where longitudinal furrow meets axial and 1p furrows. Palpebral lobe rising steeply from cheek and curving outwards distally, much lower than posterolateral cranidial lobe. Gentle eye ridge runs from front of palpebral lobe towards junction of axial and longitudinal furrows.

Anterior margin of hypostome gently convex. Middle body 1.6 times as wide as long, lateral margin notched at outer end of middle furrow; distinctly swollen maculae situated at lateral extremities of posterior lobe.

Fig. 6—A-K, *Acanthopyge (Lobopyge)* sp., from locality R25. A, cranidium NMV P78324; lateral view, ×5.5. B, E, cranidium NMV P78325; lateral and oblique views, ×7. C, cranidium NMV P78326; dorsal view, ×5. D, latex cast of external mould of cranidium NMV P78327; dorsal view, ×4.5. F, cranidium NMV P78328; dorsal view, ×6. G, pygidium NMV P78329; dorsal view, ×3.75. H, hypostome NMV P78330; ventral view, ×6.25. I, cranidium NMV P78331; dorsal view, ×5. J, almost complete dorsal exoskeleton NMV P78332; dorsal view, ×3.25. K, pygidium NMV P78333; dorsal view, ×4.5. L, *Leonaspis* sp., from 300 m east of locality R25. Cranidium NMV P78334; dorsal view, ×3. M-U, *Odontochile* cf. *formosa* Gill 1948; M, N, S, from locality R25; O, Q, R, U, from locality R31; P from between localities R25 and R30; T from 100 m south of locality R31. M, pygidium NMV P78335; dorsal view, ×2.25. N, latex cast of external mould of pygidium NMV P78336; dorsal view, ×3.5. O, latex cast of external mould of glabella NMV P78337; dorsal view, ×2.5. P, incomplete cranidium NMV P78338; dorsolateral view, ×1.75. Q, U, pygidium NMV P78339; dorsal and lateral views, ×0.9. R, cranidium NMV P78340; dorsal view, ×2. S, cephalon with glabella and anterior border broken off to reveal external mould of doublure NMV P78341; dorsal view, ×1.5. T, latex cast of pygidial mould NMV P78342; ventral view, ×1. Unless otherwise stated, specimens are internal moulds.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U

Thorax composed of 11 segments. Axis strongly rounded (tr.), subparallel sided as far as sixth or seventh segment and thereafter narrowing gently. Pleurae with a gently convex (tr.) articulated portion approximately one-half the width of the axis and with downturned distal spines curving backwards on more posterior segments.

Pygidial axis as wide anteriorly as long (sag.), narrowing only slightly backwards and broadly rounded posteriorly. Anteriormost axial ring short (sag., exsag.) and prominent, turned slightly backwards abaxially. Second ring bears a large tubercle distally and another closer to midline; between these tubercles the ring is similar in form to first ring except that it is lower and turned more strongly backwards; medial part of ring is very faint. Second ring furrow curves downwards abaxially into a weak apodeme. Third ring vaguely defined, apparently with a row of tubercles. Posterior pleural bands on first and second segments more convex than anterior bands, anterior band on second segment wider distally than posterior band. First marginal spine diverging at about 10° to sagittal axis, second spine directed straight backwards, third spine poorly preserved but situated close to sagittal axis. Pleurae steeply inclined behind axis, with a gently convex postaxial ridge bounded laterally by a shallow furrow. Doublure narrow, flattened, and bearing concentric terrace lines.

Remarks: Despite the poor preservation of the material it is possible to distinguish this species from the other species of *A. (Lobopyge)* that have been described from the Early Devonian of southeastern Australia. In *A. (L.) australiformis* Chatterton, Johnson & Campbell 1979 and *A. (L.) sinuata* (Ratte 1886), both from the Garra Formation near Wellington, New South Wales, the median glabellar lobe rises more gently from the 1p lobe, the palpebral lobes are relatively higher, and the pygidial axis is longer and narrower. In addition, the anterior margin of the hypostome in *A. (L.) australiformis* is more convex and the second pair of marginal spines on the pygidium curve slightly inwards distally, while *A. (L.) sinuata* has a definite pattern of large tubercles on the cranidium, the anterior pleural bands on the pygidium are relatively shorter (exsag.) and the anteriormost marginal spines on the pygidium are more divergent. *A. (L.) australis* (McCoy 1876) from the Humevale Formation near Lilydale, Victoria is in need of revision, but it has a relatively longer pygidial axis with a posterior lobe that is distinctly inflated and bears a number of large tubercles, and the pleural region behind the second segment is larger (Gill 1939, pl. 5, fig. 1). The fragmentary pygidia of *A. (Lobopyge)* described by Chatterton, Johnson & Campbell (1979, pl. 109, figs 22, 23) from the Warroo Limestone near Yass, New South Wales are more weakly tuberculate than those from the Mount Ida Formation and the anterior marginal spines are more divergent, at least proximally.

Amongst overseas species, the closest resemblance is with *A. (L.) consanguinea* (Clarke 1894) from the Early Devonian of New York, *A. (L.) richteri* (Vanek 1959) from the Lochkovian of Czechoslovakia, and *A. (L.) pragensis* (Boucek 1933) from the Pridolian or Lochkovian of Czechoslovakia. It is not possible definitely to distinguish the Mount Ida species from *A. (L.) richteri* or *A. (L.) pragensis* on the basis of published illustrations, but *A. (L.) consanguinea* has a distinctive arrangement of larger tubercles on the cranidium, and the anterior margin of the hypostome is more arcuate (Whittington 1956, pl. 131). Chatterton, Johnson & Campbell (1979) included *consanguinea* in *Acanthopyge (Acanthopyge)*, but on the basis of pygidial characters it clearly belongs to *Lobopyge*.

Family Odontopleuridae Burmeister 1843
Subfamily Odontopleurinae Burmeister 1843

Genus **Leonaspis** R. & E. Richter 1917

Type Species (by original designation): *Odontopleura Leonhardi* Barrande 1846 from the Kopanina Formation (Ludlovian) at Koledník near Beroun, Czechoslovakia.

Leonaspis sp.

Fig. 6L

Material: A cranidium from approximately 300 m east of locality R25.

Remarks: The most distinctive features of this cranidium are a relatively short (sag.) occipital ring with a large median tubercle or spine situated close to the posterior margin; a strongly inflated median glabellar lobe; relatively wide fixigenae; a facial suture that runs directly forwards in front of the eye before curving gently inwards; and an ornament of moderately coarse granules. These features are also characteristic of *L. rattei* (Etheridge & Mitchell 1896) from the Ludlovian-Gedinnian of the Yass Basin, New South Wales (see Chatterton 1971, pl. 22, figs. 8-14) but the present material is inadequate for meaningful comparison with that species.

ACKNOWLEDGEMENTS

We thank K. S. W. Campbell (Australian National University) for encouraging us to work on the fauna and for assistance in the initial stages; A. Ritchie and R. K. Jones (Australian Museum) for providing casts of comparative species; and K. N. Bell, A. Jenkin and H. E. Wilkinson for assistance in collecting the specimens.

REFERENCES

Alberti, G. K. B., 1966. Über einige neue Trilobiten aus dem Silurium und Devon, besonders von Marokko. *Senckenberg. leth.* 47: 111-121.

Alberti, G. K. B., 1967. Neue obersilurische sowie unter- und mitteldevonischer Trilobiten aus Marokko, Deutschland und einigen anderen europäischen Gebieten. 1. *Senckenberg. leth.* 48: 463-478.

Alberti, G. K. B., 1969. Trilobiten des jüngeren Siluriums sowie des Unter- und Mitteldevons. I. Mit Beiträgen zur Silur-Devon Stratigraphie einiger Gebiete Marokkos und Oberfrankens. *Abh. Senck. Nat. Gesell.* 520: 1-692.

Biske, J. S., Gorianov, V. B. & Rzonsnickaja, M. A., 1977. Tien-shan. In The Silurian-Devonian boundary, Martinsson, A., Ed., *IUGS Series A*, 5: 227-237.

Boucek, B., 1933. O nových trilobitech ceského gotlandienu, I. *Vest. st. geol. Úst. csl. Repub.* 9: 171-179.

Bourque, P-A. & Lesperance, P. J., 1977. Gaspé Peninsula, Québec. In The Silurian-Devonian boundary, Martinsson, A., Ed., *IUGS Series A*. 5: 245-255.

Campbell, K. S. W., 1975. The functional anatomy of phacopid trilobites: musculature and eyes. *J. Proc. R. Soc. N.S.W.* 108: 168-188.

Campbell, K. S. W., 1977. Trilobites of the Haragan, Bois d'Arc and Frisco Formations (Early Devonian) Arbuckle Mountains region, Oklahoma. *Bull. Okla. geol. Surv.* 123: 1-227.

Chapman, F., 1915. New or little-known fossils in the National Museum. Part XVIII. Some Yeringian trilobites. *Proc. R. Soc. Vict.* 28: 157-171.

Chatterton, B. D. E., 1971. Taxonomy and ontogeny of Siluro-Devonian trilobites from near Yass, New South Wales. *Palaeontographica* (A) 137: 1-108.

Chatterton, B. D. E., Johnson, B. D. & Campbell, K. S. W., 1979. Silicified Lower Devonian trilobites from New South Wales. *Palaeontology* 22: 799-837.

Clarke, J. M., 1913. Fosseis Devonianos do Paraná. *Monografias Div. geol. miner. Bras.* 1: 1-353 (not seen).

Eldredge, N., 1971. Patterns of cephalic musculature in the Phacopina (Trilobita) and their phylogenetic significance. *J. Paleont.* 45: 52-67.

Eldredge, N., 1973. Systematics of Lower and lower Middle Devonian species of the trilobite *Phacops* Emmrich in North America. *Bull. Am. Mus. nat. Hist.* 151: 285-338.

Etheridge, R. & Mitchell, J., 1895. The Silurian trilobites of New South Wales, with references to those of other parts of Australia. Part III. The Phacopidae. *Proc. Linn. Soc. N.S.W.* 10: 486-511.

Etheridge, R. J. & Mitchell, J., 1917. The Silurian trilobites of New South Wales, with references to those of other parts of Australia. Part IV. The Calymeneidae, Cheiruridae, Harpeidae, Bronteidae, etc., with an appendix. *Proc. Linn. Soc. N.S.W.* 42:480-510.

Foldvary, G., 1970. A new species of trilobite, *Cheirurus (Crotalocephalus) regius* n. sp. from the Early Devonian of Trundle district, central N.S.W. *J. Proc. R. Soc. N.S.W.* 103: 85-86.

Garratt, M. J., 1978. New evidence for a Silurian (Ludlow) age for the earliest *Baragwanathia* flora. *Alcheringa* 2: 217-224.

Gill, E. D., 1939. The Silurian trilobite *Lichas australis*. *Mem. natn. Mus. Vict.* 11: 140-142.

Gill, E. D., 1945. Trilobita of the family Calymenidae from the Palaeozoic rocks of Victoria. *Proc. R. Soc. Vict.* 56: 171-186.

Gill, E. D., 1948a. Eldon Group fossils from the Lyell Highway, Western Tasmania. *Rec. Q. Vict. Mus.* 2: 57-74.

Gill, E. D., 1948b. A gens of dalmanitid trilobites. *J. Proc. R. Soc. N.S.W.* 82: 16-24.

Gill, E. D., 1949. Palaeozoology and taxonomy of some Australian homalonotid trilobites. *Proc. R. Soc. Vict.* 61: 61-73.

Gill, E. D., 1951. Two new brachiopod genera from Devonian rocks in Victoria. *Mem. natn. Mus. Vict.* 17: 187-205.

Haas, W., 1968. Trilobiten aus dem Silur und Devon von Bithynien (NW-Türkei). *Palaeontographica* (A) 130: 60-207.

Haas, W., 1969. Lower Devonian trilobites from central Nevada and northern Mexico. *J. Paleont.* 43: 641-659.

Hall, J. & Clarke, J. M., 1888. *Natural History of New York. Palaeontology: Volume VII. Text and Plates. Containing descriptions of the trilobites and other Crustacea of the Oriskany, Upper Helderberg, Hamilton, Portage, Chemung and Catskill Groups.* 236 pp., 46 pls. Geological Survey of New York, Albany.

Holloway, D. J., 1980. Middle Silurian trilobites from Arkansas and Oklahoma, U.S.A. Part 1. *Palaeontographica* (A) 170: 1-85.

Jaeger, H., 1966. Two late *Monograptus* species from Victoria, Australia, and their significance for dating the *Baragwanathia* flora. *Proc. R. Soc. Vict.* 79: 393-413.

Kobayashi, T. & Hamada, T., 1977. Devonian trilobites of Japan in comparison with Asian, Pacific and other faunas. *Spec. Pap. palaeont. Soc. Japan* 20: i-vii, 1-202.

Kozlowski, R., 1923. Faune dévonienne de Bolivie. *Annls Paléont.* 12: 1-112.

Landrum, R. E. & Sherwin, L., 1976. *Warburgella* from central New South Wales. *Rec. geol. Surv. N.S.W.* 17: 135-146.

Lane, P. D., 1971. British Cheiruridae (Trilobita). *Palaeontogr. Soc. [Monogr.]*: 1-95.

Link, A. G., 1970. Age and correlations of the Siluro-Devonian strata in the Yass Basin, New South Wales. *J. geol. Soc. Aust.* 16: 711-722.

Link, A. G. & Druce, E. C., 1972. Ludlovian and Gedinnian conodont stratigraphy of the Yass Basin, New South Wales. *Bull. Bur. Miner. Resour. Geol. Geophys. Aust.* 134: 1-136.

Lutke, F., 1965. Zur Kenntnis herzynischer Trilobiten aus dem Unter- und Mitteldevon des Harzes. *Palaeontographica* (A) 124: 151-236.

Maksimova, Z. A., 1968. Srednepaleozojskie trilobity tsentral 'nogo Kazakhstana. *Trudy vses. nauchno-isled. geol. Inst.* 165: 1-208.

Maksimova, Z. A., 1975. Trilobity. In Kharakteristika fauny pogranichnykh sloev Silura i Devona tsentral 'nogo Kazakhstana, Menner, V. V., Ed., *Materialy po geologii tsentral 'nogo Kazakhstana* 12: 119-133.

McKellar, R. G., 1969. Brachiopods and trilobites from Siluro-Devonian strata in the Rockhampton district. *Publs geol. Surv. Qd* 337: 1-13.

McLearn, F. H., 1924. Palaeontology of the Silurian rocks of Arisaig, Nova Scotia. *Mem. geol. Surv. Can.* 137: 1-179.

Moore, R. C. 1959. (Ed.) *Treatise on Invertebrate Paleontology, Part O, Arthropoda I.* xix + 560 pp. Geological Society of America and University of Kansas Press, Lawrence.

Mozdalevskaya, T. L., 1968. *Atlas of Silurian and Early Devonian fauna of Podolia.* (Appendix to the guide.) VSEGEI, Leningrad.

Nikiforova, O. I., 1977. Podolia. In The Silurian-Devonian boundary, Martinsson, A., Ed., *IUGS Series A*, 5: 52-64.

Owens, R. M., 1973. British Ordovician and Silurian Proetidae (Trilobita). *Palaeontogr. Soc. [Monogr.]*: 1-98.

Philip, G. M., 1962. The palaeontology and stratigraphy of the Siluro-Devonian sediments of the Tyers area, Gippsland, Victoria. *Proc. R. Soc. Vict.* 75: 123-246.

Philip, G. M., 1967. Late Silurian-early Devonian relationships in the central Victorian and western Tasmanian clastic sequences, Australia. In *International Symposium on the Devonian System, Calgary,* Oswald, D. H. Ed., 1967. Volume 2: 913-920. Alberta Society of Petroleum Geologists, Calgary.

Pillet, J., 1973. Les trilobites du Dévonien inférieur et du Dévonien moyen du Sud-Est du Massif armoricain. *Mém. Soc. scient. Anjou* 1: 1-307.

PRANTL, F., 1947. Some abnormalities in *Crotalocephalus* Salter (Trilobitae). *Bull. int. Acad. tchêque Sci.* 48: 1-16.

PRIBYL, A., 1965. Proetidní trilobiti z nových sberú v ceském siluru a devonu. (Proetidae aus neueren Aufsammlungen im böhmischen Silur und Devon (Trilobitae) I). *Cas. národ. Muz.* 134: 91-98.

PRIBYL, A. & VANEK, J., 1964. Nekolik poznámek ke klasifikaci rodu *Cheirurus* Beyrich (Trilobita). *Cas. národ. Muz.* 133: 93-95.

PRIBYL, A. & VANEK, J., 1981. Studie zur Morphologie und Phylogenie der Familie Otarionidae R. and E. Richter, 1926 (Trilobita). *Palaeontographica* (A). 173: 160-208.

RICHTER, R. & E., 1926. Die Trilobiten des Oberdevons. Beiträge zur Kenntnis devonischer Trilobiten. IV. *Abh. preuss. geol. Landesanst.* 99: 1-301.

RICHTER, R. & E., 1954. Die Trilobiten des Ebbe-Sattels und zu vergleichende Arten. (Ordovizium, Gotlandium/Devon). *Abh. Senck. Nat. Gesell.* 488: 1-76.

SALTER, J. W., 1865. A monograph of the British trilobites from the Cambrian, Silurian and Devonian formations. *Palaeontogr. Soc. [Monogr.]* (2): 81-128.

SAUL, J. M., 1967. *Burmeisteria (Digonus) accraensis*, a new homalonotid trilobite from the Devonian of Ghana. *J. Paleont.* 41: 1126-1136.

SAVAGE, N. W., 1974. The brachiopods of the Lower Devonian Maradana Shale, New South Wales. *Palaeontographica* (A) 146: 1-51.

SHERGOLD, J. H., 1968. On the occurrence of the trilobite genera *Acaste* & *Acastella* in Victoria. *Proc. R. Soc. Vict.* 81: 19-30.

SHERWIN, L., 1971. Trilobites of the subfamily Phacopinae from New South Wales. *Rec. geol. Surv. N.S.W.* 13: 83-99.

STRUSZ, D. L., 1964. Devonian trilobites from the Wellington-Molong district of New South Wales. *J. Proc. R. Soc. N.S.W.*. 97: 91-97.

STRUSZ, D. L., 1980. The Encrinuridae and related trilobite families, with a description of Silurian species from southeastern Australia. *Palaeontographica* (A) 168: 1-68.

STRUSZ, D. L., BISCHOFF, G., COOPER, B. J., GILL, E. D. & TALENT, J. A., 1972. Central and eastern Victoria. In Correlation of the Lower Devonian rocks of Australasia, Strusz, D. L., *J. geol. Soc. Aust.* 18: 427-455.

TALENT, J. A., 1965a. The stratigraphic and diastrophic evolution of central and eastern Victoria in middle Palaeozoic times. *Proc. R. Soc. Vict.* 79: 179-195.

TALENT, J. A., 1965b. The Silurian and Early Devonian faunas of the Heathcote district, Victoria. *Mem. geol. Surv. Vict.* 26: 1-55.

TALENT, J. A., BERRY, W. B. N. & BOUCOT, A. J., 1975. Correlation of the Silurian rocks of Australia, New Zealand and New Guinea. *Spec. Pap. geol. Soc. Amer.* 150: 1-108.

THOMAS, D. E., 1937. Some notes on the Silurian rocks of the Heathcote district. *Min. geol. J.* 1: 64-67.

THOMAS, D. E., 1940a. Heathcote sheet, 1:31,680 geological parish plans. Department of Mines, Victoria.

THOMAS, D. E., 1940b. Redcastle sheet, 1:31,680 geological parish plans. Department of Mines, Victoria.

THOMAS, D. E., 1941. Dargile sheet, 1:31,680 geological parish plans. Department of Mines, Victoria.

TOMCZYKOWA, E., 1975. The trilobite subfamily Homalonotinae from the Upper Silurian and Lower Devonian of Poland. *Acta palaeont. pol.* 20: 3-46.

VANDENBERG, A. H. M., 1974 (compiler). Melbourne Sheet SJ 55-1, Australian 1:63,360 Geological Series. Geological Survey of Victoria.

VANDENBERG, A. H. M. & GARRATT, M. J., 1976. Melbourne Trough. *Spec. Publ. geol. Soc. Aust.* 5: 45-62.

VANEK, J., 1959. Celed Lichaidae Hawle & Corda, 1847 ze stredoceského starsího paleozoika. *Bohem. cent.* 1: 81-168.

WHITTINGTON, H. B., 1956. Beecher's lichid protaspis and *Acanthopyge consanguinea* (Trilobita). *J. Paleont.* 30: 1200-1204.

WOLFART, R., 1968. Die Trilobiten aus dem Devon Boliviens und ihre Bedeutung für Stratigraphie und Tiergeographie. In Beiträge zur Kenntnis des Devons von Bolivien, Wolfart, R. & Voges, A., *Beih. geol. Jb.* 74: 5-201.

PROC. R. SOC. VICT. vol. 94, no. 3, 155-167, September 1982

MORPHOLOGICAL AND GEOGRAPHICAL DISJUNCTIONS IN FORMS OF *EUCALYPTUS NITIDA* Hook. f. (MYRTACEAE): WITH SPECIAL REFERENCE TO THE EVOLUTIONARY SIGNIFICANCE OF BASS STRAIT, SOUTHEASTERN AUSTRALIA

By JULIE C. MARGINSON AND PAULINE Y. LADIGES

School of Botany, University of Melbourne, Parkville, Victoria 3052

ABSTRACT: Variation in seedling characters of *Eucalyptus nitida* (shining peppermint) and related species was analysed phenetically using multivariate classification and ordination techniques. The principal aims were to clarify the identity of the peppermint species occurring on some Bass Strait islands and to examine patterns of variation in seedling morphology across the geographic range of populations currently referred to *E. nitida*. Related species were included as aids to interpreting patterns. Analyses were based on seedling and juvenile foliage, the latter resolving the taxa more completely. On the basis of seedling morphology, Bass Strait island peppermint appears to be conspecific with Tasmanian *E. nitida*, and these populations appear to be separate from Victorian and South Australian populations currently referred to *E. nitida*. It is suggested that the degree of distinctness is sufficient to warrant separate taxonomic recognition of the Australian mainland populations.

Systematic affinities of Tasmanian peppermints are discussed, and an explanatory hypothesis is proposed to account for the present distribution of peppermint species and the high degree of endemism among Tasmanian peppermints.

Current usage recognizes six species of *Eucalyptus* as occurring variously on the larger islands of Bass Strait (Table 1). This contrasts with about 75 species in Victoria and 25 on the Tasmanian mainland. Five of the six species belong to the informal subgenus *Symphyomyrtus* as recognized by Pryor and Johnson (1971) and are relatively widespread on both sides of Bass Strait. They are *E. viminalis* Labill., *E. dalrympleana* Maiden, *E. globulus* Labill., *E. ovata* Labill. and *E. brookerana* A. M. Gray. Apart from the occurrence of *E. globulus* on Rodondo Island just south of Wilsons Promontory (Kirkpatrick *et al.* 1974), these species are confined to the seven largest islands.

The sixth species, *E. nitida* Hook. f., is a member of the peppermint group of eucalypts and is placed in the informal subgenus *Monocalyptus* (Pryor & Johnson 1971). It is considered to occur not only on the Tasmanian mainland but also in far southeastern South Australia, in scattered localities close to the coast of Victoria from the South Australian border to Sperm Whale Head, and in the Grampians (Willis 1970) (Fig. 1). In recent years, the name has been applied to populations of Bass Strait island peppermint (e.g. Curtis & Morris 1975). These populations occur on all the larger islands, on some smaller islands of the Furneaux Group and on two islands of the Kent Group, Deal and Dover Islands.

Willis (1972, p. 416) described all the above populations as "undoubtedly conspecific". Previously, Victorian and South Australian populations were known variously as *E. dives* (e.g. Ewart 1930, Hall *et al.* 1963), *E. vitrea* (e.g. Black 1964, Boomsma 1972, Parsons *et al.* 1972) and *E. radiata* (e.g. Parsons 1966). Similarly, island populations had been given names of Tasmanian mainland species such as *E. tenuiramis* (e.g. Brett 1938), *E. simmondsii* (e.g. Jackson 1965, Hall *et al.* 1970, Hope 1973) and *E. amygdalina* (Hope 1973). Significantly, Blakely (1934, 1965) applied the name *E. tenuiramis* Miq. to specimens collected from Deal and Flinders Islands which he had sighted at the National Herbarium of New South Wales. Willis (1967) strongly disagreed with the application of this name, mainly on the ground that the glaucousness of leaves and buds described by Miquel has not been found to occur in any Bass Strait island specimens. The name *E. tenuiramis* has since been applied strictly to lowland populations from southeastern Tasmania having connate juvenile leaves and a dense waxy bloom on shoots, buds and fruits. Subsequently, Willis (1970) reduced *E. simmondsii* of northwestern Tasmania to synonymy with *E. nitida* and made his claim for conspecificity, but without offering any reasons for his decisions.

With the other five island species occurring on both sides of Bass Strait, the notion of a comparable distribution for *E. nitida* is plausible. However, there are two *prima facie* reasons why Willis's claim should not be accepted uncritically: firstly, of the four systematic groups of eucalypts that occur in Tasmania, the peppermints show the highest degree of endemism (Table 2); secondly, variation within *E. nitida sensu* Willis is considerable, particularly with respect to habit and bark type, fruit size and shape, and juvenile leaf and stem morphology.

Bass Strait island peppermint is generally a small tree, dominant in low open-forest communities; it is 2 to 10 m tall, of poor form, sometimes multi-stemmed, and has smooth bark with a short, scaly to sub-fibrous butt; the more or less flat-topped turbinate to pyriform fruits are relatively large (to 9 mm wide); coppice leaves are ovate, sessile and opposite for many pairs. Herbarium specimens conform reasonably well with the type specimens of *E. nitida* which were collected from several Tasmanian mainland localities. The nearest Victorian

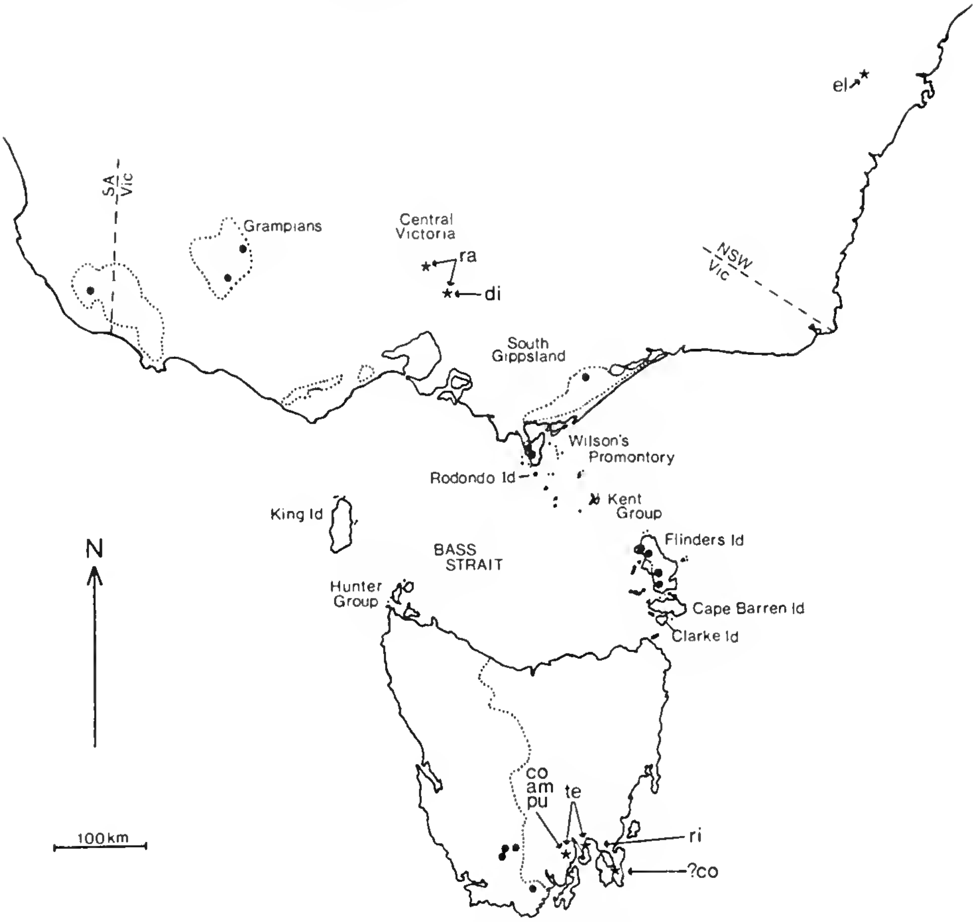


Fig. 1 – Generalised distribution limits of *E. nitida sensu* Willis and localities of seed collections: *E. nitida* (•), other species (*). Abbreviations: am = *E. amygdalina*, co = *E. coccifera*, di = *E. dives*, el = *E. elata*, n = *E. nitida*, pu = *E. pulchella*, ra = *E. radiata*, ri = *E. risdonii*, te = *E. tenuiramis*.

populations of peppermint currently referred to *E. nitida* occur on Wilsons Promontory, but they differ from island peppermint in several respects: bark is rougher, buds and fruits are smaller, and coppice leaves are lanceolate.

In some parts of its range, Tasmanian *E. nitida* is not separable from *E. amygdalina* (Hall *et al.* 1963, A. Gray pers. comm.). Some Victorian and South Australian populations include trees of intermediate status and bearing some resemblance to *E. radiata* (Parsons *et al.* 1977) or *E. pauciflora* (Willis 1970, Boomsma & Lewis 1980). Throughout the geographic range, there appear to be few readily interpretable disjunctions in adult form that might clarify the taxonomy.

The diagnostic importance of juvenile leaves has been recognized for almost a century (Maiden 1922). More recently, Brooker (1979) observed that seedling morphology can be an extremely valuable aid in assigning species to series within the genus *Eucalyptus*. Ladiges *et al.* (1981) found that differences in seedling morphology between *E. ovata* and *E. brookerana* were sufficient to justify recognition of these taxa at the specific level. It was therefore considered desirable to use seedling characters to test the adequacy of *E. nitida sensu* Willis, principally with respect to Bass Strait island populations. A seedling trial was established in a uniform environment to examine the patterns of variation in seedling morphology within *E. nitida sensu* Willis, and to assess the distinctness of *E. nitida* seedlings with respect to those of related species.

Related species were considered to be all the members of subseries *Amygdalininae* of series *Piperitae* (Pryor & Johnson 1971). Details of their geographic and altitudinal distributions, growth forms and bark types are summarized in Table 3. Typically, they occur on infertile, acidic soils derived from sedimentary, metamorphic or granitic parent materials; average annual rainfall ranges from 600 to 1300 mm. The member species are distinguished from other members of the subgenus *Monocalyptus* on the basis of possessing some combination of the following characters (modified from Wilcox 1979):

1. "Peppermint" bark – finely textured, shortly fibrous, loosely coherent rough bark which persists on larger branches.

TABLE 1

OCCURRENCE OF *Eucalyptus* SPECIES ON THE ISLANDS OF BASS STRAIT

Island	Area (km²)	Species vim	dal	glo	ova	bro	nit
King Island	1,100	+	–	+	–	+	–*
Hunter Group							
Hunter Island	70				+		+
Three Hummock Island	68				+		+?
Robbins Island	96				+		+
Furneaux Group							
Flinders Island	1,333	+	+	+	+	–	+
Cape Barren Island	450	+		+	+		+
Clarke Island	75	+		+	+		+
Prime Seal Island	10						+
Babel Island	4						+
Great Dog Island	3						+
Kent Group							
Deal Island	15						+
Dover Island	2.5						+
Erith Island	3.0						–
Rodondo Island	0.8			+			

vim = *E. viminalis*, dal = *E. dalrympleana*, glo = *E. globulus*, ova = *E. ovata*, bro = *E. brookerana*, nit = *E. nitida*.
+ = present, – = notably absent.

* The map provided by Jackson (1965) showing *E. nitida* (syn. *E. simmondsii*) as occurring on King Island is considered to be incorrect (P. Barnett, King Island, pers. comm.)

2. Seedling leaves opposite and sessile for first 4 to 6 nodes; juvenile leaves opposite and sessile for an indefinite number of following nodes.
3. Verrucae (protruding oil glands) on margins and midribs of seedling and juvenile leaves, and on seedling stems.
4. Characteristic essential oils in juvenile and mature foliage, particularly piperitone, phellandrene and cineole.
5. Mature leaves symmetrical, with more or less longitudinal secondary venation, and with the apex acuminate or hooked.
6. Buds numerous, clavate and pedicellate; capsules pyriform-turbinate with a flattened disc.

The following taxa were omitted from the study: (1) *E. radiata* ssp. *robertsonii sensu* Johnson & Blaxell (1973) occurring in upland areas of New South Wales and Victoria; (2) *E. robertsonii sensu* Jackson (1965) and Hall *et al.* (1970) considered by Johnson & Blaxell (1973) to be an undescribed subspecies of *E. amygdalina*; and (3) the two species that form subseries *Piperitinae* of series *Piperitae* (Pryor & Johnson 1971) considered by Brooker (1977) to be better classified with the ash group of eucalypts (series *Obliquae* subgenus *Monocalyptus*).

METHODS

SEED COLLECTION AND SEEDLING GROWTH

Of the nine species included in the seedling trial, eight were represented by seed collections from individual mother trees. *E. nitida sensu* Willis was represented by seed collected from five trees on Dover Island, six on Flinders Island, four in southern Tasmania, two each on Wilsons Promontory and in the Grampians, and one each in South Gippsland at Bellbird Swamp near Longford and in southeastern South Australia near Wandillo (Fig. 1). *E. tenuiramis* and *E. radiata* were represented by seed from two trees each; *E. dives, E. pulchella, E. amygdalina* and *E. risdonii* by seed from one tree each; all these trees were considered to be typical members of each taxon and accordingly were located in southeastern Tasmania or central Victoria. The subalpine Tasmanian species *E. coccifera* was represented by seed from one tree considered to be typical and from one tree representing a population considered to be anomalous on the basis of both adult morphology and its lowland locality (Devil's Kitchen, Tasman Peninsula). The ninth species, *E. elata*, was represented by seed obtained through the Forests Commission of Victoria from the vicinity of Nerriga, N.S.W. It is not known whether the seed was from a single tree or was pooled from several trees. Voucher specimens from the parent trees of all species except *E. elata* are held in herbaria: MELU or FRI.

Seed was germinated on moist filter paper in petri dishes. Young seedlings were pricked out into plastic buckets containing a general purpose potting mix and were allowed to grow in a heated glasshouse for seven months. Initially, each bucket contained six seedlings from one seed collection; after three months, these were thinned out to the most robust three per bucket. This growth system was chosen to suit the scale of the trial while providing sufficient replication and a reasonable volume of soil for individual seedlings. The trial was terminated when competitive effects on growth rate (expressed as shoot height) became apparent in some buckets, causing a reduction in the number of assessable seedlings.

PHENETIC ANALYSIS OF SEEDLING CHARACTERS

Individual seedlings were subject to multivariate analysis of morphological characters. Following the distinction made between seedling and juvenile leaves by Blake (1953) and Chippendale (1973), two data matrices were prepared. The first was based on seedlings after four months' growth; seedling leaf characters were assessed on one of the paired leaves at the third node above the cotyledonary node and the matrix incorporated data from 96 seedlings using 35 characters (Table 4). The second matrix was based on seedlings after seven months' growth. Juvenile leaf characters were assessed on one of the paired leaves at the seventh node, or at the next highest node at which a clear change to juvenile foliage had occurred. The matrix incorporated data from 85 seedlings using 36 characters. Changes in the character set used for the second matrix were due to changes in seedling morphology with age.

TABLE 2

TASMANIAN SPECIES OF *Eucalyptus*. GEOGRAPHIC AND SYSTEMATIC DISTRIBUTION

(compiled primarily from Pryor and Johnson 1971)

Species	Tas.	S.A.	Vic.	N.S.W.	Qld.	Systematic Group
E. delegatensis	+		+	+		Subg. *Monocalyptus* Sect. *Renantheria* Series *Obliquae*
E. obliqua	+	+	+	+	+	
E. pauciflora	+	+	+	+	+	
E. regnans	+		+			
E. sieberi	+		+	+		
E. amygdalina	+					Subg. *Monocalyptus* Sect. *Renantheria* Series *Piperitae* Subseries *Amygdalininae*
E. coccifera	+					
E. nitida	+	+ ?	+ ?			
E. pulchella	+					
E. risdonii	+					
E. tenuiramis	+					
*E. barberi**	+					Subg. *Symphyomyrtus* Sect. *Maidenaria* Series *Ovatae* Subseries *Ovatinae*
*E. brookerana**	+		+			
E. ovata	+	+	+	+	+	
E. rodwayi	+					
E. cordata	+					Subg. *Symphyomyrtus* Sect. *Maidenaria* Series *Viminales*
E. dalrympleana	+		+	+		
E. globulus	+		+	+		
E. gunnii	+					
E. morrisbyi	+					
E. perriniana	+		+	+		
E. rubida	+	+	+	+		
E. urnigera	+					
E. vernicosa	+					
E. viminalis	+	+	+	+	+	

* Tentative placement of *E. barberi* Johnson and Blaxell and *E. brookerana* A. M. Gray after Ladiges *et al.* (1981).

Each raw data matrix was analysed separately using classification and ordination programs from CSIRO's TAXON P2 package as follows: data were input to the polythetic program MSEUC which produces an inter-element dissimilarity matrix from mixed data using a squared Euclidean metric with Burr's standardization (see Williams 1976). The dissimilarity matrix was then input to SAHN which generates a hierarchy based on "distances" between individuals (seedlings). Output from this agglomerative procedure was restricted to the last 14 fusions (15 groups). Group data were then input to the diagnostic programs GPCOM and CRAMER to assist in interpreting relationships between groups and the characters that contributed to their formation. An inter-group dissimilarity matrix was generated using GPDIS and input to the ordination program PCOA which finds principal coordinates for group centroids. The inter-group dissimilarity matrix was also input to MST which calculates a minimum spanning tree linking "nearest" group centroids (see Gillison 1978). Groups were also redefined using GPRES and input to BACRIV which calculates correlation coefficients between characters and the vectors (axes) generated by PCOA. Output from both MST and BACRIV assists in interpreting the ordinations. Further details of these methods can be obtained from CSIRO Division of Computing Research.

RESULTS

The limited size of the seedling trial, especially with respect to species represented by progeny from only one or two trees, necessitates caution in interpreting the analyses. Only the broader elements of the patterns found will be discussed, and only then in relation to interpreting variation within *E. nitida sensu* Willis.

SEEDLING LEAF ANALYSIS

The classification based on seedling leaves produced a major dichotomy separating Victorian and South Australian seedlings of *E. nitida* from Bass Strait island seedlings (Fig. 2). Tasmanian mainland seedlings occurred equally on both sides of the dichotomy, reflecting the extent of their variability. Moreover, classification to the 15-group level did not produce a clear separation of some *E. nitida* seedlings from those of three other species: Group 2 incorporated seedlings of *E. dives* with *E. nitida* from the Grampians and South Gippsland; Groups 3 and 4 incorporated *E. radiata* with *E. nitida* from Wilsons Promontory and South Gippsland; and Groups 6 and 7 incorporated *E. coccifera* with *E. nitida* from Flinders Island and the Tasmanian mainland. Ten of the 15 groups included some representatives of *E. nitida*.

The characters contributing most to the major dichotomy in the classification were those related to leaf

TABLE 3

TASMANIAN PEPPERMINTS AND THEIR ALLIES (SUBSERIES *Amygdalininae*)
(Compiled primarily from Hall *et al.* (1970), Willis (1972), Curtis and Morris (1975))

Species	Geographic distribution	Altitudinal range	Typical habit	Bark type
E. coccifera	Tas. Central Highlands. Sub-alpine.	600-1500 m	Shrub to small tree 1-6(-12) m	Smooth
E. risdonii	Tas. Restricted to a small area near Hobart.	Near sea level to 150 m	Shrub to small tree 3-8(-20) m	Smooth with circular scars
E. tenuiramis	Tas. South-eastern quarter.	Near sea level to 450 m	Tree 10-30 m	Smooth with circular scars
E. pulchella	Tas. South-eastern quarter.	150-550 m	Tree 10-30 m	Smooth with ± subfibrous butt
E. amygdalina	Tas. Eastern half.	Near sea level to 850 m	Tree 15-35 m	Peppermint – variable
E. nitida	Tas. Western half; Bass Strait islands. Vic. Patchy, southern coast, Grampians S.A. Extreme south-east.	Near sea level to 850 m	Small to medium tree (5-)10-20(-35) m	Variable. Typically sub-fibrous on trunk, but may be smooth-barked
E. radiata	Vic. Widespread in Central Highlands and foothills. N.S.W. Eastern third.	150-1200 m	Tree 15-35 m	Peppermint
E. dives	As for *E. radiata*, but on drier sites.	150-120 m	Tree 10-30 m	Peppermint to larger branches
E. elata	Vic. Far east coast, Macalister R. valley. N.S.W. South east coast. All alluvial sites.	Near sea level to 200(-750) m	Tree 20-35(-50) m	Smooth with sub-fibrous butt

shape (principally the ratio of length to maximum width) plus the occurrence of verrucae on leaf margins (Table 5). Another leaf shape ratio (LM:LL), internode length, stem glaucousness and leaf colour were important in producing the next two dichotomies. Taking only those ten groups that incorporated *E. nitida*, the four mainland groups (1-4) included seedlings that had green, ovate to lanceolate leaves with acute apices; internodes were relatively long; verrucae were absent from the leaf margins. The six groups that incorporated island and Tasmanian *E. nitida* (5-10) included seedlings with green to blue-green, broadly ovate leaves; apices were more or less obtuse; internodes were relatively short; and verrucae were conspicuous on the margins of all seedlings in these groups. The last-mentioned character clearly separated all Tasmanian and island seedlings of *E. nitida* from all Australian mainland seedlings, including those from Wilsons Promontory. Together with the presence of more or less undulate margins, these glands were most prominent in progeny of trees from Dover Island in the Kent Group.

Ordination of the group centroids together with links between nearest neighbours are shown in Fig. 3. The first three axes (vectors) accounted for 64.4% of the total variation in the data matrix. The relative positions of group centroids confirmed the pattern of clear separation between Victorian and South Australian seedlings of *E. nitida* (Groups 1-4), and Bass Strait island and some Tasmanian mainland seedlings (Groups 5-9). The remaining Tasmanian mainland seedlings (Group 10) occupied an intermediate position with respect to the characters separating the groups on axis 1. These included the same characters that produced the major dichotomy in the classification. Axis 2 was most strongly correlated with internode length and total height and the extreme position of Group 10 suggests that some Tasmanian mainland populations may have an inherently slow growth rate relative to other populations of *E. nitida*, at least during early growth.

JUVENILE LEAF ANALYSIS

The classification based on juvenile leaves again produced a major dichotomy separating Victorian and South Australian samples of *E. nitida* from both Bass Strait island and Tasmanian mainland populations (Fig. 4). All seedlings of *E. nitida* were contained within seven groups and were clearly differentiated from all other species included in the trial. To that extent, the analysis based on juvenile leaf characters produced a more readily interpretable result.

The characters contributing most to the major dichotomy in the classification were again principally related to leaf shape; in addition, secondary vein angle and oil gland density were important (Table 6). Leaf colour and the ratio of length from leaf base to widest point over total length were important in producing the next two dichotomies respectively. Taking only those seven

TABLE 4

SEEDLING CHARACTERS SCORED FOR DATA MATRICES

Binary		
1.	Leaf margin (*S*)	revolute/not
2.	Leaf margin	undulate/not
3.	Verrucae on stem	present/absent
4.	Verrucae on abaxial midrib	present/absent
5.	Verrucae on leaf margin	present/absent
6.	Stem	glaucous/not
7.	Lignotuber	present/absent
8.	Petiole (*J*)	present/absent
9.	Leaf lamina (*J*)	concolorous/discolorous
Multistate		
10.	Leaf base shape	acute/obtuse/cordate/connate
11.	Leaf angle to stem	<80°/80-100°/>100°
12.	Leaf margin	entire/repand/sparsely serrulate/serrulate
13.	Leaf colour	yellow-green/green/blue-green/glaucous
14.	Midrib colour	yellow/pale red/intense red
15.	Margin colour	yellow/pale red/intense red
16.	Stem colour	yellow/pale red/intense red
17.	Anthocyanin on abaxial leaf surface (*S*)	absent/pale/intense
18.	Leaf orientation (*J*)	horizontal/twisted/vertical
Numerical		
19.	Leaf length (=LL) (mm)	
20.	Maximum leaf width (=MW) (mm)	
21.	Width 5 mm from leaf base (=WB) (mm)	
22.	Width 5 mm from leaf apex (=WA5) (mm)	
23.	Width 10 mm from leaf apex (=WA10) (mm)	
24.	Leaf length from base to widest point (=LM) (mm)	
25.	Total height (=TH) (mm)	
26.	Length 3rd or 7th internode (=IL) (mm)	
27.	Mean internode length (=ML) (mm)	
28.	Leaf apex angle (°)	
29.	Secondary vein angle (°)	
30.	Total number of leaf pairs (*J*)	
31.	Number of leaf pairs opposite	
32.	Leaf thickness (mm $\times 10^2$)	
33.	Oil gland density (per cm^2)	
34.	Ratio LL:MW	
35.	Ratio LM:LL	
36.	Ratio WB:MW	
37.	Ratio WA5:WA10	
38.	Ratio height to 3rd node:TH (*S*)	
39.	Ratio IL:ML	

S = scored only for the matrix based on seedling leaves at third node.

J = scored only for the matrix based on juvenile leaves at seventh or higher node.

groups that incorporated *E. nitida*, seedlings in the two Australian mainland groups had predominantly green linear to lanceolate leaves with extremely acute apices; secondary vein angles approached semi-longitudinal; oil gland density was high, especially in Group 2 from Wilsons Promontory and South Gippsland. Seedlings in the five island and Tasmanian mainland groups had more or less elliptical, green to blue-green leaves with correspondingly higher apex and secondary vein angles; oil gland density was relatively low to zero. Interestingly, the trend in oil gland density appears to be the reverse of that reported by Ladiges *et al.* (1981) for *E. ovata* and *E. brookerana*; that is, within *E. nitida sensu* Willis, values were higher at lower latitudes and low at higher latitudes.

Ordination of the group centroids together with links between nearest neighbours are shown in Fig. 5. The first three axes (vectors) accounted for 66.6% of the total variation. The relative positions of the group centroids again confirms the pattern of clear separation between Groups 1 and 2 incorporating seedlings from the Australian mainland, and Groups 3 to 7 incorporating all island and Tasmanian seedlings. As indicated by both the classification and the nearest neighbour linkages, Group 2, incorporating *E. nitida* from Wilsons Promontory and South Gippsland, is more similar to Group 14 incorporating *E. radiata* than it is to Group 1 incorporating *E. nitida* from the Grampians and South Australia. This is principally due to differences expressed on axis 3, notably in oil gland density. Axis 1 was correlated most strongly with a number of characters relating to leaf shape; axis 2 was correlated positively with internode length and negatively with total number of leaf pairs.

Comparison of the two analyses indicates that, at least on the basis of seedling morphology, Bass Strait island peppermint populations are phenetically most closely related to the Tasmanian species *E. nitida sensu stricto*. The patterns of variation in seedling morphology suggest that island and Tasmanian mainland populations are distinguishable from Australian mainland populations currently referred to *E. nitida*, principally on the basis of (1) leaf shape and presence or absence of verrucae on seedling leaf margins apparent in seedling 3 to 4 months old and (2) leaf shape and oil gland density apparent in juvenile leaves of seedlings 6 to 7 months old.

DISCUSSION

TAXONOMIC IMPLICATIONS

Since *E. nitida* is the only peppermint species considered to occur on both sides of Bass Strait at present, the disjunctive variation pattern within that species means that all Australian mainland peppermint populations can be distinguished from all Tasmanian and island populations, regardless of any taxonomic difficulties that may occur within those regions. The intermediate geographic position of Wilsons Promontory might reasonably lead to the expectation that its peppermint populations have some intermediate taxonomic status. However, results of the present study plus preliminary results of a study of adult morphology suggest that the resemblance with *E. radiata* is paramount.

The discontinuous pattern of variation within *E. nitida sensu* Willis suggests that consideration should be given to recognizing new taxa. In particular, it would appear that there are grounds for recognizing populations of peppermint occurring in western Victoria including the Grampians and in southeastern South Australia at the species level. As indicated by Pryor and

TABLE 5

SEEDLING LEAF ANALYSIS

MEANS AND FREQUENCIES (%) FOR THE SEVEN CHARACTERS THAT CONTRIBUTED MOST TO THE FIRST THREE DICHOTOMIES IN THE HIERARCHICAL CLASSIFICATION (a) AND IN THE TEN GROUPS INCORPORATING SEEDLINGS OF *E. Nitida sensu* WILLIS (b)

Group numbers and combinations are those indicated in Fig. 2. Numbers of seedlings are shown in brackets.

Characters	(a) Group Combinations		(b) Groups incorporating *E. nitida sensu* Willis									
			Vic., S.A. groups				*Bass Strait island, Tas. groups*					
1st dichotomy	1 + 2 + 3 + 4 + 10 + 11 + 12	5 + 6 + 7 + 8 + 9 + 13 + 14 + 15	1	2	3	4	5	6	7	8	9	10
	(39)	(57)	(6)	(7)	(6)	(8)	(21)	(5)	(5)	(8)	(6)	(6)
Seedling leaf apex angle (°)	60	85	65	73	52	53	83	84	96	84	77	67
Ratio seedling leaf length: maximum width	2.9	1.8	2.9	2.0	2.7	2.9	1.9	1.6	1.5	1.7	1.9	2.7
Verrucae on seedling leaf margin	28%	95%	0	0	17%*	12%*	100%	100%	100%	100%	100%	100%
2nd dichotomy	1 + 2 + 3 + 4 (27)	10 + 11 + 12 (12)										
Ratio seedling leaf length from base to widest:total length	0.25	0.48	0.37	0.26	0.18	0.18	0.34	0.29	0.28	0.30	0.25	0.45
Length 3rd internode (mm)	39.7	18.6	47.3	46.6	35.7	31.0	33.5	26.2	32.0	27.6	20.7	13.0
3rd dichotomy	5 + 6 + 7 + 8 + 9 + 13 (48)	14 + 15 (9)										
Stem glaucousness	0	100%	0	0	0	0	0	0	0	0	0	0
Seedling leaf colour—												
green	65%	0	100%	100%	100%	100%	71%	20%	80%	100%	0	0
blue-green	35%	33%	0	0	0	0	29%	80%	20%	0	100%	100%
glaucous	0	67%	0	0	0	0	0	0	0	0	0	0

* contributed by *E. radiata* only.

Johnson (1971), the name "*E. vitrea*" may not be available for these populations because the type specimen is believed to be of hybrid origin, the putative parental species being *E. radiata* and *E. pauciflora* (series *Obliquae*). It is nonetheless possible that *E. pauciflora* may have been involved in the evolution of what appears now to be a stable taxon (Boomsma 1972). Seedlings and coppice foliage from present-day populations in western Victoria and southeastern South Australia have certain ash-like characters, notably the tendency of juvenile leaves to be falcate and to be oriented in the vertical plane due to twisting of petioles.

SYSTEMATIC AFFINITIES

Blakely (1934) placed the nine species represented in this study in three subseries of peppermints based principally on juvenile leaf shape. *Augustifoliae* included *E. pulchella, E. elata, E. radiata, E. amygdalina* and *E. nitida; Latifoliae* included *E. nitida* (as *E. simmondsii*), *E. dives* and *E. coccifera*; and *Connatae* included *E. tenuiramis* and *E. risdonii*. The first two of these subseries incorporated species from both sides of Bass Strait. Pryor and Johnson (1971) fused Blakely's three subseries into one (*Amygdalininae*), but they recognized two superspecies. The first included *E. risdonii* and *E. tenuiramis* and corresponds to Blakely's subseries *Connatae*. These two species are morphologically similar in several important characters (such as having connate juvenile foliage), and moreover, in terms of geographic range, the distribution of the former is contained within the distribution of the latter. Their relative positions in the analyses reported here lend weight to the view that they are sufficiently closely related to justify grouping in a superspecies. The second superspecies recognized by Pryor and Johnson (1971) included *E. radiata, E. amygdalina* and *E. nitida*. None of the analyses reported here linked any of the three possible species pairs, let alone all three together in one group; that is, resemblances based on seedling morphology appear to be relatively weak or lacking. The justification for grouping these three species into a superspecies appears therefore to warrant further examination.

If Australian mainland populations currently referred to *E. nitida* are to be treated as taxonomically separate at the species level from Tasmanian and island populations, then all Tasmanian peppermints would be endemic (Table 2). This degree of endemism may prove

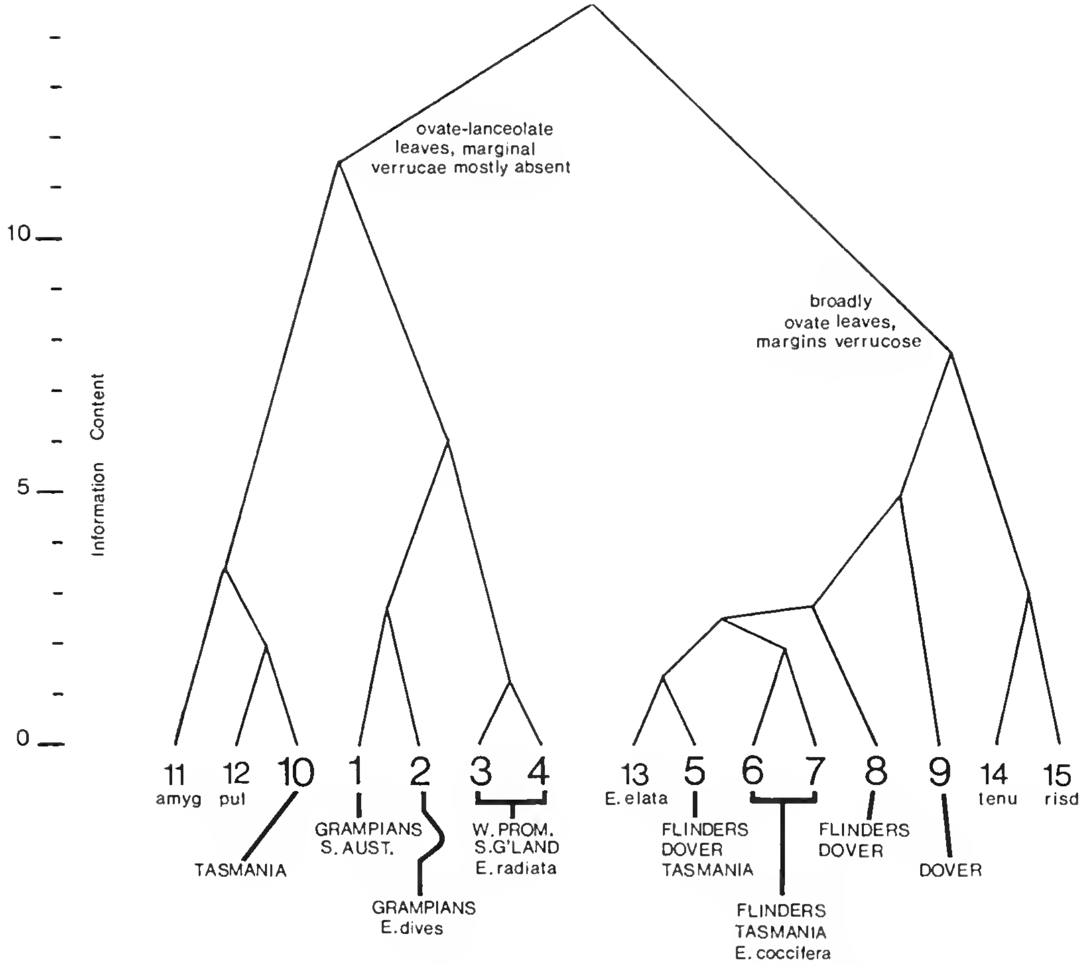


Fig. 2—Seedling leaf analysis. Hierarchical classification of 96 seedlings based on leaf morphology at the third node and truncated at the 15-group level. Groups 1-10 incorporate seedlings of *E. nitida sensu* Willis. Abbreviations: amyg = *E. amygdalina*, pul = *E. pulchella*, risd = *E. risdonii*, tenu = *E. tenuiramis*.

to be of systematic and phylogenetic significance. The present study placed considerable emphasis on continuously varying morphological characters relating particularly to leaf shape and such manifestations as apex angle and base shape. It is therefore not surprising that various combinations of these characters were important in the analyses and that the major dichotomies did not correspond to the major geographic disjunction that is Bass Strait. Juvenile leaf shape appears to be a plastic character likely to vary over a wide range of more or less related systematic groups within the genus. Its systematic and evolutionary significance is difficult to elucidate; there are, for instance, no broad-scale patterns sifting broad- and narrow-leaved species of *Eucalyptus* into particular climatic or edaphic zones (contrast leaf orientation). An alternative approach emphasizing discretely varying characters may indicate grounds for treating the Tasmanian peppermints as a distinct systematic group, possibly a subseries within a peppermint series.

EVOLUTIONARY SIGNIFICANCE

More than 50% of Tasmanian eucalypts are considered to be endemic (Table 2); this contrasts with only 8% of Victorian species. An explanatory hypothesis is required that will account for the present distribution of *E. nitida* and phenetically related species whilst recognizing the high degree of endemism among Tasmanian peppermints.

The islands of Bass Strait are considered to be remnants of a land bridge connecting the Australian mainland to Tasmania (Jennings 1971). During the Pleistocene, the land bridge formed with each period of glaciation and associated lowering of sea level. It is estimated that Tasmanian temperatures would have been about 5°C lower than at present, and the tree-line would have been as low as near present sea level on the west coast to 4-500 m above sea level on the east coast during periods of glaciation (Galloway 1965, Macphail 1979). Forests, woodlands, and scattered trees would

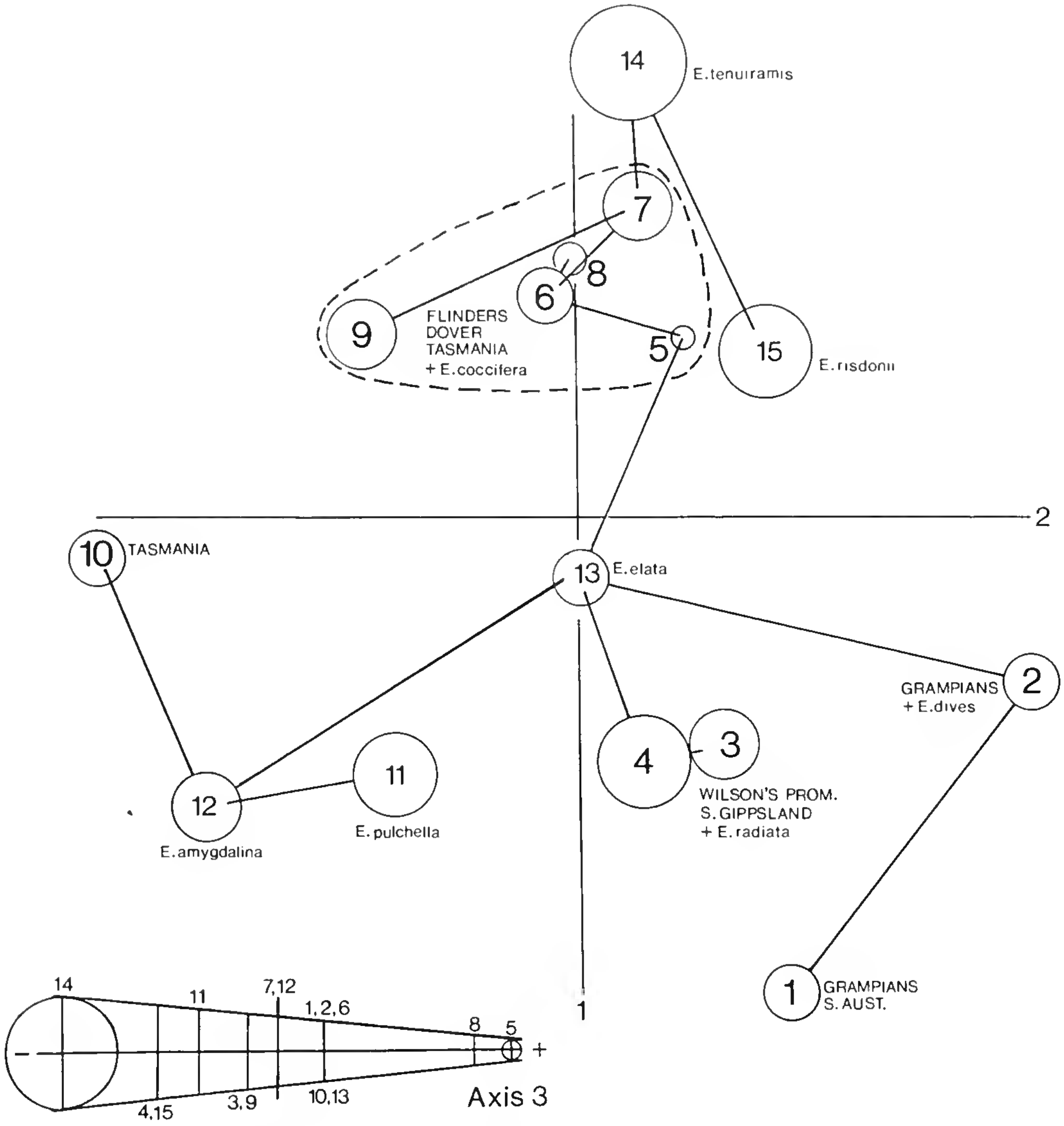


Fig. 3—Seedling leaf analysis. Ordination of group centroids and links between nearest neighbours. Groups as indicated in Fig. 2. Axis 3 is represented as the diameter of spheres (following Gillison 1978).

have been restricted to a coastal fringe, to the central midlands of Tasmania and to the land bridge (J. Hope 1973, G. Hope 1978, Macphail 1979). At the time of maximum glaciation during the late Pleistocene, open grassland communities with scattered eucalypts would have been widespread in southeastern Australia including the low-lying central part of the land bridge (Hope 1978). Outcropping granite hills that form the present islands of Bass Strait may have provided refuges for *Eucalyptus* forest communities as suggested by Ladd (1979) for the granite highlands of Wilsons Promontory. The most recent interruption of the land bridge to form Bass Strait probably occurred between 12 000 and 13 500 years ago (Jennings 1971, Hope 1973), initially separating Tasmania from the Australian mainland to the north of King and Flinders Islands and probably the Kent Group.

During interglacial periods when Bass Strait reformed, selection pressures may have resulted in divergence and speciation. During subsequent periods of glaciation, boundaries of Tasmanian eucalypt species probably shifted northward, mainly in response to climatic constraints. New habitats would have become available to lowland species as the islands increased in size and coalesced in sequence from south to north to form land corridors through both eastern and western ends of Bass Strait. As the land bridge formed, probably by connecting the eastern land corridor to Wilsons Pro-

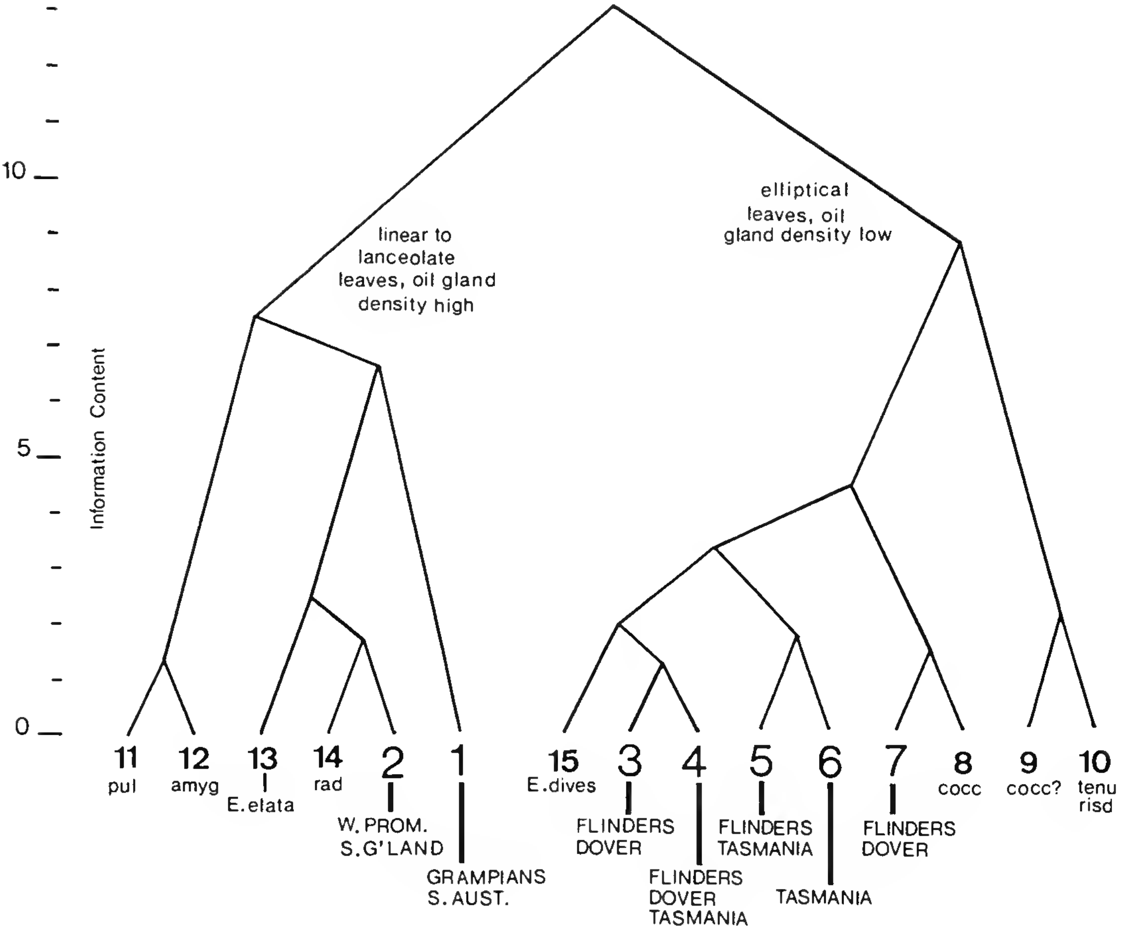


Fig. 4—Juvenile leaf analysis. Hierarchical classification of 85 seedlings based on leaf morphology at the seventh or higher node and truncated at the 15-group level. Groups 1-7 incorporate seedlings of *E. nitida sensu* Willis. Abbreviations: amyg = *E. amygdalina*, cocc = *E. coccifera*, pul = *E. pulchella*, rad = *E. radiata*, risd = *E. risdonii*, tenu = *E. tenuiramis*.

montory, northbound species occupying the land corridor may have met more widely tolerant southbound species capable of migrating against the climatic gradients into new habitats. Genetic isolation may or may not have been complete, depending on the degree of divergence that had occurred among related species (or populations) during the previous interglacial period of geographic isolation. The subsequent rise in sea level and loss of suitable habitats would, perforce, lead to the contraction of species boundaries both north and south, and may have left relatively few species able to survive on the islands of the Strait. But it may have lead to new opportunities for divergence and speciation, and geographic and phylogenetic origins may become obscured.

The distribution of *E. nitida sensu stricto* in Tasmania and on some islands of Bass Strait parallels that reported by Hope (1973) for many members of the vertebrate fauna. Following her interpretation, it is suggested that the extent of phenetic similarity between island and Tasmanian mainland populations of the species may be taken to indicate the degree of genetic isolation of that species at any time when it may have been in contact with related species migrating southward on the land bridge. If present island populations of *E. nitida* were to be intermediate between Tasmanian and Australian mainland species or populations, this would suggest that, during the last period of glaciation, populations originating from either side of the Strait and meeting on the land bridge were not reproductively isolated. We report here evidence that, at least with respect to seedling morphology, island populations are not only more similar to Tasmanian mainland populations than they are to any other population or species represented in this study, but also are not intermediate between Tasmanian and any Australian mainland populations currently referred to *E. nitida sensu* Willis. The extent of the disjunction implies at least a degree of genetic isolation, if not complete isolation. In so far as island populations differ from Tasmanian mainland populations, some divergence may have occurred since the sea-level rose isolating the present islands; alter-

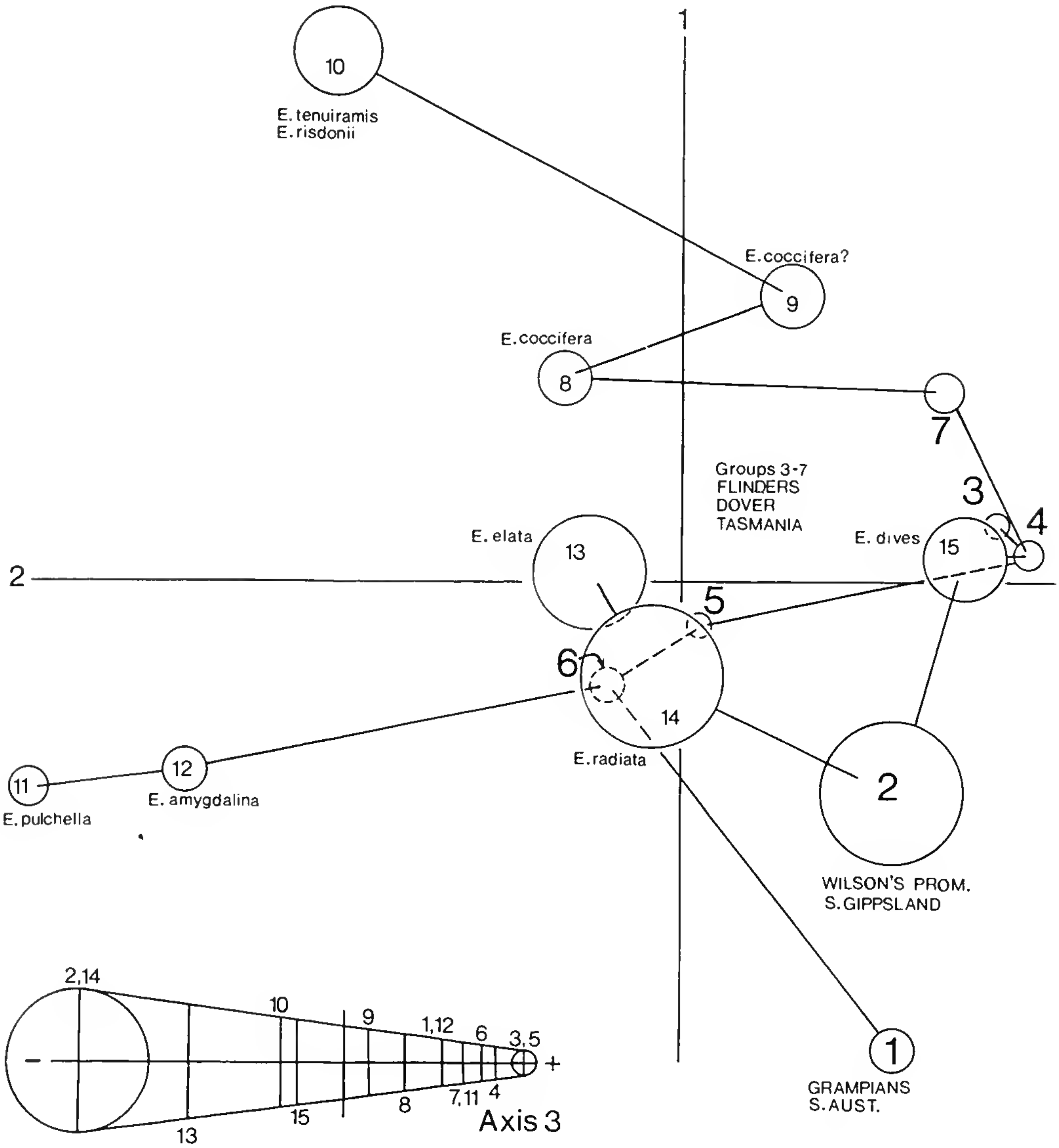


Fig. 5 — Juvenile leaf analysis. Ordination of group centroids, and links between nearest neighbours. Groups as indicated in Fig. 4. Axis 3 is represented as the diameter of spheres (following Gillison 1978).

natively, the rising sea may have disrupted a clinal sequence of variation, the island populations being at the northern end of a gradient. This study provides no way of choosing between these two options.

Australian mainland peppermint species and populations may have had various origins. Some may have originated from one or more ancestral species in response to directional selection pressures on the mainland. Others may have resulted from back-migration following radiation in Tasmania.

Further studies are in progress testing the hypotheses outlined above. These will involve sampling on a population basis, taking account of adult morphology and applying the methods of phylogenetic systematics and variance biogeography as described by Wiley (1980). In the lattermost context, it is of interest that *E. nitida* appears to be absent from the present native flora of King Island while the tall, well formed species, *E. brookerana*, has not been recorded on Flinders Island. This pattern parallels that described for some members of various vertebrate groups (summarized by Hope 1973) and has been attributed principally to higher rainfall on the western side of land bridges formed during the Pleistocene. In contrast, Tasmanian eucalypt species that occur on both islands are geographically widespread on the Australian mainland (*E. viminalis, E. globulus* and *E. ovata*), again resembling some vertebrate distribution patterns.

TABLE 6

JUVENILE LEAF ANALYSIS

MEANS AND FREQUENCIES (%) FOR THE SEVEN CHARACTERS CONTRIBUTING MOST TO THE FIRST THREE DICHOTOMIES IN THE HIERARCHICAL CLASSIFICATION (a) AND IN THE SEVEN GROUPS THAT INCORPORATED SEEDLINGS OF *E. nitida sensu* WILLIS (b) Group members and combinations are those indicated in Fig. 4. Numbers of seedlings are shown in brackets.

Characters	(a) Group Combinations		(b) Groups incorporating *E. nitida sensu* Willis						
			Vic., S.A. groups		*Bass Strait island, Tas. groups*				
1st dichotomy	1 + 2 + 11 + 12 + 13 + 14 (31)	3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 + 15 (54)	1 (8)	2 (8)	3 (14)	4 (9)	5 (7)	6 (2)	7 (4)
Secondary vein angle (°)	28	46	28	30	43	47	50	49	35
Apex angle (°)	26	64	28	25	53	58	72	54	42
Ratio juvenile leaf length: maximum width	7.3	2.6	6.0	6.0	3.0	3.0	2.2	3.4	5.0
Maximum juvenile leaf width (mm)	11.3	20.9	14.5	14.0	21.1	21.1	24.7	15.6	10.0
Oil gland density (per cm²)	505	88	279	1012	88	171	92	32	0
2nd dichotomy	3 + 4 + 5 + 6 + 7 + 8 + 15 (41)	(13)	9 + 10						
Juvenile leaf colour — yellow-green	15%	0	0	0	0	0	0	0	0
green	63%	8%	63%	100%	86%	89%	14%	0	100%
blue-green	22%	23%	37%	0	7%	11%	86%	100%	0
glaucous	0	69%	0	0	7%	0	0	0	0
3rd dichotomy	1 + 2 + 13 + 14	11 + 12							
Ratio juvenile leaf length from base to widest point over total length	0.22	0.55	0.36	0.17	0.26	0.33	0.38	0.44	0.26

ADCKNOWLEDGEMENTS

Most of the seed collections were obtained from CSIRO Division of Forest Research (courtesy M. I. H. Brooker), the Forests Commission of Victoria, M. A. Marginson, Melbourne, and A. M. Gray, Kingston, Tasmania. The interest of A. M. Gray in this project was a source of considerable stimulation. Advice, assistance and information from the following people is gratefully acknowledged: Drs D. H. Ashton, B. Gott, M. Harding, S. Murray-Smith, D. Ross; Messrs P. Barnett (King Island), G. M. Chippendale and J. Whinray (Flinders Island).

REFERENCES

BLACK, J. M., 1964. *Flora of South Australia.* Part 3. Govt. Printer, Adelaide.

BLAKE, S. T., 1953. Botanical contributions of the Northern Australia Regional Survey. 1. Studies on northern Australian species of *Eucalyptus. Aust. J. Bot.* 1: 185-352.

BLAKELY, W. F., 1934. *A Key to the Eucalypts.* 1st edition. The Worker Trustees, Sydney.

BLAKELY, W. F., 1965. *A Key to the Eucalypts.* 3rd edition. Forestry and Timber Bureau, Canberra.

BOOMSMA, C. D., 1972. *Native Trees of South Australia.* Woods and Forests Dept., Adelaide.

BOOMSMA, C. D. & LEWIS, N. B., 1980. *The Native Forest and Woodland Vegetation of South Australia.* Woods and Forests Dept., Adelaide.

BRETT, R. G., 1938. A survey of *Eucalyptus* species in Tasmania. *Pap. Proc. R. Soc. Tasm.* 1937: 75-109.

BROOKER, M. I. H., 1977. Internal bud morphology, seedling characters and classification in the ash group of eucalypts. *Aust. For. Res.* 7: 197-207.

BROOKER, M. I. H., 1979. A revision of the informal series *Foecundae* Pryor and Johnson of the genus *Eucalyptus* L'Herit. and notes on variation in the genus. *Brunonia* 2: 125-170.

CHIPPENDALE, G. M., 1973. *Eucalypts of the Western Australian Goldfields.* Aust. Govt. Publishing Service, Canberra.

CURTIS, W. M. & MORRIS, D. I., 1975. *The Student's Flora of Tasmania.* Part 1. 2nd edition. Govt. Printer, Hobart.

EWART, A. J., 1930. *Flora of Victoria.* Govt. Printer, Melbourne.

GALLOWAY, R. W., 1965. Late Quaternary climates in Australia. *J. Geol.* 73: 603-618.

GILLISON, A. N., 1978. Minimum spanning ordination — a graphic-analytic technique for three-dimensional ordination display. *Aust. J. Ecol.* 3: 233-238.

HALL, N., JOHNSTON, R. D. & CHIPPENDALE, G. W., 1970. *Forest Trees of Australia.* Aust. Govt. Publishing Service, Canberra.

HALL, N., JOHNSTON, R. D. & MARRYATT, R., 1963. *The Natural Occurrence of the Eucalypts.* Forestry and Timber Bureau Leaflet No. 65, Canberra.

HOPE, G. S., 1978. The Late Pleistocene and Holocene vegetational history of Hunter Island, north-western Tasmania. *Aust. J. Bot.* 26: 493-514.

Hope, J. H., 1973. Mammals of the Bass Strait islands. *Proc. R. Soc. Vict.* 85: 163-195.

Jackson, W. D., 1965. Vegetation. In *Atlas of Tasmania*, J. L. Davies, ed., Lands and Surveys Dept., Hobart, 30-35.

Jennings, J. N., 1971. Sea-level changes and land links. In *Aboriginal Man and Environment in Australia*, D. J. Mulvaney and J. Golson, eds, A.N.U. Press, Canberra, 1-13.

Johnson, L. A. S. & Blaxell, D. F., 1973. New taxa and combinations in *Eucalyptus*—II. *Contrib. N.S.W. Nat. Herb.* 4: 379-383.

Kirkpatrick, J. B., Massey, J. S. & Parsons, R. F., 1974. Natural history of Curtis Island, Bass Strait. 2. Soils and vegetation. With notes on Rodondo Island. *Pap. Proc. R. Soc. Tasm.* 107: 131-144.

Ladd, P. G., 1979. A Holocene vegetation record from the eastern side of Wilsons Promontory, Victoria. *New Phytol.* 82: 265-276.

Ladiges, P. Y., Gray, A. M. & Brooker, M. I. H., 1981. Patterns of geographic variation, based on seedling morphology, in *Eucalyptus ovata* Labill. and *E. brookerana* A. M. Gray and comparisons with some other *Eucalyptus* species. *Aust. J. Bot.* 29: 593-603.

Macphail, M. K., 1978. Vegetation and climate in southern Tasmania since the last glaciation. *Quat. Res.* 11: 306-341.

Maiden, J. H., 1922. *A Critical Revision of the Genus* Eucalyptus. Vol. 6, Part 6. Govt. Printer, Sydney.

Parsons, R. F., 1966. The soils and vegetation at Tidal River, Wilson's Promontory. *Proc. R. Soc. Vict.* 79: 319-354.

Parsons, R. F., Kirkpatrick, J. B. & Carr, G. W., 1977. Native vegetation of the Otway Region, Victoria. *Proc. R. Soc. Vict.* 89: 77-88.

Parsons, R. F., Scarlett, N. H. & Rosengren, N. J., 1972. Ecology of some *Eucalyptus* woodlands near Hall's Gap, Victoria. *Victorian Nat.* 89: 41-49.

Pryor, L. D. & Johnson, L. A. S., 1971. *A Classification of the Eucalypts.* A.N.U. Press, Canberra.

Wilcox, M. D., 1979. The peppermint group of eucalypts. *N.Z.J. Forestry Sci.* 9: 262-266.

Wiley, E. O., 1980. Phylogenetic systematics and vicariance biogeography. *Syst. Bot.* 5: 194-220.

Williams, W. T. (ed.), 1976. *Pattern Analysis in Agricultural Science.* C.S.I.R.O., Melbourne.

Willis, J. H., 1967. Systematic notes on the indigenous Australian flora. *Muelleria.* 1: 117-163.

Willis, J. H., 1970. The shining peppermint (*Eucalyptus nitida*). *Victorian Foresters' Newsletter.* 26: 4-5.

Willis, J. H., 1972. *A Handbook to Plants in Victoria.* Vol. 2. Melbourne University Press, Melbourne.

PROCEEDINGS

OF THE

ROYAL SOCIETY OF VICTORIA

Volume 94

NUMBER 4

ROYAL SOCIETY'S HALL
9 VICTORIA STREET, MELBOURNE 3000

CONTENTS OF VOLUME 94 NUMBER 4

PROC. R. SOC. VICT. vol. 94, no. 4, 169-172, September 1982

UPOGEBIA NIUGINI (CRUSTACEA) A NEW SHRIMP FROM PAPUA NEW GUINEA

By Gary C. B. Poore

National Museum of Victoria, 285-321 Russell Street, Melbourne, Victoria 3000

Abstract: *Upogebia niugini* sp. nov. is the fourth species of *Upogebia* from the seas north of Australia possessing ventral rostral spines. Its affinities with other species are discussed.

A small collection of Crustacea from Port Moresby, housed in the National Museum of Victoria (NMVJ), contains specimens of the thalassinidean shrimp genus *Upogebia*. Although closely related to known species these distinctive specimens demand description as a new species. The higher systematics and diagnosis of the genus, with particular reference to Australia, have been given by Poore & Griffin (1979).

Tribe Thalassinidea

Family Upogebiidae

Upogebia niugini sp. nov.

Figs 1, 2

Description of Holotype: *Carapace*

Anterior region of carapace about one-third longer than posterior region. Cervical groove well defined dorsally, not visible laterally; an alternative suture running diagonally anterior to groove. Linea thalassinica extending whole length of carapace.

Rostrum widest about one-third way along, 1.3 times as long as wide. Ventral surface with three spiniform teeth, all reaching as far forward as tip of rostrum. Dorsal surface with four irregular longitudinal rows of denticles extending onto anterior half of gastric region. Lateral margin of rostrum with eight teeth.

Gastric region 1.3 times as wide as rostrum and separated from it by broad lateral grooves; lateral crest with 11 (right) and 12 (left) tubercles. Majority of gastric region and rostrum with dense cover of plumose setae dorsally.

Anterolateral margin with five denticles; lateral region posterior to this with four minute denticles. Line of cervical groove defined laterally only by seven denticles.

Antennule and antenna

Antennule: first article with one or two distoventral spines, flagellum shorter than peduncle. Antenna: first article with one distoventral spine; second article with three small proximal dorsal spines and three distal ventral spines; third article with three ventral spines; scaphocerite a small bifid scale.

Mouthparts

Mandible with a prominent proximal tooth on denticulate mesial margin. Maxillae, first and second maxillipeds typical of genus. Third maxilliped with 2-articled exopod; coxa with an epipod and two mesial hooked spines; ischium with only feeble mesial spine row and one spine laterally.

Pereopods

Pereopod 1 subchelate. Coxa with one mesial denticle. Ischium with one minute ventral denticle. Merus 2.5 times as long as wide, with 12 ventral short spines and with one dorsal spine distally. Carpus with about 13 curved spines scattered over dorsal edge, one on ventral margin; distal mesial margin bearing two spines, one prominent. Propodus 2.3 times as long as wide, with irregular longitudinal rows of strong curved spines: 13 along anterior margin, 7-8 in each of three rows along mesial surface and three along the posterior margin leading to the fixed finger; its lateral surface with few denticles near posterior margin. Fixed finger a short, broadly based, spur. Dactyl 0.75 times as long as propodus, anterior margin denticulate.

Pereopod 2 coxa with mesial denticles; ischium with minute denticles posteriorly, one distal spine anteriorly; carpus with one posterior and four anterior spines.

Pereopod 3 coxa with mesial spines; ischium with seven denticles posteriorly; carpus with one posterior and one anterior spine.

Pereopod 4 unarmed, similar in form to pereopod 3.

Pereopod 5 subchelate, dactyl about 3 times as long as fixed finger.

Tailfan

Uropods longer than telson; exopod oval, 1.7 times as long as wide; endopod triangular, widest in proximal half.

Telson 1.2 times as wide as long, posterior margin concave; dorsally two broad transverse carinae in proximal half.

Holotype: Female (with left pereopods 1-4, right pereopods 3, 5), c.l. 9.1 mm (NMV J1653).

Type Locality: Papua New Guinea, Port Moresby, 80 m off eastern side of Esade Reef, shelly-muddy sediment, 15 m, coll. J. E. Watson and J. Carey using SCUBA, 28 July 1981.

Paratypes: Male (without pereopods), c.l. 6.9 mm; female (with left pereopod 5 only), c.l. 8.1 mm, both from type locality (NMV J1654).


b
a
d
e
f
g
i
j
k
c
h
e–h, k
a–d, j

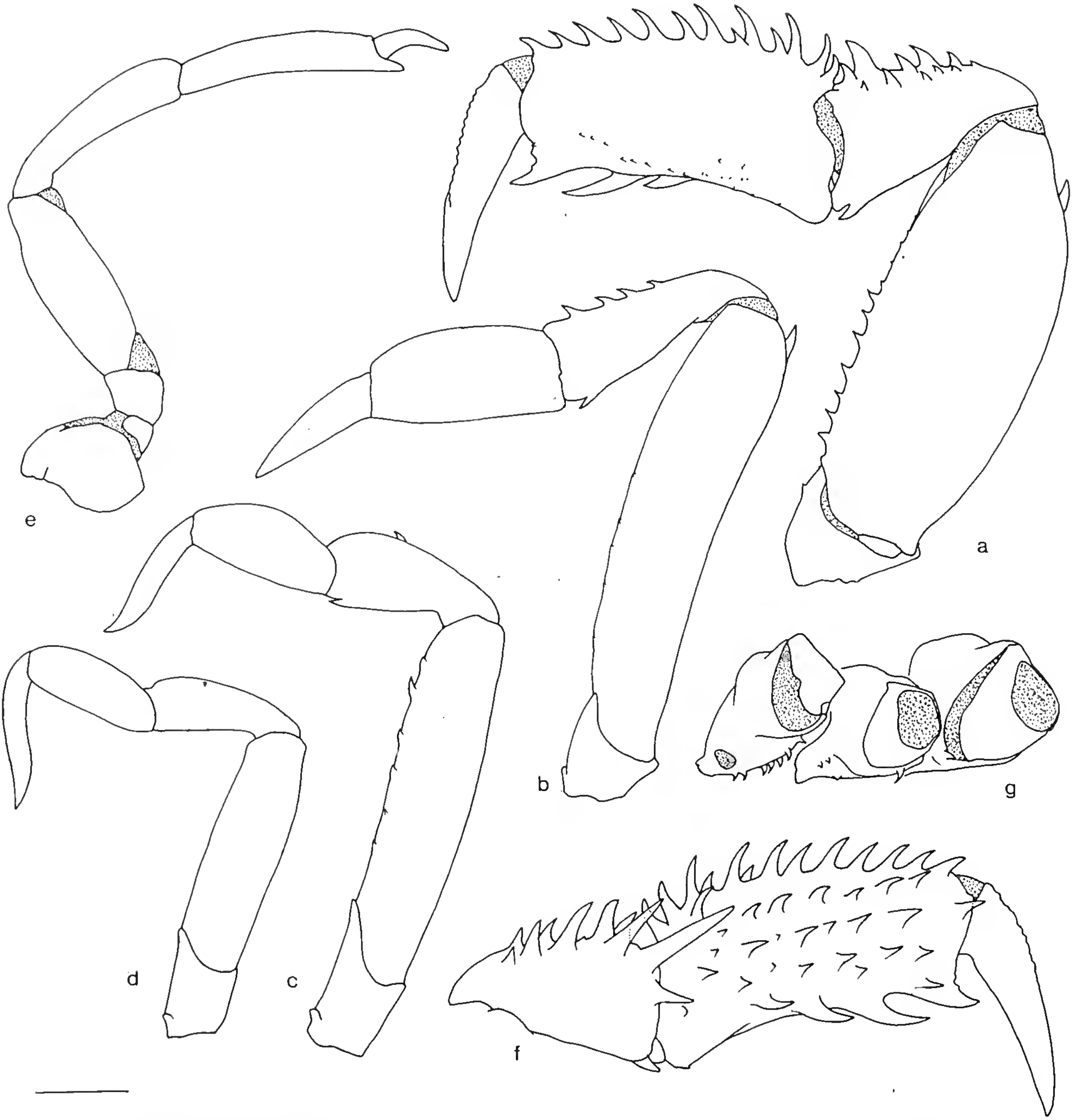


Fig. 2—*Upogebia niugini* sp. nov., holotype. *a-e*, pereopods 1-5, lateral views; *f*, pereopod 1, mesial view; *g*, coxae 1-3, ventral view of right side in situ. (Pereopods 1-4 are from left side, pereopod 5 from right side, all figures without setae.) Scale = 1 mm.

Fig. 1—*Upogebia niugini* sp. nov., holotype. *a*, *b*, lateral and dorsal views of anterior region of carapace; *c*, telson and uropod; *d*, antennules; *e*, mandible; *f*, *g*, maxillae 1, 2; *h-j*, maxillipeds 1-3; *k*, lateral view of base of ischium of maxilliped 3. (Figures are without setae, mouthparts and antennules are from left side.) Scale = 1 mm.

VARIATION: The ventral rostral spines of all three specimens are uniform. The dorsal spines of the female paratype are in only two, longitudinal rows, that are, especially on the rostrum, more regular than in the holotype.

ETYMOLOGY: The specific epithet *niugini* is from the Pidgin language and is sometimes used to refer to the nation of Papua New Guinea.

REMARKS: *Upogebia niugini* belongs to the group of Indopacific species possessing ventral rostral spines: *U. acanthochela* Sakai, *U. acutispina* de Saint Laurent & Ngoc-Ho, *U. ceratophora* De Man, and *U. monoceros* De Man. *Upogebia talismani* Bouvier, from the warm temperate and tropical Atlantic, also belongs to this group, first separated from other species of *Upogebia* by De Man (1928) in his key. De Saint Laurent & Ngoc-Ho (1979) defined the group more closely with additional characters:

- rostrum with one or several ventral spines;
- anterolateral margin of the carapace armed with a series of spinules;
- posterior margin of the telson more or less concave;
- mandible without a sharp anterior tooth;
- fixed finger of pereopod 1 reduced to a strong spiniform projection; mesial face of the propodus armed with one or several rows of spines;
- coxae of the pereopods with fine mesial spinules;
- branchial filaments simple.

Upogebia niugini is most closely related to *U. acutispina* from northwestern Australia, many features of the spination of the pereopods being virtually indistinguishable. However, the three ventral rostral spines are shorter in *U. niugini*, the telson relatively broader, and the rostrum narrower than in *U. acutispina*. *Upogebia monoceros* from Java and *U. ceratophora* from eastern Indonesia (De Man 1928, de Saint Laurent & Ngoc-Ho 1979) possess only one ventral rostral spine; *U. acanthochela* from the Yellow Sea has two (Sakai 1967).

The number of morphologically similar species in this group, revealed by a relatively small amount of sampling, suggests a high rate of species radiation in *Upogebia* in the seas around the Indonesian archipelago.

Another Indopacific species, *Upogebia spinifrons* (Haswell) from northeastern Australia also possesses ventral rostral spines but differs from the group defined by de Saint Laurent & Ngoc-Ho (1979) in several respects. Dorsal spines on the rostrum and gastric region are absent or obsolete, the posterior margin of the telson is not concave, the fixed finger of pereopod 1 is substantial and toothed, and the mesial face of the propodus of pereopod 1 is without spine rows (Poore & Griffin 1979).

ACKNOWLEDGEMENTS

I am indebted to Jan Watson, Melbourne, for making this material available for study, to Michele de Saint Laurent, Paris, for helpful comments on the manuscript, and to Ron Vanderval, Melbourne, for advice on the etymology of the specific name.

REFERENCES

MAN, J. G. DE, 1928. The decapoda of the Siboga-Expedition. Part VII. The Thalassinidae and Callianassidae collected by the Siboga-Expedition, with some remarks on the Laomediidae. *Siboga-Exped.* 39a (6): 1-187.

POORE, G. C. B., & GRIFFIN, D. J. G., 1979. The Thalassinidea (Crustacea: Decapoda) of Australia. *Rec. Aust. Mus.* 32: 217-321.

SAINT LAURENT, M. DE, & NGOC-HO, N., 1979. Description de deux espèces nouvelles du genre *Upogebia* Leach, 1814 (Decapoda, Upogebiidae). *Crustaceana* 37: 57-70.

SAKAI, K., 1967. Three new species of Thalassinidea (Decapoda, Crustacea) from Japan. *Rec. Crust. Japan* 3: 39-51.

PROC. R. SOC. VICT. vol. 94, no. 4, 173-181, December 1982

THE GEOLOGY OF CAPE EVERARD, VICTORIA

By Margaret C. Fry and C. J. L. Wilson

Department of Geology, University of Melbourne, Parkville, Victoria 3052

Abstract: The Ordovician sediments of Cape Everard constitute a sequence of sandstones, greywackes and siltstones interbedded with minor black shales. Four lithofacies are recognized and are interpreted as proximal turbidites, thought to be deposited by turbidity currents. The association of lithofacies suggests that sedimentation occurred on and around the upper mid-fan region of a submarine fan system. Palaeocurrent indicators suggest turbidity current transport in a northerly direction. The strata are folded into tight folds and have undergone low grade regional metamorphism, with little disruption of the original sedimentary texture. These sediments are intruded by granite with insignificant contact metamorphic effects and are overlain by a possibly Miocene calcarenite.

Cape Everard, which includes Point Hicks, is a granite headland 40 km southeast of Cann River township in East Gippsland (Fig. 1). Exposure is limited to shore platforms and cliffs as most of the Cape and adjacent areas are covered by a complex of Holocene transgressive dunes superimposed on older (Pleistocene) sand ridges (Rosengren 1978). The granite is considered by Douglas (1974) to be a small outlier of the Early Devonian Bega Batholith (396 ± 16 Ma, K/Ar; Richards & Singleton 1981) and intrudes folded Ordovician sedimentary rocks. Unconformably overlying the granite are restricted calcarenite deposits and the granite is intruded by three olivine bearing basaltic dykes (1 m wide).

The best exposures of the Ordovician are found on the shore between the mouths of the Thurra and Mueller Rivers, in areas 1 and 2 (Fig. 1). Here a 200 m thick succession of turbidites crops out and is comprised of three main lithologies namely: coarse sandstone, siltstone and shale. Minor chert (≤ 2 m thick) has been found with comparable rocks in the Thurra River. All these rocks bear the weak imprint of lower greenschist facies regional metamorphism and have near vertical dips (Fig. 2) and one generation of upright isoclinal folds which plunge 15° towards 356°. Faults with unknown displacements parallel the N-S trending bedding and are only recognised by comparison of sedimentary cross-sections; these are considered to be bedding plane thrusts and are similar to those described by Wilson *et al.* (1982). Other vertical faults, often accompanied by quartz veins, trend to the northwest (Fig. 2). They appear to be later features and are accompanied by minor crenulation cleavage.

These Ordovician sediments are similar to the Mallacoota Beds described by Fenton *et al.* (1982), which are of Late Ordovician age on the basis of graptolites found at Seal Creek (P. de Hedouville, unpublished data, April 1982). A conodont fauna (I. Stewart *in* Webby *et al.* 1981, p. 30) obtained from a silicified shale unit in a road cutting on the north side of the Thurra River bridge at Cape Everard, also suggests a Late Ordovician age. The sediments at Cape Everard are coarser grained and not as well-laminated as the Mallacoota succession. It is therefore the primary purpose of this paper to describe the sediments and determine the environment of deposition and compare it with the Mallacoota sequence. At the same time, the other rock types recognised in the area will be briefly described. Data were collected following the methods used in Fenton *et al.* (1982) and Wilson *et al.* (1982) and further details may be found in Fry (1981).

ORDOVICIAN SEDIMENT PETROGRAPHY

The sequence is characterised by thick-bedded and coarse-grained deposits that are comparable to those described by Walker and Mutti (1973). The turbidites show numerous sedimentary structures and different combinations of the divisions of Bouma (1962). Measured sections illustrating the sedimentary features in areas 1 and 2 are shown in Fig. 3. Sections 9A and 9B are situated on adjacent limbs of a fold. Younging evidence in Sections 14 and 15 suggests that a fold lies between them, but the lithology, thickness and sedimentary structures do not correlate. This is interpreted as being due to a bedding-plane thrust sub-parallel to the axial-surface of a tight-fold.

Three main lithologies are distinguished in the rocks at Cape Everard.

Sandstone and greywackes are mainly clast-supported with clay matrix contents of <5 to 20%. Greywackes (with more than 10% matrix) only comprise about 25% of this lithology. Quartz with undulose extinction comprises 95-100% of the framework grains, whereas metamorphic quartz displaying re-crystallization is restricted to coarse sandstone and "coarse clasts". Grains are subangular to rounded (Fig. 4) and size (<1 mm-4.0 mm) varies within individual beds and between beds. Plagioclase is present as rare grains. The matrix is composed of muscovite (<2 mm), partly recrystallized and deformed during the regional metamorphism. The accessory minerals are hornblende, zircon, tourmaline and iron oxide. Intraclasts of shale and mud are common.

Bodies interpreted as concretionary features, postdate sedimentation but predate deformation and are comparable to similar features that are folded and metamorphosed in other areas in East Gippsland (e.g. Eaton 1980). They occur at different intervals within some coarse sandstone beds as zones up to 8 cm thick that show slight colour variation and sometimes have the appearance of distinct units. These coarse layers lack

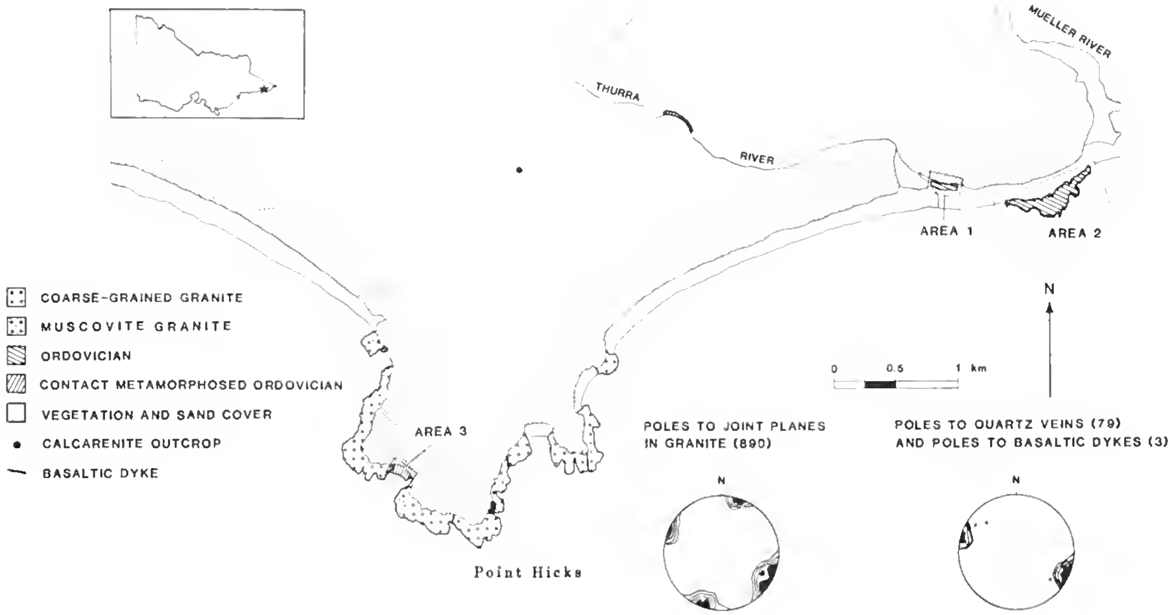


FIG. 1—Map of Cape Everard area showing location of major rock types and areas 1, 2, and 3 detailed in Fig. 2. The contoured data are poles to joints and quartz veins in the granitoid rocks, and contours are ≥1% per 1% area, ≥5% per 1% area, ≥10% per 1% area and ≥20% per 1% area.

clear fining-upwards grading and are discontinuous along their length (1-4 m) with rounded terminations. There are no obvious compositional differences in the clastic sand-grain content between these layers and the adjacent sandstones, but the matrix of these bodies may contain a trace of calcite.

Siltstones are matrix supported (>35%) with quartz (<1 mm) and rare altered plagioclase. The matrix is composed of recrystallized muscovite and chlorite. Accessory minerals are the same as in the sandstones.

Shales are a minor component of the sediments at Cape Everard. They are grey to black and are similar to those described by Fenton *et al.* (1982). They are composed of quartz, muscovite and chlorite.

ORDOVICIAN SEDIMENT LITHOFACIES

Four major lithofacies crop out along the coast and are summarized below.

Massive sandstones

These are composed of coarse sands that fall within the A division of Bouma (1962) and comprise 13% of all beds. Individual sheets range from 1-100 cm thick with a median thickness of 40 cm, and are generally not laterally persistent for more than a few tens of metres of outcrop, with marked pinch and swell. Grading, when present, is usually confined to the top of the A division and may be the only internal sedimentary structure. The base may be either erosional or sharp (Fig. 5A) with rare flame structures (Fig. 5B). Amalgamation of the graded beds has resulted in apparently massive sand sequences more than 10 m thick, such as Sections 5, 6, and 7 (Fig. 3). Other sands occur as coarse-grained lens-like bodies (<15×60 cm) that may show discontinuous coarse sandy layers up to 10 cm thick at the base.

Proximal turbidites

These comprise 57% of all beds and are composed of the AB, ABE and AE divisions of Bouma (1962). They consist predominantly of graded sandstone and siltstone, 5-35 cm thick (e.g. Sections 8, 9 and 10). Many fine sandstones and silt units have ripple cross-bedding or are slumped in the middle parts of thicker sand bodies (Fig. 5C and Sections 9B, 12, 13 in Fig. 3). There is also gradation between the two sets of structures. Coarse clasts (Fig. 5D) with lengths up to 12 cm, distributed in irregular fashion (in A division) or aligned with bedding (in B division) are particularly noticeable in Sections 4, 5 and 6 (Fig. 3).

Clasts of shale that range in length from 0.5-30 cm also occur in the A and B divisions of the more sandy units (see Sections 1 and 2 in Fig. 3). They appear to be rip-up clasts and occur in beds with an abundance of coarse sandstone clasts, suggesting an erosional history.

Distal turbidites

Where the lowest division of a bed is B, combinations of the Bouma sequences such as BCDE, BCE, CE and DE comprise 18% of all beds. They range in bed thickness from 1 to 100 cm with a median of 16 cm and have most of the features described by Fenton *et al.* (1982). Also common in the C division of these sediments is the occurrence of both coarse-grained clasts and shale clasts (Fig. 5E). The clasts are finer and smaller than those observed in the proximal turbidites and reveal internal folding and are enclosed in a bed that displays complete irregularity, except where micaceous

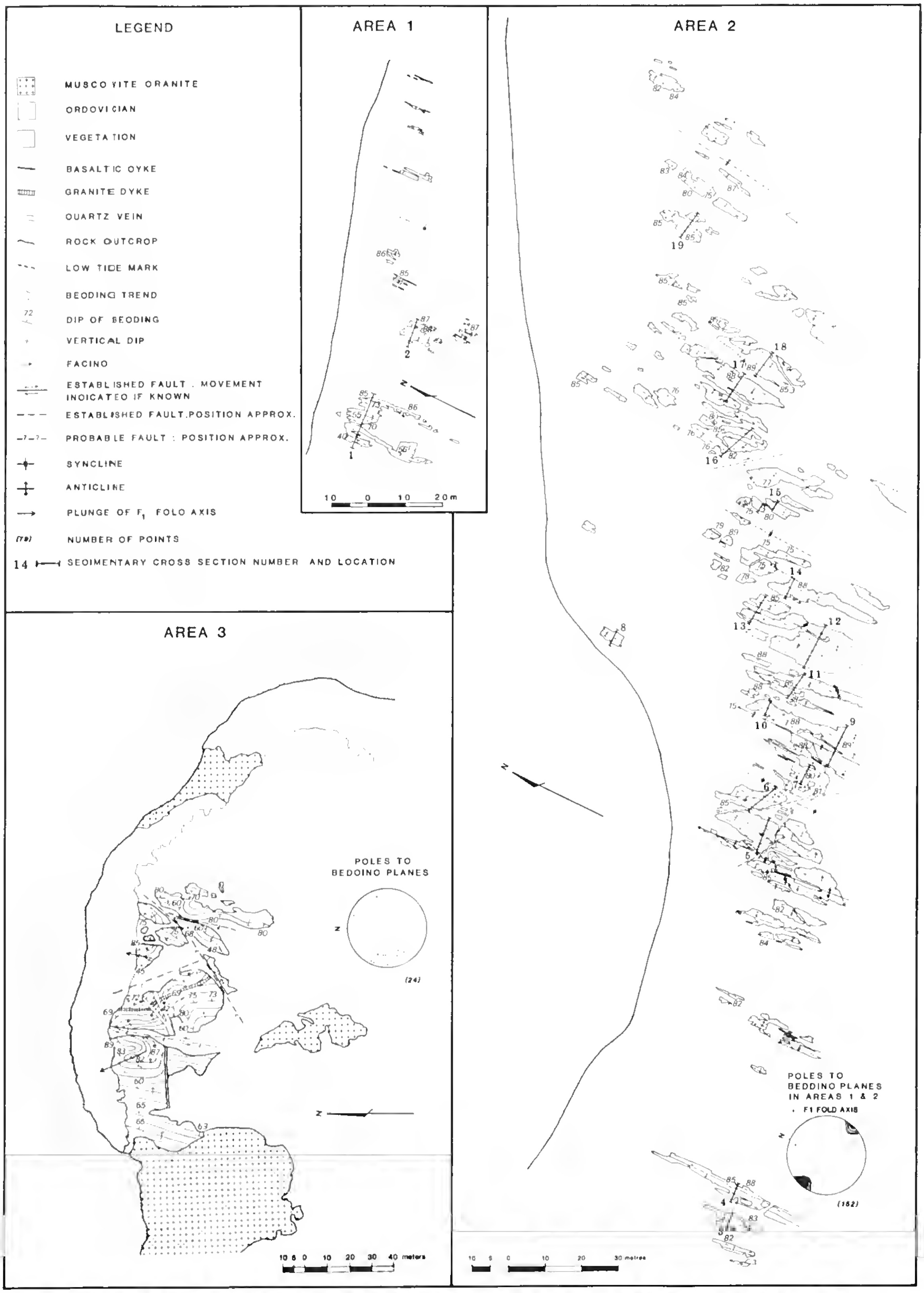


FIG. 2—Geological maps of areas 1, 2 and 3 (of Fig. 1) showing trends in bedding and location of sedimentological sections. Stereographic projections, on the lower hemisphere of an equal area net show the orientation of poles to bedding planes, contours are the same as Fig. 1.

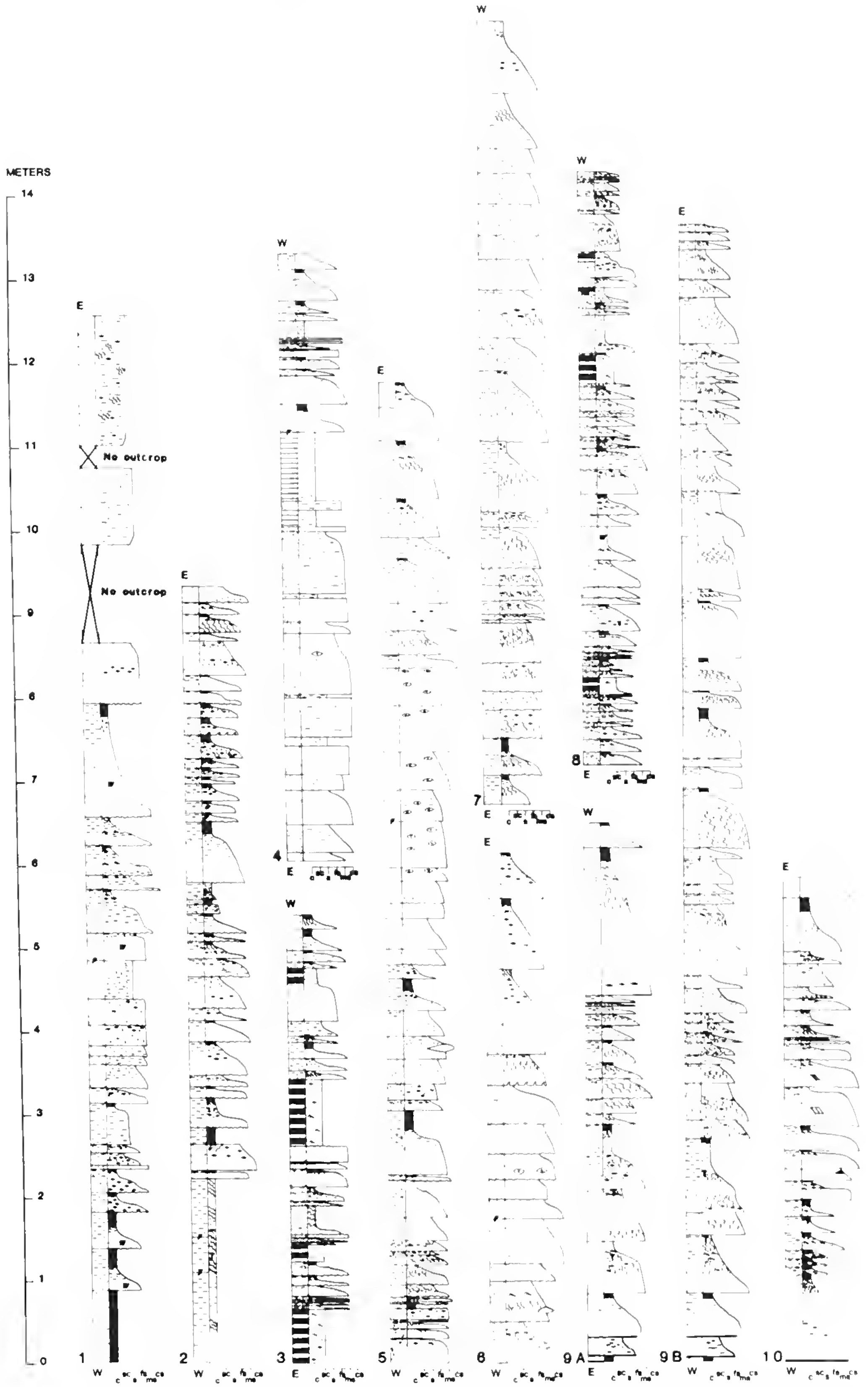


FIG. 3 — Measured sections of the Cape Everard Ordovician sequence in areas 1 and 2. Locations of the sections are shown in Fig. 2.

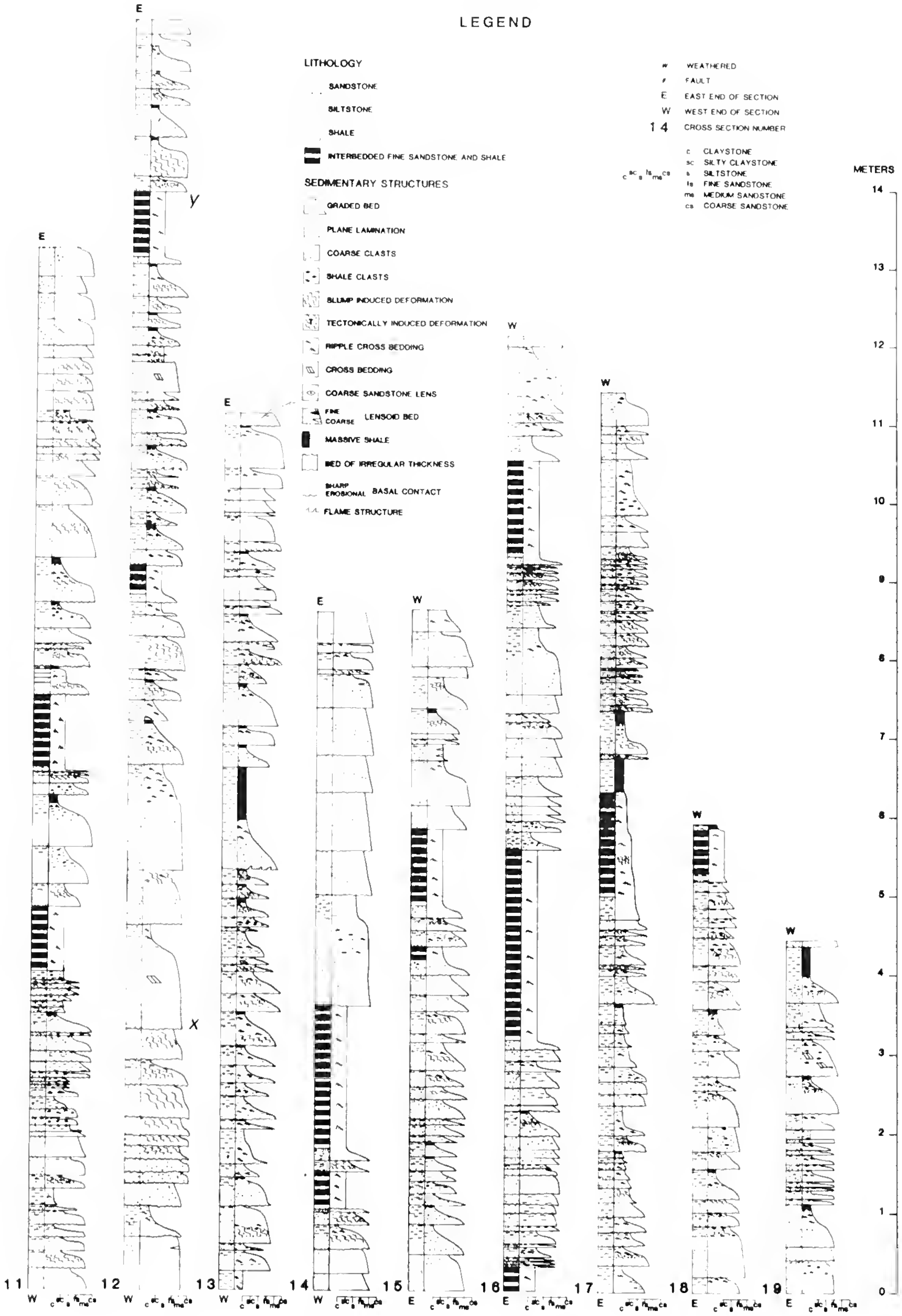


FIG. 3 (*continued*)

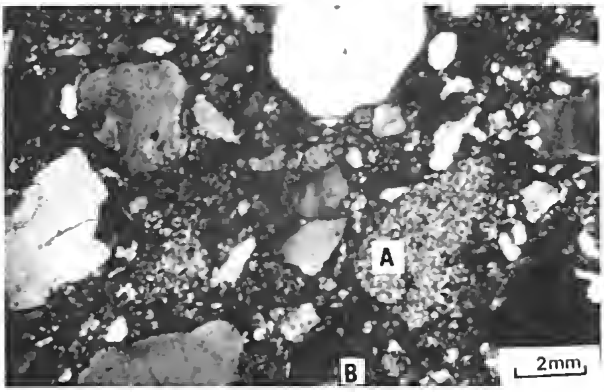


FIG. 4—Photomicrograph illustrating coarse sandstone texture in Melbourne University Geology Department sample R27859. A recrystallised quartz grain is seen at A and a rare feldspar grain at B.

minerals and shale clasts are folded around the coarse sand clasts (Fig. 6). It is suggested that some C division clasts are remnant bedding clasts disrupted by slumping whereas the others, particularly the smaller ones, may represent shale introduced with the sediment load.

Thin sandstone beds interbedded with shale

These units make up 11% of all beds and occur as sequences between 0.8-2 m thick. The presence of cross bedding and ripple cross bedding in the fine sandstones indicates a Bouma C division with the seemingly massive overlying shale characteristic of E division. The abrupt change (Fig. 5F) between the two divisions could be interpreted as showing a change to pelagic deposition and the E division would be expected to show no internal grading or sedimentary features. It is on this basis that Fenton *et al.* (1982) suggested the fine sandstones were reworked by intermittent bottom currents, with subsequent slow deposition of a pelagite layer. However, close examination revealed overall grading and ripple cross bedding within each unit, suggesting that the beds are fine-grained tail deposits of individual turbidite events.

ENVIRONMENT OF DEPOSITION

In the Ordovician sediments of Cape Everard there is a preponderance of coarse sandstones which represent beds deposited in a high flow regime. Sand deposition was interrupted now and then by accumulations of silt and mud (under normal deep marine conditions) which form intercalations of siltstone and shale in a sequence composed predominantly of sand. These changes could be accounted for in terms of modern facies interpretation (Walker 1978) as deposits near or within a rapidly changing suprafan region.

Repetition of massive and graded sandstones (Sections 4, 5 and 6) with large lenses of coarse material (e.g. Section 12) suggests channel fill or overbank deposits in the upper or mid-fan region (Walker 1978). Coarse sand and shale clasts in the Bouma A and B divisions also suggest rapid erosion with short transport distance. Such an origin also explains some of the clasts recognised in C division whereas others may be remnants in slump beds. Fining upward sequences are restricted but are seen in Sections 12 (between X and Y), 18 and 19. These are repeating beds of diminishing size which Walker and Mutti (1973) interpret as a sequence formed in a prograding sumbarine fan. However, we favour the interpretation of Fenton *et al.* (1982) that at Cape Everard and Mallacoota these sequences are part of a channelled suprafan deposit and indicate proximity to the channel. The interbedded siltstones and shale with graded CE Bouma divisions suggest that these are fine tail deposits of individual turbidite events rather than regular reworking of the sands by intermittent bottom currents as proposed by Fenton *et al.* (1982) for similar rocks at Mallacoota. Similarly as these interbedded siltstones and shales are generally grouped together (e.g. Sections 3, 11, 12 and 14 to 18) as packets of distal turbidites, they may be interpreted as deposits derived from more than one channel (M. W. Fenton pers. comm.).

The initial dips of C-division cross-bed lamellae range from 15° to 25° and have been used as indicators of directions of sediment transport. They show a northerly current direction (Fig. 7) which is in agreement with measurements on similar rocks by Fenton *et al.* (1982) and Cas *et al.* (1980). The use of underlying scour or tool-marked surfaces was not possible as all exposed surfaces were essentially two-dimensional.

There is good correlation of individual graded beds near the fold hinge in Sections 9A and 9B, but as distance from the hinge increases the correlation decreases. This lateral change would be a response to the changing environment induced by the flow and position within the channelled suprafan region.

Two isolated contact metamorphosed cherts crop out in the Thurra River but their relation to the sedimentary sequence described here is unclear. Such cherts may be deposited in regions free of turbidity flow due either to topographic highs (channel levees) or to channel movement away from the area (Fenton *et al.* 1982). This lends support to the idea that the Cape Everard sequence is part of an extensive deposit formed on a rapidly changing channelled suprafan.

A lower mid-fan depositional environment has been favoured by Fenton *et al.* (1982) for the Mallacoota Beds at Mallacoota. However at Cape Everard there is strong evidence for channelled lithofacies that suggests an upper mid-fan. Distal outer fan and basin plain associations and proximal inner fan, slope and shelf associations are absent. A possible explanation for this is that the Ordovician in this part of Victoria was not a sedimentary wedge built off a prograding continental margin, instead it was a deeper water, channelled suprafan deposit (Walker & Mutti 1973). The detritus would be in part supplied from older fan sediments that were made available for redeposition by contemporaneous tectonism or sedimentary subsidence. Such an interpretation would explain the occurrence of sandstone and shale clasts within the coarse sandstone units. The intralayer slumps in the finer sandy units apparently

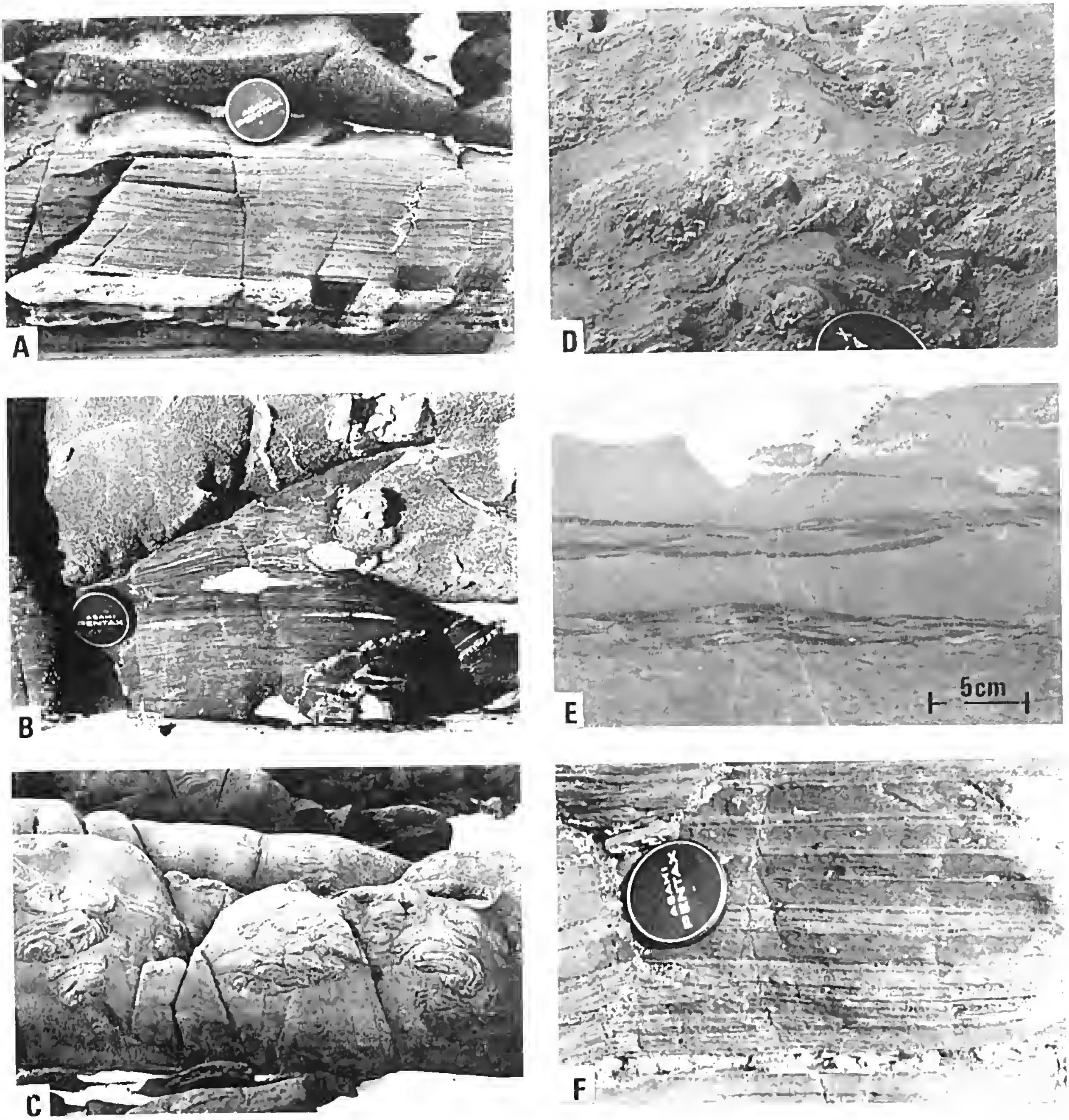


FIG. 5 – A, coarse sandstone lens with sharp base and without grading, resting on a thin E division shale and C division in section 5. B, flame structure in a coarse A division in a massive sandstone in section 13. C, slumped sandstone-siltstone unit in section 13. D, irregular coarse clasts in an A division in Section 5. The clasts are grain supported with grain sizes greater than the surrounding sand. E, shale clasts composed of clay and phyllosilicate plates in a C division in section 18. F, intercalation of shale and siltstone in section 16.

indicate minor slope failure or may have resulted from impact of large gravity flows that crevassed the graded sandstone-siltstone facies. The source-rocks for the sequence are probably, as previously proposed (Fenton *et al.* 1982), the Cambrian and Precambrian sediments of the Ross Orogen of eastern Antarctica (Tessensohn *et al.* 1981).

METAMORPHOSED ORDOVICIAN

Limited outcrops of contact metamorphosed sediments can be seen in the Thurra River and as pods isolated by the granites, for example in area 3 (Fig. 2). They are sandy units that have been transformed to quartzites with large recrystallized muscovite. Minor shale intercalations contain spots of chlorite, muscovite,

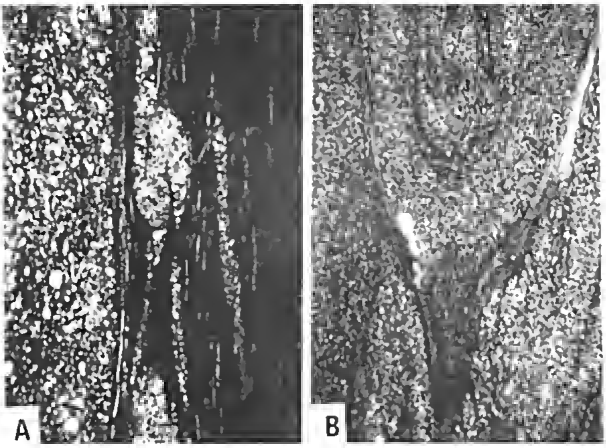


Fig. 6—Photomicrographs illustrating structures associated with sandstone and shale clasts (a) slump between siltstone and shale unit in Melbourne University Geology Department sample R27873; (b) bedding being folded adjacent to a sandstone clast in Melbourne University Geology Department sample R27863. Width of both micrographs are 4 mm.

quartz and opaques. The sediments have retained their folded pattern but display some localised refolding (area 3, Fig. 2).

GRANITOID ROCKS

Two distinct granites, crop out around the Point Hicks headland (Fig. 1). One is a muscovite bearing granite (average grain size 1 mm), found close to the Ordovician sediments; the other is a coarse-grained granite (up to 10 mm) with euhedral orthoclase phenocrysts (up to 20 mm). Both granites exhibit a hypidiomorphic-granular texture and are granites according to the I.U.G.S. classification with the modal compositions shown in Table 1. The boundary between the two types appears to be gradational. The more leucocratic, coarse-grained granite contains patches of idiomorphic tourmaline (1 to 10 cm) intergrown with the groundmass phase, especially near the boundary with the muscovite granite. A late-stage magmatic origin is favoured for much of the tourmaline as it rarely exhibits replacement textures.

Jointing is intense within all the granitoids with an average spacing of 1 m (Fig. 8). Their orientation (Fig. 1) corresponds to the regional trend of S_2 structures recognised in the Mallacoota region (Wilson *et al.* 1982) and this may reflect the stress field and deformation events occurring during the cooling of the granite. The joints occur in zones up to 30 m wide, particularly in the muscovite bearing granite, with more closely spaced joints (1 to 8 cm) that are often associated with quartz veins (2 mm to 3 cm). Thicker quartz veins are less common, but are found in the muscovite granite and contain pyrite, sphalerite and chalcopyrite.

Table 1

Modal and Textural Variation of Point Hicks Granitoid Rocks

Mineral	coarse-grained granite	muscovite-bearing granite
quartz	20	25
K-feldspar	50	50
plagioclase	10	5
biotite	15	5
muscovite	5	15
hornblende	Tr	Tr

accessories: zircon, tourmaline, sericite and apatite

MIOCENE CALCARENITE

East of the Point Hicks lighthouse the granite is overlain by a 3 m thick, cross-bedded calcarenite in which the foresets dip 33° towards 036°. The calcarenite contains calcareous clasts in a calcite matrix with less abundant well sorted and subrounded clasts of fine quartz. The biogenic fraction containing fragments of brachiopods, molluscs, forams, and bryozoans and, is unsorted. An isolated exposure of a similar rock also occurs 3 km to the north in the Pleistocene dunes (Fig. 1). This calcarenite is comparable to the Late Miocene "Bairnsdale Limestone" described in other parts of East Gippsland by Mallett (1977) and Parker (1979) and may represent a shallow water intertidal or beach deposit.

CONCLUSIONS

Deformation has not modified the sedimentary features in the Late Ordovician turbidite sequence, recognized at Cape Everard. Sedimentary structures and lithofacies suggest that:

1, the sequence is dominated by interbedded packets of sandy sediments (channels) with minor finer-grained,

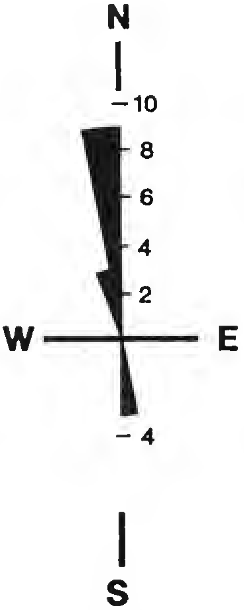


Fig. 7—Palaeocurrent directions using 10° intervals. Measurement taken from C-division ripple cross-bedding; 38 measurements taken from different beds occurring in all sections, except in sections 2 and 9.

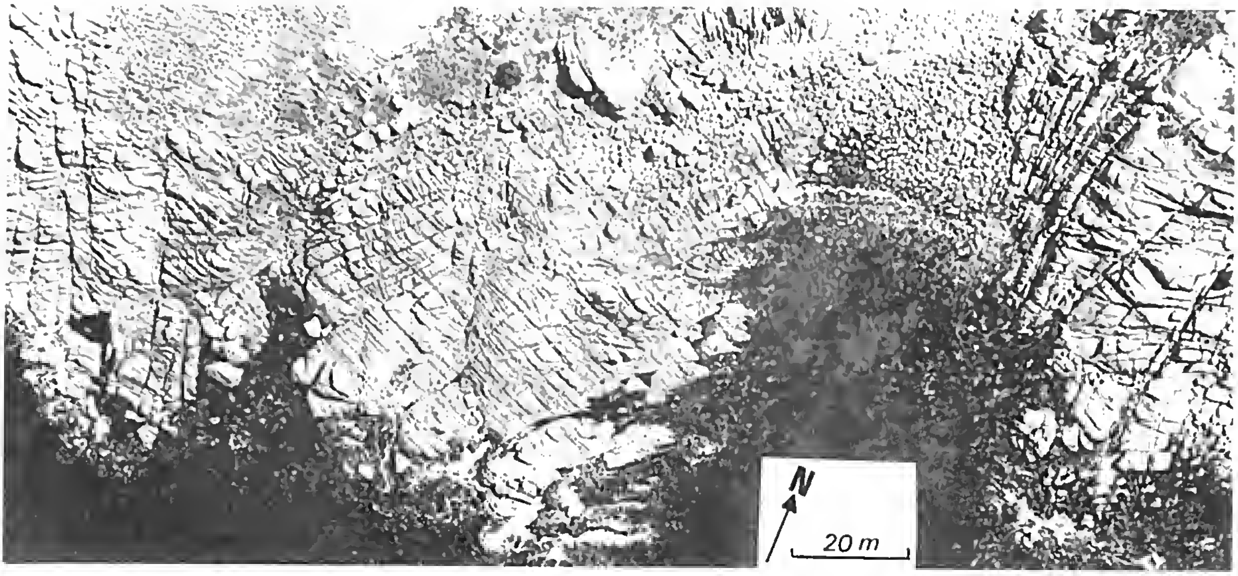


FIG. 8—Aerial view illustrating N-S and E-W joint sets in the coarse-grained granite adjacent to the Point Hicks lighthouse.

thin-bedded muddy sediments (thinner bedded channel levee or fan fringe deposits).

2, individual sand units were deposited by north flowing currents in a rapidly changing channelled suprafan.

3, coarse sandstone and shale clasts are directly related to the flow regime of the turbidity current, being deposited in or near channels on the channelled suprafan. Irregular clasts occur in the Bouma A divisions and a laminated distribution is observed in the B divisions. Clasts in the C division are either introduced or more commonly remnant bedding resulting from slumping of the deposited sediments.

A coarse-grained granite with a less orthoclase- and more muscovite-rich western margin intrudes the Ordovician sediments at Point Hicks. Minimal contact metamorphic effects are observed because of paucity of outcrop and the quartz-rich nature of the adjacent sediments. Overlying the granite is a calcarenite deposited during a Miocene marine transgression.

ACKNOWLEDGEMENTS

We wish to thank the National Parks Service for giving us permission to work at Cape Everard and Transport Australia (Victoria region) for admittance to the lighthouse reserve at Point Hicks. Dr. J. B. Keene is thanked for his discussions about the sedimentology of the region and M. W. Fenton is thanked for his comments on the manuscript. D. D. Campbell is thanked for assistance with the drafting.

REFERENCES

BOUMA, A. H., 1962. *Sedimentology of some flysch deposits. A graphic approach to facies interpretation.* Elsevier, Amsterdam, 168p.

DOUGLAS, J. G., 1974. Explanatory notes on the Mallacoota 1:250 000 geological map. *Rept. geol. Surv. Vict.* 1974/6; 1-48.

EATON, P. C., 1980. The geology of Cape Conran, East Gippsland. BSc (Hons) Thesis, Univ. Melb. (unpubl.).

FENTON, M. W., KEENE, J. B. & WILSON, C. J. L., 1982. The sedimentology and environment of the Mallacoota Beds, Eastern Victoria. *J. geol. Soc. Aust.* 29: 107-114.

FRY, M. C., 1981. The geology of Point Hicks, Croajingolong, Victoria. BSc (Hons) Thesis, Univ. Melb. (unpubl.).

MALLETT, C. W., 1977. Tertiary foraminifera. PhD Thesis, Univ. Melb. (unpubl.).

PARKER, W. A., 1979. The Bairnsdale Limestone. BSc (Hons), Univ. Melb. (unpubl.).

RICHARDS, J. R. & SINGLETON, O. P., 1981. Palaeozoic Victoria, Australia: Igneous rocks, ages and their interpretation. *J. geol. Soc. Aust.* 28: 395-421.

ROSENGREN, N., 1978. The physiography of coastal dunes, East Gippsland, Victoria. MA Thesis, Univ. Melb. (unpubl.).

TESSENSOHN, F., DUPHORN, K., JORDAN, H., KLEINSCHMIDT, G., SKINNER, D. N. B., VETTER, U., WRIGHT, T. O. & WYBORN, D., 1981. Geological comparison of basement units in Northern Victoria Land, Antarctica. *Geol. Jb.* B41: 31-88.

WALKER, R. G., 1978. Deep water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps. *Bull. Am. Assoc. Petrol. Geol.* 62: 932-966.

WALKER, R. G. & MUTTI, E., 1973. Turbidiate facies and facies associations. In *Turbidites and deep water sedimentation*, G. V. Middleton & A. H. Bouma, eds. *Soc. Econ. Paleontol. Mineral.* (Pacific Section) Short Course, Anaheim, California, 119-157.

WEBBY, B. D., VANDENBERG, A. H. M., COOPER, R. A., BANKS, M. R., BURRETT, C. F., HENDERSON, R. A., CLARKSON, P. D., HUGHES, C. P., LAURIE, J., STAIT, B., THOMSON, M. R. A. & WEBERS, G. F., 1981. The Ordovician System in Australia, New Zealand and Antarctica. Correlation Chart and Explanatory Notes. *Inter. Union Geol. Sci. Publ.* 6: 1-64.

WILSON, C. J. L., HARRIS, L. B. & RICHARDS, A. L., 1982. Structure of the Mallacoota area, Victoria. *J. geol. Soc. Aust.* 29: 91-105.

PROC. R. SOC. VICT. vol. 94, no. 4, 183-220, December 1982

HOLOCENE OSTRACODS, OTHER INVERTEBRATES AND FISH REMAINS FROM CORES OF FOUR MAAR LAKES IN SOUTHEASTERN AUSTRALIA

By P. De Deckker

Department of Biogeography and Geomorphology, Australian National University, P.O. Box 4, Canberra, A.C.T. 2600

Abstract: Cores from 4 maar lakes in Western Victoria yielded ostracods (most abundant), foraminifers, gastropods, cladocerans, isopods, sponges, chironomids, trichopterans, and some fish remains; these faunas are described herein. From the present day ecology of most of these organisms, especially the ostracods, changes in lake levels and salinities are inferred. During the last 9 000 years, fluctuation in water level and consequently salinity is nearly always synchronous in 3 of the lakes: Bullenmerri (salinity today 4.5-8.5‰), Gnotuk (today 55-63‰) and Keilambete (today 55-62‰). Lake Purrumbete (salinity ~0.4‰ today) has remained fresh during the last 7 000 years probably resulting from continuous connection to a river.

The following events are inferred as having occurred synchronously in the 3 Lakes Bullenmerri, Gnotuk and Keilambete and are thought to result from climatic changes since these lakes are small, enclosed basins. 1, during the last 100 years, lake levels have fallen significantly; 2, during the 2 000-3 000 yBP period lake levels were low; 3, between 3 800 and 6 400-6 500 yBP water levels were high and the highest lake levels occurred between 5 700 and approximately 6 400 yBP; 4, before 8 300 yBP water levels were at their lowest (i.e. highest salinities) in Lakes Keilambete and Gnotuk (no record for Lake Bullenmerri) for the Holocene.

Core from Lakes Bullenmerri, Gnotuk, Keilambete and Purrumbete exhibit changes in the fossil lacustrine fauna. These changes are attributed to changes of lake salinity which in turn are attributed to variation in water levels in the lakes; the water levels indicate fluctuations in climate during the past 10 000 years. The lakes cover a broad spectrum of salinities (see Table 1) and correspondingly have different faunas. Thus the recovery of different ostracods (the commonest fossil invertebrates) from the cores, and knowledge of salinity tolerance of the species today provide palaeosalinity data. With information on the present hydrology of each lake, a correlation of the salinity curve with that of a climatic one may be attempted as radiocarbon dates (Barton & Polach 1980, Bowler & Hamada 1971, Dodson 1974), are available for correlation between the cores.

Lakes Bullenmerri, Gnotuk, Keilambete and Purrumbete are located near Camperdown, approximately 170 km west southwest of Melbourne and about 30 km from the sea (Fig. 1). They are situated within the Western Victorian Newer Volcanic Province which is of Pliocene to Recent age (Ollier & Joyce 1964) and overlies Miocene limestone (Joyce 1975).

Each lake occurs inside a shallow volcanic crater described as a maar. According to Ollier (1968), a maar is a landform caused by volcanic explosion consisting of a crater which reaches or extends below, general ground level; it is considerably wider than it is deep and has a surrounding rim constructed of material ejected from the crater.

Physical data on the four lakes are provided in Table 1. Lakes Bullenmerri and Gnotuk are adjacent craters formed by distinct volcanic explosions (Ollier 1970) and only once in human memory is Lake Bullenmerri known to have overflowed into Lake Gnotuk (Currey 1970). Lake Bullenmerri is clover-leaf shaped, and has steep sides (Fig. 2). Present water level is 21 m below the point of overflow into Lake Gnotuk.

Lake Gnotuk is much smaller, oval shaped, and flat-bottomed (Fig. 2). The water level is about 40 m below that of Lake Bullenmerri. Circular Lake Keilambete is flat-bottomed. Salinity varied between 55.3 and 62.4‰ in the last 15 years (Maddocks 1967, Hussainy 1969a, Bowler 1970).

Lake Purrumbete has steep flanks with a gentle slope towards its centre (Fig. 2).

Lakes Bullenmerri, Gnotuk and Keilambete are internal drainage basins: water in the lakes results from precipitation and crater slope run-off and in each case there does not seem to be much interference with groundwater (Bowler 1970, Currey 1970). An exception occurs when Lake Bullenmerri overflows into Lake Gnotuk. Lake Purrumbete can also overflow into Curdies River which is at about the same altitude as the lake at its present level. Water chemistry of the four lakes has been studied by Maddocks (1967). The fauna of Lakes Bullenmerri, Gnotuk and Purrumbete was studied during the 1969-72 period (Timms 1973, 1980, 1981) and the 1967-68 period (Hussainy 1969a). The flora of the four maars was examined by Yezdani (1970) and Tudor (1973). The latter concentrated on the diatoms.

Palaeolimnological work has already been carried out on these four maar lakes. Yezdani (1970) described changes in the aquatic flora (using pollen and diatoms) of Lakes Gnotuk and Bullenmerri. Tudor (1973), using diatoms only, described changes in water quality for some periods of the history of Lakes Keilambete and Gnotuk. Bowler (1970, 1981) examined the sediments in cores from Lake Keilambete and its margins; he established a water level curve for the last 30 000 years

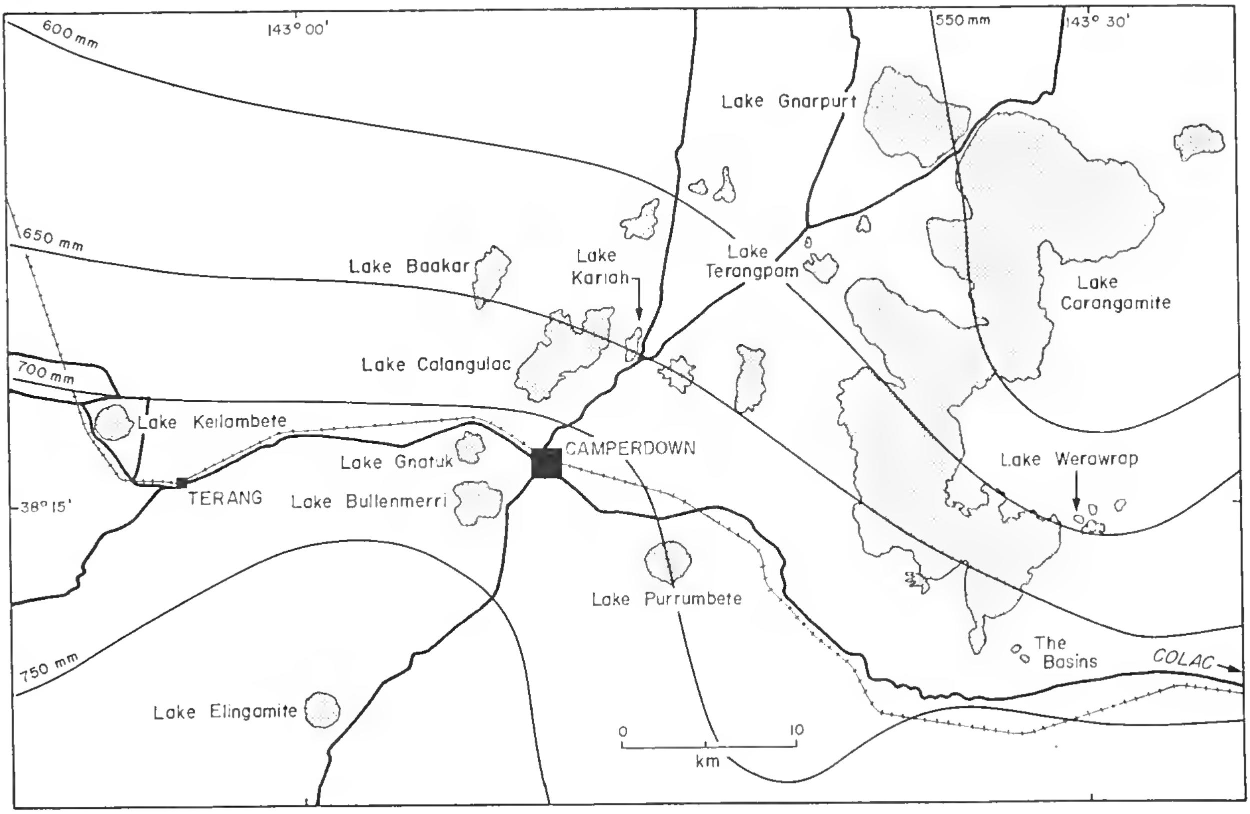


FIG. 1—Map showing the location of the four maar lakes in Victoria; Camperdown is situated 190 km west of Melbourne.

(Bowler & Hamada 1971, Bowler 1981). Dodson (1974) presented a palynological curve for the same lake for the last 10 000 years. His data reveal changes in vegetation surrounding the lake, accompanied at times, by modifications in the aquatic vegetation because of changes in water salinity. Churchill *et al.* (1978) published a water level curve derived from salinities indicated by diatom communities for Lakes Bullenmerri and Gnotuk extending back to 5 500 and 7 500 years respectively. Barton (1978), Barton & Polach (1980) and Barton & McElhinny (1981) have collated a 10 000 year geomagnetic secular variation record from many cores of Lakes Bullenmerri, Gnotuk and Keilambete. Finally, Dodson (1979) presented a pollen record from a core taken from the deepest part of Lake Bullenmerri and covering the 8 000 to 16 000 yBP period.

METHODS

A 6 m long pneumatic corer, similar to that designed by Mackereth (1958) fitted with an orientating device (Barton & Burden 1979) was used to core each lake. The 54 mm diameter cores were originally taken for palaeomagnetic investigation of the sediments (Barton 1978). Cores were cut into 1 to 2 m sections to facilitate transport. Rubber bungs inserted at the ends of most sections compressed sediment by about 2 cm. The cores were later split open lengthwise and sedimentological decription was completed, often under a binocular microscope. Sampling was carried out by extracting 3 g of sediments each time. The numbers of each sample for all cores refer to their appropriate levels in cm below the top of the core. Each sample was kept in a sealed 200 ml jar in a 10% hydrogen peroxide solution for one to two weeks depending on the separation rate of clays and dissolution of organic matter. The contents of the jar were then gently washed with a water jet over a 200 μm sieve (a finer sieve would have retained valves of unidentifiable juvenile ostracods). The residue was dried in a low temperature oven and picked under a binocular

TABLE I
MORPHOMETRIC AND SALINITY DATA ON THE FOUR MAARS

	Bullenmerri	Gnotuk	Keilambete	Purrumbete
Surface area (ha)	448[1]	208[1]	277[2]	522[1]
Volume (10^6 m^3)	192[1]	32[1]	13.3[3]	157[1]
Maximum depth (m) *	66[1], 67[6]	18.5[1], 20[6]	11[2], 10[6]	45[1], 42[5]
Mean depth (m)	39.3[1]	15.3[1]	9.54	28.5[1]
Salinity (TDS °/oo) 1979-80	4.49-8.57	55-63	62.4 (Jan. 1980)	0.37-0.44
Other periods	7.8-8.5[1]	56-62[1]	55.3[4], 61.3[6]	0.42-0.50[1]

[1] Timms, 1976; [2] Bowler, 1970; [3] calculated from Bowler, 1970; [4] Maddocks, 1967; [5] Barton, 1978; [6] Hussainy, 1969a.

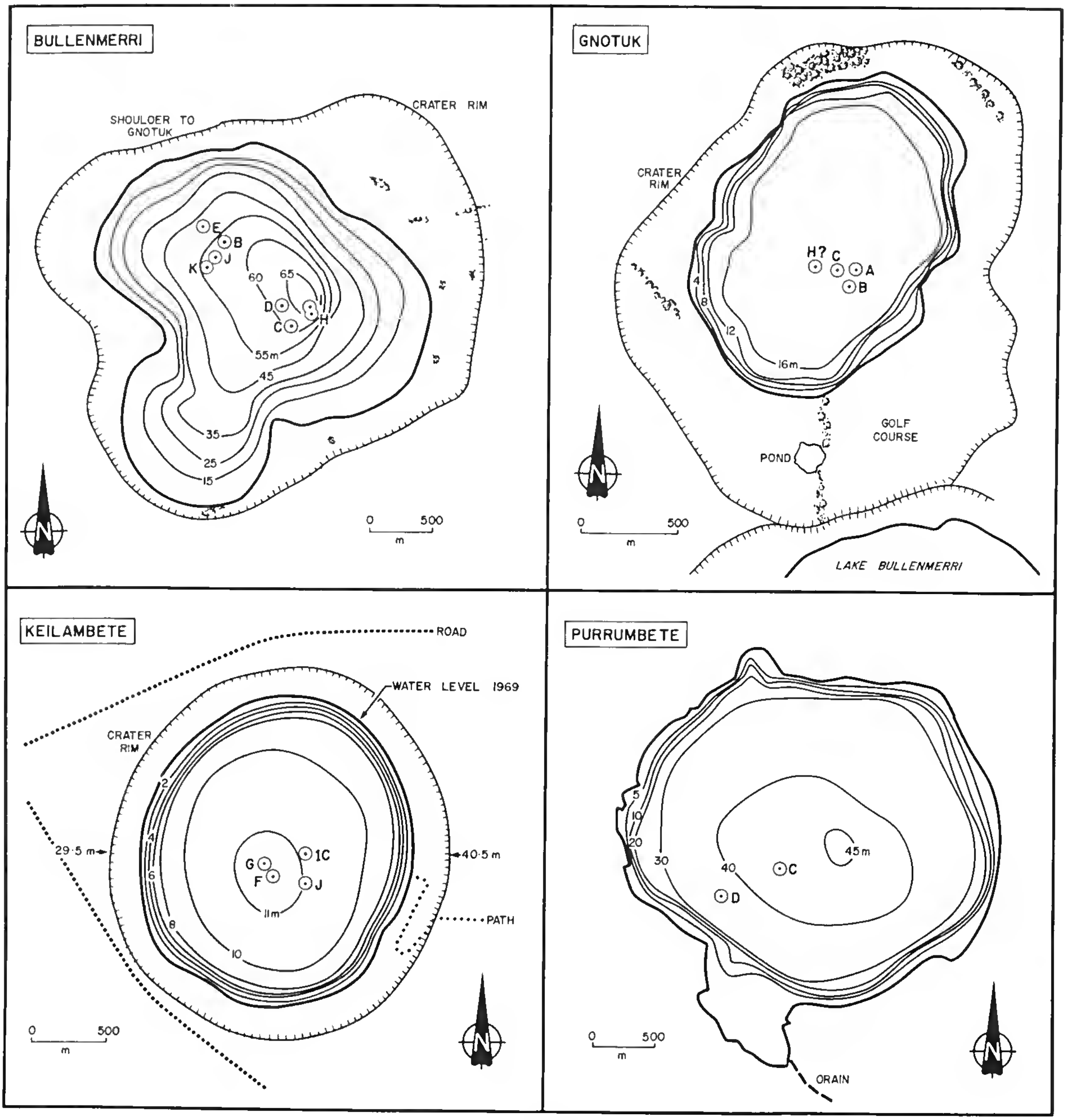


FIG. 2—Bathymetry and location of core sites for each of the four maar lakes.

microscope. Every ostracod was examined and counted. When specimens were particularly numerous (> 1 500 individuals), an estimate of their number was made. The presence of other fossil remains was also noted. Conventional ^{14}C dates are used throughout this paper.

DESCRIPTION OF THE CORES

LAKE BULLENMERRI

A core 533.5 cm long was taken on 1 March, 1977 at a depth of 55.5 m in the northwestern part of the lake (Fig. 2, location K). The coring site could differ from this location by about 100 m (C. E. Barton pers. comm.). The core is labelled BK. Details of the core are given in Fig. 6. The core consists mainly of fairly homogeneous organic mud. Two colorations occur:

a, brown to dark brown to grey brown organic mud with abundant fine (100-200 μm thick) or occasionally coarse (ca. 1 mm) laminations. The fine laminations are usually black whereas some of the coarse ones vary from beige brown to orange brown to white in colour;

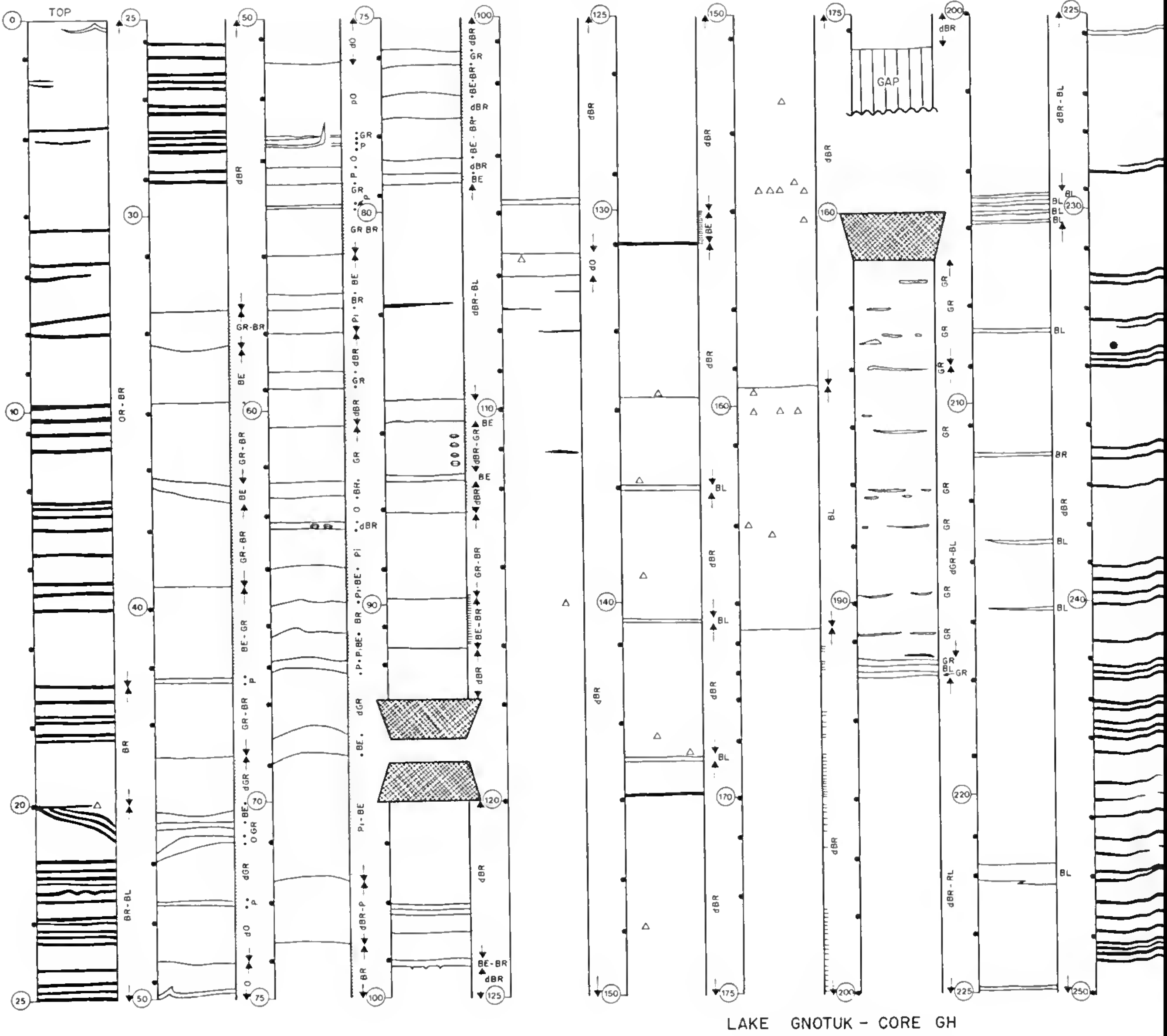


FIG. 3 — Detailed lithological description of core GH from Lake Gontuk. For legend see Fig. 4. Black dots indicate the position of the samples in the core.

b, dark grey to black unlaminated organic mud below level 400 cm.

After treatment of some of the samples with H_2O_2, small grains (>200 μm) consisting mainly of scoria fragments were found. Their presence in the core is referred to in Fig. 9 and their significance will be discussed later. The "sulfureous orange muds" described by Barton (1978) at the bottom of his much longer cores (ca. 10 m long) are not encountered in core BK.

LAKE GNOTUK

A core 362.5 cm long was taken on 7 March, 1977 at a water depth of 19 m near the centre of the lake. Its exact location is queried by Barton (1978). The core is labelled GH. Details of the core are given in Fig. 3.

A variety of sediment types was encountered and these are described in descending order:

- brown to dark brown organic mud with numerous white to beige carbonate bands (ca. 1 mm) down to 32 cm. A small hiatus with contorted bedding was noticeable at level 21 cm.
- dark brown to black organic mud alternating with light and dark thick layers (ca. 1 cm) with many ostracod shells (*Diacypris compacta*) down to 88 cm. The shells are sometimes so abundant that the layers have a sandy appearance.
- brown to dark brown to black organic mud with some pale brown to olive green layers and many very fine black laminations (ca. 100 μm) down to 175 cm.

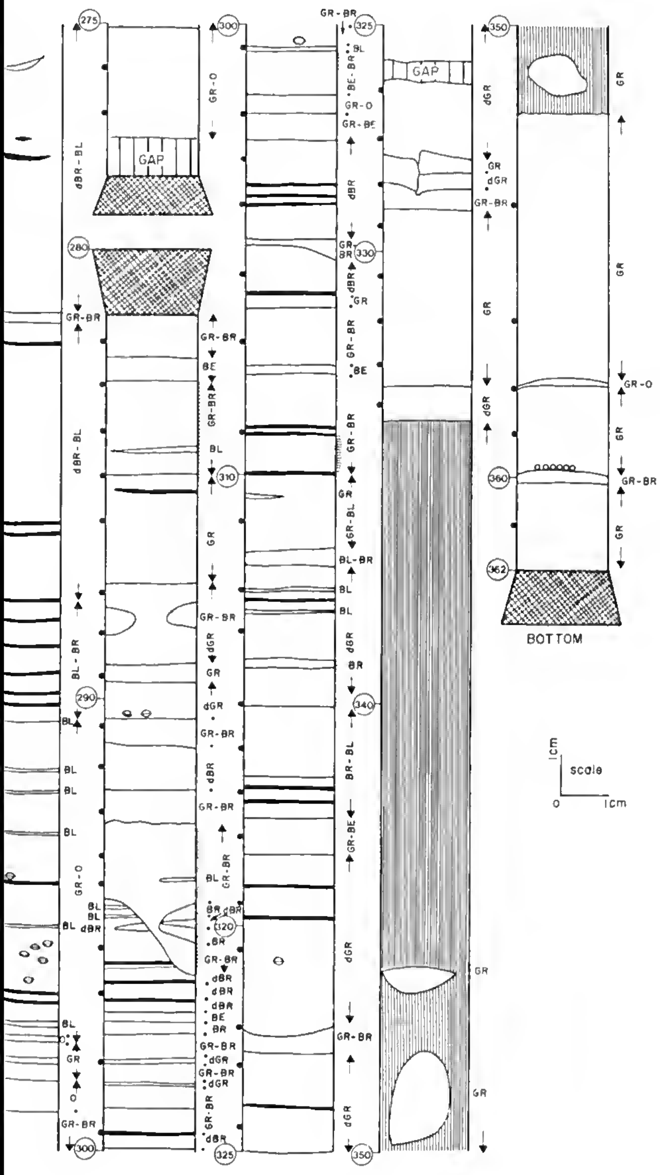


FIG. 3—(*continued*).

The average distance between these thin black laminations ranged between 450 μm and 600 μm.

- dark brown to black organic mud with thin (< 1 mm) grey or black or brown layers at irregular intervals down to 231 cm.
- between 231 cm and 266 cm, dark brown to black organic mud with abundant white to grey layers, especially between level 231 and 250 cm (large crystals of aragonite occur in some of these light coloured layers)
- grey-green organic mud down to 285 cm grading into grey to dark grey organic mud down to 325 cm. Pale coloured thin bands more common in the upper part. A small truncation of bedding was noticeable around level 295 cm.
- grey to dark grey organic mud down to 333.5 cm. No sediments recovered between that layer and level 346 cm.
- grey clay from 346 cm to 362 cm. The upper 6 cm appear to have been mixed. This entire layer is probably displaced as suggested by the gap above it.

LAKE KEILAMBETE

Two cores were taken: a short one, 127 cm long and labelled K1C was collected on 5 December, 1976, slightly east of centre of the lake where it is about 10 m deep. This core was taken to obtain the uppermost layers of sediments not recovered in the longer core. The latter, labelled KG and collected on 29 April, 1975, is 419 cm long and was taken at the centre of the lake at a depth of 10.5 m. For location of both cores, see Fig. 2, and their lithological description, see Figs 4, 5. The top of core KG is at about 40 cm below the water sediment interface (see correlation between the two cores—Table 3 and Figs 4, 5, 8 and 9). Forty-nine samples were examined from core K1C and 172 from core KG. Bowler (1970, 1981) provided a detailed stratigraphic log of a 440 cm long core (labelled K4) from Lake Keilambete. This will not be repeated here as the core was taken from another part of the lake with distinct facies differences. Notably, the grey mud recovered at the bottom of core KG (Fig. 5) was not found by Bowler in core K4. Additionally, the sandy layers mentioned by Bowler (*op. cit.*) in his cores K4 and K5 are not found in core KG. The broad sedimentary divisions given by Bowler (1981) are used here:

- top of core to 200 cm (core K4) = *Upper Keilambete Muds* consisting of fine grained dark calcareous muds with paler carbonate rich bands and occasional sandy horizons (150 cm, 100 cm). This unit apparently terminates at level 153 cm in core KG and comprises the whole of core K1C.
- 200 cm to 375 cm (core K4) = *Lower Keilambete Muds* consisting of fine grained dark muds which are weakly calcareous. The basal part of this unit cannot be defined in core KG as the other two units described by Bowler (1981) as the *basal saline sands* (zone 375-440 cm) and the basal soil (400-440 cm) are missing in core KG. It is thought that the *basal soil* probably is facies equivalent to the grey to brown mud found in core KG below level 350.5 cm and finally grading into the grey mud below level 385.5 cm.

Throughout the entire core, there are many bands, sometimes more than 1 cm thick, which consist mainly of ostracod shells (Fig. 4). Below levels 355 cm and 387 cm in core KG, bedding is disturbed: these are probable signs of aerial exposure of the lake floor.

LAKE PURRUMBETE

A 581 cm long core, labelled PC, was taken on 2 June, 1975, at a depth of 40.8 cm near the centre of the lake (Fig. 2). Note the bathymetric map provided by Barton (1978) differs from Timms' map (1976). The core is entirely homogeneous dark brown organic mud. Small gas vesicles are common in the more fluid upper 113 cm of the core; below that level, the organic mud becomes

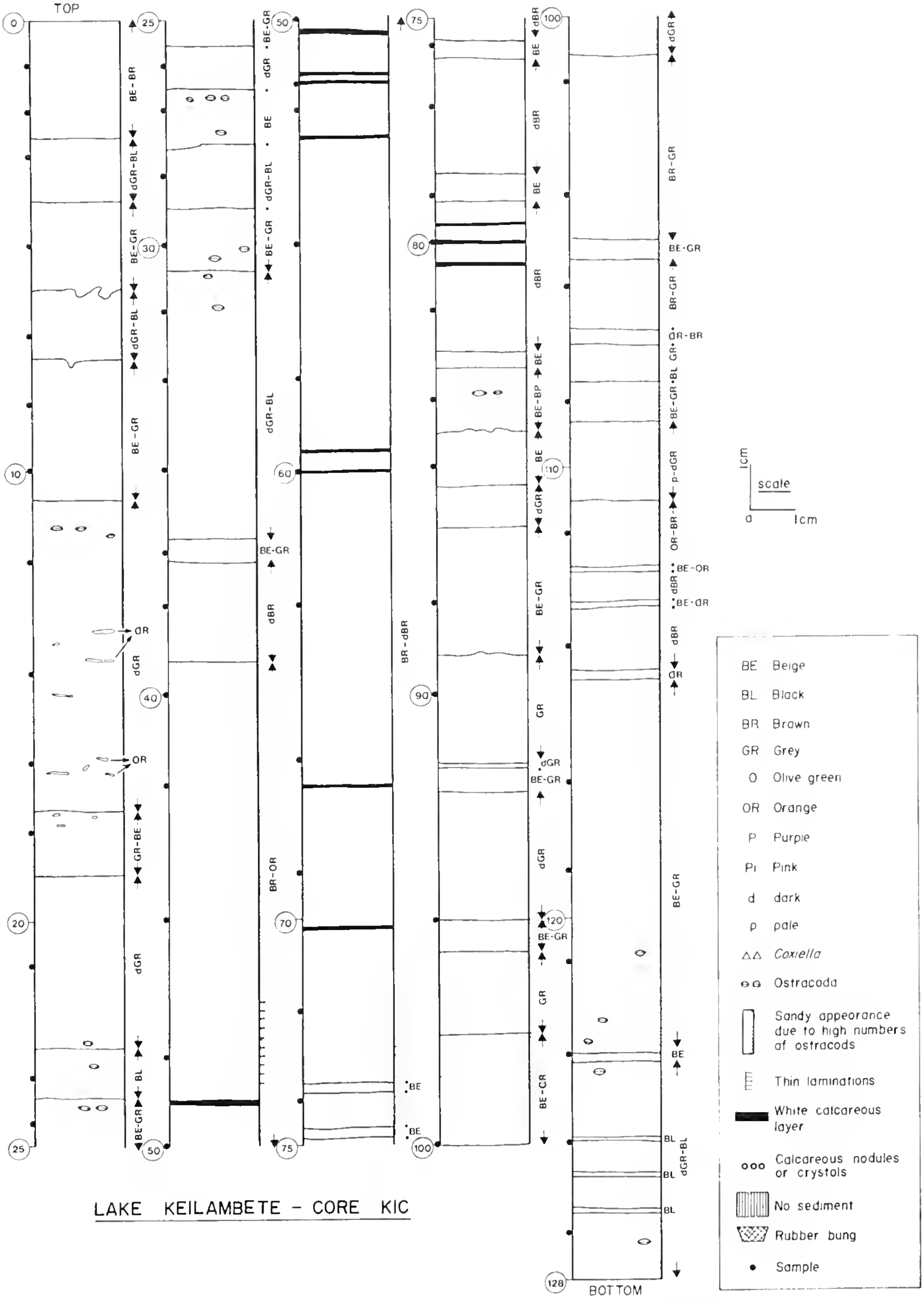


Fig. 4—Detailed lithological description of core KIC from Lake Keilambete.

more compact with increasing depth. 195 samples, usually taken at 3 cm intervals were analyzed from core PC (Fig. 10).

SYSTEMATICS

Distribution of fossils in the cores is given in Figs 6-10.

OSTRACODA

Ostracods, which have a calcareous shell, are readily preserved in lake sediments. Their fossils are informative on the environmental conditions in the lakes at the time these ostracods lived. The study of fossil ostracods from Australian salt lakes is of importance since the halobiont ostracod fauna is unusually diverse (De Deckker 1981d) as many species have distinct ranges of salinity tolerance. In addition, as the ostracod fauna in salt lakes is represented mostly by planktonic species, shells of the same species should be fairly evenly distributed on lake floors. This should permit easy correlation between cores taken from any part of a lake.

Australocypris robusta De Deckker 1974

Fig. 13M-Y

1974 *Australocypris robusta* De Deckker, p. 65.

Description: Adult: valves large (ca. 3 mm), oblong, extremely thin, and smooth to pseudopunctate; greatest height at about 0.4 from anterior which is broadly rounded compared to the narrower posterior; ventral margin almost straight except for the slightly concave mouth region; inner margin narrow anteriorly and posteriorly. Juvenile: valves subtriangular to almost round; greatest height between 0.3 and 0.5 from anterior.

Ecology: *A. robusta* is a good swimmer but is also found on lake floors. Its salinity range in Victoria is 7-145‰ (De Deckker 1981a) but in South Australia, in lakes near the Coorong Lagoon, it is 15-38‰ (De Deckker & Geddes 1980). The broader salinity range of the Victoria specimens probably relates to the fact there is no other *Australocypris* species in salt lakes in that area (i.e. interspecific competition is lacking) whereas in the lakes near the Coorong Lagoon, 3 additional species (*A. insularis* (Chapman 1966), *A. rectangularis* De Deckker 1978 and *A. dispar* De Deckker 1981) probably have to compete for similar niches. The salinity range of the present day Victorian specimens is attributed to the fossil material as, so far, no fossil remains of *A. insularis* have yet been found in Victorian lacustrine sediments. In Victorian lakes, *A. robusta* is encountered in high numbers between 45 and 77.5‰ salinities and nearly always it co-occurs with large numbers of *D. compacta*. At higher salinities, these 2 species are found with *P. baueri*.

Remarks: *A. robusta* specimens are rarely found intact, especially at the adult stage, because they are very brittle—fracture of the shell often results from slight compaction even during a very careful extraction of a sample from a core. Juveniles of *A. robusta* are distinguished from both *Diacypris* species by: the greatest height of *A. robusta* being very close to the anterior margin (ca. 1/4), its shell more rounded and its valves much broader in dorsal view. No carapaces of *A. robusta* were ever found nor large quantities of large specimens typical of layers occasionally found on the shore of lakes which dry up. This suggests that the edge of the lake, where such a phenomenon would occur, has never been near the coring sites (in Lakes Gnotuk and Keilambete).

Candonocypris novaezelandiae (Baird 1843)

Fig. 12W

Description and Synonymy: See De Deckker (1981b).

Ecology: This freshwater species is common in farm dams and eutrophic waterbodies. For more details see De Deckker (1981b). *C. novaezelandiae* lives today in Lake Purrumbete (Hussainy 1969, Timms 1981, called by them *C.assimilis*) down to 33 m (Timms 1973).

Remarks: Very few specimens were found in the cores. The adult shells were either partly decalcified or partly perforated. This was probably caused by waters of low pH. This phenomenon can be expected as *C. novaezelandiae* is often crawling in among decaying vegetal debris.

Diacypris compacta (Herbst 1958)

Fig. 15A-P

1958 *Pseudocypris compacta* Herbst, p. 181.
1960 *Diacypris compacta*; Herbst, p. 143.
1981e *Diacypris occidentalis* McKenzie; De Deckker p. 54.
1981e *Diacypris paracompacta* McKenzie; De Deckker, p. 54.
1981e *Diacypris parva* Hartmann; De Deckker, p. 54.

Description: Adult: valves pesudopunctate, almost circular in shape and narrow in dorsal view; greatest height at about 0.3 to 0.5 from anterior margin; posterior area broadly rounded. Inner lamellae broader anteriorly. Left valve overlaps right one all along its periphery but overlap is more obvious in dorsal area where a hump is present in left valve only. This hump is variable; occasionally it is pointed. Juvenile: valves more triangular in lateral view and dorsal hump usually absent.

Ecology: This is an ubiquitous halobiont species; its salinity range is very broad and it is an excellent swimmer. It occurs in large numbers over its entire salinity range. In the lakes near the Coorong Lagoon in South Australia, its range is 8-132‰ (De Deckker & Geddes 1980) and in western Victorian lakes it is 14-181‰ (one specimen was even collected at 0.34‰). In West Australian lakes, it has been collected in ten lakes in the range of 2.9-87.9‰ (Geddes *et al.* 1981).

As for *A. robusta*, the salinity range of *D. compacta* in Victoria appears to be wider; this probably results from the absence there of the *Diacypris* species which have a higher salinity tolerance as those from the lakes near the Coorong Lagoon, e.g. *D. dictyote*, *D. fodiens* and *D. whitei*. *D. compacta* has been found on many occasions in extremely large numbers (e.g. ca. 20-40 ml of settled ostracods filtered from 1 m of lake water) resulting from "blooms" of that species. This phenomenon usually occurred at salinities around 45-77‰

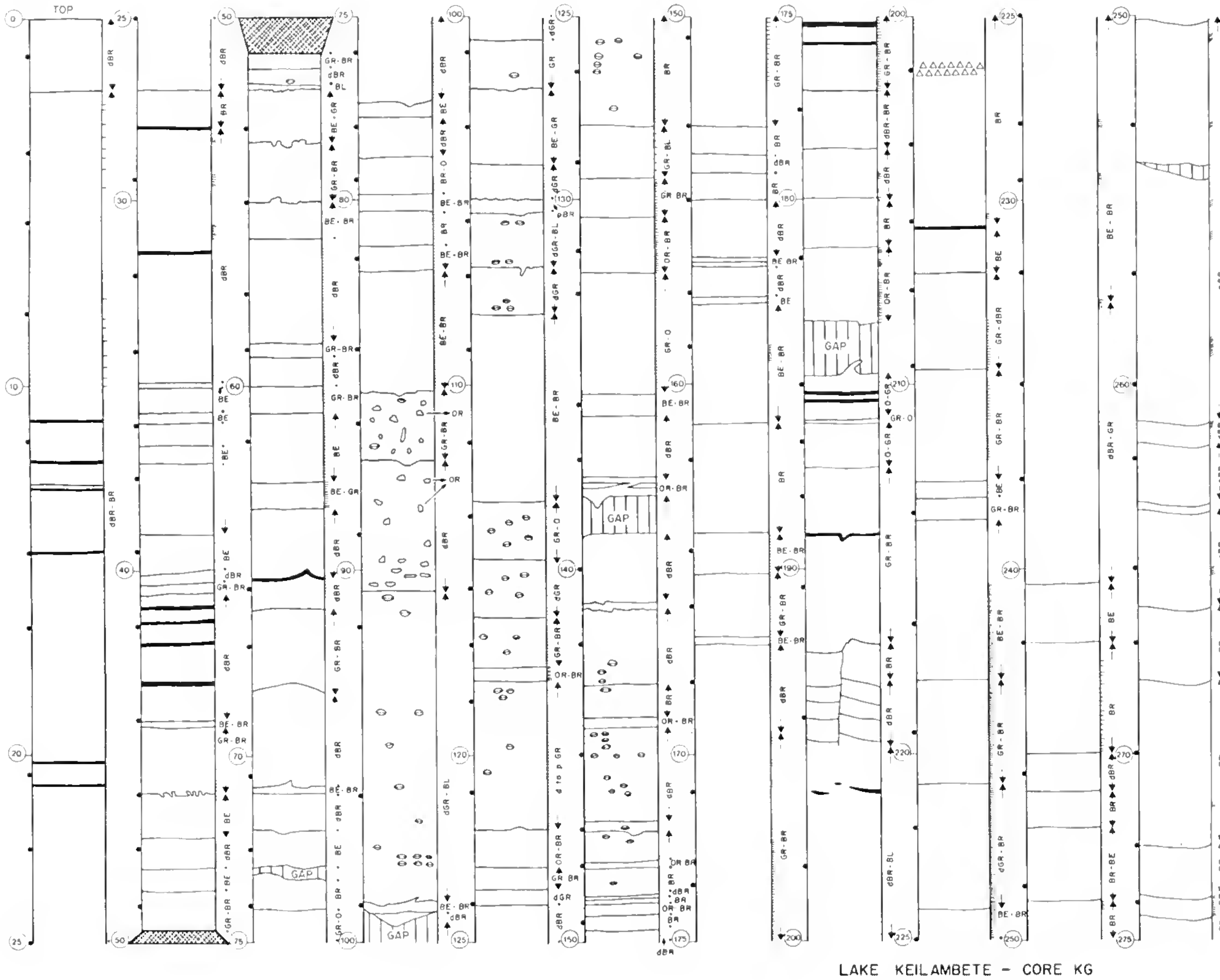


FIG. 5—Detailed lithological description of core KG from Lake Keilambete. For legend see Fig. 4.

in Victorian lakes and in lakes near the Coorong Lagoon. In the cores from Lakes Gnotuk and Keilambete, there are layers (up to 2 cm thick) which have a sandy texture and which consist mainly of *D. compacta* shells. This feature is thought to derive from such "blooms". Once *D. compacta* was found in large numbers at 124°/₀₀ in Pink Lake in western Victoria; in the Coorong area, the "bloom" condition extends down to lower salinities: 21-69°/₀₀ with also two high records at 96 and 123°/₀₀ (see De Deckker & Geddes 1980).

It is not known whether the wide variations of the dorsum of *D. compacta*, which is a diagnostic feature for the species, is of any ecological significance.

Diacypris dictyote De Deckker 1981
Fig. 14EE-II, KK

1980 *Diacypris* n.sp.1 De Deckker & Geddes, p. 692.
1981 *Diacypris dictyote* De Deckker, p. 49

DESCRIPTION: see De Deckker (1981e).

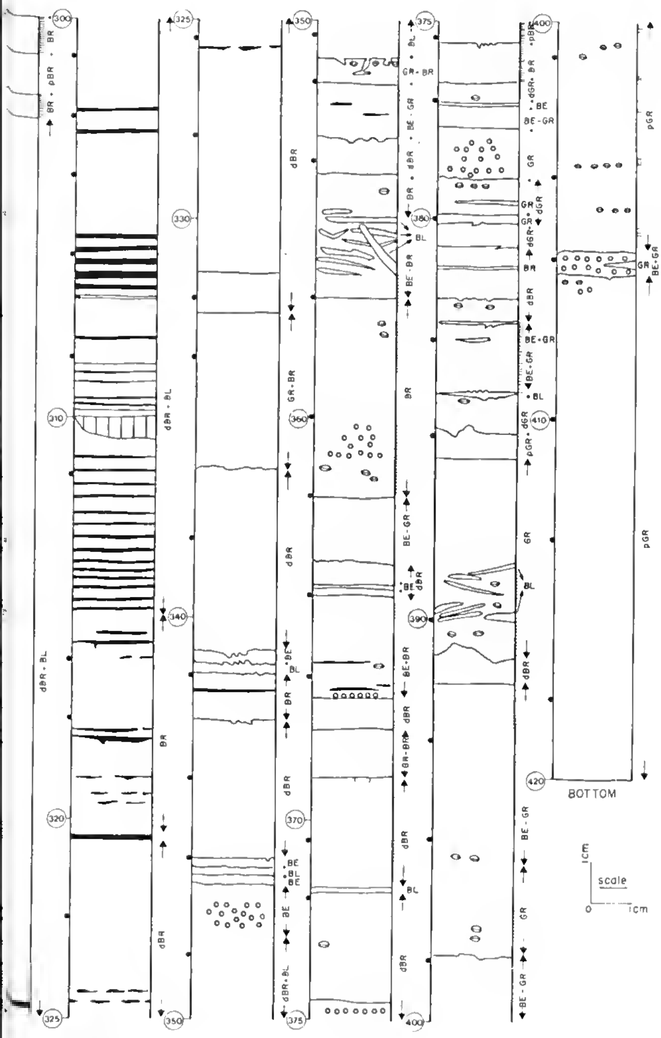
ECOLOGY: So far this species has only been found living in South Australia, in many ephemeral lakes near the Coorong Lagoon, (De Deckker & Geddes 1980), some on Kangaroo Island and on the Yorke Peninsula. In the Coorong area, the salinity range of this species over a year was 12-143°/₀₀ with one record at 195°/₀₀.

REMARKS: *D. compacta*, which also has a sharp dorsal "keel" is easily distinguished from this species by its smooth and smaller shell, the absence of spines and its narrow shape in dorsal view.

Diacypris dietzi (Herbst 1958)
Fig. 14U-Z, AA, JJ

1958 *Pseudocypris dietzi* Herbst, p. 177.
1960 *Diacypris dietzi*; Herbst, p. 143.

DESCRIPTION: Triangular shell in lateral view with greatest height at about middle; dorsum steeply inclined and straight behind the highest point of the shell; no strong overlap of left valve over right one in dorsal area; valves narrow in dorsal view.



Ecology: This species is not common in salt lakes: in a survey of 79 lakes in western Victoria it was collected only six times whereas *D. compacta* was collected twenty times and *Australocypris robusta* nineteen times. In the Victorian lakes, its salinity range was 35-127°/oo with one specimen collected at 0.34°/oo. In the lakes near the Coorong Lagoon, its salinity range is broader: 4-141°/oo with a few specimens found once at 216°/oo (De Deckker & Geddes 1980). Presence of valves of fossil *D. dietzi* in low numbers in the cores cannot suggest more than a broad range of salinity.

Diacypris whitei (Herbst 1958)

Fig. 14BB-DD.

1958 *Pseudocypris whitei* Herbst, p. 185.
1968 *Diacypris whitei*; Herbst, p. 143.

Description: Smooth, rectangular shell with arched dorsum and broadly rounded anterior. Shell depressed dorsally in front of hinge area and in dorsal view, oval in shape. Greatest height just before mid-length; convex area of the ventrum behind mid-length. Left valve slightly larger than right valve all along. Selvage thin and peripheral on both valves except in the posteroventral area of right valve.

Ecology: This rare species inhabits highly saline lakes in which halophytes cannot grow. Its salinity range for this species in the lakes adjacent to the Coorong Lagoon in South Australia is 14-195°/oo (De Deckker & Geddes 1980). The low salinity records were taken during winter when water was plentiful for a short period of time and consequently water salinity temporarily reduced. This species has not yet been recorded living in Victoria.

Remarks: Only a few valves of this species have been found in one sample each from Lakes Keilambete (KG 410) and Gnotuk (GH 315). It is distinguished from the other *Diacypris* species by its more rectangular outline and oval shape in dorsal view.

Ilyocypris australiensis Sars 1889

Fig. 12Z, AA-II

1889 *Ilyocypris australiensis* Sars, p. 46.

Description: Adult: rectangular and pitted shell occasionally covered with fine denticles especially along periphery; 3 main depressions on shell; a central round one, another round one above it and below the hinge line and a third one vertically enlogated in front, starting below the hinge line and ending at mid-height between the other 2. Greatest height at about 1/4 from anterior. Hinge adont. Inner lamella broadest anteriorly and selvage broad all along in both valves. Juvenile: compared to adults, length height ratio of valves greater and height of shell of the hinge much greater than at posterior.

Ecology: *I. australiensis* occurs in temporary freshwater pools but it has been found in slightly saline lakes in Victoria. In the latter, it is usually found at salinities ranging between 4 and 7°/oo. The uppermost salinity record of 10.37°/oo is from Lake Kariah.

Remarks: The ornamentation of the shell of *I. australiensis* is very variable: the shell can be nearly smooth, faintly spinose or reticulated all over. For further details, see De Deckker (1981a).

Leptocythere lacustris De Deckker 1981

Fig. 12A-O

1981a *Leptocythere lacustris* De Deckker, p. 129.

Description: See De Deckker (1981a).

Ecology: *L. lacustris* is a benthic species which requires permanent water conditions. Its salinity range is 19-28°/oo with one collection at 2.8°/oo. Being of marine ancestry its salinity range probably extends up to 35°/oo; for more detail see De Deckker (1981a).

Remarks: The shell ornamentation of *L. lacustris* varies from almost smooth to coarsely reticulated.

Limnocythere dorsosicula De Deckker 1981

Fig. 12Q-X

1981b *Limnocythere dorsosicula* De Deckker, p. 43.

Description: See De Deckker (1981b).

Ecology: This species is known from four localities: two in Victoria (Lake Terangpom and South Nerrin Nerrin Lagoon) and two in New South Wales (Lake Bathurst and The Morass). Its salinity range is 0.42-3.3°/oo and therefore indicates fresh or slightly

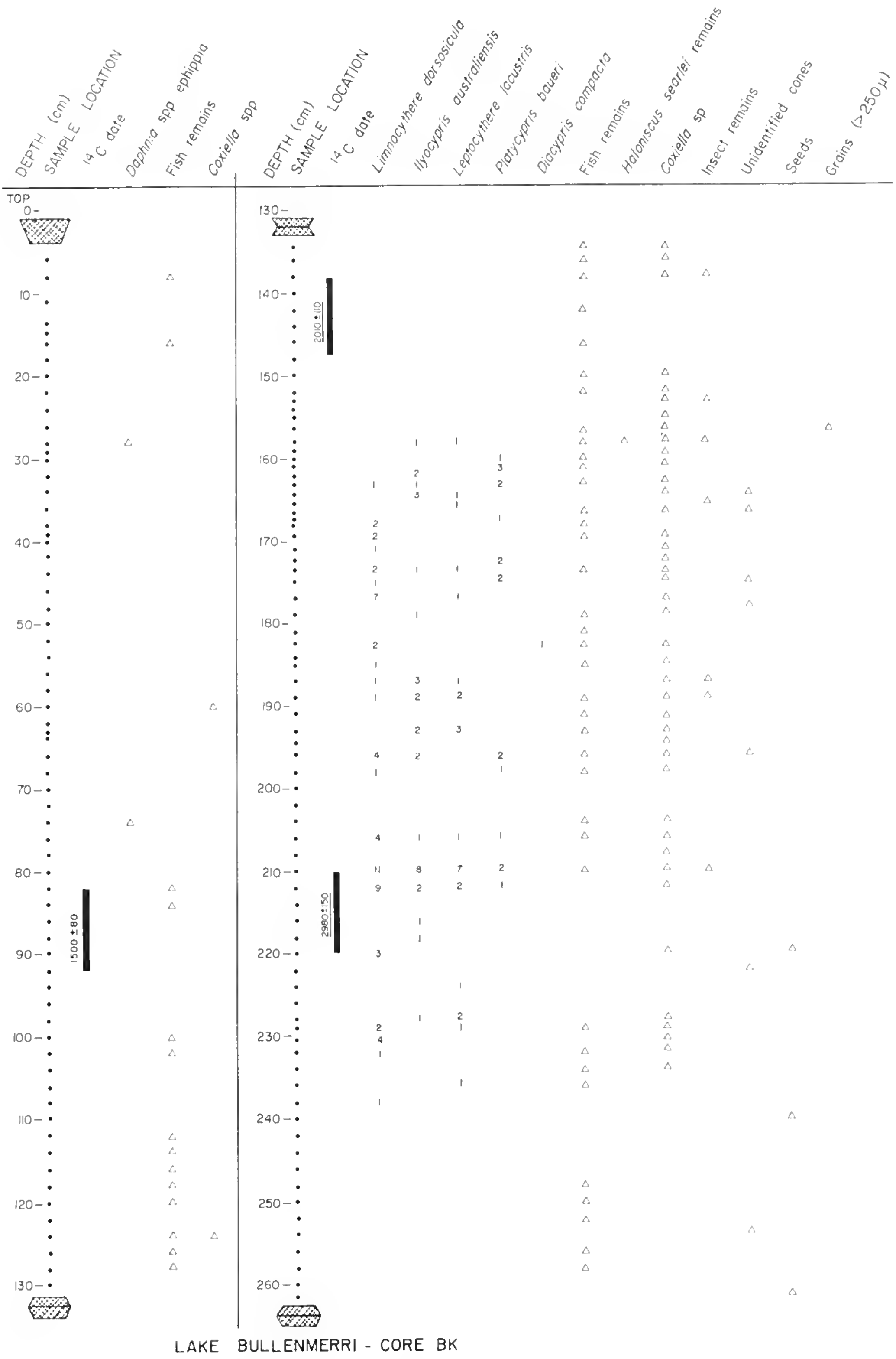


FIG. 6—Distribution of fossil remains and grains in the upper part of core BK from Lake Bullenmerri. Numbers in the ostracod columns are the number of ostracod valves recovered per 3 gm of sediment. Triangles indicate the position of samples taken from the core. Underlined dates are those which were obtained from core BK, others were obtained by correlation with other dated cores.

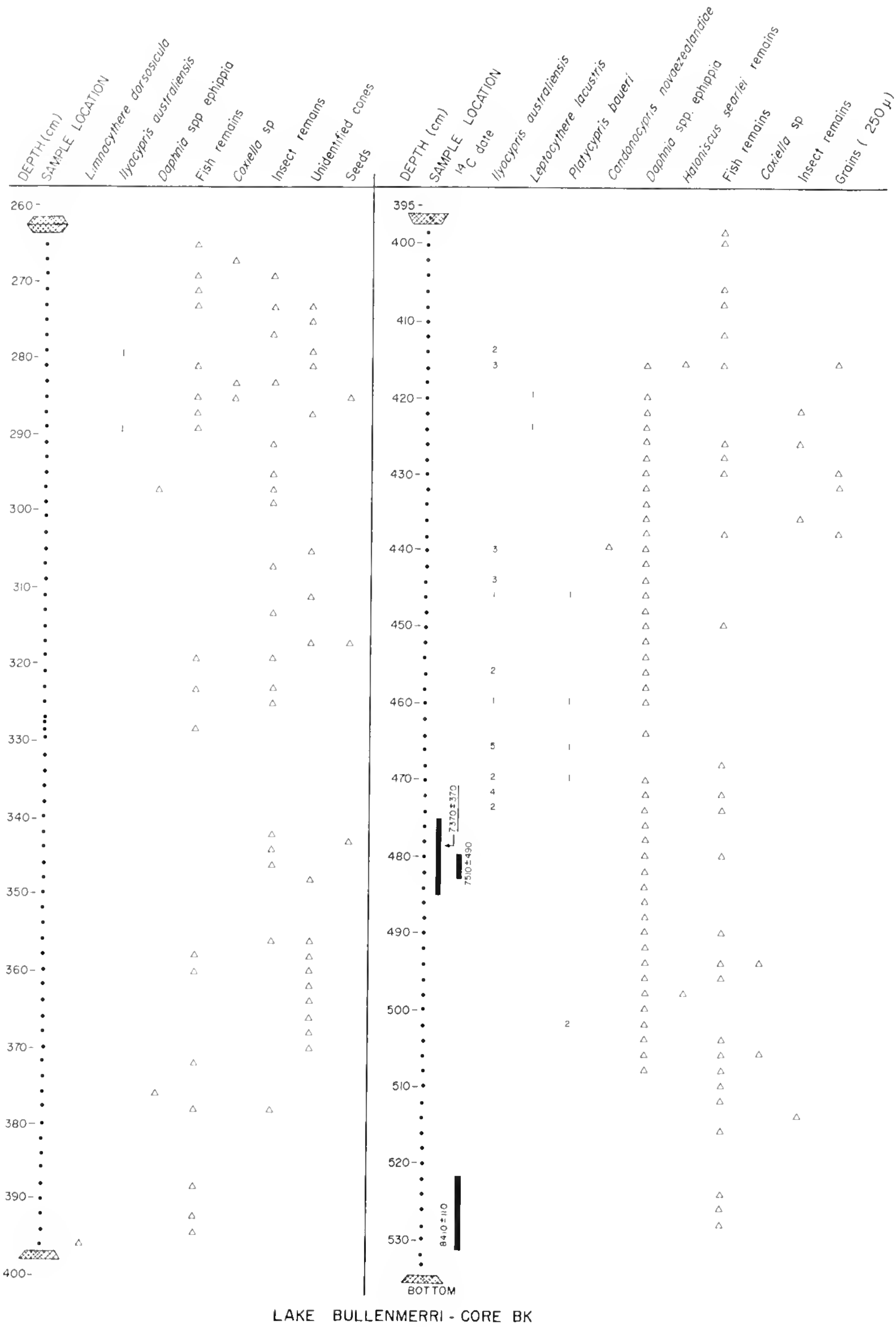


FIG. 6—(*continued*) Distribution of fossil remains and grains in the lower part of core BK from Lake Bullenmerri.

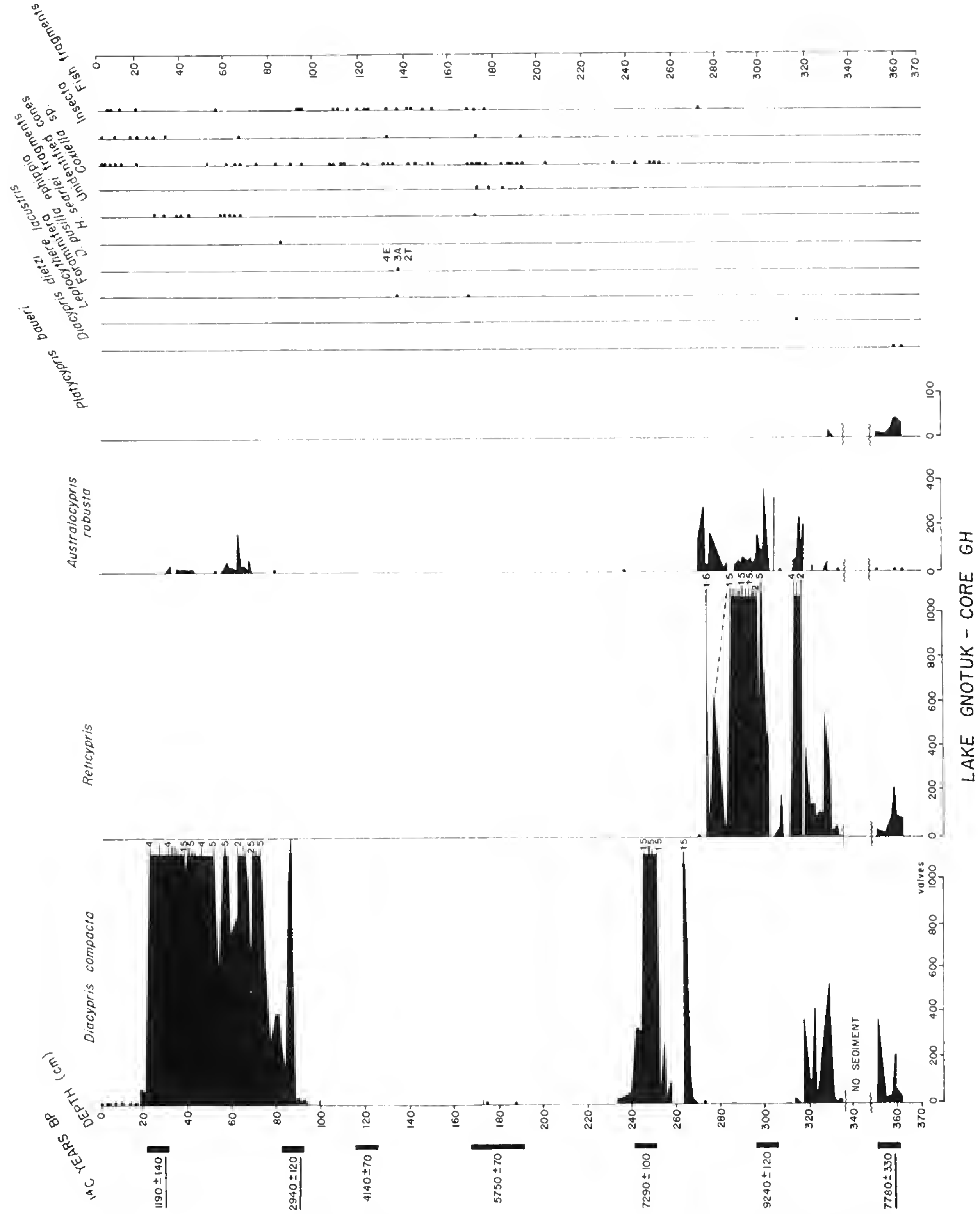


FIG. 7—Distribution of fossil ostracods and other remains in core GH from Lake Gnotuk. Numbers in the ostracod columns are the number of ostracod valves recovered per 3 gm of sediment. Dots in the other columns refer to the presence of remains recovered only in low numbers. In Foraminifera column: E = *Elphidium* sp., A = *Ammonia beccarii*, T = *Triloculina rotunda*. For ¹⁴C dates, refer to the text and caption of Fig. 6. The underlined dates are those obtained from core GH.

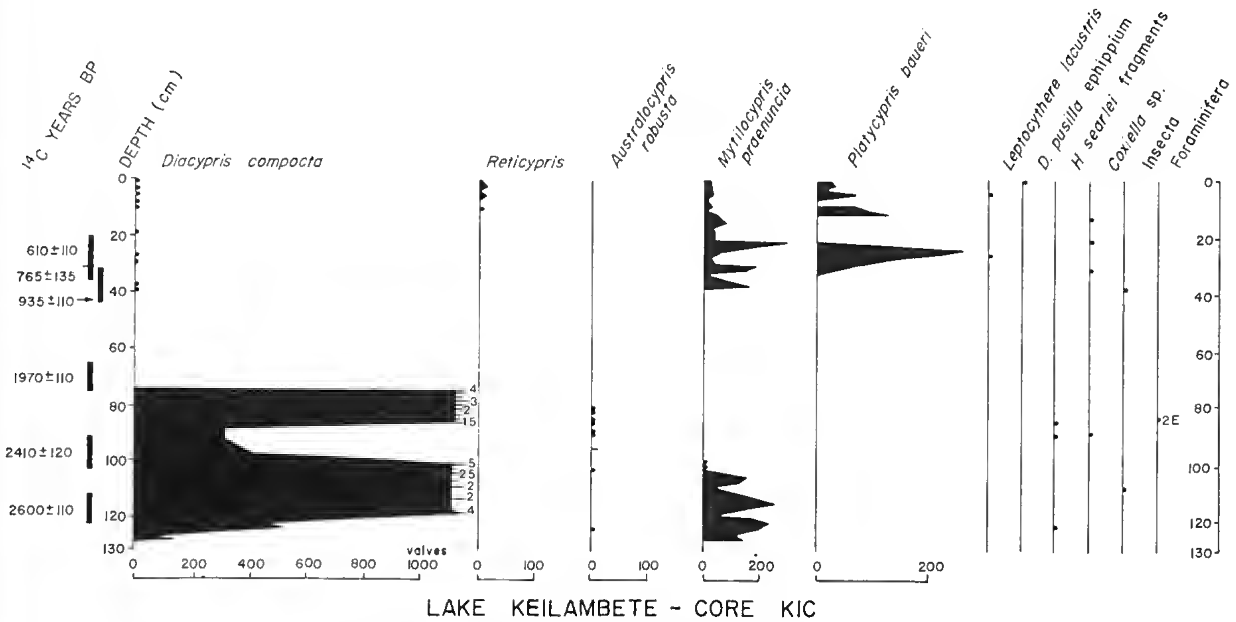


FIG. 8—Distribution of fossil ostracods and other remains in core KIC from Lake Keilambete. Some remarks as for Fig. 7 except for Foraminifera column.

saline water. Very likely it requires permanent water conditions.

Mytilocypris praenuncia (Chapman 1936)

Fig. 13A-L

1936 *Cypris praenuncia* Chapman, p. 298.
1978 *Mytilocypris praenuncia*; De Deckker, p. 24.

DESCRIPTION: Adult: valves large (ca. 3 mm), smooth, fairly thin, subtriangular in shape with a steeply inclined dorsum. Greatest height at about 0.3 from anterior; posteroventral area of shell broadly curved in lateral view. Inner lamellae broad anteriorly and posteriorly. Juvenile: more triangular in shape with posteroventral area more pointed; distance of greatest height from anterior between 0.3 and 0.5 of length.

ECOLOGY: *M. praenuncia* can swim easily but is often seen on the lake floor or in among beds of halophytic plants such as *Ruppia* sp., *Lepilaena* sp. and the charophyte *Lamprothamnium papulosum*. Its salinity range varies between 5 and 42°/oo in Victorian waters. The same species has previously been recorded in the Coorong area (De Deckker & Geddes 1980) at salinities between 12 and 35°/oo with one additional record at 43°/oo. It is usually found in samples with *P. baueri* and can occur with *Diacypris spinosa* (salinity range: 5-16°/oo) at lower salinities. As the latter species has never been found in the cores studied here the records of the fossil *M. praenuncia* probably represent the upper part of the salinity range of the species. The presence of *M. praenuncia* indicates waters of much lower salinities than for *A. robusta*.

REMARKS: *M. praenuncia* may be distinguished from *A. robusta* by its very obvious triangular shape, its broader inner lamella and its more compressed outline in dorsal view. Remarks made for large concentrations of shells of *A. robusta* on shore lines also apply for this species.

Platycypris baueri Herbst 1957

Fig. 13Z, AA-LL

1957 *Platycypris baueri* Herbst, p. 217.

DESCRIPTION: Adult: valves smooth, very thin and oval to rectangular in shape; greatest height at about 0.6 from anterior. Slightly concave ventrum about 0.3 from anterior. In dorsal view, valves very narrow. Inner lamella almost non-existent posteriorly and broad only in the anterodorsal margin. Muscle scar area minute. Juvenile: oval in largest to almost circular in smallest specimens. Faint concavity in ventral area also present 0.3 from anterior.

ECOLOGY: *P. baueri* is a good swimmer but it also burrows into soft lake sediments. It has the broadest salinity range of any ostracod found in Australia; in Victorian lakes it is 9.3-176°/oo (Geddes 1976) and 5-182°/oo (De Deckker unpubl.) and for the lakes near the Coorong Lagoon it is 5-195°/oo (De Deckker & Geddes 1980). This species occurs in low numbers at low salinities and usually is much more abundant at salinities above approximately 70°/oo (Geddes 1976, De Deckker & Geddes 1980). High water salinity of the order of 100±50°/oo is inferred when fossil *P. baueri* is found with no other ostracod species or only with *A. robusta*. On the other hand when fossil *P. baueri* is found with *M. praenuncia*, water salinity is thought to be of the range of the latter species, viz. 20-43°/oo.

REMARKS: Some specimens of *P. baueri* were recovered from the cores with both valves still attached in the hinge area (Fig. 13FF). This is surprising as valves, especially for this species, become separated fairly rapidly after death of the animal. It is suggested that these fossil carapaces belong to animals which were burrowing

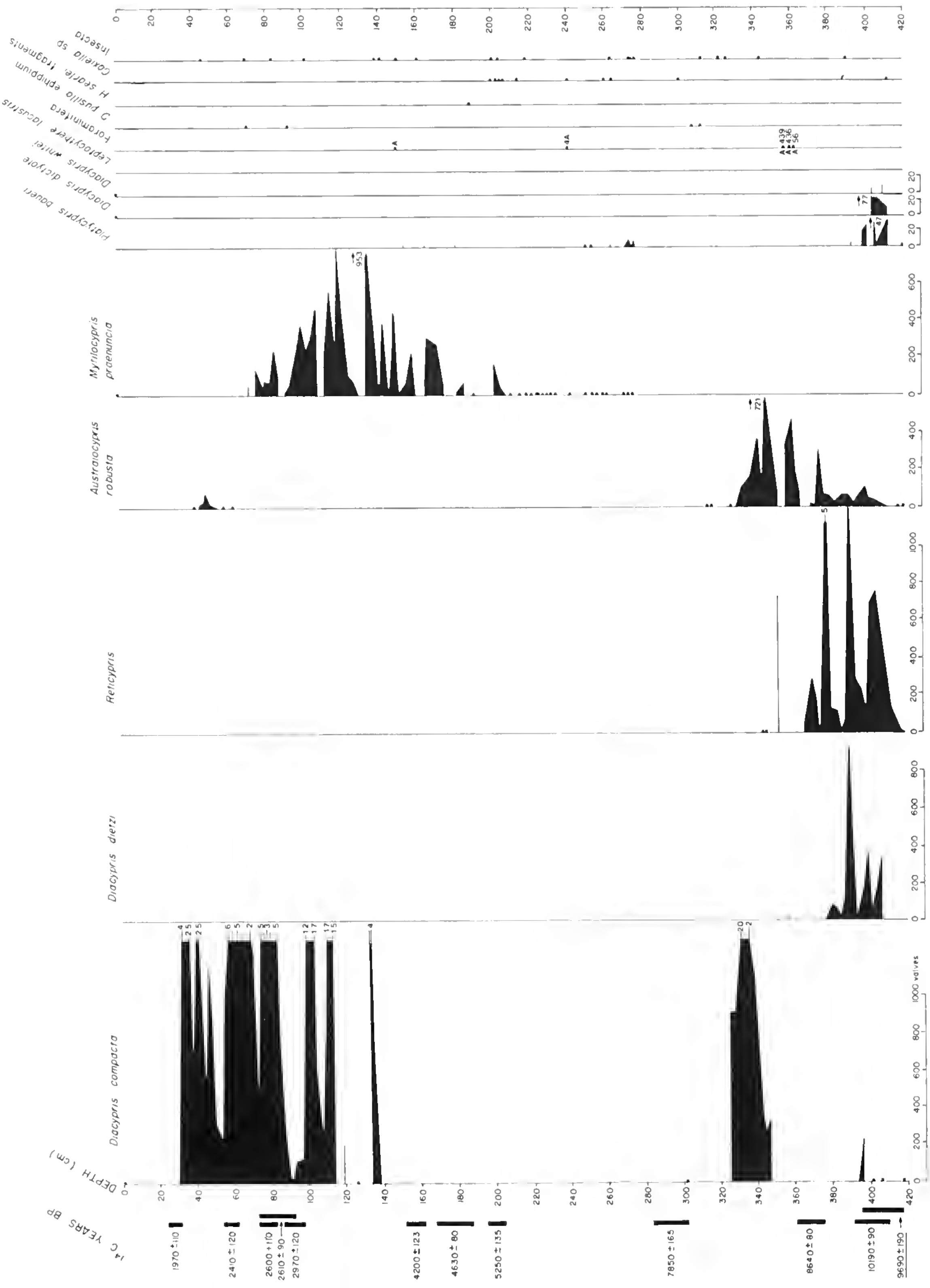


FIG. 9 – Distribution of fossil ostracods and other remains in core KG from Lake Keilambete. Some remarks as for Fig. 7 except that for ^{14}C dates, refer to Table 3. The underlined date is the only one obtained from core KG.

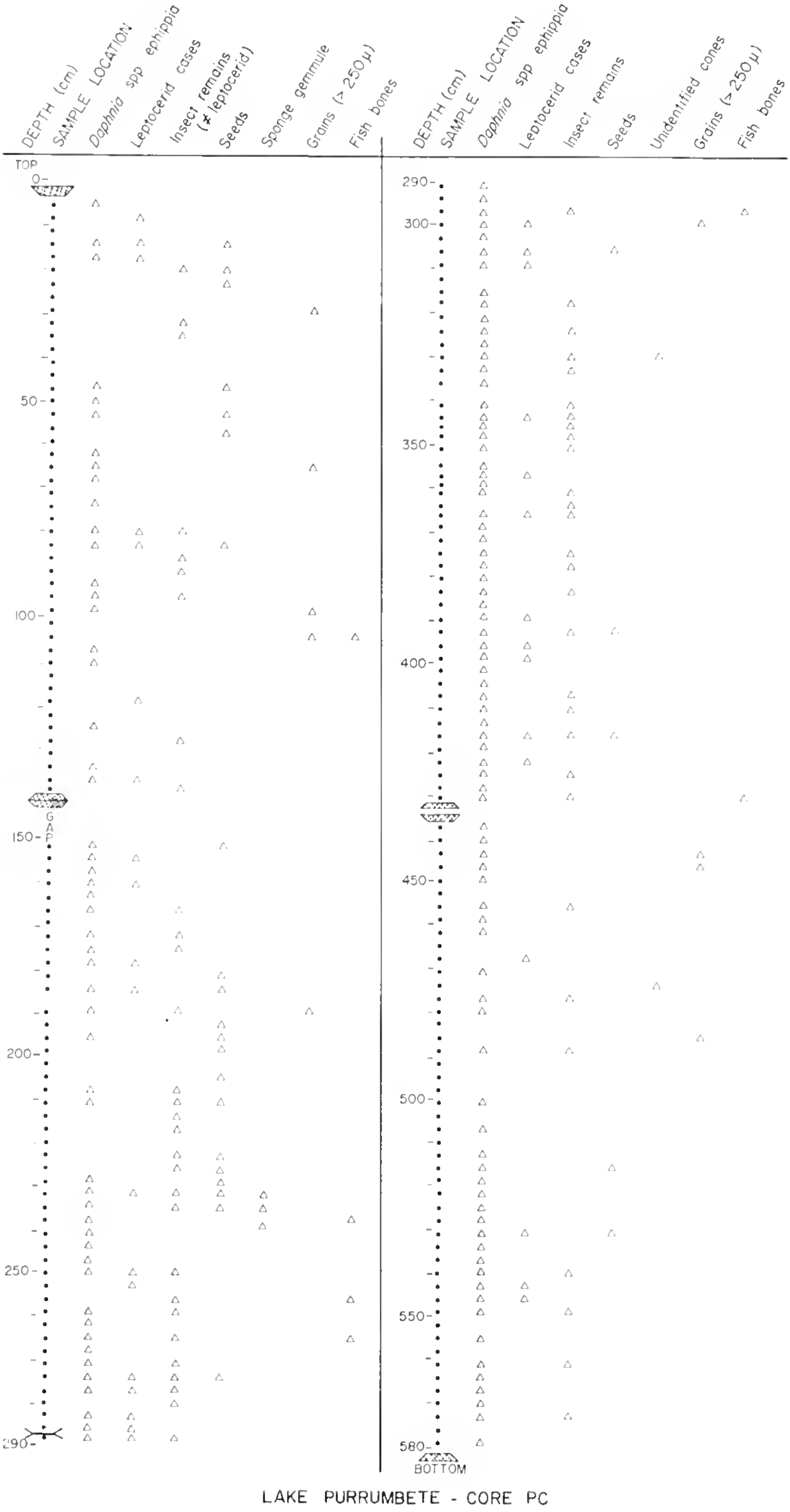


Fig. 10—Distribution of fossil remains and grains in core PC from Lake Purrumbete. Dots indicate the position of samples taken from the core. Triangles indicate only the presence of remains and grains in the core.

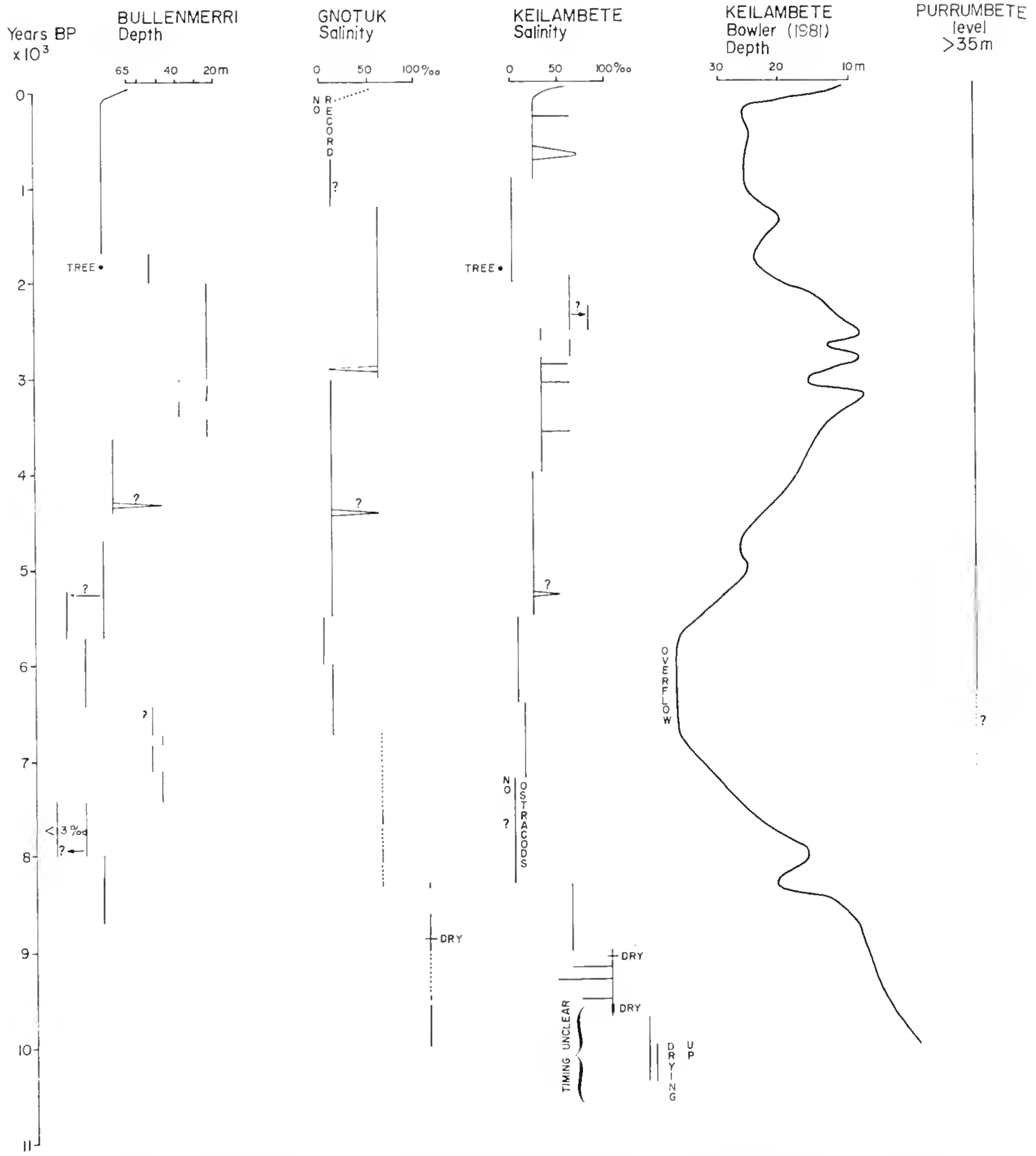


FIG. 11—Lake-level curves for Lakes Bullenmerri and Purrumbete, and salinity-level curves for Lakes Gnotuk and Keilambete postulated from the data obtained from fossil ostracods and other remains. These curves are compared with the water-level curve for Lake Keilambete of Bowler (1981).

in sediments and remained there until death. These ostracods are likely to be of a younger age than the other organisms found with them in the samples. There is however no way of controlling this possible discrepancy, unless signs of bioturbation are observed, and it will be ignored here as only few carapaces of *P. baueri* have been recovered in the cores.

Genus **Reticypris** McKenzie 1978

The species *R. herbsti* McKenzie 1978 and *R. clava* De Deckker 1981 are easily recognized on anatomical features but may not be distinguished on shell character alone. However, their fossils recovered from Lakes Gnotuk and Keilambete cores have been identified at the specific level because of their association with other ostracod species (see discussion on ecology below). The descriptive notes refer to both species.

Reticypris spp.

Fig. 14A-T, LL-MM

Description: Adult: shell subrectangular with dorsum slightly arched; valve reticulated all over except along periphery; inner lamellae broader anteriorly; greatest height of shell between 0.3 and 0.5 from anterior. Left valve larger than right one with often obvious overlap of left valve in the dorsal area. Juvenile: often shell more circular to subtriangular in shape; reticulation on shell more patchy (Fig. 14O-Q). In some specimens, ventral ridge visible on both valves.

Ecology: In collections from Victorian lakes, *R. clava* always accompanied low salinity tolerant ostracods such as *Mytilocypris splendida* or *M. praenuncia* and occasionally *Diacypris spinosa.* Salinity for these collections ranged between 4 and 42°/oo. *R. herbsti,* on the other hand, was collected in other lakes in Victoria with *D. compacta* at salinities between 99 and 172°/oo. Therefore, the absence of *D. compacta* and presence of either a *Mytilocypris* species or *D. spinosa* as fossil with *Reticypris* valves should help in identifying *R. clava.* The opposite association would point out to the presence of *R. herbsti.*

In the lakes near the Coorong Lagoon, data for both *Reticypris* species are less clear: the salinity range for *R. clava* was 5-131°/oo but it was never found in high numbers above 68°/oo; for *R. herbsti,* the salinity range was 12-141°/oo with 3 additional records at 195, 216 and 218°/oo (De Deckker & Geddes 1980). The latter species occurred in high numbers between 104 and 124°/oo. Apart from the broader ranges for each species, the salinity values at which each species was found in high numbers is similar to that for the Victorian specimens. The latter values from Victoria are used here for the interpretation of the cores.

FORAMINIFERA

Foraminifers have recently been recognized as common benthic inhabitants of salt lakes in Australia (De Deckker & Geddes 1980, Cann & De Deckker 1981). Although they may prefer salinities close to that of sea water they "survive" fluctuating salinities and some even withstand periods of lake desiccation (Cann & De Deckker 1981). Their transport into lakes like that for ostracods is probably by birds (De Deckker 1977).

Some of the foraminifer species found in the cores can survive periods of desiccation, e.g. *Elphidium* sp. *sensu* Cann & De Deckker (1981) whereas others apparently cannot as they are only found in permanent water e.g. *Ammonia beccarii* and *Triloculina rotunda.*

Ammonia beccarii (Linné 1758)

Fig. 15W-Z, AA-FF

1758 *Nautilus beccarii* Linné, p. 710.

1949 *Ammonia beccarii*; Frizzell & Keen, p. 106.

Description: Finely perforated, trochospiral text more convex dorsally; sutures usually thick and smooth; ventrally gradation of umbilicus from empty to a plug and often finely to coarsely spinose. Some aberrant growth forms (Fig. 15BB, FF) have been found in some samples.

Ecology: This cosmopolitan species indicates a salinity close to that of sea water, although it is known to survive a broad range of salinities, from 7-67°/oo (Bradshaw 1957). It only reproduces and grows best at salinities between 20-40°/oo (Bradshaw 1957). At level 362-367 cm in core KG from Lake Keilambete, the large number of specimens of all sizes of *A. beccarii* represent a series of thriving populations and indicates a salinity similar to that of sea water.

Discorbis sp.

Fig. 15GG

Remarks: One specimen was found at level GH135 in the Lake Gnotuk core. This species has not been found in present day salt lakes.

Elphidium sp. *sensu* Cann & De Deckker 1981

Fig. 15Q-R, U-V

Description: See Cann & De Decker (1981).

Ecology: The salinity range of this species is not yet known although it is known to "survive" high salinities: at 88°/oo no pseudopodia were seen protruding from the test but the same specimens, put in sea water, became active (Cann & De Deckker 1981).

Triloculina rotunda d'Orbigny 1893

Fig. 15S-T

1893 *Triloculina rotunda* d'Orbigny, p. 20.

Description: Test triloculine, oval in shape, flattened at aperture and ellipsoidal in section. Aperture with narrow bifid tooth.

Ecology: This species is rare in the core samples and has only been collected in a lake with a salinity range of 17-24°/oo and in permanent water. *T. rotunda* was never found in the ephemeral Coorong lakes samples, collected over a year by De Deckker & Geddes (1980).

MOLLUSCA

Only shells (no opercula) of the halobiont gastropod *Coxiella* sp. have been recovered in the cores. The gastropod *Potamopyrgus niger* (Quoy & Gaimard 1835) and the bivalve *Sphaerium* sp., are both found today in Lake Purrumbete (Timms 1981) and their absence in the cores has some relevance to the lake histories.

Coxiella sp.

Fig. 17P-Z, DD-EE

Description: Conical to elongate shell with up to 7 whorls; round to oval aperture with broad lip in adults; extent of umbilicus variable; shell finely ribbed and sutures deep. Up to 10 mm in length.

Ecology: Species of *Coxiella* can withstand lake desiccation phases and also survive high salinity ranges by sealing their aperture with the operculum. No salinity information can be obtained from their fossils except that they exclude fresh water as *Coxiella* is a halobiont genus. In lakes below 100°/oo salinity *Coxiella* spp. often graze on algal mats or crawl in among halophytic grasses such as *Ruppia* sp., *Lepilaena* sp. and the charophyte *Lamprothamnium papulosum.* Live specimens of *Coxiella* have never been found at great water depths: in Lake Bullenmerri, Timms (1973, 1981) collected juveniles (length <5 mm) of *Coxiella striata* (Reeve 1842) down to 25 m and larger specimens of the same species rarely below 6 m. He also recorded large numbers of emptied juvenile shells between depths of 12 and 25 m. Consequently, a large concentration of adult *Coxiella* shells in cores (e.g. 201.5-202.5 cm in core KG from Lake Keilambete) very likely indicates that lake depth was probably less than 25 m and most probably less than 6 m.

After death of the animals, shells become filled with gas resulting from body decay and float and are often blown by the wind onto the lake shore. As a result extensive layers of *Coxiella* shells are common on many lake shores. Such layers should easily be recognized in cores. Juveniles of *Coxiella,* on the other hand, have been seen to float upside down at the surface tension in some lakes. Their failure to remain near the surface and subsequent death by sinking to the bottom of the lake, would explain the presence of few shells of juveniles found in a number of samples: their occurrence in sediments in this case adds no information on the depth of the lake at the time of their death.

REMARKS: As pointed out by Mellor (1979) and De Deckker & Geddes (1980), the taxonomy of all *Coxiella* species is in a confused state. Doubt is now placed on the value of previously considered diagnostic features of the shell and this is the reason for which no specific identification is attempted here. See Fig. 17P-Z for an illustration of variations in shell morphology.

Timms' data (1973, 1981) on *C. striata* found living in Lake Bullenmerri today are used to interpret the fossil material. Ecological requirements are likely to be similar for both fossil and living material.

Chapman (1919) identified the fossil *Coxiella striatula* (Menke 1842) from the Pleistocene (*sic* Chapman 1919) deposit at Bonco Swamp in Victoria but gave no consideration to the fact that it is found with other molluscs, apparently freshwater inhabitants.

The freshwater gastropod *Potamopyrgus niger* (Quoy & Gaimard 1835) occurs in Lake Purrumbete (Timms 1973, 1981) over a wide depth range (0.5-35 m) but is most common between 1 and 6 m (Timms 1973). As this gastropod was never recorded in any of the cores, it appears that especially in the case of Lake Purrumbete, which is thought to have remained fresh for the period represented in the entire core, the shore of the lake has never been close to the coring site, otherwise shells of *P. niger* would have been found. This remark also applies to the freshwater bivalve *Sphaerium* sp., found today in Lake Purrumbete between 0.5 and 22.5 m in depth (Timms 1981) but never recovered in any of the cores.

CLADOCERA

Only ephippial sac remains have been recorded from the cores—cuticular fragments of cladocerans were noticed in some samples but were not studied further. Two main types of ephippium were found: one belonging to the halobiont *Daphniopsis pusilla* and the other to the mainly freshwater inhabitant *Daphnia* spp.

Daphniopsis pusilla Serventy 1929

Fig. 16A-D

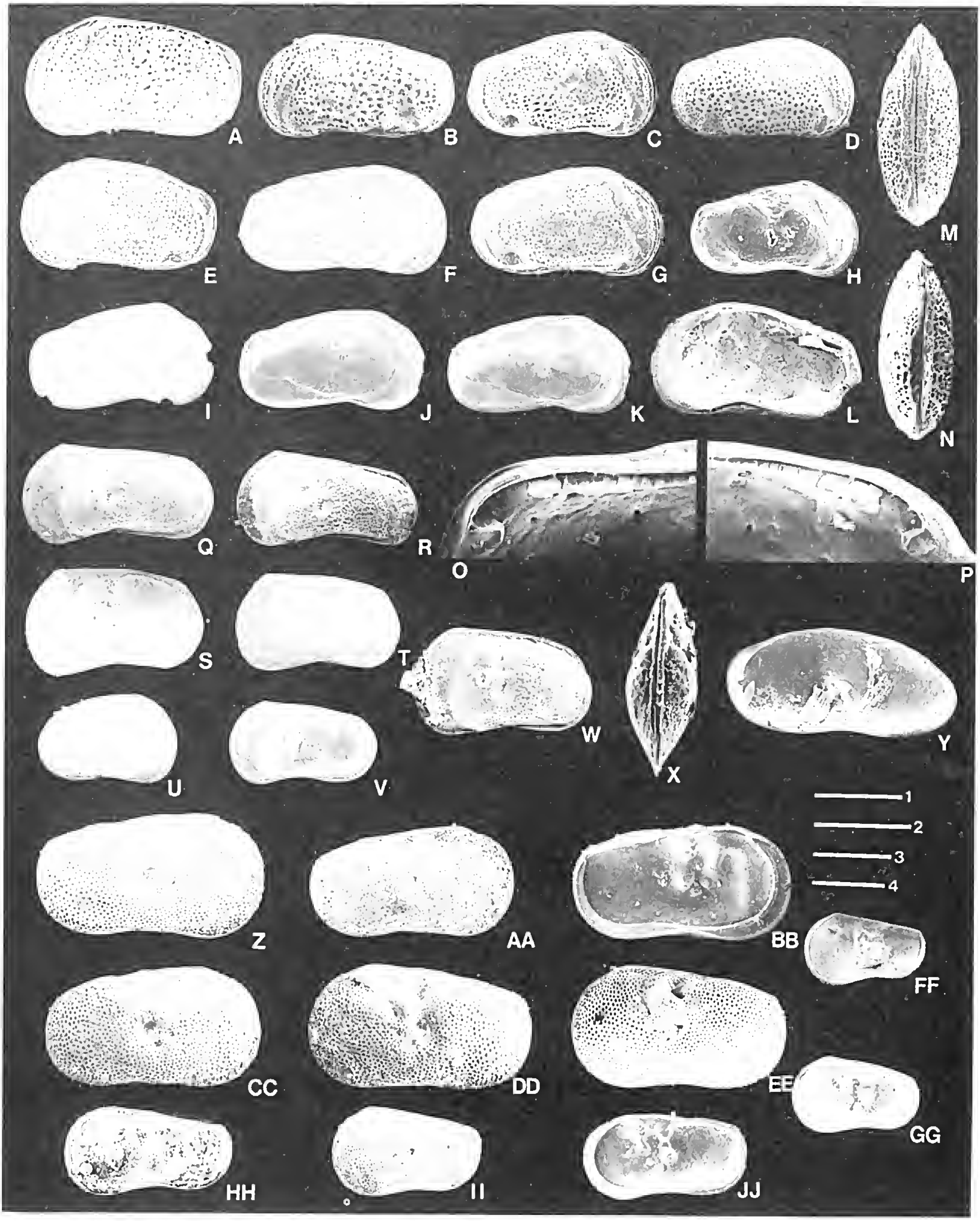
1929 *Daphniopsis pusilla* Serventy, p. 65.

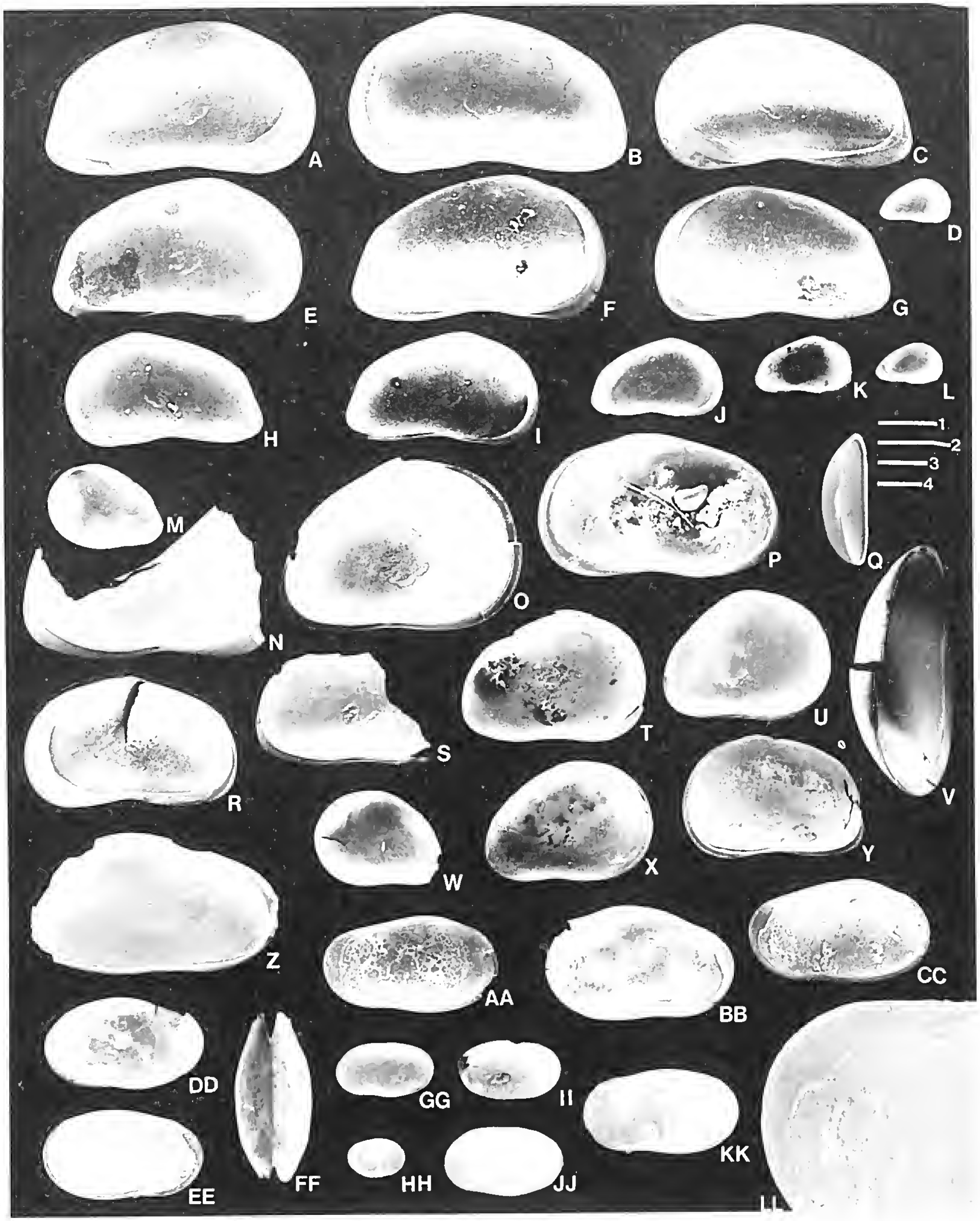
DESCRIPTION OF EPHIPPIUM: Ephippial sac almost rectangular and asymmetrical: posterior side forming almost a right angle with small extension of dorsal chitinous rod (which is occasionally bifid) whereas anterior side forming an acute angle with the longer and often bifid chitinous rod. Greatest length of ephippial sac at about 0.65 from its dorsal side. In dorsal view, very compressed.

ECOLOGY: The ecology of *D. pusilla,* which is endemic to Australia, has been recently reviewed by De Deckker & Geddes (1980). The salinity range of this cladoceran in the lakes near the Coorong is 5.8-68.1°/oo, although few specimens were recorded at the 68.1°/oo. Geddes (1976) noted that hatching of the species occurred between 4.4 and 33.4°/oo. The presence of ephippial sacs at a particular level in a core should imply that the lake water had been at some stage between 4.4 and 33.4°/oo for that level. On lake floors today, occasional bundles of 20 or more ephippial sacs of *D. pusilla* entangled together by the bifid chitinous rods are found. This phenomenon was not observed in fossil material.

REMARKS: The most diagnostic feature of the ephippium for this species is the acute angle formed by the anterior dorsal chitinous rod and the anterior side of the ephippial sac.

FIG. 12—A-O, *Leptocythere lacustris* De Deckker 1981. A, LV external, BK 159. B, LV external, BK 210. C, RV external, KIC 27. D, RV external, BK 210. E, LV external, GH 135. F, RV external, BK 177. G, RV external, GH 135. H, LV internal, KIC 5. I, LV internal, BK 187. J, LV internal, BK 210. K, LV internal, BK 210. L, RV internal, BK 187. M, C dorsal, GH 135. N, C dorsal, GH 135. O, LV internal, hinge posterior of I. P, LV internal, hinge anterior of I. Q-X, *Limnocythere dorsosicula* De Deckker 1981. Q, LV external, male, BK 187. R, LV external, male, BK 171. S, LV external, female, BK 210. T, LV external, female, BK 206. U, RV external, juvenile (female?), BK 210. V, LV external, juvenile (male?), BK 210. W, LV external, female, BK 175. X, C dorsal, BK 182.5. Y, *Candonocypris novaezelandiae* (Baird 1843), RV internal, juv., BK 17. Z, AA-II, *Ilyocypris australiensis* Sars 1889, Z, RV external, BK 187. AA, RV external, BK 187. BB, LV internal, BK 470. CC, RV external, BK 210. DD, LV external, BK 210. EE, LV external, BK 472. FF, RV internal, juv., BK 193. GG, LV external, juv., BK 158. HH, RV internal, juvenile male, BK 206. II, RV internal, juv., BK 189. JJ, RV internal, juv., BK 193.
Scales: 1-200 μm for A-N; 2-50 μm for O-P; 3-200 μm for Q-Y; 4-250 μm for Z-JJ. Note: BK, GH, KIC, GH, PC = Core label followed by depth in cm from top of core. C = carapace; LV, RV = left and right valves; juv. = juvenile.


A
B
C
D
M
E
F
G
H
I
J
K
L
N
Q
R
O
P
S
T
W
X
Y
U
V
1
2
3
4
Z
AA
BB
FF
CC
DD
EE
GG
HH
II
JJ


A
B
C
D
E
F
G
H
I
J
K
L
1
2
3
4
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB
CC
DD
FF
GG
II
KK
EE
HH
JJ
LL

Daphnia spp.

Fig. 16E-H

Description of ephippium: Epphipial sac ellipsoid in shape and at least twice as long as wide; in dorsal view narrow to bulbous; external surface sometimes faintly reticulated. Dorsal chitinous rod longer anteriorly and forming a right angle with posterior side of the ephippial sac; posterior angle obtuse. Internal capsule often with a ridge along its periphery (broadest anteriorly and posteriorly) and with a vertical groove in the middle separating the two egg spaces; external surface of capsule reticulated.

Ecology: No identification at the species level of ephippial sacs of daphniid species is yet possible. Their presence, however, indicates a water salinity between fresh and 5.8°/oo. The upper record refers to a collection made in January 1980 from a small lake near Lake Coragulac in Victoria. Five records of *Daphnia* spp. observed in a survey of 79 lakes during the same period, ranged between 1.90 and 4.91°/oo. *Daphnia carinata* King 1853 was recorded by Geddes *et al.* (1981) from three localities in Western Australia where salinity values ranged between 3.57 and 4.76°/oo. The value of 5.8°/oo is the upper value recorded so far in Australia for a *Daphnia* species and it will be regarded as the maximum value for the fossil material studied here.

Remarks: Sars (1885) accurately illustrated the morphology of the ephippium of *D. lumholtzii* Sars 1885 by providing adequate illustrations of ephippial sacs and internal egg capsules. These resemble the material recovered from the Lakes Bullenmerri and Purrumbete cores, but the latter deflated or partly shrunk after the drying process prior to picking and preparation for SEM photography. However, Sars' illustrations show a double row of tiny spines along the dorsal chitinous rod attached to the ephippial sac. These were rarely seen on the specimens recovered from the cores (e.g. Fig. 16F). No further identification has been carried out.

Isopoda

Remains of the aquatic halobiont isopod *Haloniscus searlei* have been recovered from a number of core samples and are described below.

Haloniscus searlei Chilton 1920

Fig. 15HH-PP

1920 *Haloniscus searlei* Chilton, p. 724.

Description of remains found in the cores:

Cones: Slightly curved and hollow, partly calcareous? and brittle; external surface consisting of parallel rows of disconnected and alternating faint and arched grooves; some with occasional rimmed triangular pores with two small pores inside and one at base of triangle. The cones with pores correspond to distal segments of the posterior appendages of the animal, and those without pores belong to spines attached to the telson.

Others: These are of various shapes and are illustrated in Fig. 15KK-PP. The fragment illustrated in Fig. 15MM is a proximal segment of one of the appendages whereas fragments illustrated in Fig. 15NN-PP are thought to be part of ventral parts of the animal's head. In most cases, the external surface of these fragments is characterized by faint grooves similar to those found on the cones (Fig. 15HH-II).

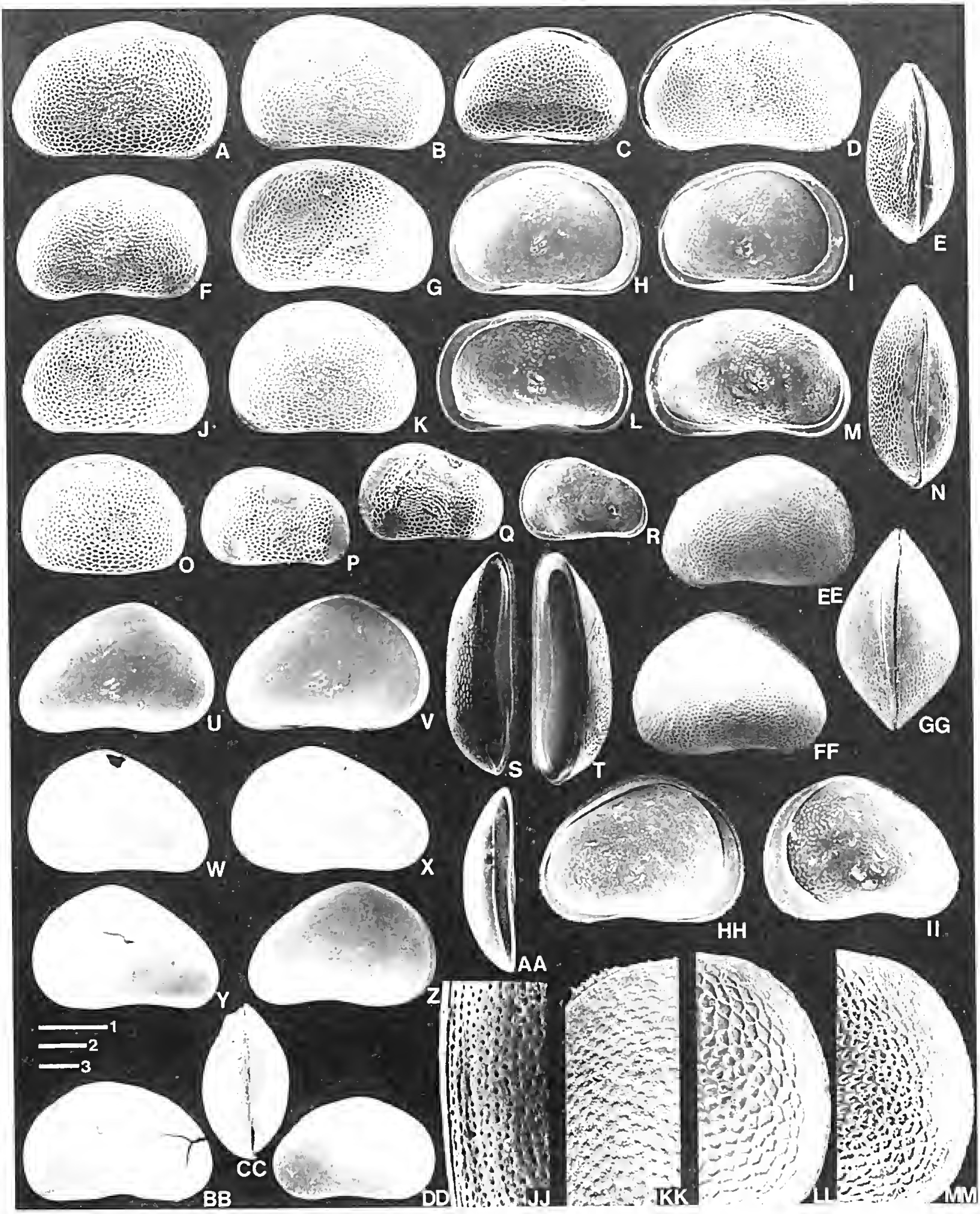
Ecology: The biology of *Haloniscus searlei* has been thoroughly reviewed recently by Williams (in prep.). It is an Australian endemic oniscoid isopod which is aquatic and tolerates a high range of water salinities: 3.6-191.7°/oo. It is also known to survive periods of lake desiccation (De Deckker & Geddes 1980, Williams in prep.).

Remarks: Similar fragments have been found in other lacustrine deposits (Pillie Lake in South Australia) (De Deckker *et al.* 1982). Their presence cannot provide much ecological information as *H. searlei* is found in both ephemeral and permanent saline lakes. Although *H. searlei* occurs in ephemeral lakes, annual rainfall is necessary each year for the animal to survive as it cannot survive complete desiccation (Ellis & Williams 1970). This explains its absence in Central Australian lakes which are dry for long periods.

Porifera

Only three specimens of the asexual reproductive bodies of spongillid sponges have been recovered from the Lake Purrumbete core. These gemmules are all distinct and will be briefly described below. They all

Fig. 13 – A-L, *Mytilocypris praenuncia* (Chapman 1936). A, LV internal, KG 135.5. B, RV internal, KG 135.5. C, RV internal, KG 135.5. D, RV external, juv., KG 201.5. E, LV internal, KG 164.5. F, LV internal, KG 181.5. G, RV internal, KG 181.5. H, RV internal, juv., KG 201.5. I, LV internal, juv., KG 135.5. J, LV internal, juv., KG 135.5. K, LV internal, juv., KG 135.5. L, RV external, juv., KG 135.5. M-Y, *Australocypris robusta* De Deckker 1974. M, LV external, juv., KG 380. N, LV internal, fragment, GH 62.5. O, LV internal, juv., KG 362. P, RV internal, GH 300.5 (note juvenile *Diacypris* sp. inside). Q, LV dorsal, juv., KG 377. R, RV internal, KG 362. S, LV internal, fragment, KIC 95. T, RV external, juv., KIC 95. U, LV internal, juv., KIC 95. V, LV dorsal, juv., KG 360. W, LV external, partly broken, juv., KG 360. X, RV external, juv., KG 360. Y, RV internal, partly broken, KG 360. Z-LL, *Platycypris baueri* Herbst 1957. Z, LV internal, partly broken, juv., KG 274. AA, RV internal, partly broken, KG 404. BB, LV internal, partly broken, KG 404. CC, RV internal, KG 404. DD, RV internal, juv., KG 393. EE, LV internal, juv., KG 393. FF, C dorsal, KIC 26. GG, LV external, juv., KIC 26. HH, LV external, juv., KIC 26. II, RV external, juv., KIC 26. JJ, LV external, ? juv., KIC 26. KK, LV external, KIC 26. LL, RV internal, anterior detail of CC.
Scales: 1-1 000 µm for A-L, N, P-T, Y; 2-500 µm for M, U, AA-KK; 3-500 µm for O and 250 µm for V; 4-100 µm for LL.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
EE
S
T
U
V
GG
FF
W
X
AA
HH
II
Y
Z
1
2
3
CC
BB
DD
JJ
KK
LL
MM

belong to the Australasian genus *Heterorotula* Penney & Racek 1968. All three indicate freshwater conditions as none respond to the description of *H. capewelli* (Bowerbank 1863) which is known to tolerate athalassic saline environments from Central Australia to the Dividing Range (Racek 1969).

Heterorotula nigra (Lendenfeld 1887) (Fig. 16P-R) is distinguished by the usually granulated gemmosceleral shafts and the absence of megascleres from the pneumatic layer. The foramen has not been examined.

Heterorotula multidentata (Weltner 1895) (Fig. 16O-T) is recognized here by its smooth to microspined megascleres and the occasional reinforcement of the outer coat of the pneumatic layer by megascleres. The foramen is simple and bears no collar.

The gemmule of *Heterorotula* sp. (Fig. 16N,S) resembles *H. capewelli* as many megascleres are present around its periphery. It is distinguished from the latter species on the following details: the gemoscleres are present only on the outside of the pneumatic layer in *H. capewelli* (for comparison see Penney & Racek 1968, Plate 8, Fig. 5); the megascleres in *H.* sp. are more pectinate and the edge of the gemmosclere rotules is spinose rather than crenulate as in *H. capewelli.*

REMARKS: Few megascleres, cemented on trichopteran cases were noticed in samples from the Lake Purrumbete core (Fig. 17FF-HH). These belong to *Heterorotula* spp., and although megascleres recovered from lacustrine sediments can provide some palaeoecological information as already demonstrated by Racek (1966) for Guatemalan material, no similar attempt was made to systematically recover spongillid remains.

No remains of *Radiospongilla sceptioides* (Haswell 1882) have been found in the cores even though the species has been recorded twice from Lake Purrumbete (Nov. 1969, May 1970) by Timms (1973, 1981).

VERTEBRATA

Four types of fish remains were recovered from the cores: jaw bones, scales, otoliths and other bone fragments. Only some items of the first type could be identified and subsequently provide palaeoecological information. The other remains in lakes Bullenmerri, Gnotuk and Keilambete, which are not connected to rivers indicate permanent water when fish were present.

Two categories of jaws are recognized: those with a single or a double row of teeth (Fig. 17A-C, F-G) and those with more than two rows along most of their length (Fig. 17E, I-J). For their classification see Table 2. Also a few remains bearing teeth (Fig. 17D, H, L) are identified as being part of the mouth of fishes—they usually consist of straight rods with fewer teeth and occasionally have a flat base (Fig. 17D); others are large vomer plates covered with many teeth (Fig. 17H). Only the latter could not be identified at the generic level.

Table 2 lists also the species which are found today in Lakes Bullenmerri and Purrumbete. In addition, the hardyhead *Craterocehalus stercusmuscarum* (Guenther 1867) is also listed as it is a common inhabitant of slightly saline lakes in Victoria. The following palaeoecological information can be obtained from the fossil material: jaws with more than two rows of teeth belong to fish which live in water of salinities between <3 and 13.4°/oo; for the other jaws, the salinity range referred to lies between <3 and 30.3°/oo.

Although Lake Gnotuk is devoid of fish today very likely fish would more easily be introduced in it, compared to Lake Keilambete, as the former lake can receive overflowing waters from the adjacent less saline Lake Bullenmerri. The record of two fish species (see Table 2) from Lake Gnotuk in 1916 probably resulted from the last overflow recorded in 1841. As the lake level dropped continuously since 1841 (Currey 1970), salinity would have progressively increased and eventually fish would not have been able to survive the highly saline waters such as those found today. Salinity of Lake Gnotuk was between 3-13.4°/oo at the time of deposition of level 6.5 cm (see Fig. 7), a period probably following an overflow from Lake Bullenmerri as jaws with more than two rows of teeth are found in the samples. Such an overflow must have occurred on a number of occasions since fish remains are sparsely distributed in the upper 200 cm of the Lake Gnotuk core.

DIPTERA-CHIRONOMIDAE

Head capsules, mandibles and labia of chironomid larvae can be useful in tracing past changes of lake productivity as a number of chironomid species are very sensitive to changes of sediment types and oxygen concentration. The only work dealing with the recovery of chironomids in Australia is that of Paterson & Walker

FIG. 14—A-T, LL-MM, *Reticypris*. A, RV external, KG 372. B, LV external, KG 372. C, C showing RV, juv., KG 372. D, C showing RV, KG 372. E, C dorsal, KG 372. F, RV external, KG 372. G, LV external, KG 351.5. H, LV internal, KG 372. I, LV internal, KG 351.5. J, RV external, KG 372. K, LV external, KG 372. L, RV internal, KG 351.5. M, RV internal, KG 351.5. N, C ventral, KG 351.5. O, LV external, juv., KG 372. P, LV external, juv., KG 372. Q, LV external, juv., KG 372. R, RV internal, juv., KG 351.5. S, LV dorsal, KG 351.5. T, RV dorsal, KG 351.5. LL, RV external, anterior detail of J. MM, RV external, anterior of F. U-Z, AA, JJ, *Diacypris dietzi* (Herbst 1958). U, LV internal, KG 393. V, LV internal, KG 393. W, LV external, KG 398.5. X, LV external, KG 398.5. Y, LV external, KG 398.5. Z, RV external, KG 398.5. AA, LV dorsal, KG 398.5. JJ, LV external, anterior detail of U. BB-DD, *Diacypris whitei* (Herbst 1958). BB, LV external, KG 410. CC, C dorsal (note valves dislocated), KG 410. DD, RV external, KG 410. EE-II, KK, *Diacypris dictyote* De Deckker 1981. EE, RV external, KG 410. FF, LV external, KG 410. GG, C dorsal, KG 410. HH, LV internal, KG 410. II, RV internal, KG 410. KK, LV external, anterior detail of FF.

Scales: 1-20 μm for A-T; 2-250 μm for U-Z, AA-II and 20 μm for JJ and 10 μm for KK; 3-50 μm for LL-MM.

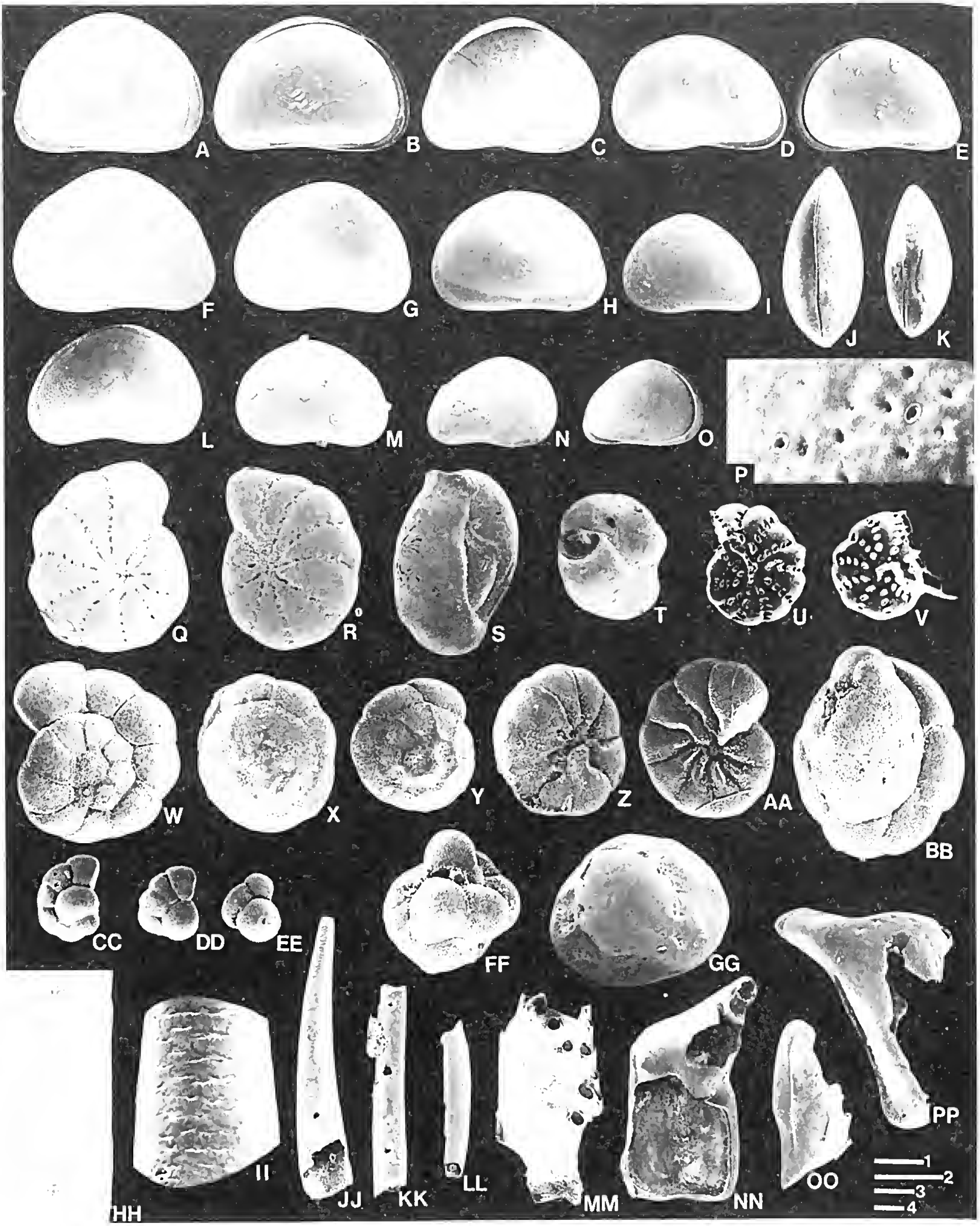

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB
CC
DD
EE
FF
GG
HH
II
JJ
KK
LL
MM
NN
OO
PP
1
2
3
4

TABLE 2

NATIVE FISHES IN THE MAAR LAKES WITH NOTES ON SALINITY TOLERANCE OF EACH SPECIES AND ON JAW MORPHOLOGY

	Present day occurrence[1,2]				Salinity tolerance	Type of Jaws		
	Lake Purrumbete	Lake Bullenmerri	Lake Gnotuk	Lake Keilambete	°/oo[2]	single or double row	more than double row along most of length of jaw	vomer plate with many teeth
Philypnodon grandiceps	+	+	$+^3$		<3-7.3		+	
Pseudophrites urvilli	+	+	$+^3$		<3-3.3	+	+	
Nannoperca australis	+				<3-3.3		+	
Anguilla australis occidentalis	+	none found[2]	none found[2]		<3-13.4[5]		+	+
Galaxias maculatus	+				<3-30.3			
Retropinna victoriae	+				<3-8.8			
Craterocephalus stercusmuscarum					<3-8.8[4]			

[1] Timms (1973); [2] Chessman & Williams (1974); [3] Timms (1973) said that these two species were collected once from L. Gnotuk on 8.12.1916—record from National Museum of Victoria; [4] *Craterocephalus eyeresii* (salinity 3.8-30.9°/oo in Chessman & Williams (1974) and up to 110°/oo in Glover & Sim (1978) has been recorded in the Murray Darling drainage system in northern Victoria. This species will be ignored here as it has not been recorded in any of the salt lakes in central Victoria; [5] Record for *A.* cf. *australis* in Chessman & Williams (1974).

(1974) from Lake Werowrap in Western Victoria. They recovered head capsules of *Procladius paludicola, Chironomus duplex* and *Tanytarsus barbitarsis* from two one metre long cores. The latter two species were mutually exclusive. *T. barbitarsis* appears to be restricted to highly saline waters (in Victoria up to 82°/oo—Paterson & Walker 1974) whereas *C. duplex* is an indicator of a freshwater condition, although it has been found by these authors in Lake Coragulac between ca. 5.1-5.8°/oo.

In the present study, only three head capsules were found; they could not be identified. They are illustrated in Fig. 16 I-M. This paucity of material might result from the treatment of the samples with dilute hydrogen peroxide which is inappropriate for the recovery of chironomid remains.

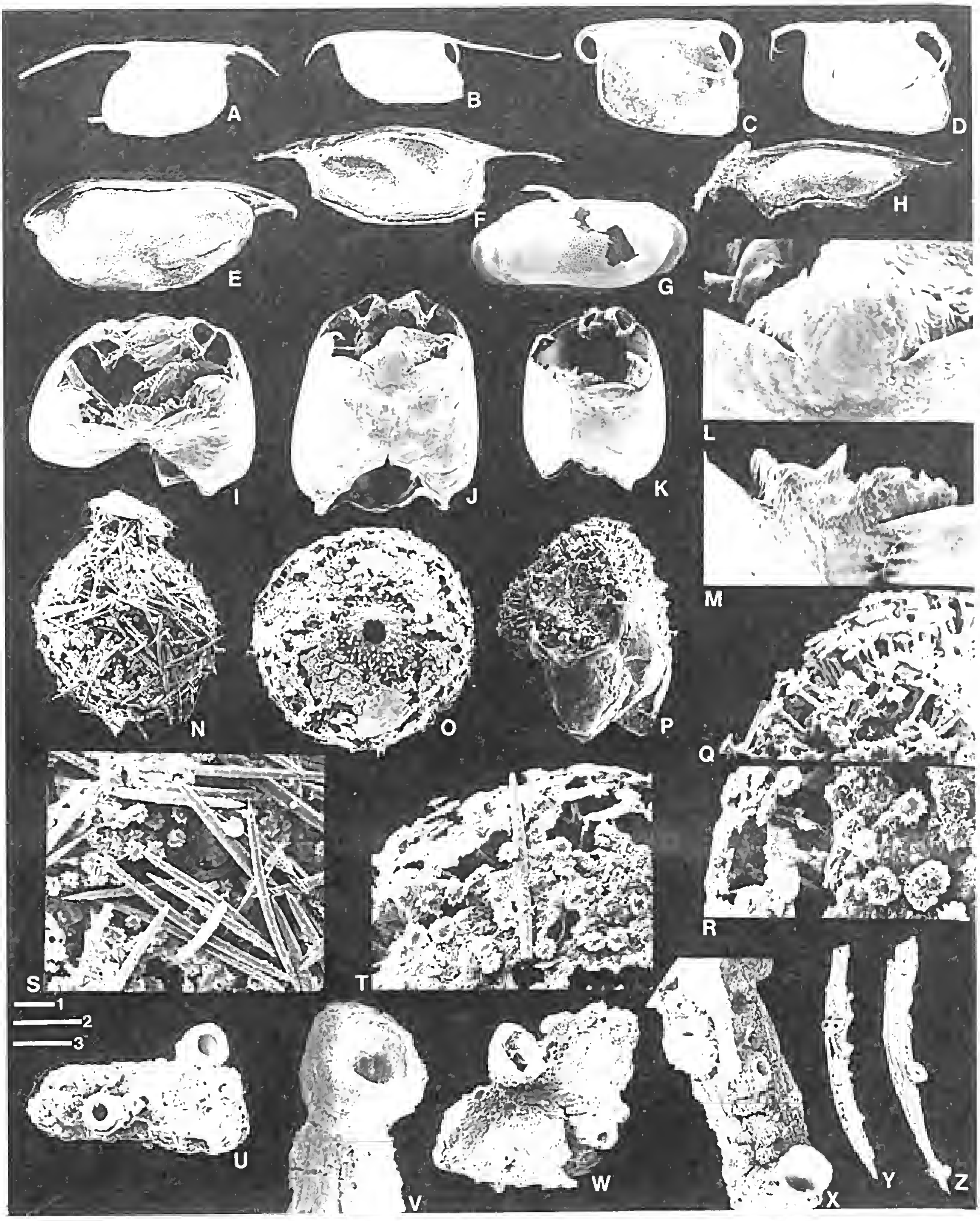
COLEOPTERA

Many fragments of beetles have been recovered but none have been identified. It is of interest to note that their occurrence, in the cores of Lakes Gnotuk and Keilambete, corresponds to the less saline water phases as extrapolated from other fossil remains such as ostracods and pollen. No systematic search for coleopteran remains was conducted; only large fragments such as elitra, thoraxes, and more rarely cephalon fragments and some appendages were noted.

TRICHOPTERA

Only cases of trichopterans were found in samples from Lakes Bullenmerri and Purrumbete (Fig. 17 AA-CC, FF-HH). These most likely belong to the family Leptoceridae (A. Neboiss pers. comm.). Some leptocerids are good swimmers and therefore their presence in the samples is not surprising even for those which are thought to have been deposited in deep water (>30 m) far away from the shore. The leptocerid cases found here cannot be indicative of water quality as some species also occur in saline waters. It is worth noting, however, that no leptocerid cases have been found in

FIG. 15—A-P, *Diacypris compacta* (Herbst 1958). A, LV internal, GH 62.5. B, LV internal, KG 346. C, LV internal, GH 361. D, RV internal, KG 338. E, RV internal, juv., GH 62.5. F, LV external, GH 350. G, LV external, KG 346. H, LV external, KG 338. I, LV external, juv., GH 350. J, C dorsal, KG 338. K, C ventral, KG 338. L, RV external, KG 47.5. M, LV external, KG 39.5 (note aragonite crystals). N, RV external, KG 39.5. O, LV internal, juv., GH 62.5. P, RV external, detail of L. Q-R, U-V, *Elphidium* sp. Q, side view, GH 135. R, side view, GH 135. U, side view, KIC 104. V, side view, KIC 104. S-T, *Triloculina rotunda d'Orbigny 1893*. S, side view, GH 135. T, apertural view, GH 135. W-Z, AA-FF, *Ammonia beccarii* (Linné 1758). W, spiral view, KG 362. X, spiral view, KG 362. Y, spiral view, KG 362. Z, umbilical view, KG 362. AA, umbilical view, KG 362. BB, spiral view, KG 362. CC, spiral view, KG 362. DD, spiral view, KG 362. EE, spiral view, KG 362. FF, apertural view, KG 362. GG, *Discorbis* sp. spiral view, GH 135. HH-PP, *Haloniscus searlei* Chilton 1920. HH, detail of KK. II, detail of JJ. JJ, fragment of spine attached to telson, KIC. KK, fragment of distal segment of a posterior appendage, GH 29. LL, fragment of distal segment of a posterior appendage, GH 29. MM, fragment of proximal segment of an appendage, KIC 90. NN, fragment of ventral portion of cephalon, GH 29. OO, fragment of ventral portion of cephalon, GH 29. PP, fragment of ventral portion of cephalon, GH 29.
Scales: 1-200 μm for A-O, MM-PP; 2-20 μm for P and 40 μm for HH-II; 3-100 μm for Q-Z, AA; 4-200 μm for KK-LL.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
1
2
3
U
V
W
X
Y
Z

Lakes Gnotuk and Keilambete even in the samples representing the less saline phases.

"UNIDENTIFIED CONES"

Small calcareous cones (average diameter: 50-100 μm) (Fig. 16 U-Z) have been found attached to vegetal fragments in samples from Lakes Bullenmerri, Gnotuk and Purrumbete. They have not been identified. They are not part of fern sporocarps and it is suggested that they could be of fungal origin (H. Aston pers. com.). It is interesting to note that they occur in the samples from Lake Gnotuk where a freshwater phase is postulated. The presence of these cones in the samples studied here is recorded in Figs. 6, 7, 10 but will not be discussed further until they are identified.

DIATOMOPHYCEAE

A few specimens of the large mesohalobic diatom *Campilodiscus* sp. were found. A systematic search for diatoms was not undertaken as they have been dealt with by Yezdani (1970) and Tudor (1973) for various portions of cores from the lakes studied here except Purrumbete.

SEQUENCE OF FOSSIL REMAINS FROM THE CORES AND THEIR PALAEOECOLOGICAL SIGNIFICANCE

Note that salinity values estimated in this section represent annual averages, bearing in mind that salinities for Lakes Gnotuk and Keilambete fluctuate by ca. 8-10°/∘∘ each year, whereas for the less saline Lake Bullenmerri, the fluctuation is by about 3°/∘∘.

LAKE BULLENMERRI

The main components of the various faunas in core BK are shown on Fig. 6. In addition a few large diatoms (*Campilodiscus* sp.), one valve of *Diacypris compacta* and one fragment of a mytilocypridinid ostracod were recovered. Fish remains include jaws, scales and bones; insect fragments consist mainly of coleopterans, with a few trichopteran cases.

Major zones are defined in the core on the basis of faunal assemblages and also on the presence or absence of some species (Fig. 6). These are examined in descending order and water depth refers here to the height of the water column above the core site.

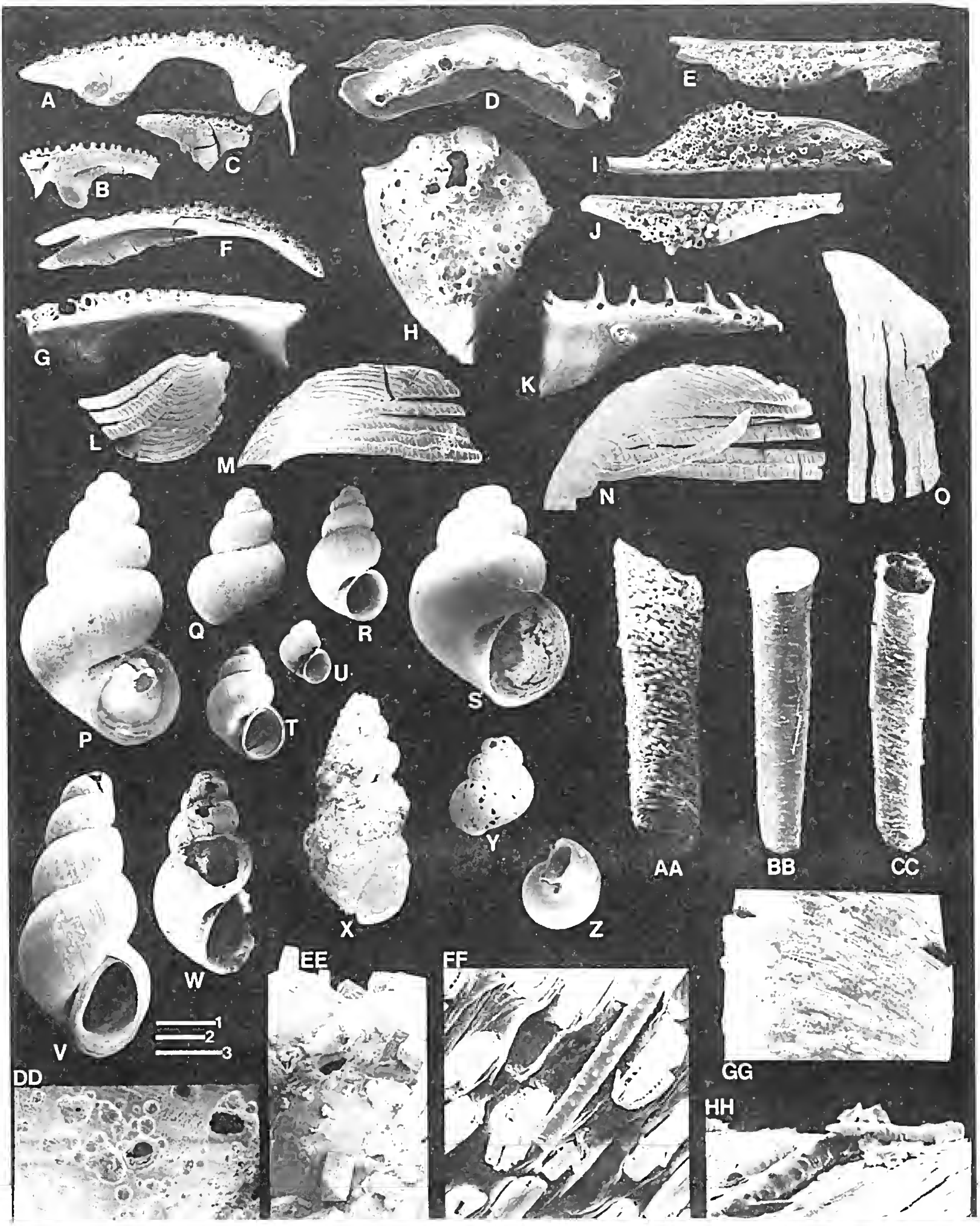
0-112 cm: Fossil remains are extremely rare indicating great depth with lake level (and therefore water salinity) similar to that of today (50-60 m) or even higher. No ostracod shells are to be found at such depth as there are no truly planktonic ostracods in Australia which live at a low salinity with little fluctuation, nor would any benthic ones be found living at such depth because the lake would be anoxic. (Although some ostracod species, such as *Diacypris spinosa* and *Mytilocypris splendida,* inhabit lakes of low salinity, it appears that they only live in lakes with broader fluctuating salinities.)

112-144 cm: Fish bones and scales are found in most samples but with few other fossils. The fish jaw at level 128 cm has more than two rows of teeth so the salinity of the water was apparently less than 13.4°/∘∘ at the time. The presence of few *Coxiella* sp. could indicate a lower water level as today *Coxiella striata* is restricted to depths less than 25 m in Lake Bullenmerri (Timms 1973, 1981). Their small numbers might only indicate that the lake level was in the vicinity of 25 m and that this sequence is a transitory one between the deep water one above and the shallow one below.

144-238 cm: This sequence yields the most diverse fauna: all the ostracod species recorded throughout the core are present in it; fish bones and scales are more abundant than above; *Coxiella* is present in substantial numbers in nearly all samples, and a few insect fragments and the body of a water mite are encountered. In some samples, fine scoria material and other terrigenous grains (>200 μm) are found. These indicate that the core position was a short distance from the lake shore and consequently testify to a major drop in lake level: the water level was less than 25 m because *Coxiella* sp. abound. This is confirmed by the diversified ostracod fauna which consist mainly of benthic animals requiring oxygenated sediments to live on, except for *C. novaezelandiae* (level 154 cm). Only two specimens of the latter ostracod were found. Lake salinity during this period probably fluctuated more, a change supported by the presence of some species with different salinity tolerance in the same samples. Salinity fluctuated most often between 2 and 7°/∘∘ as *L. dorsosicula* and *I. australiensis* are the most common species. Salinity may have gone higher at times (either for some years or during parts of some years) as indicated by the presence of more salt tolerant species such as *P. baueri* and *L. lacustris.* The presence of the latter species points to permanent water conditions. On two occasions (198-204 cm, 214-226 cm), water levels must have increased as ostracods and other fossils are either absent or rare.

238-290 cm: Fish and a few insects are present; *Coxiella* is rare which in turn indicates a high water level as for sequence 114-145 cm. At level 285 cm, the vomer plate of an eel (*Anguilla* sp.) suggests water salinity of less than

FIG. 16 – A-D, *Daphniopsis pusilla* Serventy 1929. A, ephippial sac, GH 87.5. B, ephippial sac, GH 87.5. C, ephippial sac, KG 92.5. D, ephippial sac, KG 92.5. E-H, *Daphnia* sp. E, ephippial sac, PC 579. F, ephippial sac, PC 167. G, internal capsule of ephippial sac, BK 416. H, ephippial sac, PC 137. I-M: Chironomidae. I, head case, PC 417. J, head case, GH 129. K, head case, GH 1. L, head case, detail of J. M, head case, detail of K. N-R: Porifera. N, *Heterotula* sp., gemmule, PC 229. O, *Heterotula multidentata* (Weltner 1895), gemmule, PC 235. P, *Heterotula nigra* (Lendenfeld 1887), gemmule, PC 232. Q-R, *Heterotula nigra,* detail of P. S, *Heterotula* sp., detail of N. T, *Heterotula multidentata,* detail of N. U-Z, "Unidentified cones". U, BK 177. V, BK 356. W, BK 194.5. X, BK 356. Y, BK 362. Z, BK 362.
Scales: 1-200 μm for A-D; 100 μm for I-K, W-X; 40 μm for Q, S; 20 μm for R; 400 μm for Y-Z; 2-200 μm for E-H, N-P; 3-40 μm for L-M, T; 100 μm for U-V.


A
D
E
B
C
I
J
F
H
G
K
O
L
M
N
Q
R
P
S
T
U
AA
BB
CC
X
Y
V
W
Z
1
2
3
EE
FF
GG
DD
HH

13.4°/oo. *Coxiella* occurs in large numbers at that level – water level could have dropped for a short period of time.

290-346 cm: Fish bones are rare and insect fragments present in most samples.

346-413 cm: Few fish bones are found, insect fragments rare. Between 348 and 370 cm "unidentified cones" are abundant in every sample. The absence of many fossils, especially at levels 370-413 cm may indicate a general increase in water level. The lake would then stratify with the bottom becoming anoxic, stagnant and inhospitable to organisms such as ostracods. At level 410 cm large *Campilodiscus* sp. diatoms were recovered.

413-474 cm: Ostracods are present in some samples; ephippia of *Daphnia* spp. occur in nearly all samples treated (sometimes up to 50 per 3 gm of sediment). Salinity probably ranged from fresh to 5.8°/oo, remaining lower than 5.8°/oo for a number of seasons. Some *Daphnia*, which are truly planktonic species, at times tolerate slightly saline waters. In central Victoria, Martin Lake was sampled bimonthly for one year and yielded *Daphnia* sp., *I. australiensis* and *P. baueri*. Water salinity fluctuated there between 3.25 and 7.92°/oo although adult *Daphnia* sp. were only found at 4.83°/oo. Additionally, in the same sample, halobiont ostracods (*sensu* De Deckker 1981b) were recorded: *Reticypris clava, M. praenuncia, M. splendida* and *D. spinosa*. Thus, the lower diversity of ostracod species in the Lake Bullemerri core samples and the absence of halobiont species point to a water salinity probably less than 3°/oo at most times. This would explain the absence of the halobiont *Coxiella* in the samples. Ostracods with daphniid ephippia between 460 and 474 cm suggest a salinity range as in Martin Lake (3.26-7.92°/oo). Ostracods in many samples indicate a decrease in water level and this is substantiated by the presence of scoria fragments (found especially at levels between 430 and 438 cm where, surprisingly, ostracods are absent) and other terrigenous grains in some of the samples. The shore of the lake was, at times, in the vicinity of the coring site, but it is not possible to be more precise.

474-535 cm: Fish bones and scales are common in most samples. The absence of ostracods probably indicates a high water level associated with lake stratification. Water remained near fresh at least for level 474-508 cm.

^{14}C dates from core BK are shown on Fig. 6. Good correlation exists with other cores ^{14}C dated by Barton & Polach (1980) especially between cores BK and BB of Barton (1978) (with corresponding levels 480 cm of given age 7 510 ± 490 yBP (ANU-1659) and 525 cm = 8 140 ± 110 yBP (ANU-1657)). It is assumed that cores BK and BB cover similar time sequences as they are located close together (Fig. 2), and that the rate of sedimentation was fairly uniform through time as shown for other cores taken in the lake by Barton (1978). This is further demonstrated as levels BK 475-485 and BB 480 have statistically the same age. It becomes therefore, possible to estimate the timing of events described for Lake Bullenmerri. These are summarized below. (Note: – Comparisons of lake levels here refer to the height of the water column above the deepest part of the lake for today and the past. The additional 5 m of sediments deposited on the lake floor in approximately the last 8 000 years is not considered in the calculations.)

0.112 cm (0-1 700 yBP): Lake stratification and high water level similar to that of today or even higher.

112-144 cm (1 700-2 000 yBP): Water level lower than that of today but more than 35 m and lake stratification.

144-238 cm (2 000-3 600 yBP): Water level less than 25 m and water salinity most often between 2 and 7°/oo with possible periodic fluctuations to fresh (level 154 cm = 2 250 yBP) and more than 8°/oo (2 800 yBP). Water level higher at least on two occasions: 3 000 and 3 200-3 400 yBP.

238-290 cm (3 600-4 400 yBP): Water level lower than that of today with stratification of water. At level 285 cm (4 300 yBP) salinity was below 13.4°/oo and water level could have been below 35 m.

290-413 cm (4 400-6 400 yBP): Water level probably equivalent to that of today and lake stratified – level probably shallower at level 290-346 cm (4 400-5 250 yBP) and the highest at level 370-413 cm (5 700-6 400 yBP).

413-474 cm (6 400-7 400 yBP): Drop in lake level and at times, especially between 430-438 cm (6 700-6 800 yBP) and 460-474 cm (7 100-7 400 yBP), probably of the order of 35 m or less. Surprisingly, salinity less than 3°/oo at most times.

474-508 cm (7 400-8 000 yBP): Water level probably similar to that of today or above it and salinity less than 3°/oo; lake stratification present.

FIG. 17 – A-N Fish, A, jaw, BK 189. B, jaw, GH 166.5. C, jaw, fragment of B. D, jaw?, BK 358. E, jaw, GH 6.5. F, jaw, GH 166.5. G, jaw, BK 114. H, vomer plate *Anguilla* sp., BK 285. I, jaw, GH 6.5. J, jaw, BK 128. K, jaw?, BK 398.5. L, scale BK 117. M, scale BK 126. N, scale GH 117. O, scale, GH 117. P-Z, DD-EE. *Coxiella* sp. P, apertural view, BK 169.5. Q, dorsal view, KG 201.5. R, apertural view, KG 201.5. S, apertural view, BK 189. T, apertural view. KG 201.5. U, apertural view, K 201.5. V, apertural view, GH 170. W, apertural view, KG 201.5. X, apertural view, BK 126. Y. dorsal view, GH 187. Z, ventral view, BK 158. DD, detail of X showing gnawing or leaching marks on shell surface. EE, detail of W showing aragonite crystals on shell surface. AA-CC, FF-HH. Trichoptera. AA, case of leptocerid, PC 17. BB, case of leptocerid PC 185. CC, case of leptocerid PC 179. FF, case detail of BB (note sponge megasclere). GG case detail of AA (note sponge megasclere). HH, case detail of AA (note sponge megasclere).

Scale: 1-400 μm for A-C, F, H; 200 μm for D; 300 μm for E, I, K; 600 μm for G, P, W, Z. BB-CC; 30 μm for FF; 2-200 μm for J, L-O, Z-AA; 100 μm for Q-R, T-V, W-X; 50 μm for DD-EE; 20 μm for HH; 3-20 μm for GG.

508-535 cm (8 000-8 700 yBP): Water level probably similar to that of today with salinity more than 3°/oo and lake stratification. Therefore the lake level was likely to have been lower than for period 7 400-8 000 yBP.

Churchill *et al.* (1978) curve for surface water level at Lake Bullenmerri between 2 500 and 5 500 yBP corresponds in broad terms with the data presented here although there is some disagreement regarding the amplitude of lake level fluctuation. Both works agree with the lake level having been the highest before 5 500 yBP. My data do not identify the extremely low lake level around 5 000 yBP shown by Churchill *et al.* (1978) but fossil invertebrate data for that interval is poor.

LAKE GNOTUK

The lithological units described previously for the 362.5 cm long core correspond to most zones based on ostracod assemblages apart from one section of the core (92-230 cm) which yielded very few ostracods (Fig. 7). Ostracod assemblages are described in descending order.

0-22 cm: A few *D. compacta* as well as rare *Diacypris* juveniles. Insect fragments and *Coxiella* sp. are common at some levels. At level 6.5 cm, two jaws with more than a double row of teeth were found among abundant fish remains (Fig. 17 A, I). These two indicate a salinity less than 13.4°/oo. Note that fishes with similar types of jaws (see Table 2) were recorded from the lake in 1916; it is likely that these would result from Lake Bullenmerri overflowing into Lake Gnotuk and consequently would allow fish to populate both lakes.

22-92 cm: The great abundance of *D. compacta* results from "blooms" of that species usually recorded at salinities between 45 and 77.5°/oo today. (Samples registering such phenomenon also contained *A. robusta* but in lower numbers.) Salinity values for corresponding fossil material are therefore in the vicinity of 45-77.5°/oo whereas when numbers of *D. compacta* are lower, the salinity range should be broadened to that of when the two species have been found together in some Victorian lakes at 98-100°/oo, and up to 144°/oo.) At level 82.5 cm *D. pusilla* ephippia indicate a salinity of 4.4-68°/oo, and the water would have had to go at least below 33.4°/oo for the cladoceran to hatch.

92-233 cm: This large portion of the core is depauperate in ostracods. Its upper part, however, is fossiliferous down to 202 cm whereas it is barren below it. In most upper samples *Coxiella* shells are present and even numerous at times (ca. 10 specimens per 3 gm sediment) and fish bones are occasionally found. At level 166.5 cm, two jaws are recovered but little information on salinity can be drawn from them as they only possess one to two rows of teeth inferring a salinity range of 3-30.3°/oo. The fauna at level 135 cm indicates permanent saline water conditions in the vicinity of 35°/oo. At levels 171, 175.5, 182, 190 cm are "unidentified cones" which are common in samples from Lake Bullenmerri for which salinity must have been in the vicinity of 2-7°/oo.

233-270 cm: This zone was probably deposited under similar conditions to those for levels 22-92 cm but *A. robusta* valves are rare with only fragments recovered. For section 245-260 cm, where *Coxiella* juveniles are also found, salinity was in the vicinity of 45-77.5°/oo. For the other levels, where *D. compacta* are found, the salinity range is <3-182°/oo.

270-317 cm: *Reticypris* valves are common in most samples and are present in great numbers at times. As explained before, the absence in these samples of the low salinity ostracods *Mytilocypris* spp. and *D. spinosa* warrants the specific identification of *R. herbsti* for the specimens found in this core. Salinity of the lake in the presence of *R. herbsti* in high numbers (levels 272, 284-300, 313-316 cm) was of the order of 99-172°/oo. At level 315 cm, the presence of two valves of the highly saline *D. whitei* supports the values suggested above. Salinity was probably lower when *R. herbsti* numbers were lower and with *A. robusta* co-occurring. When the latter species was common (>200 valves per 3 gm sediment) salinity was between 45 and 77.5°/oo. Near level 294 cm, disruption in the bedding resulted from the lake having dried.

317-333.5 cm: Salinity of the lake must have varied because of the different associations and variations in abundance of ostracods. The salinity range was probably similar to that of level 270-317 cm. This is supported by a collection made once in an unnamed lake near Lake Bolac where the three species were collected together at 99.4°/oo.

333.5-346 cm: No sediments.

346-349 cm: Mixed sediments.

350-363.5 cm: *R. herbsti, D. compacta* and *P. baueri* are found together in most samples. These three species have been found together in various lakes in Victoria at salinities between 99-172°/oo. *A. robusta* and *D. dietzi* are poorly represented and occur only in a few samples. Their presence does not contradict the salinity range postulated for this zone.

^{14}C dates from core GH are shown on Fig. 7. The alternation of light and dark coloured bands with diffused carbonate rich layers between 84 and 109 cm in core GB ends at level 79 cm in core GH. Dodson (1974) identified this band in his core from Lake Gnotuk and dated it between 3 790±100 yBP and 3 530±100 yBP. He suggested that this layer, which he described as being dolomite-rich, represented a period of low water level and hypersalinity. The ostracods suggest that salinity should have between 45 and 77.5°/oo.

The carbonate layer in core GB at level 130 cm could not be correlated with any layer in core GH but the 10 cm thick layer below (dated at 4 140±70 yBP (ANU-1987)) probably corresponds to level 115-125 cm in core GH.

The well defined zone characterized in core GB by black to dark grey mud at 188-210 cm (dated as 5 750±70 yBP (ANU-1988)) corresponds to layer 166-191 cm in core GH. Also, the base of the approximately 17 cm thick layer consisting of white laminae in dark grey to black organic mud at level 263 cm in core GB, correlates with level 249 cm in core GH. 10 cm of this layer above level 260 cm in core GB was dated as

7 290± 100 yBP (ANU-1989). It appears that layer 300.5-301.5 cm (rich in *R. herbsti*) in core GH corresponds to the one labelled "ostracod layer" in core GB (at about 316 cm) by Barton (1978). If this is correct, the date of 9 240± 120 yBP (ANU-1990) relates to level 295-305 cm in core GH. This correlation remains uncertain though as the description by Barton (1978) of that section of the core does not mention the conspicuous alternation of dark and pale layers seen in GH. Finally, the pale grey layer in core GB below 323 cm is not recorded in core GH until below level 346 cm (note that there is a gap of 12 cm above that layer in core GH). The ^{14}C date of 7 780± 330 yBP (ANU-2487) for level 352-361 cm in core GH suggests that the sediments recovered in that core below level 334 cm are either contaminated or displaced.

As it appears that the levels in core GB which are equivalent to those in core GH, are always on the average 15 cm above the latter ones in respect to the top of each core, the top of core GH should be 25 cm below the water sediment interface, as the top of core GB is said to be 10 cm below the same interface by Barton (1978). The results are summarized below:

0-22cm (700-1 200 yBP): Little information available but probably low salinity (around 10°/∘∘) most of the time as halobiont ostracods are rare and insect fragments are present. At level 6.5 cm (850 yBP) salinity was below 13.4°/∘∘.

22-92 cm (1 200-3 000 yBP): Increase in salinity which is maintained between 45 and 77.5°/∘∘ except on one occasion at level 82.5 cm (2 900 yBP) when water salinity had to go below 33.4°/∘∘ for a short period of time. Note that there is some disagreement between Dodson's dating for the dolomite-rich layers (between 3 790 yBP (I-4611) and 3 530 yBP (I-4612) and the date of 3 000 yBP extrapolated from the dates given by Barton & Polach (1980) for level 92 cm in GH.

92-233 cm (3 000-7 250 yBP): Return to less saline conditions and water salinity was probably around 10°/∘∘.

233-270 cm (7 250-8 250 yBP): Salinity of the water ranging definitely between 45 and 77.5°/∘∘ for levels 246-250 cm (=7 700 yBP) and probably in the same range for the remainder.

270-317 cm (8 250-9 500 yBP): Salinity of the water fluctuated; it was often between 99-172°/∘∘ when *R. herbsti* was present alone and sometimes between 45-77.5°/∘∘ when *A. robusta* was present in high numbers. There is evidence at level 294 cm (8 900 yBP) of a dry phase shown by disrupted bedding.

317-335.5 cm (9 500-10 000 yBP): Salinity of the water fluctuated; it remained constantly high in the vicinity of 100°/∘∘.

350-363.5 cm No date is available because there is a gap in the core above this level, and it is thought that this material could have been reworked, although some of the fauna (*P. baueri, D. dietzi*) is not found elsewhere in the core. The ^{14}C date of 7 780± 330 yBP for level 352-361 cm remains unexplained in comparison with core GB which is presumed to be much older (> 10 000 yBP) by correlation. It will not be considered further.

The plotted curve for corrected annual salt accumulation of Churchill *et al.* (1978) ought to be revised in the light of Timms's (1975) remarks on Currey's original data (1970) and, since no such correction was considered in the present work, it is not further discussed. The uncorrected water level curve of Churchill *et al.* (1978) indicates a number of water level fluctuations not evidenced by the invertebrate remains. These are: a major drop in water level at 5 000 yBP and around 3 600 yBP, increase in level around 4 500 and 1 700 yBP and also a fairly high level for the period of 4 000 to 3 000 yBP. For other periods, data from both works are compatible.

LAKE KEILAMBETE

The overlapping parts of the upper core K1C with the top of core KG are described together.

CORE K1C (Fig. 8)

0-38 cm: Water salinity lower than that of today.

0-10 cm: The range of *R. clava* in Victoria today is 12-42°/∘∘, with one rare record at 5°/∘∘; at salinities below 17.5°/∘∘, the species is not found with *M. praenuncia* but always accompanied by *D. spinosa*. (This species was never recorded in the core.) I infer that salinity was between 17.5-42°/∘∘.

10-38 cm: The range of *M. praenuncia* in Victoria today (8-43°/∘∘, with an additional collection with very few specimens at 5°/∘∘) is postulated for the water during this period of sedimentation. It is likely that salinities below 10°/∘∘ were rarely reached as no low salinity water inhabitants are present. The absence of *P. baueri* in some samples cannot be explained since that species is tolerant to a broad range of salinities. In addition, the presence of this species in high numbers at other times indicates temporary fluctuations to higher salinities (70°/∘∘) for levels 10-12 and 25-30 cm. The presence of *M. praenuncia* in this level indicates that salinity must have also gone below 43°/∘∘ at times. At level 27 cm, one *L. lacustris* was found indicating permanent water of salinity range 19-35°/∘∘ for it. No explanation can be provided for the poor representation of *D. compacta*.

38-72 cm: Note that a few quartz grains are found at level 69 cm in K1C—this level is probably facies equivalent to the sand lens occurring at level 100 cm in Bowler's (1970) core K4. The water level must have been low at that particular time. The absence of ostracods suggests the presence of a stratified layer and very diluted (fresh?) water otherwise saline ostracods would have been found in the core since there are a number of planktonic species.

CORES K1C AND KG (Figs. 8, 9)

32-140 cm in KG (72-127 cm at least in K1C): This zone, characterized by the high numbers of *D. compacta* (1 500 valves per 3 gm sediment) in nearly all samples, can be subdivided into a few distinct events as registered by changes of ostracod species.

32-62 cm in KG (72-101 cm in K1C): *D. compacta* "bloom" with salinity of the lake water probably between 45-77.5°/∘∘ because of the presence of *A. robusta*. The salinity range could have fluctuated up to

144‰ as *A. robusta* are few in number. At level 49-53 cm in KG (88-91 cm in K1C) *D. compacta* is less abundant: the salinity range for the lake water at the time has to be broadened to 42-145‰ (it is likely that salinity did not drop below 42‰ as *M. praenuncia* is absent). Note that fragments of *H. searlei* are recorded in core K1C during this short event.

62-140 cm in KG (102-127 cm in K1C—no record below): Water salinity below that of today for most times. The salinity range was approximately 19-43‰ as *D. spinosa* and *M. splendida* (both with a range of 5-18‰) are absent. The recorded high numbers of *D. compacta* representing "blooms" of that species at various levels in KG can be explained by temporary excursions to high salinities ranging between 45 and 77.5‰. At level 104 cm, two *Elphidium* sp. (Fig. 15 U-V) are found: salinity was probably similar to that of sea water. Only once, at level 99-102 cm, were high numbers of *M. praenuncia* found associated with a *D. compacta* "bloom". As such a phenomenon has never been recorded in the Victorian lakes today, it is thought that this level represents two distinct events. The occurrence of the fragile shells of *P. baueri* in low numbers is consistent with the salinity values given above since this animal can be found over a broad range of salinities and is usually recorded in small numbers below 70‰ salinity. At level 81-84 cm in KG (= 114-123 cm in K1C), few *A. robusta* valves are found. This event, recorded in both cores, represents fluctuations to higher salinities (up to a maximum possible value of 145‰ for *A. robusta* during short periods of time for a phase which saw salinities remaining generally between 19-43‰ (for *M. praenuncia*). Some insect fragments are found in a few samples from both cores. The presence of *D. pusilla* ephippia at level 92.5 cm in core KG, indicates a salinity range of 4.4-68‰, with values having to drop below 33.4‰, at least temporarily, for the animal to hatch. This is consistent with other data as for this level *D. compacta* numbers are very low.

CORE KG (Fig. 9)

141-280 cm: This zone covers two distinct events:

141-210 cm: Numbers of *M. praenuncia* fluctuate often and *D. compacta* valves are present in most samples but their numbers are very low (< 10 valves per 3 gm sediment). Valves of *P. baueri* are also found in some samples. Salinity postulated for this event is of the order of 19-43‰. The low species numbers cannot be explained when compared to the zone above, except by suggesting that salinities were low (20‰) and as a consequence there would be very few *D. compacta*. Insect fragments are present in a number of samples. At level 201.5-202.5 cm the conspicuous layer with many *Coxiella* shells also recorded in Bowler's core K4 (Bowler 1970) is considered to represent a phenomenon registered over most of the lake floor: water depth was probably less than 6 m because shells of adults are found. A few quartz grains (> 250 μm) also found in this layer in core KG confirm this assumption.

210-280 cm: The low numbers of *M. praenuncia* and *P. baueri* probably indicate unfavourable conditions for both species. The absence of *P. baueri* between 210 and 245 cm is considered to represent the less saline portion of this event.

280-323 cm: No data available as no ostracods are recovered except for level 302 cm where one *D. compacta* is found.

323-348.5 cm: Fairly high numbers of *D. compacta* and subdivided into a series of events:

323-325.5 cm: *D. compacta* present alone in fairly large numbers—salinity ranged between 43-182‰ (the range of this species is 3-182‰ in Victorian lakes, but *M. praenuncia* is absent here).

325.5-332 cm: *D. compacta* and *A. robusta* co-occur and both are abundant at times. Salinity range: 28-145‰ (this corresponds to the present day range of *A. robusta* in Victorian lakes when it is found only in large numbers).

332-336 cm: *D. compacta* "bloom" (at level 332: 6 000 valves per gm of sediment!!) accompanied by many *A. robusta*. Salinity range: 45-77.5‰.

336-348.5 cm: *D. compacta* in fair numbers and *A. robusta*, at times, in high numbers for the species (at level 346 cm: 720 valves!). Presence of *R. herbsti* in small numbers (species identification extrapolated because of the core and occurrence of *A. robusta* and *D. compacta* as explained before and this remark refers to all *Reticypris* specimens found in the samples below level 342 cm). Salinity range broadened to a maximum value of 145‰ (= upper limit of *A. robusta*) when *A. robusta* is found in high numbers (341.5 cm, 346 cm) and between 45-77.5‰ for other times.

348.5-393 cm: Period of high salinity at most times with extensive fluctuations: when *R. herbsti* is the most abundant species, salinity was about 99-172‰ (level 351 cm, 377 cm). High numbers of *A. robusta* (357-362 cm, 375.5 cm) represent a salinity range of 45-77.5‰. The presence of few *D. dietzi* is consistent with the given salinity values. When it is found in high numbers (level 390 cm) with *R. herbsti* and quite a few *A. robusta*, salinity was around 75‰. At levels 362-367 cm, a large quantity of all sizes of *A. beccarii* indicates permanent water around 35‰. On two occasions (levels 355-357 cm and 387.5-392 cm) the lake dried as shown by the disturbed bedding.

393-419 cm: Salinity fluctuations and values often very high. At level 401 cm, *P. baueri* is numerous and accompanied by many *R. herbsti* and a few valves of three other species (*D. compacta*, *D. dietzi* and *A. robusta*). This association indicates a salinity range of 99-172‰. This is confirmed by the presence of *D. dictyote* at levels 404 and 410 cm and *D. whitei* at 410 cm. Level 404 cm probably experienced a higher salinity (as level 401 cm) as *P. baueri* and *R. herbsti* are numerous. The same range is extrapolated for level 413 cm when *A. robusta* and *D. compacta* are absent and *R. herbsti* in smaller numbers and *P. baueri* more common than usual. Between levels 401 and 413 cm, salinity probably remained high as *R. herbsti* and *P. baueri* are either abundant or common in the samples. Salinity was probably lower at level 417 cm, as *A. robusta* is recorded with few *D. com-*

TABLE 3

CORRELATIONS FOR LEVELS OF CORES K1C AND KG WITH CORRESPONDING ONES ALREADY ¹⁴C DATED IN CORES STUDIED BY BOWLER (1970), BOWLER & HAMADA (1971), DODSON (1974) AND BARTON (1978)

¹⁴C date	Lab.	K1C	KG	K4 Bowler (1970)	KF Barton	KJ (1978)	Dodson Dodson (1974)	Justification of correlation
610 ± 110	N517	19-30.5		10-20				Marl band at 15-20 cm in K4 = 24-30.5 cm in K1C.
765 ± 135	15245	30.5-35.5					105-110	5 cm below marl band in Dodson = 30.5-35.5 in K1C.
935 ± 110	N518	30.5-42		21-33				Start at 1 cm below marl band – see sample N517.
1 970 ± 110	N519	63.5-73.5	24.5-34.5	55-65				4 cm below 2 thin carbonate layers (52 cm in K4 = 20.5 cm in KG and 60 cm in K1C).
2 410 ± 120	N520	90-101	53-63	79-90				4 cm below start of ostracod rich mud and 8 cm below beige layer in both cores.
2 600 ± 110	N521	110-120	72-82	102-112				10 cm band with strong lamination; this level is compressed in K1C as many distinctive layers are much thinner than in KG.
2 610 ± 90	ANU2035		72-92		90-110	50-70		
2 970 ± 120	N522		85-97	130-140				132-141 in K4 with dark brown to black weakly calcareous mud = 87-98.5 in KG.
3 500 ± 100	ANU2054		?		141-161	110-120		Cannot be correlated as no diagnostic layer present.
3 580 ± 125	N523		?	165-175				
4 200 ± 125	N524		151-161	190-202				End of lamination and start of weakly calcareous mud at 202 in K4 = 161 in KG.
4 630 ± 80	ANU2055		~ 167-187		202-222	160-180		5 cm band of thin lamination at around 210 cm in KF is probably similar layer at 173-176 cm in KG.
4 930 ± 200	15244						275-280	Cannot be correlated as no diagnostic layer.
5 250 ± 135	N525		193.5-204.5	235-245				Shell layer of *Coxiella* at 242 in K4 corresponds to 158 in KG.
5 980 ± 110	ANU2056		?		267-287	225-245		Cannot be correlated as no diagnostic layer in the middle of black mud of KF.
6 440 ± 145	N526		?	290-300				Cannot be correlated as no diagnostic layer.
6 470 ± 110	16225		?				370-375	
7 850 ± 165	N527		283-303	335-345*				The 2 carbonate bands ending at 355 cm in K4 = those ending at 303 in KG.
8 640 ± 80	ANU1807		360-375		390-405			The "striated" layer of Barton (1978) at 389 cm in KF = the layer with disrupted layering at 355-357 cm in KG.
9 670 ± 135	16226						480-485	Cannot be correlated as no diagnostic layer.
10 190 ± 90	ANU1808		390-410		420-440			The "striated" layer of Barton (1978) at 420 cm in KF = the band with disrupted layering at 388.5-392 cm in KG.
14 300 ± 300	N528			395-412				This level (swamp plant debris) is not present in KG.

* Erroneously labelled as 325-345 by Bowler & Hamada (1971).
Layers which are underlined are those which were originally dated.

pacta and *R. herbsti*, but it cannot be adequately defined. Between levels 407 and 419 cm, the lake was probably subject to drying up at times, as no lamination is visible in the grey clay.

Correlation with other cores, which is possible on lithological grounds, is necessary for the dating of events in cores K1C and KG here as a number of ¹⁴C dates associated with cores from Lake Keilambete are already available (Table 3, Fig. 9).

The results are summarized below:

0-10 cm in K1C (0-300 yBP): Water salinity: 17.5-42°/₀₀. At level 5 cm, permanent water conditions and salinity: 19-35°/₀₀.

10-38 cm in K1C (300-900 yBP): Water salinity: 10-42°/₀₀; at level 27 cm, same conditions as for level 6 cm and temporary fluctuations to higher salinities at 10-12 cm (300 yBP) and 24-30 cm (600-750 yBP).

38-72 cm in K1C (900-2 000 yBP): Little data available. At level 69 cm in K1C (= 2 000 yBP) water level must have been low.

72-101 cm in K1C (= 32-62 cm in KG) (2 000-2 500 yBP): Water salinity 45-77.5°/₀₀. For levels 80-101 cm in K1C (= 2 250-2 500 yBP) the salinity range has to be broadened to 42-145°/₀₀.

62-140 cm in KG (2 500-[3 800-4 000] yBP): Salinity below that of today and of the order of 19-43°/₀₀;

possibly with records of higher salinities up to 45-77.5°/oo for levels 99-102 cm (2 900 yBP), 108-112 cm (3 100 yBP), 131-134 cm (3 600 yBP). Also, at levels 81-84 cm (2 600-2 800 yBP), the presence of a few *A. robusta* suggests higher salinity: up to a maximum of 145°/oo. At level 92.5 cm (2 800 or 3 000 yBP), salinity was below 33.4°/oo at least once.

141-210 cm in KG (4 000-5 500 yBP): Salinity between 19.43°/oo but probably around 20°/oo. At level 201.5-202.5 cm (5 300 yBP) a *Coxiella*-rich layer signifies a water level below 6 m.

210-280 cm in KG (5 500-7 200 yBP): Conditions of slightly saline to near fresh water, at times. Between 210-245 cm (5 500-6 400 yBP), the absence of *P. baueri* reflects the less saline portion of this phase. The absence of low salinity ostracods could be explained by the lake being stratified.

280-323 cm (7 200-8 300 yBP): The suggestion of the presence of stratified layer, as for level 210-280 cm, also applies here.

323-348.5 cm (8 300-9 000 yBP): Water salinity fluctuations around today's value.

323-325.5 cm (8 300 yBP): Salinity 43-182°/oo.

325.5.5-332 cm (8 300-8 500 yBP): Salinity 28-145°/oo.

332-348.5 cm (8 500-9 000 yBP): Salinity 45-77.5°/oo.

348.5-393 cm (9 000 + yBP): [Note: available ^{14}C dates are conflicting and therefore no timing for the various events is presented here.] Salinity values high and extensive fluctuations of water level.

351 cm: Salinity 99-172°/oo.

355-357 cm: The lake dried temporarily.

357-362 cm: Salinity 45-77.5°/oo.

362-367 cm: Permanent water—35°/oo salinity.

375 cm: Salinity 45-77.5°/oo.

377 cm: Salinity 99-172°/oo.

387.5-392 cm: The lake dried temporarily sometimes during that period.

Around 390 cm: Salinity around 75°/oo.

393-419 cm (9 700 yBP): Wide fluctuation of salinity which was often very high similar to the 348.5-393 cm section.

401 cm: Salinity 99-172°/oo.

404 cm: Salinity 99-172°/oo.

407-419 cm: Lake subject to drying up.

413 cm: Salinity 99-172°/oo.

The water level curve for Lake Keilambete, calibrated by ^{14}C dates, was first proposed by Bowler and Hamada (1971) and later a more detailed version was produced by Bowler (1981).

It should be noted that Bowler's (1970) core K4 was not recovered from the deepest part of the lake whereas Barton's (1978) cores (those studied here) were taken near the centre, and therefore yielded different sediments (than core K4) resulting from changes in lake levels.

Around 1 300 yBP, an increase in salinity detected in core K4 is not found in core KG. Between about 900 and 2 000 yBP, core K4 suggests that water level was high.

From 2 000-4 000 yBP, water level fluctuated but remained generally low. There is an exception around 3 000 yBP. The two peaks of high salinity and low water level between 2 000 and 3 000 yBP registered in core K4 are also recorded in core KG and the two opposite peaks (lower salinity and higher water levels correspondingly) are detected in core KG.

Between 4 000-8 300 yBP core K4 suggests less saline conditions. Dodson's (1974) record of *Pediastrum* (salinity less than 3.5°/oo) for the period 5 000-6 500 yBP is slightly inconsistent with the ostracod data obtained in core KG as, for the 4 000-5 500 yBP period, the extrapolated salinity range is 10-43°/oo with a probable lowering of the lake level down to 6 m or less at about 5 300 yBP (*Coxiella*-rich layer). It appears therefore, that salinity must have fluctuated at times between less than 3.5°/oo and more than 19°/oo.

Between 5 500-6 500 yBP freshwater conditions prevailed most of the time as *Pediastrum* is abundant but occasional returns to slightly saline conditions are necessary to justify the presence of *M. praenuncia* in some samples. During the 6 500-7 200 yBP period, slightly saline conditions must have prevailed at times as *Pediastrum* is absent while *P. baueri* and *M. praenuncia* co-occurred. *Botryococcus* in these samples indicates oligotrophic conditions.

Dodson (1974) recorded *Ruppia* between approximately 6 900-8 200 yBP (calculated from his diagram) with the highest value around 7 800 yBP. It is likely that this phenomenon corresponds to the lowering of the lake level registered at around 7 900-8 000 yBP by Bowler (1981).

The highest lake level of Bowler (1981) could be explained by a period of lake stratification which would exclude benthic ostracods.

Between 8 300 and approximately 10 000 yBP, the generally low and fluctuating water level drawn by Bowler (1981) is in agreement with the ostracod data especially during the period older than 9 500 yBP which experienced the highest salinities.

Dodson (1974) discussed the formation of the creamy yellow band of dolomite at depth 96-103 cm in his core (= marl band of Bowler 1970), and concluded that it represented a dry period in the lake history. In the corresponding band in core K1C at level 24-30.5 cm, valves of *P. baueri* abound and those of *M. praenuncia*, common on either side of this band, are numerically low. Salinity of the lake must have therefore been high (above 70°/oo) at times with fluctuations down below 43°/oo. At level 27 cm, water must have been permanent and of lower salinity (17-35°/oo) as indicated by the presence of *L. lacustris*. It is most unlikely then that the lake dried during the period of the dolomite formation but salinity could have been high at times.

LAKE PURRUMBETE

No ostracods have been recovered in the 195 samples taken throughout the core which consists of homogeneous dark brown organic mud. At first glance there is no indication of the lake having been saline. On the other hand, most samples yielded daphniid ephippia and egg capsules (Fig. 10). Their state of preservation was often very good as most sacs or capsules were still swollen after treatment in H_2O_2 and prior to the drying of the residues in an oven. It appears, therefore, that during approximately the last 7 000 years water of Lake Purrumbete remained either fresh or as the upper salinity range recorded for *Daphnia* spp. viz. 5.8°/₀₀. (Barton (pers. comm.) suggested that by using intensity of magnetization correlation with one of his ^{14}C dated core PD, level around 5 m in core PC studied here is approximately equivalent to 6 140 ± 110 yBP). As mentioned before, the absence of shells of the freshwater gastropod *P. niger* and the bivalve *Sphaerium* sp. in the samples suggest that the shore of the lake was never close to the coring site and that the height of the water column above this site remained higher than 35 m at all times. This would also explain the absence of the benthic ostracods *Gomphodella australica* (Hussainy 1969) found today in the lake by Timms (1973) in collections between 0.5-1 m, *Candonocypris novaezelandiae* (= *C. assimilis* in Hussainy 1969b, Timms 1973) recorded down to 33 m by Timms (1973), and of the free swimming ostracod *Newnhamia fenestrata* King 1855 inhabiting waters near the shore of the lake at present.

No fluctuation of water level, resulting from changes of climate, has been registered during the last 7 000 years of the lake history, probably due to a connection of Lake Purrumbete to the Curdies River which would have permitted exchange of water and salts.

CONCLUSIONS

The four maar lakes are situated in a subhumid area close to a semi-arid area today. Any change in evaporation and/or precipitation in the area is likely to affect levels of lakes, especially those which have closed basins, such as maars. Unfortunately, at present a change of this ratio cannot be properly assessed for a number of reasons. First of all, it is not possible to plot an accurate water level curve from known past salinities for various phases of the lakes as it appears that the amount of total dissolved salts (TDS) did not remain constant in all the lakes; the waters of Lakes Bullenmerri and Gnotuk which now have a similar volume of TDS (Currey 1970) must have mixed at some stage. Prior to mixing the TDS volume in Lake Bullenmerri must have been different as water salinity is thought to have been between 3.26-7.92°/₀₀ but then water depth is considered to have been less than half of today's between 7 100 and 7 400 yBP. Another example applies to water depth of Lake Keilambete thought to have been below 6 m at about 5 300 yBP when salinity was between 19 and 45°/₀₀. It appears that TDS are either lost or introduced into the lakes by percolation and via the water table. Finally, it is not possible to assess how much of the TDS volume is lost periodically by precipitation of salts especially in Lakes Keilambete and Gnotuk.

Although at present no hydrological budget can be calculated for the four maar lakes, the synchronous fluctuations of water levels and salinities, recognized mainly from fossil ostracod data, in Lakes Bullenmerri, Gnotuk and Keilambete should inform on climate in central Victoria during the last 10 000 years. Data for the lakes is schematized in Fig. 11 and comments are given below. It is interesting to note, however, that Lakes Gnotuk and Keilambete, which have similar salinities and faunas today, registered almost identical changes of ostracod faunas at most times. Water levels and salinities, are inferred to have responded to changes of climate. Unfortunately, it is not yet possible to state how these changes related to either evaporation or precipitation.

The following sequence of events is deduced from the foregoing analyses:

(a) During about the last 100 years, lake levels for the three maars (Lake Purrumbete is not discussed here) have decreased drastically (Currey 1970; Bowler 1970, 1981).

(b) At 300 yBP and around 600-750 yBP, there were fluctuations of salinity to higher values in Lake Keilambete.

(c) At 1 300-1 800 yBP there is a discrepancy for Lake Gnotuk with high salinity values whereas the other lakes have a high water level (Keilambete with a suspected very low salinity).

(d) At around 2 000 yBP a change in water level in Lakes Keilambete and Bullenmerri is supported by ^{14}C dated trees which were drowned (Yezdani 1970, Bowler 1970). [Fig. 11 indicates that water level rose before the particular tree existed at Lake Keilambete. This discrepancy is caused by the approximation in dating events but, after consideration of the limits of error for ^{14}C dates, the above statement is still considered valid.]

(e) During the 2 000-3 000 yBP period lake levels were low in all three lakes.

(f) At about 3 000 yBP there was a change in level in Lakes Bullenmerri and Gnotuk; it is noticeable a bit later in Keilambete.

(g) Between 3 000 and 3 600-3 800 yBP lake levels fluctuated in Bullenmerri and Keilambete.

(h) Between 3 800 and 6 400-6 500 yBP water levels were high in all three lakes. The highest lake level occurred between 5 700 and approximately 6 400 yBP.

(i) The changes in water levels recorded at about the same time in Lakes Gnotuk and Bullenmerri before 6 400 yBP are not detected in Lake Keilambete.

(j) Between 7 400 and 8 000 yBP water was high in Lake Bullenmerri also presumably in Lake Keilambete. It appears not to be the case at Lake Gnotuk.

(k) There was a drastic change of water level for Lakes Keilambete and Gnotuk at 8 300 yBP. This corresponds to a probable change in level seen by a change of fauna in Lake Bullenmerri at the same time.

(l) Before 8 300 yBP salinities in Lakes Keilambete and Gnotuk were the highest ever recorded in the lakes for the last 10 000 years. Lake Keilambete water level and salinity seem to have fluctuated more.

Lakes Gnotuk and Keilambete appear to be more sensitive recorders of "climatic change" since salinity fluctuated more drastically and frequently there. This is a direct result of their smaller volume of water and shallower water depth compared to Lake Bullenmerri.

These 2 lakes (Gnotuk and Keilambete), dried up during the very arid phase prior to the last 10 000 years and this would explain the flat bottom topography of each lake as pedogenesis must have prevailed during that period. (This phase is already documented for Lake Keilambete in Bowler and Hamada (1971)). Lake Bullenmerri did not dry up during that period (Dodson 1979).

It is interesting to note that at times the similar Lakes Gnotuk and Keilambete did not register identical and synchronous salinity changes. The total dissolved solids content of the water of Lake Gnotuk must have changed fairly drastically after each flooding from Lake Bullenmerri. Lake Keilambete therefore should prove to be the most reliable and accurate recorder. However there are also difficulties in interpreting changes of salinity for Lake Keilambete since some salts must have been lost during the high water levels with lake overflow.

ACKNOWLEDGEMENTS

I am grateful to Dr C. E. Barton who provided me with cores from the 4 maar lakes which he used for his study of Holocene magnetic stratigraphy. He also made available a vast amount of unpublished data.

The paper was written during the tenure of a Commonwealth Postgraduate Research Award at the University of Adelaide under the supervision of Professor W. D. Williams. Being able to accompany him on many field trips in western Victoria enabled me to collect limnological data, especially on the ecology of ostracods, pertinent to the interpretation of the fossil remains recovered in the cores.

I also wish to thank Dr J. R. Dodson for offering comments on a draft of the manuscript and Mr J. Head who provided useful comments regarding the radiocarbon dating.

REFERENCES

Barton, C. E., 1978. Magnetic studies of some Australian lake sediments. PhD Thesis, Australian National University (unpubl).

Barton, C. E. & Burden, F., 1979. Modifications to the Mackereth corer. *Limnol. Oceanogr.* 24: 977-983.

Barton, C. E. & McElhinny, M. W., 1981. A 10000 yr geomagnetic secular variation record from three Australian maars. *Geophys. J.R.astr.* Soc. 67: 465-485.

Barton, C. E. & Polach, H. A., 1980. ^{14}C ages and magnetic stratigraphy in three Australian maars. *Radiocarbon* 22: 728-739.

Bayly, I. A. E. & Williams, W. D., 1966. Chemical and biological studies on some saline lakes of south-east Australia. *Aust. J. Mar. Freshwat. Res.* 17: 177-228.

Bowler, J. M., 1970. Late Quaternary environments: a study of lakes and associated sediments in south-eastern Australia. PhD Thesis, Australian National University (unpubl).

Bowler, J. M., 1981. Australian salt lakes: a palaeohydrological approach. *Hydrobiologia* 82: 431-444.

Bowler, J. M. & Hamada, T., 1971. Late Quaternary stratigraphy and radiocarbon chronology of water level fluctuation in Lake Keilambete, Victoria. *Nature, Lond.* 237: 330-332.

Bradshaw, J. S., 1957. Laboratory studies on the rate of growth of the foraminifer "*Streblus beccarii* (Linné) var. *tepida* (Cushman)". *J. Paleont.* 31: 1138-1147.

Cann, J. H. & De Deckker, P., 1981. Fossil Quaternary and living Foraminifera from athalassic (non-marine) saline lakes, southern Australia. *J. Paleont.* 55: 660-670.

Chapman, F., 1919. On an ostracod and shell marl of Pleiostocene age from Boneo Swamp, West of Cape Schanck, Victoria. *Proc. R. Soc. Vict.* 32: 24-32.

Chessman, B. C. & Williams, W. D., 1974. Distribution of fish in inland saline waters in Victoria, Australia. *Aust. J. Mar. Freshwat. Res.* 25: 167-172.

Churchill, D. M., Galloway, R. W. & Singh, G., 1978. Closed lakes and the palaeoclimatic record. In *Climatic change and variability*, A. B. P. Pittock, L. A. Frakes, D. Jensen, J. A. Peterson and J. W. Zilman, eds, Cambridge University Press, Cambridge, 97-108.

Currey, D. T., 1970. Lake systems. Western Victoria. *Bull. Aust. Soc. Limn.* 3: 1-13.

De Deckker, P., 1974. *Australocypris* a new ostracod genus from Australia. *Aust. J. Zool.* 22: 91-104.

De Deckker, P., 1977. The distribution of the "giant" ostracods (family: Cyprididae Baird, 1845) endemic to Australia. In *Aspects of Ecology and Zoogeography of Recent and Fossil Ostracoda,* H. Löffler & D. L. Danielopol, eds, Junk, The Hague, 285-294.

De Deckker, P., 1978. Comparative morphology and review of Mytilocypridinid ostracods (Family Cyprididae). *Aust. J. Zool. (suppl. ser.)* 58: 1-62.

De Deckker, P., 1981a. Taxonomy and ecological notes for some ostracods from Australian inland waters. *Trans. R. Soc. S. Aust.* 105: 91-138.

De Deckker, P., 1981b. Ostracoda from Australian inland waters—Notes on taxonomy and ecology. *Proc. R. Soc. Vict.* 93: 43-85.

De Deckker, P., 1981c. Taxonomy, ecology and palaeoecology of ostracods from Australian inland waters. PhD Thesis, University of Adelaide (unpubl.).

De Deckker, P., 1981d. Ostracods of athalassic salt lakes: a review. *Hydrobiologia* 81: 131-144.

De Deckker, P., 1981e. Taxonomic notes on some Australian ostracods with description of new species. *Zool. Scr.* 10: 37-55.

De Deckker, P., Bauld, J. & Burne, R. V., 1982. Pillie Lake, Eyre Peninsula, South Australia: modern environment and biota, dolomite sedimentation, and Holocene history. *Trans. R. Soc. S. Aust.* 106: 169-181.

De Deckker, P. & Geddes, M. C., 1980. Seasonal fauna of ephemeral saline lakes near the Coorong Lagoon, South Australia. *Aust. J. Mar. Freshwat. Res.* 31: 677-699.

Dodson, J. R., 1974. Vegetation and climatic history near Lake Keilambete, Western Victoria. *Aust. J. Bot.* 22: 709-717.

Dodson, J. R., 1979. Late Pleistocene vegetation and environments near Lake Bullenmerri, Western Victoria. *Aust. J. Ecol.* 4: 419-427.

Ellis, P. & Williams, W. D., 1970. The biology of *Haloniscus searlei* Chilton, an isopod living in Australian salt lakes. *Aust. J. Mar. Freshwat. Res.* 21: 51-69.

Geddes, M. C., 1976. Seasonal fauna of some ephemeral saline waters in western Victoria with particular reference to *Parartemia zietziana* Sayce (Crustacea: Anostraca). *Aust. J. Mar. Freshwat. Res.* 27: 1-22.

Geddes, M. C., De Deckker, P., Williams, W. D., Morton, D. & Topping, M., 1981. On the chemistry and biota of some saline lakes in Western Australia. *Hydrobiologia* 82: 201-222.

Glover, C. J. M. & Sim, T. C., 1978. Studies on Central Australian fishes. A progress report. *S. Aust. Nat.* 52: 35-44.

Hussainy, S. U., 1969a. Ecological studies on some microbiota of lakes in western Victoria. PhD Thesis, Monash University (unpubl.).

Hussainy, S. U., 1969b. Description of the male of *Candonocypris assimilis* G. O. Sars 1894 (Cyprididae, Ostracoda). *Proc. R. Soc. Vict.* 82: 305-307.

Joyce, E. B., 1975. Quaternary volcanism and tectonism in southeastern Australia. *Bull. R. Soc. N.Z.* 13: 169-176.

Mackereth, F. J. H., 1958. A portable core sampler for lake deposits. *Limnol. Oceanogr.* 3: 181-191.

Maddocks, G. E., 1957. The geochemistry of surface waters of the Western District of Victoria. *Aust. J. Mar. Freshwat. Res.* 15: 35-52.

Mellor, M., 1979. A study of the salt lake snail *Coxiella* Smith 1894, *sensu lato*. BSc (Hons) Thesis, University of Adelaide (unpubl.).

Ollier, C. D., 1968. Maars. Their characteristics, varieties and definition. *Bull. Volcan.* 31: 45-73.

Ollier, C. D. & Joyce, E. B., 1964. Volcanic physiography of the western plains of Victoria. *Proc. R. Soc. Vict.* 77: 357-376.

Patterson, C. G. & Walker, K. F., 1974. Recent history of *Tanytarsus babitarsis* Freeman (Diptera: Chironomidae) in the sediments of a shallow, saline lake. *Aus. J. Mar. Freshwat. Res.* 25: 315-325.

Penney, J. T. & Racek, A. A., 1968. Comprehensive revision of a worldwide collection of freshwater sponges (Porifera-Spongillidae). *Bull. U.S. Natn. Mus.* 272: 1-184.

Racek, A. A., 1966. Spicular remains of freshwater sponges. *Mem. Conn. Acad. Arts Sci.* 17: 78-83.

Racek, A. A., 1969. The freshwater sponges of Australia (Porifera: Spongillidae). *Aust. J. Mar. Freshwat. Res.* 20: 267-310.

Sars, G. O., 1885. On some Australian Cladocera raised from dried mud. *Vid. Selsk. Forh. Christiana* 8.

Timms, B. V., 1973. A comparative study of the limnology of three maar lakes in western Victoria. PhD Thesis, Monash University (unpubl.).

Timms, B. V., 1975. On the origin of salts in Lakes Bullenmerri and Gnotuk, western Victoria. *Bull. Aust. Soc. Limn.* 6: 5-8.

Timms, B. V., 1976. A comparative study of the limnology of three maar lakes in western Victoria I. Physiography and physiochemical features. *Aust. J. Mar. Freshwat. Res.* 27: 35-60.

Timms, B. V., 1980. The benthos of Australian lakes. In *An ecological basis for water resource management*, W. D. Williams, ed., ANU Press, Canberra, 23-29.

Timms, B. V., 1981. Animal communities in three Victorian lakes of different salinity. *Hydrobiologia* 81: 181-193.

Tudor, E. R., 1973. Hydrological interpretation of diatom assemblages in 2 Victorian western district crater lakes. MSc Thesis, University of Melbourne (unpubl.).

Williams, W. D., (in prep.) On the ecology of *Haloniscus searlei* (Isopoda, Oniscoidea) an inhabitant of Australian salt lakes.

Yezdani, G. H., 1970. A study of the Quaternary vegetation history in the volcanic lakes region of western Victoria. PhD Thesis, Monash University (unpubl.).

PROC. R. SOC. VICT. vol. 94, no. 4, 221-247, December 1982

MAMMALS OF SOUTHWESTERN VICTORIA FROM THE LITTLE DESERT TO THE COAST

By P. W. Menkhorst and C. M. Beardsell

Arthur Rylah Institute for Environmental Research, Fisheries and Wildlife Division, Ministry for Conservation, 123 Brown Street, Heidelberg, Victoria 3084

Abstract: Mammals in southwestern Victoria were surveyed between 1974 and 1980. Fifty-three species were recorded during the survey period. A further thirteen taxa have probably disappeared from the area since European settlement. The results of our survey, together with previously documented records, are presented as an annotated list of species giving the distribution, abundance and habitat of each species. The recent history and zoogeography of the mammalian fauna is discussed and the mammalian fauna is considered in terms of the distribution of species across five physiographic regions. Most species of small mammal were significantly associated with only one region. The results are used to test the adequacy of the present system of conservation reserves. Most species are adequately catered for. However, further reservations are necessary to protect the remnants of the mammalian fauna of River Red Gum woodland, Yellow Gum woodland and Brown Stringybark open-forest.

Some areas in southwestern Victoria have long been recognized as having high value for the conservation of flora and fauna (Frankenberg 1971) and two areas, the Little Desert and the Lower Glenelg forest have been the subject of land use controversies. Despite this, there have been no systematic surveys of the mammalian fauna of southwestern Victoria, apart from the Grampians-Edenhope area (Emison *et al.* 1978), and few published data are available. Wakefield (1974) summarized data from research collections, the literature and his field work and highlighted the lack of knowledge concerning mammals in western Victoria. Land use reviews by the Land Conservation Council of Victoria (LCC 1972, 1979, 1981a) demonstrated an urgent need for greater knowledge of the status of fauna in the area and inventory surveys of various vertebrate groups were conducted by the Fisheries and Wildlife Division of Victoria (FWD) between October 1974 and July 1980. In this paper we present the results of the mammal survey of the Little Desert, the LCC's South West Study Area, District One and the contiguous area of District Two.

SURVEY AREA

The survey area is bounded to the west by the South Australian border, to the north by the northern edge of the Little Desert (36°25'S), to the south by the Southern Ocean and to the east by 142°E, Glenelg River and eastern boundary of the LCC's South West Study Area, District 1 (Fig. 1). The area so defined (roughly 15 300 km^2) is between 180 and 220 km from north to south and between 40 and 92 km from east to west. About 28% of this area is Crown Land, most of which supports native vegetation. Figure 1 shows the distribution of Crown Land and main towns in the survey area.

Physiography and Topography

Five physiographic regions as defined by Hills (1975) occur in the survey area (Fig. 2). Further details of all except the Little Desert are given by LCC (1972, 1979, 1981a). The Little Desert consists of marine Cainozoic deposits overlain by a veneer of aeolian siliceous sands. In places Cainozoic red sandstone and ironstone project through the sand sheets forming NW-SE ridges, the most noticeable being the Lawloit Range. In the west and sand sheet is broken by large clay flats. In this region the altitude ranges from 120 to 200 m and the boundary betwen the Wimmera Plains and the Little Desert is well defined by soil and vegetation changes.

Climate

There is considerable variation in climate in the survey area. The Coastal Plains, Volcanic Plains, Tablelands and Wimmera Plains (except the Mt Arapiles area) have a temperate climate (rainfall more than 500 mm per annum, warm dry summers and wet winters with mild temperatures). The Little Desert and Mt Arapiles have a semi-arid climate (rainfall less than 500 mm per annum, hot dry summers and only moderately wet winters).

Rainfall

Isohyets are shown in Fig. 2; average annual rainfall is greatest near the coast and decreases steadily with increasing distance inland. At Nhill, on the northern edge of the survey area, the average annual rainfall and the winter monthly peaks in rainfall are approximately half those at Portland at the southern tip of the survey area. At Portland, the months May to August produce 50% of the total annual rainfall while further inland rainfall is more evenly distributed throughout the year (Bureau of Meteorology 1975).

Temperature

The average daily range of temperatures increases with distance from the coast. The daily maximum temperatures for January and February are about 10°C higher at Nhill than at Portland while the daily minimum temperatures for June, July and August at Nhill are less than half those at Portland (Bureau of Meteorology 1975). Frosts are more frequent and severe in inland areas and late frosts (September/October) are more likely to occur as are daily maximum temperatures greater than 38°C. The number of months per annum

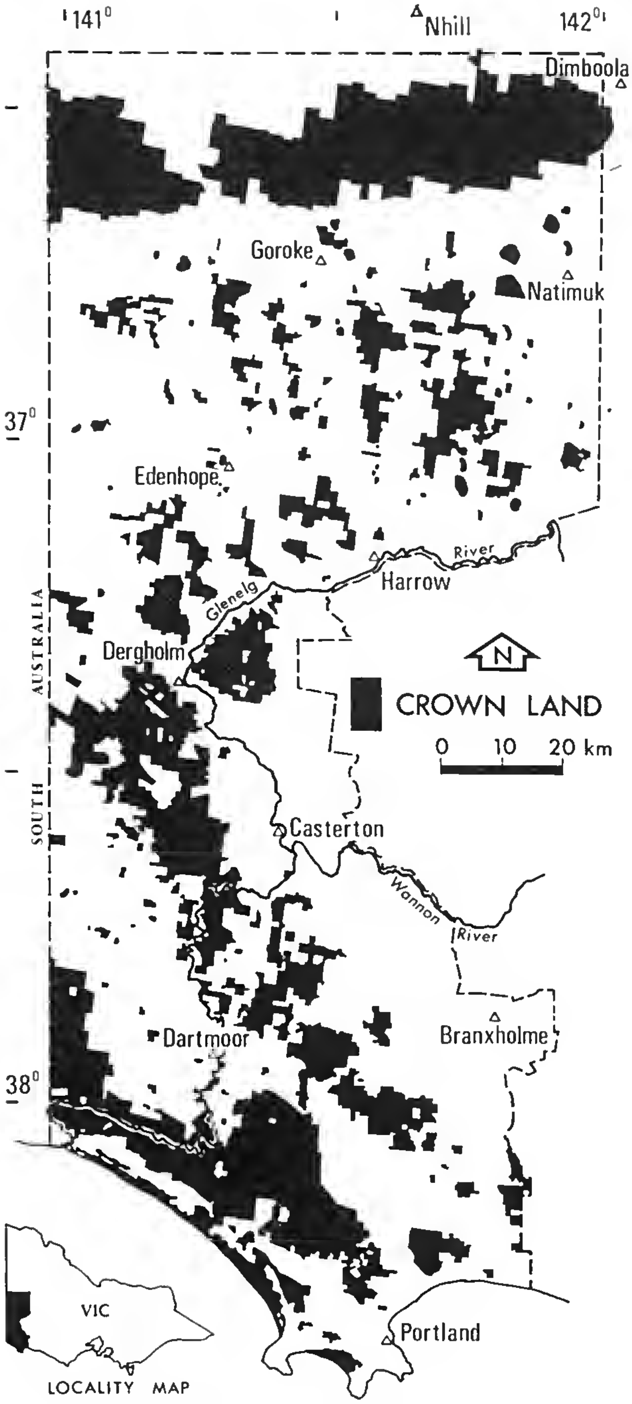


FIG. 1—The survey area showing place names and the distribution of Crown Land.

when effective rainfall (the amount of moisture available for growth of plants after evaporation) is received are: Portland 11, Casterton 9, and Nhill 7 (LCC 1972), thus the growing season for plants is longest in the south.

VEGETATION

There is considerable variation in vegetation from north to south as the climate changes from semi-arid to cool-temperate. We used 15 plant alliances, based on the classification of Specht *et al.* (1974, Table 7.3), to describe the habitats in the areas surveyed. These are listed below. Further details of the floristic composition, structure and distribution of each alliance are available from the authors and some details can be gleaned from LCC (1972, 1979 and 1981a).

Open-forest

1. Messmate *Eucalyptus obliqua*
2. Manna Gum *E. viminalis*
3. Brown Stringybark *E. baxteri*

Woodland

4. River Red Gum *E. camaldulensis*
5. Yellow Gum *E. leucoxylon*
6. Manna Gum

Low open-forest

7. Brown Stringybark

Closed-scrub

8. Scented Paper-bark *Melaleuca squarrosa*

Open-scrub

9. Broom Honey-myrtle *M. uncinata*
10. Yellow Mallee *Eucalyptus incrassata*
11. Coast Wattle *Acacia sophorae*

Closed-heath

12. Silver Banksia *Banksia marginata*

Open-heath

13. Silver Banksia
14. Desert Banksia *B. ornata*

Closed-grassland

15. Blue Tussock Grass *Poa poiformis*

METHODS

The survey consisted of two parts:

(i) the collation of existing data from museum collections and the literature. This was carried out at the National Museum of Victoria (NMV) (Gedye *et al.* 1979, Evans & Dixon 1980). In addition we examined field notes of previous workers and interviewed local naturalists;

(ii) field surveys to supplement data derived from (i).

Field work took place between October 1974 and April 1975 (Wimmera Plains and Volcanic Plains) and October 1978 and July 1980 (Coastal Plains, remaining areas of Volcanic Plains and Wimmera Plains, and Little Desert) (see Fig. 3). Field trips were held in all months except January and September.

Because of the large area involved (15 300 km²) and time constraints, a primary survey was designed to produce an inventory of terrestial species, their broad habitat preferences and distribution within a 5′ (230 cell) latitude-longitude grid. Emphasis was on areas of Crown Land (28% of the survey area) although all incidental observations on private land were recorded. Figure 3 shows the temporal and geographical distribution of survey effort.

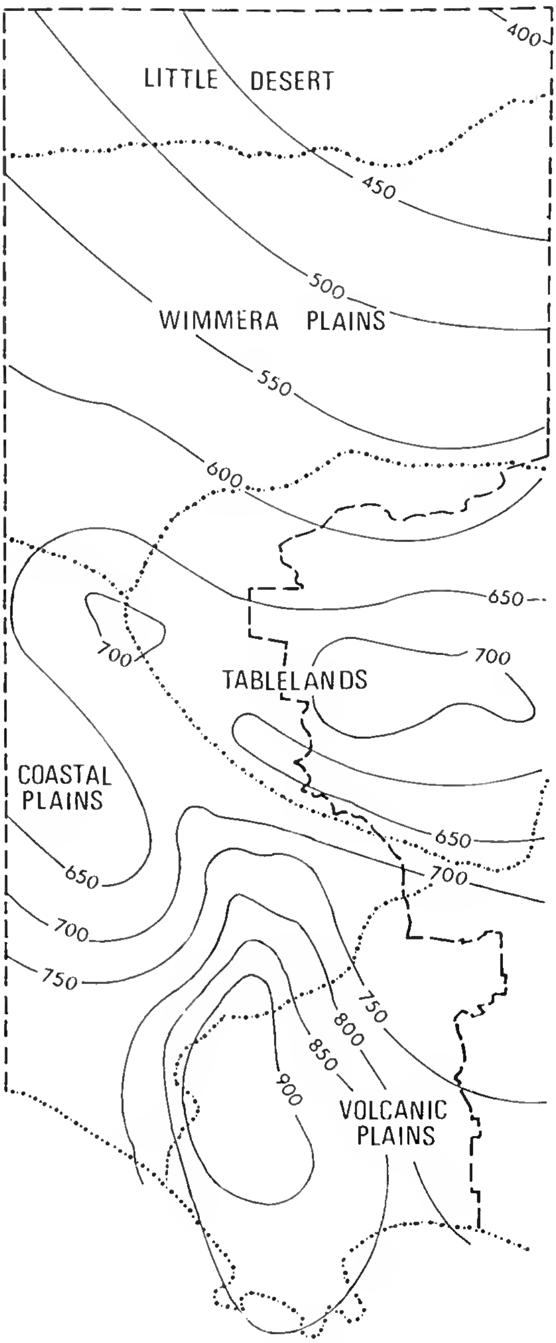


Fig. 2 — Isohyets and physiographic regions in the survey area.

Cage Trapping

Cage traps were set in 113 cells and in almost all areas of Crown Land (Fig. 3).

In each 5′ cell 20 traps were set in 2 lines of 10, at each of 4 sites and left in place for 2 or more nights giving a minimum of 160 trapnights per cell. Trapping sites were selected to cover a range of vegetation alliances within each cell. Traps were cleared each morning and then reset; they were therefore open day and night. Captured animals were identified and sexed, their breeding condition was assessed and they were either marked and released or retained as specimens.

Wire cage traps (36 × 20 × 16 cm) were used most of the time but occasionally Elliott type A traps (Elliott Scientific Instruments, Upwey, Victoria) were used. Bait consisted of a mixture of peanut butter, rolled oats and honey.

Drift Fence Pitfall Trapping

Pitfalls with drift fences were used in 15 grids in sandy areas (Fig. 3). Drift fences consisted of PVC Damp Course (0.3 m × 60 m) held up by wire or wooden stakes. Pits consisted of metal tins (20 cm diameter × 28 cm deep) or cylinders (15-25 cm diameter × 45 cm deep) sunk into the soil so that the rim was flush with the soil surface. Eight to ten pits were spaced evenly along the fence and were straddled by it. Pits were not baited and were left in place for 10 nights and checked morning and evening.

Bat Catching

Constantine traps, modified from the design of Tidemann and Woodside (1978), were set in 22 cells (Fig. 3) and fine nylon lines were strung just above the surface of the water of dams (Parnaby 1977) in 4 cells.

Direct Observation

Daylight observations of large mammals (e.g. large macropods *Macropus* spp., Koala *Phascolarctos cinereus*, Common Wombat *Vombatus ursinus*, Fox *Vulpes vulpes* and European Rabbit *Oryctolagus cuniculus*) were made and details of road-killed mammals were also recorded. Night observations were made along tracks from a slowly-moving vehicle using 12 volt spotlights powered by the vehicle battery or on foot using portable 6 volt batteries and lights. Spotlighting took place in 74 cells and in most areas of Crown Land containing mature open-forest or woodland.

Indirect Evidence

Characteristic diggings of 3 species (Echidna *Tachyglossus aculeatus*, Common Wombat and European Rabbit); seats of 5 species (Common Brushtail Possum *Trichosurus vulpecula*, Wombat, Dog *Canis familiaris*, Fox and European Rabbit); nests of Common Ringtail Possums *Pseudocheirus peregrinus* and feeding scars of Yellow-bellied Gliders *Petaurus australis* were taken as evidence of the presence of these species.

Mapping

All field, literature and museum records were scrutinised and those accepted are included in the distribution maps presented in Appendix 2. Most records listed by Gedye *et al.* (1979) and Evans & Dixon (1980) have been accepted but a few which have not are discussed in the Annotated List. All accepted records from any source during our survey (October 1974 to November 1980) are shown by closed circles in the appropriate 5′ cell on the distribution maps; those dated before October 1974 are shown by open circles. Records

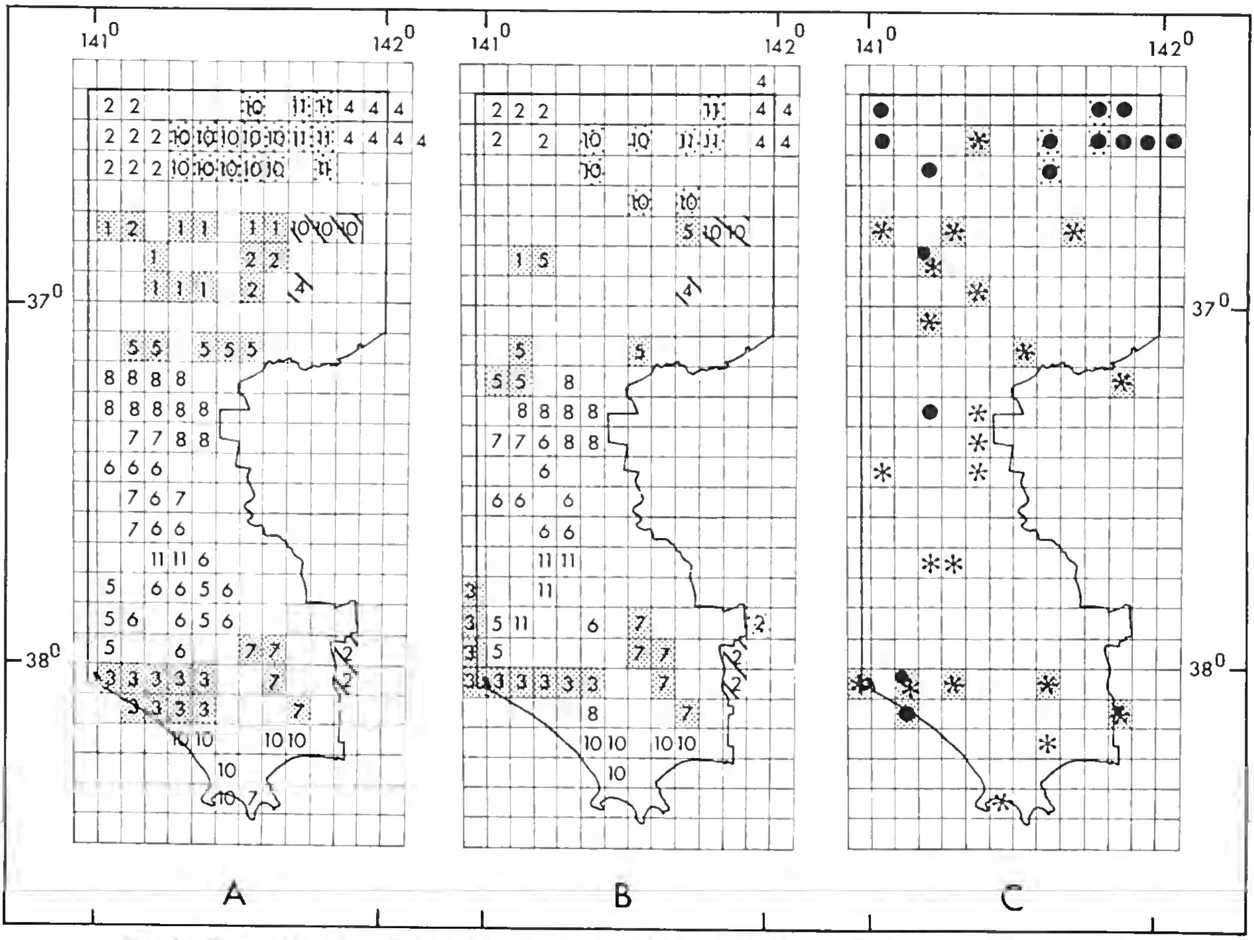


FIG. 3—Temporal and spatial spread of survey effort. Months, years and 5′ cells in which cage trapping (A), spotlighting (B), bat trapping (*), and pitfall trapping (●) were conducted. Diagonal lines indicate 1974-1975, open stippling indicates 1978, clear indicates 1979, and close stippling indicates 1980.

with imprecise localities are shown as large circles in the general area of the record.

The distribution maps should be read in conjunction with Fig. 1, showing the distribution of Crown Land which represents most of the remaining timbered areas, and with Fig. 3 showing trapping and spotlighting coverage during the field survey.

Annotated List of Mammals

Summaries of relative abundance, distribution and habitats of each species are given in the Annotated List (Appendix 1). Where appropriate, breeding data, specimen numbers and taxonomic notes are included. For species not recorded during our survey the most recent record is given. All acceptable records of each species are mapped in Appendix 2.

RESULTS

Fifty species of mammal were recorded during our survey (41 native, 9 introduced with feral populations), three others have been recorded in recent years (2 native, 1 introduced) and as many as 12 species and one subspecies may have become extinct since European settlement began in the 1830s (see Discussion). Details of the abundance, distribution and habitat of each species are presented in the Annotated List.

Forty-nine species have been reported from deposits of late Pleistocene and Recent skeletal material in caves from southwestern Victoria and southeastern South Australia. About half of these species are no longer present in the survey area (Table 1).

Cage Trapping

A total of 17 440 trap nights in 113 5′ cells yielded 2045 captures of 20 species of mammals at an overall trapping success rate of 12%. Trapping results for each species are presented in Table 2.

Five species accounted for over 75% of captures (Bush Rat *Rattus fuscipes*, House Mouse *Mus musculus*, Swamp Rat *Rattus lutreolus*, Silky Mouse *Pseudomys apodemoides* and Yellow-footed Antechinus *Antechinus flavipes*) with the Bush Rat accounting for over 33% of all captures.

Trapping rates and diversity of trapped species were highest near the coast and lowest in the Little Desert (Table 3). The latter also produced the lowest trapping rate (2%) of any area surveyed by FWD (unpublished data).

TABLE 1

SPECIES REPRESENTED IN SUB-FOSSIL BONE DEPOSITS FROM WESTERN VICTORIA AND SOUTHEASTERN SOUTH AUSTRALIA

SPECIES	DEPOSITS															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
DASYURIDAE																
Antechinus flavipes		●	●													●
A. stuartii	●	●	●		●			●	●	●						●
A. swainsonii	●	●	●		●			●	●							●
Dasyurus maculatus	●			●	●	●	●	●							●	●
**D. viverrinus*	●	●	●	●	●	●	●	●					●	●		●
Phascogale tapoatafa	●		●					●								
**Sarcophilus harrisii*	●			●	●	●		●								●
Sminthopsis crassicaudata	●	●	●	●				●								●
S. murina																●
S. leucopus	●	●	●		●			●	●							
**Thylacinus cynocephalus*				●				●								●
PERAMELIDAE																
Isoodon obesulus	●	●	●	●	●	●		●	●					●	●	●
**Perameles gunnii*	●	●	●	●	●	●		●	●					●	●	●
**P. bougainville*									●							●
**P. nasuta*	●					●		●								
PHALANGERIDAE																
Trichosurus vulpecula	●	●	●	●	●	●	●	●					●	●	●	
BURRAMYIDAE																
Acrobates pygmaeus	●	●						●	●							
Cercartetus nanus	●	●	●					●	●	●						●
PETAURIDAE																
Petaurus breviceps	●	●	●		●			●	●							●
**P. norfolcensis*			●													
Pseudocheirus peregrinus	●		●		●	●		●	●							●
MACROPODIDAE																
**Aepyprymnus rufescens*	●			●		●		●								
**Bettongia gaimardi*	●			●				●	●							●
**B. lesueur*				●	●			●								
**B. penicillata*																●
**Lagorchestes leporides*	●			●				●				●				
Macropus giganteus/fuliginosus	●			●	●	●		●				●	●		●	
**M. greyi*				●		●		●							●	
M. rufogriseus	●	●	●		●	●	●	●				●	●	●	●	
**Onychogalea fraenata*				●				●								
**O. unguifera*				●												
**Petrogale penicillata*			●								●					
**Potorous platyops*	●	●		●	●	●	●	●	●							●
P. tridactylus																●
**Thylogale billardierii*	●				●	●		●								
**Wallabia bicolor*	●							●								
PHASCOLARCTIDAE																
Phascolarctos cinereus								●								
VOMBATIDAE																
Vombatus ursinus	●	●		●	●	●	●	●				●		●	●	
MURIDAE																
**Conilurus albipes*	●	●	●	●				●	●		●					
Hydromys chrysogaster	●		●	●	●			●								
**Mastacomys fuscus*	●	●	●		●		●	●	●							
**Pseudomys australis*	●	●	●	●	●		●		●		●					
**P. fumeus*								●	●	●						
**P. cf. gracilicaudatus*	●	●	●						●	●						
**P. cf. novaehollandiae*	●	●	●					●	●							
P. shortridgei								●								
**P. sp. nov.*		●	●	●	●						●					
Rattus fuscipes greyi	●	●	●					●	●	●						
R. lutreolus	●	●	●	●	●	●		●	●					●		

● present in bone deposits

* no longer present in the survey area

1, Fern Cave (Wakefield 1964). 2, Mt Eccles (Wakefield 1964). 3, Byaduck Caves (Wakefield 1964). 4, Mt Hamilton (Wakefield 1964). 5, Bushfield (Wakefield 1964). 6, Tower Hill Beach (Wakefield 1964). 7, Mt Porndon (Wakefield 1964). 8, McEacherns Cave (Wakefield 1967). 9, Victoria Range (Wakefield 1963). 10, Black Range (Wakefield 1963). 11, Mt Arapiles (Wakefield 1971). 12, Yallum Cave, Penola (Tidemann 1967). 13, Tantanoola Cave (Tidemann 1967). 14, Bat Cave, Naracoorte (Tidemann 1967). 15, Wombat and Cave Park Caves (Maddock 1971). 16, Victoria Cave, Naracoorte (Smith 1971 and 1972).

TABLE 2
RESULTS OF TRAPPING SMALL MAMMALS IN SOUTHWESTERN VICTORIA

Species	Total No. trapped	% of total catch	Cell frequency (%) n=113	No. of trapping sites n=396	Mean trapping success per 100 trapnights where captured (range)
Rattus fuscipes	706	34	46 (41)	121	14 (2-60)
Mus musculus	378	18	60 (53)	104	7 (1-25)
Rattus lutreolus	275	13	37 (33)	68	9 (1-43)
Pseudomys apodemoides	130	6	36 (32)	71	4 (2-13)
Antechinus flavipes	120	6	35 (31)	55	4 (0.5-25)
Pseudomys shortridgei	92	5	24 (21)	41	6 (2-20)
Antechinus swainsonii	69	3	15 (13)	29	5 (1-23)
A. stuartii	67	3	11 (10)	28	5 (1-20)
A. minimus	60	3	15 (13)	22	6 (3-20)
Isoodon obesulus	52	3	29 (26)	34	4 (1-15)
Trichosurus vulpecula	37	2	19 (17)	22	3 (1-8)
Rattus rattus	22	1	6 (5)	6	5 (3-8)
Potorous tridactylus	19	1	11 (10)	13	4 (3-8)
Hydromys chrysogaster	8	0.4	2 (2)	2	9 (5-15)
Pseudocheirus peregrinus	3	0.1	3 (3)	3	2
Dasyurus maculatus	2	0.1	1 (1)	2	1
Oryctolagus cuniculus	2	0.1	2 (2)	2	1 (1-3)
Sminthopsis leucopus	1	0.1	1 (1)	1	2
S. murina	1	0.1	1 (1)	1	2
Cercartetus nanus	1	0.1	1 (1)	1	2
Total	2045				

Pitfall Trapping

Pitfalls yielded only 14 mammals, 9 of which were House Mice. However, these traps caught 2 species not captured in wire cage traps; Fat-tailed Dunnart *Sminthopsis crassicaudata* and Western Pygmy-possum *Cercartetus concinnus*.

Bat Catching

One hundred and forty-seven bats of 11 species were captured (Table 4). Constantine traps captured 117 (79%) of these but trip wires over dams captured 3 species not captured in Constantine traps; White-striped Mastiff-bat *Tadarida australis,* Western Broad-nosed

TABLE 3
SMALL MAMMAL TRAPPING EFFORT AND SUCCESS IN EACH PHYSIOGRAPHIC REGION
Includes only species comprising >1% of total catch.

	Little Desert	Wimmera Plains	Tablelands	Coastal Plains	Volcanic Plains	Overall
Number of trapnights	5470	3076	1502	5240	2150	17440
Number of trapping sites	127	62	28	135	44	396
Total captures	117	308	81	929	593	2028
Percentage of captures comprised by each species within each physiographic region.						
Antechinus flavipes	0	1.3	0.5	1.3	0.1	
A. minimus	0	0	0	1.1	0.1	
A. stuartii	0	0	0	0.2	2.4	
A. swainsonii	0	0	0	0.2	2.8	
Isoodon obesulus	0	0.1	0.2	0.8	0.2	
Trichosurus vulpecula	0.02	0.6	0	0.3	0.1	
Potorous tridactylus	0	0	0	0.1	0.6	
Mus musculus	0.6	5.5	2.5	2.0	1.7	
Pseudomys apodemoides	1.5	1.4	0.1	0	0	
P. shortridgei	0	0	0	1.5	0.7	
Rattus fuscipes	0	0.2	1.0	6.0	17.6	
R. lutreolus	0	0.4	1.1	4.0	1.6	
R. rattus	0	0.5	0	0.1	0.1	
Total trapping success (%)	2.1	10.0	5.4	17.7	28	12

Bat *Nycticeius balstoni* and Great Pipistrelle *Pipistrellus tasmaniensis. Eptesicus* spp. comprised 69% of all bats captured, followed by Chocolate Wattled Bat *Chalinolobus morio* (8%) and Lesser Long-eared Bat *Nyctophilus geoffroyi* (7%). The small number of sites at which bat trapping took place and variation in bat activity patterns in different seasons and weather conditions preclude a more detailed analysis of trapping results.

Spotlighting

Results of spotlighting arboreal mammals are given in Table 5. Three hundred and twenty-two sightings involving 5 species were made. More than half of these were Common Ringtail Possums although the species was observed in only 36% of cells in which spotlighting took place. Common Brushtail Possums were the most widespread arboreal mammal, being found in 44% of cells where spotlighting occurred.

Observations of arboreal species could not be quantified because of variation in ease of observation in different habitats, in different weather and by different observers. However, species richness of arboreal mammals ranged from 3 species in the Little Desert (Western Pygmy-possum, Sugar Glider *Petaurus breviceps,* and Common Brushtail Possum), to 7 in the open-forests of both the Coastal Plains and the Volcanic Plains (Common Brushtail Possum, Eastern Pygmy-possum *Cercartetus nanus,* Feathertail Glider *Acrobates pygmaeus,* Sugar Glider, Yellow-bellied Glider, Common Ringtail Possum, and Koala). Records of species of Burramyidae were too few to allow comment, However, all other arboreal species are probably common in suitable habitat.

ZOOGEOGRAPHY

Mammal species present in the broad physiographic regions within the survey area and the food niches they occupy are shown in Table 6. The number of species in the Little Desert was about half that on the Coastal and Volcanic Plains. Greatest differences were in the small ground carnivore and large arboreal herbivore categories (Table 6).

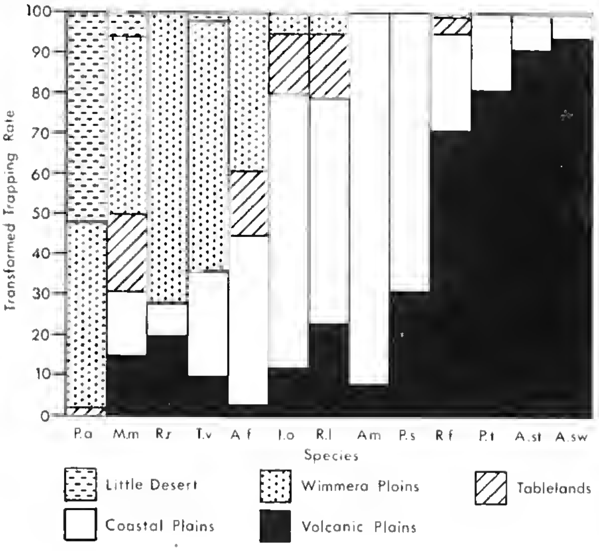


FIG. 4—Comparative trapping rates of each species within each physiographic region. Figures from Table 3 are transformed to a scale of 1 to 100. Species are arranged to show associations of small mammals occurring in each region but trapping rates are not directly comparable between species. P.a.-*Pseudomys apodemoides*, M.m.—*Mus musculus*, R.r.—*Rattus rattus*, T.v.—*Trichosurus vulpecula*, A.f.—*Antechinus flavipes*, I.o.—*Isoodon obesulus*, R.l.—*Rattus lutreolus*, A.m.—*Antechinus minimus*, P.s.—*Pseudomys shortridgei*, R.f.—*Rattus fuscipes*, P.t.—*Potorous tridactylus*, A.st.—*Antechinus stuartii*, A.sw.—*Antechinus swainsonii*.

TABLE 4

RESULTS OF TRAPPING BATS IN SOUTHWESTERN VICTORIA

For each species the numbers captured by each method, the percentage frequency in 5′ cells sampled and, for Constantine traps, the mean trapping success per night are given.

Species	Number Captured (%) Constantine traps	Lines over dams	Percentage of total catch $n = 147$	Cell frequency $n = 25$	Mean trapping success per night where captured (range). Constantine traps only
Tadarida australis	–	3 (10)	2	12	–
T. planiceps	3 (3)	2 (7)	3	16	2 (1-2)
Chalinolobus gouldii	3 (3)	3 (10)	4	16	1 (0.3-1)
C. morio	11 (9)	1 (3)	8	28	1 (0.5-1)
Eptesicus regulus	8 (7)	–	5	12	3 (2-3)
E. sagittula	24 (21)	10 (33)	23	20	6 (1-8)
E. vulturnus	54 (46)	6 (20)	41	60	2 (0.2-8)
Miniopteris schreibersii	2 (2)	–	1	4	2
Myotis adversus	2 (2)	–	1	4	2
Nycticeius balstoni	–	1 (3)	1	4	–
Nyctophilus geoffroyi	10 (9)	–	7	24	1 (0.2-2)
Pipistrellus tasmaniensis	–	4 (13)	3	4	–
Total	117	30	100		

Comparisons of trapping rates of each species of small mammal in each physiographic region were used to investigate the relationship between species abundance and physiographic regions. In Table 3, trapping rates for each physiographic region are transformed into rates for each of the species present. These differences are further illustrated in Fig. 4, where the trapping rates of each species in each physiographic region are compared on a scale of 1 to 100.

The significance of different trapping rates between pairs of physiographic regions having the highest trapping rates for each species are shown in Table 7. All species except the Yellow-footed Antechinus and Silky Mouse were significantly associated with a single region.

DISCUSSION

RECENT HISTORY OF THE MAMMALIAN FAUNA

The mammalian fauna of the survey area has changed dramatically since the Pleistocene. Species represented in Late Pleistocene and Recent bone deposits from caves in western Victoria and southeastern South Australia are listed in Table 1. About half the 49 taxa listed are no longer present in the area. Reasons for this decline in species diversity are not clear as the difficulties of accurately ageing bone deposits (e.g. Wakefield 1967, 1969) and problems of interpretation (Calaby 1971) preclude detailed analysis. Several taxa, which may have been present at the time of European settlement (1830-1880) have disappeared. These include Eastern Quoll *Dasyurus viverrinus,* Red-bellied Pademelon *Thylogale billardierii,* Brush-tailed Bettong *Bettongia pencillata,* Eastern Hare Wallaby *Lagorchestes leporides,* Bridled Nailtail Wallaby *Onychogalea fraenata,* Toolache Wallaby *Marcropus greyi,* Swamp Wallaby *Wallabia bicolor,* Rabbit-eared Tree-rat *Conilurus albipes,* and Dingo *Canis familiaris dingo* (Wakefield 1974). Cockburn (1979) believes a further 4 rodent species were also probably present at that time but are no longer extant in the area. These were: Broad-toothed Rat *Mastacomys fuscus,* Plains Mouse *Pseudomys australis,* New Holland Mouse, *P. novaehollandiae* and an undescribed *Pseudomys.*

TABLE 5

RESULTS OF SPOTLIGHTING FOR ARBOREAL MAMMALS IN SOUTHWESTERN VICTORIA

Species	Total number observed	% of all observations	Cell frequency (%) $n = 74$
Trichosurus vulpecula	127	37	44 (59)
Petaurus australis	21	6	10 (13)
Petaurus breviceps	7	2	6 (8)
Pseudocheirus peregrinus	178	52	27 (36)
Phascolarctos cinereus	8	3	6 (8)
Total	341	100	

The decline of these taxa was probably due to various combinations of the effects of land clearance, grazing of stock, changed fire regimes, the introduction and subsequent effects of European Rabbits, and general persecution. The writings of some early settlers describe how the fauna of the Wimmera Plains declined in the face of European settlement. In the 1860s Edward Townsend described, amongst others, 'Wallabies, Kangaroo-rats, Native Cats and Dingoes' as occurring in the Nhill area (Blake 1976, p. 2). Of these only the Red-necked Wallaby *Macropus rufogriseus* occurs there now and it is rare. In 1861 William Lockhart Morton travelled north from Antwerp to Pine Plains and beyond (north of our survey area). He described 'Kangaroos, Wallabies, Paddymelons and Kangaroo-rats' (An Old Bushman 1861). From his descriptions of their behaviour these may have included the Western Grey Kangaroo *Macropus fuliginosus,* Bridled Nailtail Wallaby or Eastern Hare Wallaby, and Brush-tailed Bettong. Sub-fossil remains of Bridled Nailtail Wallaby were reported from Lake Hindmarsh in 1959 (Wakefield 1966). No small macropods are mentioned by subsequent naturalists who visited the area (e.g. Le Souef 1887, French 1888a, Le Souef 1893, Campbell 1899)

TABLE 6

COMPARISON OF FOOD NICHES OCCUPIED BY EACH SPECIES AND THE PHYSIOGRAPHIC REGIONS IN WHICH THEY OCCUR

Food niche	Species	Physiographic region				
		LD	WP	T	CP	VP
CARNIVORE						
Large Ground	*Dasyurus maculatus*					X
Small Soil Fossicking	*Tachyglossus aculeatus*	X	X	X	X	X
	Sminthopsis crassicaudata	X	X	X		
	S. murina		X	X		
	S. leucopus				X	X
	Antechinus swainsonii				X	X
	A. minimus				X	X
	Isoodon obesulus				X	X
	Potorous tridactylus					X
Small Scansorial	*Antechinus flavipes*		X	X	X	
	A. stuartii				X	X
	Phascogale tapoatafa		X	X		
Small Aerial	*Tadarida australis*	X	X	X		
	T. planiceps	X	X			
	Chalinolobus gouldii	X	X	X	X	X
	C. morio	X	X		X	X
	Eptesicus spp	X	X	X	X	X
	Miniopteris schreibersii				X	X
	Myotis adversus			X		
	Nycticeius balstoni	X	X			
	Nyctophilus geoffroyi	X	X	X	X	X
	Pipistrellus tasmaniensis				X	
OMNIVORE						
Large Ground	*Vulpes vulpes*	X	X	X	X	X
Small Ground	*Mus musculus*	X	X	X	X	X
	Rattus rattus		X		X	X
	R. fuscipes			X	X	X
Large Arboreal	*Trichosurus vulpecula*	X	X	X	X	X
	Petaurus breviceps	X	X	X	X	X
Small Arboreal	*Cercartetus concinnus*	X	X			
	C. nanus					X
	Acrobates pygmaeus		X	X	X	X
HERBIVORE						
Large Ground	*Macropus fuliginosus*	X	X			
	M. giganteus				X	X
	M. rufogriseus	X	X		X	X
	Vombatus ursinus				X	
Small Ground	*Oryctolagus cuniculus*		X	X	X	X
	Lepus capensis		X	X	X	X
	Pseudomys apodemoides	X	X			
	P. shortridgei				X	X
	Rattus lutreolus			X	X	X
Large Arboreal	*Pseudocheirus peregrinus*		X	X	X	X
	Petaurus australis				X	X
	Phascolarctos cinereus				X	X
Small Arboreal	*Pteropus scapulatus*		X			X
Totals (%)	44	17 (39)	26 (59)	20 (45)	30 (68)	31 (70)

LD - Little Desert, WP - Wimmera Plains, T - Tablelands, CP - Coastal Plains,

VP - Volcanic Plains

Table 7

Significance of Differences in Trapping Rates Between Physiographic Regions

Only the 2 regions with the highest trapping rates for each species are compared. Values in parentheses are the number of captures in each region. LD-Little Desert (5470 trap nights), WP-Wimmera Plains (3076), T-Tablelands (1502), CP-Coastal Plains (5240), VP-Volcanic Plains (2150).

Species	Physiographic regions compared	χ^2 value	Significance level
Antechinus flavipes	WP:CP (39:71)	0.2	NS
A. minimus	CP:VP (58:2)	18.7	0.001
A. stuartii	CP:VP (13.54)	89.1	0.001
A. swainsonii	CP:VP (10:59)	109.7	0.001
Isoodon obesulus	T:CP (3:44)	7.3	0.01
Trichosurus vulpecula	WP:CP (20:14)	6.6	0.01
Potorous tridactylus	CP:VP (7:12)	13.3	0.005
Mus musculus	WP:T (168:37)	21.5	0.001
Pseudomys apodemoides	LD:WP (85:44)	0.3	NS
P. shortridgei	CP:VP (78:14)	8.0	0.005
Rattus fuscipes	CP:VP (316:368)	213.5	0.001
R. lutreolus	CP:VP (211:35)	24.8	0.001
R. rattus	WP:VP (16:3)	4.7	0.05

although French (1888) says that he saw hardly any small mammals 'save a large Paddy-melon and a couple of Kangaroo-rats' [possibly Bridled Nailtail Wallaby and Brush-tailed Bettong]. These species would have inhabited woodland and disappeared soon after selectors moved into the Wimmera Plains with their flocks of sheep in the 1840s and 1850s. Wholesale clearing of woodlands and mallee for crops took place in the 1880s and the concurrent plagues of European Rabbits (Campbell 1884, French 1888, 1888a, Rolls 1969, p. 37) may have hastened the decline of the small macropods through competition for food and shelter. Details of the introduction and spread of European Rabbits are given in the Annotated List. Dingoes were poisoned with strychnine from the time sheep were first grazed in the area (Le Souef 1887, French 1888, D'Alton 1913) and Eastern Quolls may have suffered by taking baits laid for Dingoes. Marlow (1958) has noted a similar decline in the marsupial fauna of New South Wales, particularly the small marsupials of the woodlands and plains, during the late 19th century.

Zoogeography of the Present Fauna

Trapping rates obtained in this survey (20 species trapped at a success rate of 12%) were greater than or similar to results from previous FWD surveys in areas of similar size (e.g. North Central Victoria, 6 species trapped, 2% success rate (Menkhorst & Gilmore 1979) or Gippsland Lakes Catchment, 19 species trapped, 14% success rate (FWD unpublished data). This diverse mammal fauna reflects the broad range of habitats present, a consequence mainly of the wide variation in rainfall and soil types from north to south. Table 6 illustrates the increasing diversity of species towards the coast and the food niches occupied in each physiographic region. On the Volcanic Plains and Coastal Plains several species from all food niches were present. Data for the Tablelands are lacking due to the lack of native vegetation. However, at least one species from each food niche was recorded. The Wimmera Plains had fewer species of small ground and scansorial carnivores and only one large arboreal herbivore while the Little Desert was depauperate in small ground and scansorial carnivores, small ground omnivores, small ground herbivores and arboreal herbivores.

The trend of reducing species richness from the coast inland is not continued, in the case of small mammals, in the Big Desert to the north of our survey area. Four small mammal species occur there but not in the Little Desert; two small ground carnivores (*Ningaui* sp., Mouse Dunnart *Sminthopsis murina*), one small arboreal omnivore (Little Pygmy-possum *Cercartetus lepidus*) and one small ground herbivore (Mitchell's Hopping-mouse *Notomys mitchellii*). Reasons for the depauperate small mammal fauna in the Little Desert are not clear as the floristically rich heath comunities should result in a reliable food source for small herbivores and small carnivores and the climate is not as severe as in the Big Desert.

The associations between species of small mammals and physiographic regions, as revealed by comparisons of trapping rates, are shown in Fig. 4 and Table 7. The Silky Mouse was captured at similar rates in the Little Desert and Wimmera Plains and the Yellow-footed Antechinus in the Wimmera Plains and Coastal Plains.

Table 8

Major Existing and Proposed Conservation Reserves in Southwestern Victoria

There are approximately 428 400 ha of Crown Land in the survey area.

Reserve	Area (ha)	Physiographic region
Little Desert National Park	35300	Little Desert
Lower Glenelg National Park	27300	Coastal Plains
Jilpanger Flora and Fauna Reserve (proposed)	8990	Wimmera Plains
Discovery Bay Coastal Park	8450	Coastal Plains
Mt Eccles State Park	6200	Volcanic Plains
Mt Arapiles-Tooan State Park (proposed)	4860	Wimmera Plains
Tooloy-Lake Mundi Game Reserve	4012	Coastal Plains
Mt Richmond National Park	1707	Volcanic Plains
Bailleys Rocks Scenic and Recreation Reserve	489	Coastal Plains
Bats Ridges Faunal Reserve	324	Volcanic Plains
Cape Nelson State Park	210	Volcanic Plains
Total	97842	

TABLE 9

AREAS OF CONSERVATION RESERVES IN EACH PHYSIOGRAPHIC REGION

Figures in parentheses are the percentages of Crown Land in conservation reserves within each region.

Region	Area reserved (ha)	Percentage of total reserved area in Southwestern Victoria
Little Desert	35300 (22)	36
Wimmera Plains	13850 (46)	14
Tablelands	0	0
Coastal Plains	40251 (30)	41
Volcanic Plains	8442 (12)	9
Totals	97842	100

The Brown Antechinus *Antechinus stuartii,* Dusky antechinus *A. swainsonii,* Long-nosed Potoroo *Potorous tridactylus,* and Bush Rat were all trapped at significantly higher rates on the Volcanic Plains where the vegetation is predominantly Messmate open-forest and Manna Gum open-forest and the rainfall is the highest in the survey area (Fig. 2).

The Swamp Antechinus *A. minimus,* Short-nosed Bandicoot *Isoodon obesulus,* Swamp Rat, and Heath Mouse *Pseudomys shortridgei* were significantly associated with the Coastal Plains where they occur in the extensive heathlands and Brown Stringybark open-forest with a heath understory.

On the Wimmera Plains the two introduced rodents House Mouse and Black Rat *Rattus rattus* were trapped at higher rates than elsewhere, as was the Common Brushtail Possum. The predominance of the two introduced rodents probably reflects the greater extent of disturbance of the native vegetation in this region.

CONSERVATION RESERVES

Conservation reserves are defined here as any area of Crown Land having flora and fauna conservation as a primary management aim and being large enough to maintain communities of mammals. Areas used for hardwood or softwood production and the numerous small wetland reserves are excluded from the following discussion.

About 98 000 ha of Crown Land (23%) in the survey area is held in existing or proposed conservation reserves (LCC 1973, 1981, Ministry for Conservation 1981) (Table 8). This proportion of Crown Land held in conservation reserves is similar to that in most areas for which the LCC has produced Final Recommendations. However, the proportion for each physiographic region varies from 12% on the Volcanic Plains to 46% on the Wimmera Plains (Table 9). Further reserves are justified on the Volcanic Plains where most Crown Land is now used for hardwood production.

Most vegetation alliances are well represented within the present reserve system. However, River Red Gum woodland, Yellow Gum woodland and Brown Stringybark open-forest are inadequately catered for despite the fact that Brown Stringybark open-forest supports more mammal species than any other alliance and the two woodland alliances each support more than 40% of species (data from Appendix 1). The two woodland alliances occurred extensively on the Wimmera Plains, Tablelands and northern Coastal Plains but were cleared to form prime grazing and cropping country. The small areas of woodland remaining on Crown Land are now used for hardwood production threatening the existence of one species (Tuan *Phascogale tapoatafa*) in the survey area. The extensive areas of Brown Stringybark open-forest north and west of the Glenelg River are only reserved in Tooloy-Lake Mundi Game Reseve yet this alliance supports a diverse small mammal fauna consisting of Yellow-footed Antechinus, Swamp Antechinus, Short-nosed Bandicoot, Bush Rat, Swamp Rat, Silky Mouse and Heath Rat. This fauna is transitional between those of the Desert Banksia open-heaths of the Wimmera Plains and the wetter Silver Banksia closed-heaths near the coast. Further reserves of all 3 alliances are necessary to adequately cater for the range of mammals in the survey area.

ACKNOWLEDGEMENTS

We are grateful to the following for assistance in collecting field data: Fisheries and Wildlife Division: G. Apps, W. Bren, K. Cherry, S. Craig, D. Deerson, W. Emison, A. Gilmore, D. Hespe, G. Horrocks, J. Marcius, K. Norris, M. O'Sullivan, J. Porter, J. Seebeck,

TABLE 10

HABITAT PREFERENCE OF *Mus musculus* AND *Pseudomys apodemoides* IN THE LITTLE DESERT

Combined trapping data from October to November 1978 and February and April 1979.

Habitat	Number of sites	Percentage of sites where trapped		Mean trapping success per 100 trapnights	
		P. apodemoides	*M. musculus*	*P. apodemoides*	*M. musculus*
Desert Banksia open-heath	20	55	15	2	1
Yellow Mallee open-scrub	3	33	0	1	
Broom Honey-myrtle open-scrub	21	52	10	2	0.3
Brown Stringybark low open-forest	40	65	12	2	1
Yellow Gum woodland	24	0	20		1
Red Gum woodland	3	0	100		5

and I. Temby; National Museum of Victoria: A. Coventry, A. Gedye, and R. Wilson; National Herbarium: Dr. P. Gullan, D. Parkes, and N. Walsh. J. Alexander and R. Adair also assisted. Information from personal files and records was provided by C. Brownsea (National Parks Service), G. Cerini (FWD), A. Cockburn (Monash University), C. Crouch (Nhill), J. Davies (NPS), K. Hateley (Kiata), R. Howlett (Dergholm), P. Kelly (FWD), W. Middleton (Forests Commission Victoria), R. and P. Reichelt (Nhill), F. Rogers (Quantong), J. Seebeck (FWD), and R. Warneke (FWD).

The collations of museum specimens and literature records carried out at the NMV (Gedye *et al.* 1979, Evans & Dixon 1980) were a major source of information and saved much tedium. P. Aitken provided lists of relevant specimens held in the South Australian Museum.

A. F. Bennett, W. B. Emison, Dr. F. I. Norman, and J. H. Seebeck kindly commented on drafts of this paper. J. Marcius helped with proof reading.

REFERENCES

An Old Bushman [William Lockhart Morton], 1861. Notes of a tour in the Wimmera District. *The Yeoman and Australian Acclimatiser* Vol. 1.

Anonymous, 1846. Miscellanea. *The Tasmanian Journal* 2: 460.

Anonymous, 1907. Natural History Note. *Victorian Nat.* 23: 243.

Australian Mammal Society, 1980. Recommended common names of Australian mammals. *Aust. Mamm. Soc. Bull.* 6(2): 13-23..

Bentley, A., 1978. *An introduction to the Deer of Australia with special reference to Victoria* (Revised ed.). Koetong Trust Service Fund, Forests Commission Victoria, Melbourne.

Blake, L., 1976. *The Land of the Lowan: 100 Years in Nhill and West Wimmera.* Nhill and District Historical Society, Nhill.

Braithwaite, R. W., 1980. The ecology of *Rattus lutreolus.* II. Reproductive tactics. *Aust. Wildl. Res.* 7: 53-62.

Braithwaite, R. W., Cockburn, A. & Lee, A. K., 1978. Resource partitioning by small mammals in lowland heath communities of south-eastern Australia. *Aust. J. Ecol.* 3: 423-445.

Braithwaite, R. W. & Lee, A. K., 1979. The ecology of *Rattus lutreolus.* I. A Victorian heathland population. *Aust. Wildl. Res.* 6: 173-189.

Braithwaite, R. W. & Lee, A. K., 1979a. A mammalian example of semelparity. *American Nat.* 113: 151-5.

Brazenor, C. W., 1936. Muridae recorded from Victoria. *Mem. Natn. Mus. Melb.* 10: 62-85.

Brazenor, C. W., 1958. Mitchells Hopping Mouse. *Proc. R. Zool. Soc. NSW* (1956-7): 19-22.

Bureau of Meteorology, 1975. *Climatic Averages Australia.* Metric ed. Aust. Government Publishing Service, Canberra.

Calaby, J. H., 1971. Man, fauna and climate in aboriginal Australia. In *Aboriginal Man and Environment in Australia,* Mulvaney, D. J. and Galson, J., eds, ANU Press, Canberra.

Campbell, A. J., 1884. Mallee Hens and their Egg Mounds. *Victorian Nat.* 1: 124-129.

Campbell, A. J., 1899. Field notes from the lower Wimmera. *Victorian Nat.* 16: 121-131, 149-158.

Cockburn, A., 1979. The ecology of *Pseudomys* spp. in south-eastern Australia. PhD Thesis, Monash University, (unpubl.).

Cockburn, A., 1981. Diet and habitat preference of the Silky Desert Mouse, *Pseudomys apodemoides* (Rodentia). *Aust. Wildl. Res.* 8: 475-497.

Cockburn, A., 1981a. Population processes of the Silky Desert Mouse *Pseudomys apodemoides* (Rodentia), in mature heathland. *Aust. Wildl. Res.* 8: 499-514.

Cockburn, A., Brathwatie, R. W. & Lee, A. K., 1981. The response of the Heath Rat, *Pseudomys shortridgei,* to pyric succession: a temporally dynamic life-history strategy. *J. Anim. Ecol.* 50: 649-666.

D'Alton, St Elroy, 1913. The botany of the Little Desert, Wimmera, Victoria. *Victorian Nat.* 30: 65-78.

Dwyer, P. D., 1970. Foraging of the Australian Large-footed Myotis (Chiroptera). *Mammalia* 34: 76-80.

Dwyer, P. D. & Hamilton-Smith, E., 1965. Breeding caves and maternity colonies of the Bent-winged Bat in south-eastern Australia. *Helictite* 4: 3-21.

Emison, W. B., Porter, J. W., Norris, K. C. & Apps, G. J., 1978. Survey of the vertebrate fauna in the Grampians-Edenhope area of southwestern Victoria. *Mem. natn. Mus. Vict.* 39: 281-363.

Evans, S. & Dixon, J. M., 1980. *Report on the mammalian fauna of the South Western Study Area (District 1).* Mammal Dept., National Museum of Victoria, Melbourne.

Finlayson, H. H., 1927. Observations on the South Australian members of the subgenus "*Wallabia*". *Trans. R. Soc. S. Aust.* 51: 363-377.

Finlayson, H. H., 1944. A further account of the murid, *Pseudomys (Gyomys) apodemoides* Finlayson. *Trans. R. Soc. S. Aust.* 68: 210-224.

Frankenberg, Judith, 1971. *Nature Conservation in Victoria: a survey.* Victorian National Parks Association, Melbourne.

French, Charles, 1888. Notes on the Zoology of Lake Albacutya District. *Victorian Nat.* 5: 35-42.

French, C., 1888a. Notes on the natural history of the western Wimmera. *Victorian Nat.* 5: 145-152.

Gedye, A., Wilson, R., Dixon, J. M. & Huxley, L., 1979. *Report on the mammalian fauna of the Wimmera, Victoria.* Mammal Dept., National Museum of Victoria, Melbourne.

Hall, K. S. & Richards, G. C., 1979. *Bats of Eastern Australia.* Queensland Museum Booklet No. 12, Brisbane.

Hamilton, J. C., 1914. *Pioneering Days in Western Victoria.* Exchange Press, Melbourne.

Hamilton-Smith, E., 1965. Distribution of cave-dwelling bats in Victoria. *Victorian Nat.* 82: 132-137.

Happold, M., 1976. Reproductive biology and development in the conilurine rodents (Muridae) of Australia. *Aust. J. Zool.* 24: 19-26.

Hills, E. S., 1975. *The Physiography of Victoria.* Whitcombe and Tombs, Melbourne.

Jones, F. W., 1924. *The Mammals of South Australia. Pt. 2 Bandicoots and the Herbivorous Marsupials.* Government Printer, Adelaide.

Keiller, H., 1940. Wildlife of Portland. *B.O.C. Monthly Notes* (Aug.).

Land Conservation Council of Victoria, 1972. *Report on the South West Study Area, District 1.* Government Printer, Melbourne.

Land Conservation Council of Victoria, 1973. *Final Recommendations, South-western Study Area, District 1.* Government Printer, Melbourne.

Land Conservation Council of Victoria, 1979. *Report on the South West Study Area, District 2.* Government Printer, Melbourne.

Land Conservation Council of Victoria, 1981. *Proposed Recommendations, South-western Area, District 2.* Government Printer, Melbourne.

Land Conservation Council of Victoria, 1981a. *South-western Area, District 1—Review.* Government Printer, Melbourne.

Le Souef, D., 1887. Trip to Lake Albacutya. *Victorian Nat.* 4: 44-47.

Le Souef, D., 1893. Notes on a visit to the Ebenezer Mission Station. *Victorian Nat.* 10: 123-128.

Le Souef, J. C., 1965. Acclimatization in Victoria. *The Victorian Historical Magazine* 36: 8-29.

Maddock, T. H., 1971. Some mammal remains from caves in the Naracoorte area. *S. Aust. Nat.* 46: 24-27.

Mahoney, J. A., 1982. Identities of the rodents (Muridae) listed in T. L. Mitchell's "Three Expeditions into the Interior of Eastern Australia, with Descriptions of the Recently Explored Region of Australia Felix, and of the Present Colony of New South Wales". *Aust. Mamm.* 5: 15-36.

Marlow, B. J., 1958. A survey of the marsupials of New South Wales. *CSIRO Wildl. Res.* 3: 71-114.

McKean, J. L. & Hall, L. S., 1965. Distribution of the Large-footed Myotis, *Myotis adversus*, in Australia. *Victorian Nat.* 82: 164-168.

McKean, J. L., Richards, G. C. & Price, W. J., 1978. A taxonomic appraisal of *Eptesicus* (Chiroptera: Mammalia) in Australia. *Aust. J. Zool.* 26: 529-537.

Menkhorst, P. W. & Gilmore, A. M., 1979. Mammals and reptiles of North Central Victoria. *Mem. natn. Mus. Vict.* 40: 1-33.

Ministry for Conservation, 1981. *A guide to the Ministry for Conservation.* 3rd ed., Government Printer, Melbourne.

Morton, S. R., 1978. An ecological study of *Sminthopsis crassicaudata* (Marsupialia: Dasyuridae). III. Reproduction and life history. *Aust. Wildl. Res.* 5: 183-212.

Morton, S. R., Wainer, J. W. & Thwaites, T. P., 1980. Distribution and habitats of *Sminthopsis leucopus* and *S. murina* (Marsupialia: Dasyuridae) in south-eastern Australia. *Aust. Mamm.* 3: 19-30.

Newsome, A. E., 1969. A population study of house-mice temporarily inhabiting a South Australian wheatfield. *J. Anim. Ecol.* 38: 341-359.

N. F. L. [Noel Learmonth] 1947. Random Notes. *Portland Guardian* 28 May, 1947.

Norris, K. C., Gilmore, A. M. & Menkhorst, P. W., 1979. Vertebrate fauna of South Gippsland, Victoria. *Mem. natn. Mus. Vict.* 40: 105-199.

Parnaby, H., 1977. Bat survey of the Daylesford area, Victoria. *Victorian Nat.* 94: 191-197.

Poole, W. E., 1973. A study of breeding in Grey Kangaroos, *Macropus giganteus* Shaw and *M. fuliginosus* (Desmarest), in central New South Wales. *Aust. J. Zool.* 21: 183-212.

Poole, W. E., 1977. The Eastern Grey Kangaroo, *Macropus giganteus*, in South-east South Australia: its limited distribution and need of conservation. *CSIRO Div. Wildl. Res. Tech. Pap.* No. 31.

Poole, W. E., Carpenter, S. M. & Simms, N. G., 1980. Multivariate analyses of skull morphometrics from the two species of Grey Kangaroos, *Macropus giganteus* Shaw and *M. fuliginosus* (Desmarest). *Aust. J. Zool.* 28: 591-605.

Robinson, A. C., 1976. Population ecology of *Rattus fuscipes* Waterhouse (Muridae:Rodentia). PhD Thesis, Monash University (unpubl.).

Rolls, E. C., 1969. *They all Ran Wild: the story of pests on the land in Australia.* Angus & Robertson, Sydney.

Ryan, R. M., 1963. Extension of range of *Pesudomys apodemoides. Victorian Nat.* 79: 363.

Saunders, G. R. & Giles, J. R., 1977. A relationship between plagues of the house mouse, *Mus musculus* (Rodentia: Muridae) and prolonged periods of dry weather in south-eastern Australia. *Aust. Wildl. Res.* 4: 151-157.

Seebeck, J. H. & Hamilton-Smith, E., 1967. Notes on a wintering colony of bats. *Victorian Nat.* 84: 348-351.

Smith, M., 1971. Small fossil vertebrates from Victoria Cave, Naracoorte, South Australia. I. Potoroinae (Macropodidae), Petauridae and Burramyidae (Marsupialia). *Trans. R. Soc. S. Aust.* 95: 185-198.

Smith, M., 1972. Small fossil vertebrates from Victoria Cave, Naracoorte, South Australia. II. Peramelidae, Thylacinidae and Dasyuridae (Marsupialia). *Trans. R. Soc. S. Aust.* 96: 125-137.

Specht, R. L., Roe, E. M. & Broughton, V. H., 1974. Conservation of major plant communities in Australia and Papua New Guinea. *Aust. J. Bot. Suppl.* No. 7.

Stoddart, D. M. & Braithwaite, R. W., 1979. A strategy for utilization of regenerating heathland habitat by the Brown Bandicoot (*Isoodon obesulus*; Marsupialia, Peramelidae). *J. Anim. Ecol.* 48: 165-179.

Tidemann, C. R., 1967. Some mammal remains from cave deposits in the south-east of South Australia. *S. Aust. Nat.* 42: 21-27.

Tidemann, C. R. & Woodside, D. P., 1978. A collapsible bat-trap and a comparison of results obtained with the trap and with mist nets. *Aust. Wildl. Res.* 5: 355-362.

Wainer, J. W., 1976. Studies of an island population of *Antechinus minimus* (Marsupialia, Dasyuridae). *Aust. Zoologist* 19: 1-7.

Wainer, J. W. & Gibson, R. J., 1976. Habitat of the Swamp Antechinus in Victoria. *Victorian Nat.* 93: 253-255.

Wakefield, N. A., 1963. Mammal remains from The Grampians, Victoria. *Victorian Nat.* 80: 130-133.

Wakefield, N. A., 1964. Recent mammalian sub-fossils of the basalt plains of Victoria. *Proc. R. Soc. Vict.* 77: 419-425.

Wakefield, N. A., 1964a. Mammal sub-fossils from near Portland, Victoria. *Victorian Nat.* 80: 39-45.

Wakefield, N. A., 1966. Mammals recorded for the Mallee, Victoria. *Proc. R. Soc. Vict.* 79: 627-633.

Wakefield, N. A., 1967. Preliminary report on McEachern's Cave, S.W. Victoria. *Victorian Nat.* 84: 363-383.

Wakefield, N. A., 1969. Interpretation of data from McEachern's Cave, S.W. Victoria. *Helictite* 7: 17-20.

Wakefield, N. A., 1970. Notes on the glider-possum, *Petaurus australis* (Phalangeridae, Marsupialia). *Victorian Nat.* 87: 221-236.

Wakefield, N. A., 1971. The Brush-tailed Rock-wallaby (*Petrogale penicillata*) in Western Victoria. *Victorian Nat.* 88: 92-102.

Wakefield, N. A., 1974. Mammals of Western Victoria. In *The Natural History of Western Victoria,* Douglas, M. H. & O'Brien, L., eds, Western Victorian Sub-branch, Aust. Inst. Ag. Sci., Horsham, 35-51.

WALLIS, R. & BAXTER, G., 1980. The Swamp *Antechinus* (Antechinus minimus maritimus)—notes on a captive specimen. *Victorian Nat.* 97: 211-213.

WATSON, I. GARNET, J. R., LEE, R. D., BURKE, A. & CUDMORE, F. A., 1947. The proposed Glenelg National Forest and Sanctuary. *Victorian Nat.* 64: 62-73.

WATTS, C. H. S. & ASLIN, H. J., 1981. *The Rodents of Australia.* Angus & Robertson, Sydney.

WARNEKE, R. M., 1971. Field study of the Bush Rat (*Rattus fuscipes*). *Wildl. Contrib. Vict.* 14.

WARNEKE, R. M., 1978. The status of the Koala in Victoria. In *The Koala: proceedings of the Toronga Symposium,* Bergin, T. J. ed., Zoological Parks Board, New South Wales, Sydney.

WILLIS, J. H., 1970. *A Handbook to Plants in Victoria. Volume I.* Ferns, Conifers and Monocotyledons. 2nd Ed. Melbourne University Press, Melbourne.

WILLIS, J. H., 1972. *A Handbook to Plants in Victoria. Volume II.* Dicotyledons. Melbourne University Press, Melbourne.

WOOLLEY, P., 1966. Reproduction in *Antechinus* spp. and other dasyurid marsupials. *Symp. Zool. Soc. Lond.* 15: 281-294.

APPENDIX 1

ANNOTATED LIST OF MAMMALS

Nomenclature and taxonomic order follow Australian Mammal Society (1980) and names of plants follow Willis (1970, 1972). Vegetation alliances listed under habitat include only those in which we recorded the species unless otherwise stated. Specimen numbers prefixed by C refer to specimens held in the NMV, those listed under Specimens were taken during this survey. FWD indicates Fisheries and Wildlife Division, Ministry for Conservation. Previous records are listed by Gedye *et al.* (1977) and Evans and Dixon (1980). For species not recorded during our survey the most recent record from the survey area is given.

TACHYGLOSSIDAE

1. **Tachyglossus aculeatus**—Short-beaked Echidna
Abundance and distribution. Uncommon and widespread. Only 18 observed during our survey, 5 of which were road mortalities. Most sightings (66%) were in spring and summer. Observed in 12 cells although characteristic diggings were found in 43% of all cells in which trapping took place.
Habitat. All terrestrial environments except closed-scrub, closed-heath and extensive tracts of farmland.

ORNITHORYNCHIDAE

2. **Ornithorhynchus anatinus**—Platypus
Abundance and distribution. Common and restricted to streams. Recorded from the Glenelg, Wannon (B. Burchell *pers. comm.*) Surrey (N.F.L. 1947) and Wimmera Rivers (W. Middelton *pers. comm.*); from Bryon Creek at Coleraine; Darlots Creek (Keiller 1940) and Lake Monibeong (NPS records). Not observed during our survey although several recent sightings were reported by local naturalists. The zoogeographic interest of the isolated population in the Wimmera River has been mentioned by Emison *et al.* (1978).
Habitat. Aquatic. Requires permanent freshwater with a mud or gravel substrate and friable banks in which to construct burrows. In the Glenelg River it occurs in tidal, brackish water as far downstream as Sapling Creek some 30 km from the mouth (J. Davies *pers. comm.*) although Watson *et al.* (1947) reported a sighting about 1.6 km from the mouth.

DASYURIDAE

3. **Antechinus flavipes**—Yellow-footed Antechinus
Abundance and distribution. Widespread and common but absent from the Little Desert and rare on the Volcanic Plains. A specimen labelled 'Kaniva area' (NMV C15870) actually came from 20 km S of Kaniva on the southern edge of the Little Desert (C. Crouch *pers. comm.*).
Habitat. Brown Stringybark open-forest and low open-forest, all woodland types, Silver Banksia open-heath and Desert Banksia open-heath on the Wimmera Plains. Trapping rates were highest in Manna Gum woodland (8%) and lowest in Desert Banksia open-heath (4%).
Breeding. Females with pouch young were trapped between 15 and 23 August. All females had ten nipples, and ten pouch young were recorded in all five litters examined. By 14 November females were still lactating but had no young in the pouch. Male die-off (Braithwaite & Lee 1979a) was complete by 15 August, the last male being trapped on 6 July and one was found dead on 17 August (FWD 12016). First year males were first trapped on 28 January.
Specimens. C13176, C14052, C22268, C24363-9, C24548, C25208, FWD 12016.

4. **Anetchinus minimus**—Swamp Antechinus
Abundance and distribution. Restricted to the Volcanic Plains near the coast and those parts of the Coastal Plains having >650 mm rainfall per year. Locally common.
Habitat. Brown Stringybark open-forest with wet heath understory, Silver Banksia closed-heath, Coast Wattle open-scrub and Blue Tussock Grass closed-grassland. Only 50% of trap sites were in treeless heath (cf. Wainer & Gibson 1976) and mean trapping success rates were similar in Brown Stringybark open-forest (8%) and treeless Silver Banksia closed-heaths (7%). Floristic data were collected at 14 of the 22 capture sites. Commonly occurring species of plants from these sites are listed below. Many of these species were also dominant in heaths preferred by *A. minimus* at Cape Liptrap, South Gippsland (Braithwaite *et al.* 1978).

Species	% Occurrence
Leptospermum juniperinum	85
Xanthorrhoea minor	86
Banksia marginata	71
Melaleuca squarrosa	71
Leptocarpus tenax	64
Sprengelia incarnata	43
Casuarina pusilla	36
Eucalyptus baxteri	36

Breeding. Little trapping took place within the range of this species during the supposed breeding period (June-September). A female trapped on 1 June (NMV C22267) had a pouch similar to other *Antechinus* spp. at the time of mating (Woolley 1966), and independent young were trapped between 13 and 16 November. Assuming the age of weaning is roughly 14 weeks (Wallis & Baxter 1980), mating must have occurred before early August. Sex ratios of trapped animals in March, May and June were 1.7:1 (12♂, 7♀), 1.6:1 (8♂, 5♀) and 1.7:1 (15♂,

9♀) respectively, showing a similar preponderance of males to that found by Wainer (1976). No males were trapped in July. All females had 8 nipples. Thus the breeding cycle in southwestern Victoria appears similar to that on Great Glennie Island (Wainer 1976) and in South Gippsland (Norris *et al.* 1979, Wallis & Baxter 1980).
Specimens. C22267, C24345-7, FWD 12398.

5. **Antechinus stuartii**—Brown Antechinus
Abundance and distribution. Restricted to the Volcanic Plains near the coast and high rainfall (>800 mm per annum) areas of the Coastal Plains where it is locally common. Not recorded in South Australia.
Habitat. Messmate open-forest and Silver Banksia closed-heath.
Breeding. Trapping took place within the range of this species only in October and March. Male die-off was complete before October when females had nest young. One independent male juvenile was captured on 12 October. All females examined had 6 nipples.
Specimens. C13559, C24358, C24382.

6. **Antechinus swainsonii**—Dusky Antechinus
Abundance and distribution. Restricted to the Volcanic Plains near the coast and high rainfall (>800 mm per annum) areas of the Coastal Plains. Locally common. Not recorded from South Australia.
Habitat. Messmate open-forest and Silver Banksia closed-heath.
Breeding. Trapping within the range of this species began on 12 October when male die-off was complete. Lactating females without pouch young were captured between 12 and 19 October, as were independent juveniles. All females had 8 nipples.
Specimens. C13558, C24379-81, FWD 12152, FWD 12226.

7. **Dasyurus maculatus**—Tiger Quoll
Abundance and distribution. Restricted to the high rainfall (>750 mm per annum) areas of the Volcanic Plains except for a specimen from Hamilton in 1958 (NMV C2806). Uncommon in The Stones State Faunal Reserve, rare in the Heywood area. The population in The Stones State Faunal Reserve is one of the most stable and accessible in Victoria, the only other areas where regular reports are made being the upper Snowy River and Otway Ranges.
Habitat. Manna Gum woodland with an understorey of *Pteridium esculentum* and grasses covering jumbled basalt boulders. Occasionally in Messmate open-forest and Manna Gum open-forest in Cobobboonee Forest. During the breeding season from May to late July wandering adult males occur in farmland surrounding the main habitat.

8. **Dasyurus viverrinus**—Eastern Quoll
Abundance and distribution. Formerly widespread but no longer present. Listed by Edward Townsend, an early Nhill resident, as occurring in the Nhill district in the 1860s (Blake 1976, p. 2). Reported to have killed young Ostriches *Struthio camelus* being bred at Longerenong Station in 1867 (Rolls 1969, p. 251).
Habitat. Presumably most woodland alliances.

9. **Phascogale tapoatafa**—Tuan
Abundance and distribution. Restricted and rare. Recorded only on the Tablelands and Wimmera Plains where small remnants of Crown Land and roadside and streamside reserves provide the only remaining habitat. During our survey a road-killed animal was found at Apsley and we were told of one captured 13 km WNW of Edenhope and 2 killed by cats near Balmoral. Also recorded from: Telangatuk East (FWD 785), Bulart (FWD D587), 29 km N of Casterton (C13969), 23 km N of Coleraine (C3135), Brit Brit (C2475), Casterton (C2655) and Coleraine (FWD DB251). The provenance of two specimens labelled Portland (C2042-3) is uncertain. They may have come from further north.
Habitat. All woodland alliances.
Specimen. C13164.

10. **Sminthopsis crassicaudata**—Fat-tailed Dunnart
Abundance and distribution. Widespread and uncommon in the Tablelands and Wimmera Plains; rare in the Little Desert. Not recorded from the Coastal or Volcanic Plains. Only one captured during our survey in a pitfall in the Little Desert 16 km S of Gerang Gerung. Probably more common than our results suggest as it mostly inhabits farmland.
Habitat. Desert Banksia open-heath. Usually associated with farmland. Morton (1978) claims that it does not occur in closed or open-scrub. However, the only animal captured during our survey was collected in low open-heath dominated by *Casuarina muellerana, Xanthorrhoea australis* and *Hibbertia* sp. on a dune adjacent to a small claypan with Yellow Gum woodland.
Specimen. C22264.

11. **Sminthopsis leucopus**—White-footed Dunnart
Abundance and distribution. Restricted to areas of the Volcanic Plains and Coastal Plains having >700 mm rainfall per annum. Not recorded from adjacent parts of South Australia. Probably more common than records suggest as it is difficult to trap.
Habitat. Brown Stringybark open-forest with a dense heath understory and Silver Banksia closed-heath. Dominant plant species from our trapping site were: *Acacia verticillata, Banksia marginata, Hibbertia* sp. *Leptocarpus tenax, Leptospermum juniperinum, Melaleuca squarrosa, Sprengelia incarnata* and *Xanthorrhoea minor.* Morton *et al.* (1980) describe the habitat from the Mt Clay site and Cockburn (*pers. comm.*) trapped and released several individuals on Bald Hill, Lower Glenelg National Park in dense wet heath.
Specimen. C22668.

12. **Sminthopsis murina**—Common Dunnart
Abundance and distribution. Restricted to the Tablelands and Wimmera Plains. All records come from the Edenhope-Chetwynd area where the mean annual rainfall is between 700 and 550 mm (cf. Morton *et al.* 1980); we consider its presence in the lower Glenelg River area to be unconfirmed as specimen C14017 is intermediate and the habitat is atypical. Only one (0.1%) was trapped 15 km SW of Edenhope, and the remains of another were found in a fox stomach (FWD 8993) taken 10 km W of Chetwynd in March 1973. Also recorded from 24 km N of Casterton (C14020, C14028) in 1967 and from 23 km NNW of Coleraine in 1962 (C4510). Not recorded from the Little Desert although it occurs in the Big Desert to the north and at similar latitudes in South Australia (Morton *et al.* 1980, fig. 2).
Habitat. Brown Stringybark open-forest. Our capture was made in a thicket of *Leptospermum juniperinum* with a sparse ground cover of *Hibbertia fasciculata, Lepidosperma longitudinale* and *Hypolaena fastigiata.* This thicket was surrounded by Brown Stringybark open-forest with a sparse heath understorey dominated by *Xanthorrhoea minor, Brachyloma daphnoides, Leucopogon virgatus* and *Calytrix tetragona.*
Specimens. C24357, FWD 8993.

PERAMELIDAE

13. **Isodoon obesulus**—Southern Brown Bandicoot
Abundance and distribution. Widespread and common on the Coastal Plains and Volcanic Plains. The most northerly record in the survey area (37°10'S) approximates the 600 mm isohyet. Not recorded from adjacent parts of South Australia.

Habitat. Messmate open-forest, Brown Stringybark open-forest and low open-forest, Scented Paper-bark closed-scrub and Silver Banksia closed-heath and open-heath. Not recorded in Coast Wattle open-scrub in contrast to South Gippsland (Norris *et al.* 1979) nor in Desert Banksia open-heath. Trapping success in Brown Stringybark open-forest (3.7%) was similar to that in Silver Banksia closed-heath (3.3%).
Breeding. Trapping within the range of *I. obesulus* took place in March, May, June, July, August, October and November. Pouch young were present in June, October and November but not in July and August when few females were trapped. Mean litter size was 2.5 ($n=6$). Stoddart and Braithwaite (1979) found a distinct breeding peak between July and December at Cranbourne, Victoria and a mean litter size of 3 but claim that breeding occurs year round in Western Victoria.
Specimens. C22269, C24374-5.

PHALANGERIDAE

14. **Trichosurus vulpecula**—Common Brushtail Possum
Abundance and distribution. Widespread and common except in the Little Desert where it is rare. The most widespread arboreal mammal in the survey area (Table 5).
Habitat. All open-forest and woodland types and farmland with trees. Of the 164 animals trapped or spotlighted during our survey 44% were in River Red Gum woodland, 16% in Brown Stringybark open-forest, 4% in Brown Stringybark low open-forest, 16% in Manna Gum open-forest, 8% in Manna Gum woodland, 3% in Messmate open-forest, 6% in Yellow Gum woodland, 3% in *Casuarina luehmannii* in farmland and 1% in *Eucalyptus cladocalyx* plantation.

BURRAMYIDAE

15. **Acrobates pygmaeus**—Feathertail Glider
Abundance and distribution. Widespread and uncommon. Not recorded in the Little Desert or on the Coastal Plains. Specimen records are from Portland, Gorae Forest and 24 km NW of Casterton (Evans & Dixon 1980); Golter South (Gedye *et al.* 1979); Frances (SAM M2088); and Lower Norton (FWD 12273). Sight records are from Coleraine in 1975 (B. Burchell *pers. comm.*), 3 km NE of Balmoral in March 1980 (I. Temby *pers. comm.*) and 4 km E of Comaum in 1974 (A. Roper *pers. comm.*). The provenance of a record from the Kaniva area (Wakefield 1966) remains uncertain.
Habitat. Recorded in Yellow Gum woodland (I. Temby *pers. comm.*), Messmate open-forest in Gorae Forest (V. Peterson *pers. comm.* to J. Seebeck), in an old building in Coleraine (B. Burchell *pers. comm.*) and in a fruit and vegetable garden with nearby River Red Gum woodland at Lower Norton. Brown Stringybark open-forest may be unsuitable.

16. **Cercartetus concinnus**—Western Pygmy-possum
Abundance and distribution. Widespread and probably common in the Little Desert, rare on the Wimmera Plains (Emison *et al.* 1978) and absent from elsewhere in the survey area. All records are from areas with <600 mm rainfall per annum. Recorded in only 2 grids during our survey. It does not readily enter cage traps and was recorded by drift fence pitfall trapping and the chance finding of skeletal remains. Probably more common than records suggest.
Habitat. Recorded in Brown Stringybark low open-forest and Yellow Gum woodland. Two individuals were captured in pitfalls in Yellow Gum woodland with an understorey of *Melaleuca wilsonii* and nearby heath with *Triodia* sp. Another was found dead in an old building surrounded by Brown Stringybark low open-forest.
Breeding. A female examined on 30 March 1970 on the edge of the Little Desert S of Broughtons Waterhole had 5 pouch young.
Specimens. C21025, C22245.

17. **Cercartetus nanus**—Eastern Pygmy-possum
Abundance and distribution. Restricted to the high rainfall (>800 mm per annum) areas of the Volcanic Plains where it is uncommon. Only 1 (0.1%) trapped during our survey, 5 km NNE of Mt Kincaid in Lower Glenelg National Park. Previous specimen records are from Portland, Surrey River west of Portland, Gorae area and Mt Richmond (Evans & Dixon 1980). A specimen from Edenhope (C2471) registered as *C. nanus* is actually *C. concinnus* (L. Huxley *pers. comm.*).
Habitat. Messmate open-forest, Manna Gum open-forest and Silver Banksia closed-heath with emergent eucalypts. The animal trapped during our survey was captured on the ground in closed-heath dominated by *Casuarina pusilla, Leptospermum juniperinum, L. myrsinoides, Hypolaena fastigiata, Xanthorrhoea australis, Banksia marginata, Melaleuca squarrosa, Persoonia juniperina* and *Leucopogon australis* with emergent *Eucalyptus nitida.*
Specimen. C24378.

PETAURIDAE

18. **Petaurus australis**—Yellow-bellied Glider
Abundance and distribution. Restricted to the Volcanic Plains, Coastal Plains and south Wimmera Plains where the mean annual rainfall exceeds 600 mm. The most northerly record during our survey was 14 km SW of Edenhope. Formerly present in streamside Manna Gum woodland in the Kanawinka area (R. Keeble *pers. comm.*).
Habitat. Manna Gum open-forest, Messmate open-forest, Brown Stringybark open-forest, particularly where gum-barked eucalypts (*E. viminalis, E. aromaphloia* and *E. ovata*) are also present and Yellow Gum woodland. The 58 trees with incisions made by this species, "feed-trees" (Wakefield 1970), included *E. viminalis* (45%), *E. leucoxylon* (33%), *E. obliqua* (16%), *E. baxteri* (2%), *E. pauciflora* (2%) and *E. aromaphloia* (2%).

19. **Petaurus breviceps**—Sugar Glider
Abundance and distribution. Widespread and uncommon; becomes progressively rarer to the north. Not recorded north of the Little Desert.
Habitat. All open-forest and woodland alliances except in the Little Desert where they appear to be restricted to Yellow Gum woodland. Most common in open-forest or woodland with a tall shrub understorey including *Acacia mearnsii* and *Banksia marginata.* Of the seven observed during our survey three were in Manna Gum open-forest and one was in each of River Red Gum woodland, Yellow Gum woodland, Messmate open-forest and Brown Stringybark open-forest.

20. **Pseudocheirus peregrinus**—Common Ringtail Possum
Abundance and distribution. Restricted to the Volcanic Plains, Coastal Plains, Tablelands and Mt Arapiles in the Wimmera Plains. Common in the south becoming progressively less common to the north. Not recorded in the Little Desert and the only population on the Wimmera Plains is on Mt Arapiles. All records, except those from Mt Arapiles, fall within the 650 mm isohyet. This species was the most commonly observed arboreal mammal although it was recorded in only 36% of cells where spotlighting occurred (Table 5).
Habitat. All open-forest alliances, River Red Gum woodland, Manna Gum woodland and Silver Banksia open-heath with emergent eucalypts. Of the 171 animals recorded 48% were in Manna Gum open-forest, 25% in Brown Stringybark open-forest, 19% in Messmate open-forest, 3% in River Red Gum woodland, 3% in Manna Gum woodland and 0.6% in Silver Banksia open-heath with emergent *Eucalyptus nitida.*

MACROPODIDAE

Genus **Macropus**

Difficulties in field identification of *Macropus* spp. in western Victoria have been discussed by Poole (1973), Emison *et al.* (1978) and Poole *et al.* (1980). Two species (*M. fuliginosus* and *M. rufogriseus*) occur widely in the survey area and *M. giganteus* is restricted to the south. *M. rufogriseus* is distinctive in colour and form. However, great difficulty was experienced in distinguishing between *M. giganteus* and *M. fuliginosus*. After careful field observations and the examination of numerous road-casualties we consider that *M. giganteus* and *M. fuliginosus* are sympatric between about 37°35′S and 38°00′S (see also Poole 1977). Within this zone our specific identifications are not certain and the distributions shown are provisional. Morphometric data from a large series of skulls would be necessary to accurately determine the extent of sympatry (Poole *et al.* 1980).

21. **Macropus fuliginosus**—Western Grey Kangaroo

Abundance and distribution. Widespread and common north of about 38°S. Uncommon on the Tablelands where little native vegetation remains. Recorded in 60% of cells surveyed with chance sightings in a further 7.

Habitat. Brown Stringybark open-forest and low open-forest, all woodland alliances, Broom Honey-myrtle open-scrub, Yellow Mallee open-scrub, all open-heath alliances, farmland adjacent to uncleared land and the edges of pine plantations.

Specimens. C24376, FWD 8995.

22. **Macropus giganteus**—Eastern Grey Kangaroo

Abundance and distribution. Restricted to the Volcanic Plains and Coastal Plains south of about 37°35′S, where it is common. Recorded in 16% of cells surveyed with chance sightings in a further 5.

Habitat. All open-forest alliances, River Red Gum woodland, Manna Gum woodland, Coast Wattle open-scrub, Silver Banksia open-heath, farmland adjacent to uncleared land and the edges of pine plantations.

23. **Macropus greyi**—Toolache Wallaby

Abundance and distribution. Extinct. Formerly locally common in southeastern South Australia (Jones 1924) and, possibly, adjacent parts of Victoria. Evidence of its presence in Victoria since European settlement appears to be based entirely on a footnote in Finlayson (1927, p. 366) as Jones (1924) considered it endemic to South Australia.

Habitat. Described by Finlayson (1927) as 'essentially clear country, avoiding heavy timber and thick scrub.' It was most abundant in swampy depressions with *Lepidosperma laterale, Xanthorrhoea minor, Poa* sp. and *Themeda australis* with isolated clumps of *Banksia marginata* and *B. ornata* (Finlayson 1927).

24. **Macropus rufogriseus**—Red-necked Wallaby

Abundance and distribution. Widespread and common on the Volcanic Plains. Also recorded at Mt Arapiles and NW of Kay Swamp on the Wimmera Plains; and the Broughtons Waterhole area in the Little Desert where it is rare and restricted (cf. Gedye *et al.* 1979). One was also observed 12 km S of Kiata in late November 1978 (P. Cheal *pers. comm.*). Recorded in 45% of cells surveyed with chance sightings in a further 8.

Habitat. All open-forest alliances, Manna Gum woodland, Yellow Gum woodland and Silver Banksia heath. Grazes in farmland adjacent to cover and in grassy firebreaks in pine plantations. In the Little Desert all our sightings were in Yellow Gum woodland around clay pans.

Specimens. C17590, C24855.

25. **Potorus tridactylus**—Long-nosed Potoroo

Abundance and distribution. Restricted to the Volcanic Plains and southern Coastal Plains where the mean annual rainfall exceeds 750 mm. Locally common.

Habitat. Messmate open-forest, Brown Stringybark open-forest and Silver Banksia closed-heath with emergent eucalypts. Invariably associated with a dense shrub layer.

Breeding. Trapping within the range of this species took place in October and March. In October, 2 of 4 females trapped had a single naked pouch young and in March, 2 of 3 females trapped had pouch young.

Specimen. C24377.

26. **Thylogale billardierii**—Red-bellied Pademelon

Abundance and distribution. Presumed extinct in Victoria. Formerly present in coastal areas (NMV records) the only records from the survey area being a specimen from Portland (C6556) and a mandible of unknown age found in a blowout on the dunes of Discovery Bay (C23668). Reasons for its decline are not clear.

Habitat. Presumably dense coastal vegetation such as Brown Stringybark open-forest, Scented Paper-bark closed-scrub and Silver Banksia closed-heath.

27. **Wallabia bicolor**—Swamp Wallaby

Abundance and distribution. Probably no longer present in the survey area. Remains have been found in several cave deposits (Table 2) and Wakefield (1964a) had evidence of its presence in the Lower Glenelg area around 1900. A recent specimen (C17568), listed by Gedye *et al.* (1979, p. 120) as having come from Mt Elgin, was actually collected at Mt Erip (37°45′S, 143°36′E) (FWD records) and sightings in Lower Glenelg National Park (Gedye *et al.* 1979) are considered doubtful.

PHASCOLARCTIDAE

28. **Phascolarctos cinereus**—Koala

Abundance and distribution. Widespread and uncommon in the south, the most northerly record being 37°15′S. Formerly more widespread, the present distribution reflects the FWD restocking program following the general decline of the species in the early 1900s (Warneke 1978). Between December 1952 and December 1978 approximately 192 Koalas were released in the survey area. Details are given below.

Date	No. released	Origin	Point of release
Dec. 1952	32	Phillip Island	Gorae Forest
Sep. 1953	33	Phillip Island	Tyrendarra
Dec. 1970	44	French Island	Lower Glenelg Nat. Park
Dec. 1970	44	French Island	Mt Richmond Nat. Park
Feb. 1973	15	Phillip Island	Mt Eccles Nat. Park
Nov. 1975	24	Phillip Island	Bats Ridges State Faunal Reserve

Habitat. Messmate open-forest, River Red Gum woodland and Manna Gum open-forest and woodland. Eucalypts known to be eaten (Warneke 1978) which occur in the survey area are: *E. camaldulensis, E. obliqua, E. ovata, E. viminalis* and *E. microcarpa*. We observed Koalas in the first 3 of these as well as *E. aromaphloia* and *E. baxteri.*

VOMBATIDAE

29. **Vombatus ursinus**—Common Wombat

Abundance and distribution. Formerly widespread along creeks throughout the Coastal Plains, e.g. Mosquito Creek (C. Halahan *pers. comm.*) and in dune swales behind Discovery Bay (J. Davies *pers. comm.*). Skeletal remains have been found at Bats Ridges State Faunal Reserve (Anon 1907, C22349) and Bridgewater Lakes (J. Seebeck *pers. comm.*). The population at Bats Ridges died out in the early 1960s (J. Seebeck *pers. comm.*) as did a colony at Malseed Lake (N. Learmonth *pers. comm.* to J. Seebeck). Now restricted to a few small, isolated colonies in the Dorodong-Dergholm area and along Dry Creek, S.A.; animals from this colony occasionally wander to the banks of the Glenelg River as far east as Sandy Waterholes (37°59'S, 141°01'E) (J. Davies *pers. comm.*). Recently several animals from eastern Victoria were introduced to Bats Ridges State Faunal Reserve (P. Kelly *pers. comm.*). Most colonies are threatened as they are small and occur in isolated patches of bushland on freehold land.

We were directed to occupied burrows at 4 localities: 7 km NW of Dorodong; along Prospect Creek 6 km SE of Dergholm; along Wombat or Wild Pig Creek 7.3 km NNE of Dergholm (includes the population adjacent to Baileys Rocks Scenic and Recreation Reserve) and along Dry Creek 6 km NW of Nelson. In the Dergholm area the largest and most stable population is the Wombat Creek colony (R. Howlett *pers. comm.*) where numerous occupied burrows were found during our visit.

Habitat. All remaining colonies are along creeks, 2 in outcrops of Glenelg Limestone and 2 in sandy loam soils. The Dry Creek colony is in cleared pasture and Brown Stringybark open-forest; the Prospect Creek colony is in a remnant of Brown Stringybark open-forest with *Pteridium esculentum* dominating the understorey and the other 2 are in Manna Gum woodland with a tall shrub layer and grassy ground layer.

PTEROPODIDAE

30. **Pteropus scapulatus** — Little Red Flying-fox

Abundance and distribution. A rare vagrant to the survey area. Only recorded from Heywood (undated specimen C19778) and Dimboola and Quantong in November 1980 (M. Donaldson *pers. comm.*). This species is a sporadic visitor to Victoria, usually in summer and autumn.

Habitat. In Victoria usually associated with orchards or flowering eucalypts.

MOLOSSIDAE

31. **Tadarida australis** — White-striped Mastiff-bat

Abundance and distribution. Widespread but uncommon in the Little Desert and Wimmera Plains, also recorded from Brit Brit (C10738) on the Tablelands. Comprised 6% of 34 bats collected over Broughtons Waterhole, Little Desert between February and April 1970 (FWD unpubl. data).

Habitat. River Red Gum and Yellow Gum woodland, Yellow Mallee open-scrub and farmland. Requires tree hollows for shelter and breeding.

Specimen. C21026.

32. **Tadarida planiceps** — Little Mastiff-bat

Abundance and distribution. Widespread and uncommon in the Little Desert and Wimmera Plains. Also recorded from Portland in July 1970 (C17904). Comprised 6% of 34 bats collected over Broughtons Waterhole between February and April 1970 (FWD unpubl. data).

Habitat. River Red Gum and Yellow Gum woodland, Yellow Mallee open-scrub and farmland with trees. Requires tree hollows for shelter and breeding.

Specimens. C24335, C24337-9.

VESPERTILIONIDAE

33. **Chalinolobus gouldii** — Gould's Wattled Bat

Abundance and distribution. Widespread and common. The most commonly collected bat over Broughtons Waterhole, Little Desert between February and April 1970 (65% of 34 bats collected, FWD unpubl. data).

Habitat. Brown Stringybark open-forest, all woodland alliances, fringes of Yellow Mallee open-scrub and farmland with trees. Requires tree hollows for shelter and breeding.

Specimens. C24307, C24309-10.

34. **Chalinolobus morio** — Chocolate Wattled Bat

Abundance and distribution. Widespread and common, recorded from all physiographic regions. A total of 12 captured (8%) in 28% of grids trapped. Comprised 9% of 34 bats collected over Broughtons Waterhole, Little Desert between February and April 1970 (FWD unpubl. data).

Habitat. All open-forest and woodland alliances, fringes of Yellow Mallee open-scrub and farmland with trees. Requires tree hollows for shelter and breeding.

Specimens. C24304-6, C24308.

35-37. **Eptesicus** spp.

In the second half of the field survey identifications of the species described by McKean *et al.* (1978) were attempted using Hall & Richards (1979) but these are provisional and all *Eptesicus* forms are discussed together although they are mapped separately and may now be specifically identified.

Abundance and distribution. Widespread and common. *Eptesicus* spp. comprised 69.4% of all bats captured during our survey and 18% of 34 bats collected at Broughtons Waterhole, Little Desert between February and April 1970 (FWD unpubl. data). Of 102 *Eptesicus* captured 59% were clearly *E. vulturnus*, 33% probably *E. sagittula*, and 8% probably *E. regulus* (Table 4). All three species probably occur throughout the survey area.

Habitat. All open-forest and woodland alliances. All 3 species require tree hollows for shelter and breeding.

Specimens. C24871, 24872 = *E. regulus*; C24315-18, C24331-4, C24873 = *E. sagittula*; C24311-14, C24319-30, C24874 = *E. vulturnus*.

38. **Miniopteris schreibersii** — Common Bent-wing Bat

Abundance and distribution. Only recorded from the Volcanic Plains and Coastal Plains. Distribution is centred on suitable breeding caves, 4 of which occur in the survey area: Amphitheatre Cave, Fern Cave and caves in Bats Ridges State Faunal Reserve (Hamilton-Smith 1965); and Cave Hill, Heywood (CSIRO Bat-banding records). Of these, only the main cave at Bats Ridges houses a major colony with bats present year round, being used as a wintering site by part of the larger population based at Naracoorte Caves (Hamilton-Smith 1965). On 24 June 1970 an estimated 1500 bats were present in this cave (J. Seebeck *pers. comm.*). During our survey about 50 were present in Amphitheatre Cave on 18 October 1979.

Habitat. Requires caves for breeding and daytime shelter. Dwyer and Hamilton-Smith (1965) describe the structure and physical environment of maternity caves in southeastern Australia. Forages in open-forest, woodland and farmland.

Specimens. C24343-4.

39. **Myotis adversus** — Large-footed Myotis

Abundance and distribution. Recorded from the Coastal Plains and Tablelands but its actual distribution is probably wider than the few records suggest. Small numbers inhabit at least 3 caves along the lower Glenelg River — Dry Creek Cave, Amphitheatre Cave and Kates Slide Cave (McKean & Hall 1965). Seebeck and Hamilton-Smith (1967) highlighted the vulnerability to disturbance of wintering colonies.

Habitat. Characteristically found near water from which insects are scooped with the large, strongly clawed feet (Dwyer 1970). Known roosting sites include caves (McKean & Hall 1965) and beneath bridges, aquaducts, storm-water tunnels etc. (Dwyer 1970).

Specimen. C24870.

40. **Nycticeius balstoni**—Western Broad-nosed Bat
Abundance and distribution. Restricted to the Little Desert and Wimmera Plains; uncommon. Recorded only from Broughtons Waterhole (C7479) and 10 km SW of Edenhope.
Habitat. Collected in Yellow Gum woodland and Yellow Mallee open-scrub.
Specimen. C24336.

41. **Nyctophilus geoffroyi**—Lesser Long-eared Bat
Abundance and distribution. Widespread and common. Recorded from all physiographic regions. Not collected over Broughtons Waterhole in 1970 although specimens were found nearby in old buildings and beneath bark (FWD unpubl. data).
Habitat. Brown Stringybark open-forest, River Red Gum woodland, Yellow Gum woodland, Yellow Mallee open-scrub and *Pinus radiata* plantation. Requires tree hollows for shelter and breeding.
Specimens. C24340-42.

42. **Pipistrellus tasmaniensis**—Great Pipistrelle
Abundance and distribution. Only recorded from 9.5 km SSE of Dartmoor in Lower Glenelg National Park.
Habitat. Manna Gum open-forest. Elsewhere in Victoria it is confined to open-forest and tall open-forest (FWD records).
Specimens. C24300-303

MURIDAE

43. **Conilurus albipes**—Rabbit-eared Tree-rat
Abundance and distribution. Extinct. The only record from the survey area since European settlement is a specimen said to have come from Portland Bay around August 1845 (Anonymous 1846). However, Mahoney (1982) discusses the possibility that Mitchell collected a specimen between the Wannon and Stokes Rivers in 1835. May have been widespread in the survey area up until the time of settlement. Subfossil remains have been found in all bone deposits examined from the survey area: McEacherns Cave; Fern Cave; Natural Bridge at Mt Eccles and Mt Arapiles (Table 2).

44. **Hydromys chrysogaster**—Water-rat
Abundance and distribution. Common and widespread. During our survey it was recorded from the Wimmera River at Dimboola, Wannon River near Coleraine, Glenelg River near Dergholm and Nelson, Moleside Creek and Piccaninny Blue Pond. Presumably occurs in most streams, freshwater lakes and permanent swamps in the survey area (cf. Gedye *et al.* 1979).
Habitat. Aquatic, occurring in freshwater streams, lakes, permanent swamps and irrigation channels. Occurs in brackish tidal reaches of the Glenelg River.
Specimen. C22252.

45. **Mus musculus**—House Mouse
Abundance and distribution. Widespread and common, although uncommon in the Little Desert during our survey. Numbers fluctuate greatly according to seasonal food availability, level of predation, and suitability of the soil for burrowing (Newsome 1969, Saunders & Giles 1977).
Habitat. Brown Stringybark open-forest and low open-forest, all woodland types, Scented Paper-bark closed-scrub, Broom Honey-myrtle open-scrub, Coast Wattle open-scrub, all heath alliances, closed-grassland, farmland and commensal (with man) situations. Trapping rates were highest in Coast Wattle open-scrub, closed-grassland and regenerating Silver Banksia open-heath. In the Little Desert it was using different habitats to *Pseudomys apodemoides*, the only other murid present (Table 10).
Breeding. Lactating females, males with distended scrota and juveniles were trapped beside the Wimmera River during early April 1979, and juveniles were captured along the Glenelg River in March 1980. Animals elsewhere were not breeding during the survey.
Specimens. C22241, C22243, C22262-3.

46. **Notomys mitchellii**—Mitchell's Hopping-mouse
Abundance and distribution. There is much confusion over the possible occurrence of the species in the Little Desert. Brazenor (1936) reported a sighting near Natimuk but this is not an acceptable record (see also Wakefield 1966, p. 633). NMV specimens labelled 'near Horsham' (NMV C2598-9) in fact came from the NE end of Lake Albacutya (J. M. Dixon *pers. comm.*). Burrows investigated by Brazenor in the Little Desert S of Kiata yielded no animals and were almost certainly those of *Pseudomys apodemoides* (A. J. Coventry *pers. comm.*), not *N. mitchellii* as claimed by Brazenor (1958). The confusion presumably arose because *P. apodemoides* was not known to occur in Victoria at that time (Ryan 1963). The provenance of 2 specimens labelled Kiata (NMV C2866, C2841) remains questionable and was not accepted by Wakefield (1966, 1974). A specimen reported in the Nhill Free Press (15 Nov. 1955) as *N. mitchellii* collected by J. Oldfield, 8 km SSW of Kiata, was in fact *P. apodemoides* (NMV C15076). We agree with Wakefield (1974) that records of *N. mitchellii* from the Little Desert are not authentic. The southern limit of distribution is roughly a line from the southern edge of Lake Hindmarsh to Bordertown (Wakefield 1974).

47. **Pseudomys apodemoides**—Silky Mouse
Abundance and distribution. Not known in Victoria until 1963 when specimens collected by K. Hateley in 1957 were identified (Ryan 1963). Uncommon and widespread in the Little Desert, Wail Forest Reserve and Wimmera Plains south to near Dergholm (37°20'S). Southern limit of distribution corresponds to the 650 mm isohyet.
Mean trapping success rate where captured was 4% (range 1-13). Trapping success peaked in August (5%) and April (7%) and was lowest in June (2%).
Habitat. Recorded in Desert Banksia open-heath, Brown Stringybark low open-forest on dunes, Broom Honey-myrtle open-scrub and Yellow Mallee open-scrub. In the Little Desert it was most abundant in Desert Banksia open-heath and Brown Stringybark low open-forest and was using different environments to *M. musculus* during our survey (Table 10). Cockburn (1981) showed that the species prefers dense low vegetation containing *Banksia ornata*, beneath which most burrows are located.
Breeding. Pregnant females were trapped in October, November and December, and lactating females in November. One female gave birth to three young between 13 and 16 December 1979. Juveniles were trapped in February and in April. Cockburn (1981a) also found that breeding in the Little Desert occurred in late spring and summer and related this to peaks in flowering and seed production. However, Finlayson (1944) reported the breeding peak to be late autumn and early winter in southeastern South Australia but also collected young in November. Crouch (in Happold 1976) believes that litters occur throughout the year but reproductive activity peaks in August following winter rains. Sex ratios of trapped animals varied seasonally. There was a strong female bias in April, October and November and male bias in February and August. Cockburn (1981a) also found a female bias at breeding (late spring and summer) and suggested this may enhance colonization of regenerating habitat.
Specimens. C12610-11, FWD 8990, FWD 9971-2, C14053-7, C21015, C21024, C21027-30, C22242, C22244, C22249-51, C22253-5, C24348-51.

48. **Pseudomys shortridgei**—Heath Mouse

Abundance and distribution. Restricted to the Volcanic Plains and Coastal Plains north to 37°25'S. Occurs only in areas having a mean annual rainfall of >650mm (cf. *P. apodemoides*). The entire population of this species may occur within the range shown, together with The Grampians, as the population in southwestern Western Australia may be extinct (Watts & Aslin 1981).

Habitat. Brown Stringybark open-forest and low open-forest, Silver Banksia closed-heath and open-heath, Scented Paper-bark closed-scrub. Trapping success was higher in Silver Banksia open-heath (8%) than in Brown Stringybark open-forest (4%) or Scented Paper-bark closed-scrub (4%). Floristic data were collected at 15 of the 41 trapping sites.

Commonly occurring plant species from these sites were:

Species	% Occurrence
**Banksia marginata*	80
Leptospermum juniperinum	60
Melaleuca squarrosa	60
**Epacris impressa*	53
Xanthorrhoea minor	47
**Eucalyptus baxteri*	40
**Leptospermum myrsinoides*	40
**Xanthorrhoea australis*	40
**Boronia pilosa*	33
Eucalypts other than *E. baxteri*	33
**Hypolaena fastigiata*	33

* These species are characteristic of Silver Banksia open-heath rather than the wetter closed-heaths preferred by, for example, *Antechinus minimus*.

Breeding. This species was captured during March (7 individuals), May (4), June (44), July (14), October (15) and November (4). Little evidence of breeding was found except for one juvenile captured on 15 November and a male with scrotal testes on 26 July. Cockburn *et al.* (1981) have shown breeding to be seasonal, occurring in spring and early summer.

Specimen. C24361.

49. **Rattus fuscipes**—Bush Rat

Taxonomy. All animals captured showed the pale pelage colour and smaller dimensions and weight of the subspecies *R.f. greyi* (Warneke 1971).

Abundance and distribution. Widespread and common on the Volcanic Plains, Coastal Plains, western Tablelands and southern Wimmera Plains. Limits of distribution approximate the 650 mm isohyet. By far the most commonly trapped small mammal (Table 2).

Habitat. All open-forest alliances, Manna Gum woodland, Scented Paper-bark closed-scrub, Coast Wattle open-scrub, Silver Banksia open and closed-heath and closed-sedgeland.

Breeding. Trapping within the range of this species took place in all months except September, January and February. Lactating females were trapped in March and May, and juveniles or sub-adults between March and August. As juveniles were absent in October, November and December most breeding probably takes place in summer and autumn. Elsewhere Warneke (1971) and Robinson (1976) have recorded breeding peaks in summer.

Specimens. C13560, C22265, C24370-3, C24359.

50. **Rattus lutreolus**—Swamp Rat

Abundance and distribution. Widespread and common on the Volcanic Plains, Coastal Plains, western Tablelands and southern Wimmera Plains. Limits of distribution approximate the 650 mm isohyet.

Habitat. Messmate open-forest, Brown Stringybark open-forest and low open-forest, Manna Gum open-forest, Scented Paper-bark closed-scrub, Coast Wattle open-scrub, Silver Banksia closed-heath, some Silver Banksia open-heath, Desert Banksia open-heath (once only), Blue Tussock Grass closed-grassland, and roadside grassland.

Breeding. Juveniles were trapped between late August and late March, a longer period than that reported by Braithwaite & Lee (1979) for Cranbourne. Braithwaite (1980) has shown that the length of the breeding season varies considerably between areas and with variations in food availability in different years.

Specimens. C22266, C24384-8, FWD 12035.

51. **Rattus rattus**—Black rat

Abundance and distribution. Usually absent in undisturbed native vegetation, but occasional local concentrations occur. Probably widespread throughout the survey area, particularly near towns and other human habitation. During our survey, recorded only from: beside the Wimmera River near Dimboola, Mt Arapiles and on coastal dunes.

Habitat. Recorded in dense stands of *Phragmites communis* beside the Wimmera River, in rock screes on Mt Arapiles and in Coast Wattle open-scrub on coastal dunes.

Specimens. C22256-61, C24360.

CANIDAE

52. **Canis familiaris**—Feral Dog and Dingo

Abundance and distribution. Widespread and uncommon. There are a few early records of dingoes from the survey area (cf. Gedye *et al.* 1979). E. Townsend reported dingoes in the Nhill area in the 1860s (Blake 1976, p. 2) and French (1888, 1888a), Le Souef (1887), D'Alton (1913) and Hamilton (1914) all mention wild dogs as pests and the methods used to destroy them. Dingoes (*C. familiaris dingo*) are now extinct in the survey area but feral dogs occasionally occur in the Little Desert (C. Brownsea *pers. comm.*), Lower Glenelg National Park and Discovery Bay Coastal Park (J. Davies *pers. comm.*) and presumably in other large tracts of bushland. Recorded in 0.8% of grids surveyed.

Habitat. Formerly all terrestrial environments. Recent records are from Yellow Mallee open-scrub, Coast Wattle open-scrub and Messmate open-forest.

53. **Vulpes vulpes**—Fox

Abundance and distribution. Widespread and common. Recorded from all physiographic regions.

Recorded in 30% of cells surveyed with chance sightings in a further 10.

Habitat. All terrestrial environments except closed-scrub and closed-heath.

54. **Felis catus**—Feral Cat

Abundance and distribution. Widespread and uncommon, more common in the south. Recorded from all physiographic regions. Free-ranging cats were observed in 20% of cells surveyed with chance observations (mainly road mortalities) in a further 14.

Habitat. Observed in all open-forest and woodland alliances, pine plantations, Coast Wattle open-scrub, Silver Banksia open-heath and farmland.

BOVIDAE

55. **Capra hircus**—Goat

Abundance and distribution. Restricted to the south-east where a feral population is centred on The Stones State Faunal Reserve (Emison *et al.* 1978).

Habitat. Manna Gum woodland with a grass and bracken understorey growing amongst tumbled granite boulders.

56. **Ovis aries**—Sheep

Abundance and distribution. Small numbers of feral sheep

were present in the Little Desert until recent years (G. Edwards *pers. comm.*). These animals were presumably escapees from nearby farms. Flocks were agisted in the Little Desert heaths during droughts up until the early 1900s when the practise was discontinued (D'Alton 1913). A feral population exists in The Stones State Faunal Reserve (Emison *et al.* 1978).
Habitat. Desert Banksia open-heath, Yellow Gum woodland and Brown Stringybark low open-forest in the Little Desert and Manna Gum woodland in The Stones State Faunal Reserve.

57. **Dama dama**—Fallow Deer
Abundance and distribution. Restricted to the area around Lake Mundi where local farmers have made several recent sightings (R. Keeble *pers. comm.*). Presumably these animals originate from a population in the Pinnaroo-Bordertown-Naracoorte area of South Australia (Bentley 1978, p. 91).
Habitat. Yellow Gum woodland and River Red Gum woodland where fresh grass and browse is available.

58. **Lepus capensis**—Brown Hare
Abundance and distribution. Widespread and generally uncommon. More common in the north. Recorded in all physiographic regions. Recorded in 5% of cells surveyed with chance sightings in a further 8. Introduced to Victoria in the 1860s (Le Souef 1965).

No information on the spread of Brown Hares into the survey area is available; however, they apparently did not become well established until after the initial plague of rabbits had decreased in the early 1900s.
Habitat. All woodland alliances, fringes of Yellow Mallee open-scrub and farmland. Absent from areas with dense shrub or ground layers.

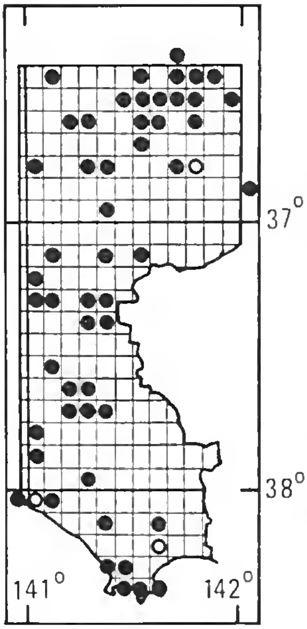
59. **Oryctolagus cuniculus**—European Rabbit
Abundance and distribution. Widespread and common. Recorded in 67% of cells surveyed with chance sightings in 79 others. First introduced to the Wimmera at Yannock Station, NW of Kaniva, in 1860 (Rolls 1969, p. 22). Released at Morton Plains, 25 km N of Donald, in 1866, and had reached plague proportions at Lake Buloke in 1878 by which time rabbits had spread W to the Wimmera River, E to the Avoca River and N to the Murray River (Rolls 1969, p. 37). Campbell (1884) refers to a plague in the Lawloit Range in 1884 and French (1888) states that the scrub around Serviceton was swarming with rabbits. They were a pest in the Lake Albacutya area in the 1880s (French 1888a) where large numbers were killed in the dry season with poisoned water (Le Souef 1887).

Little information is available on the spread of rabbits further south but they were present in the Stony Rises in the mid 1870s (Rolls 1969, p. 38) and had probably spread through most of the survey area by 1880 (C. Halahan *pers. comm.*).
Habitat. All terrestrial environments except those with dense ground or shrub layers.

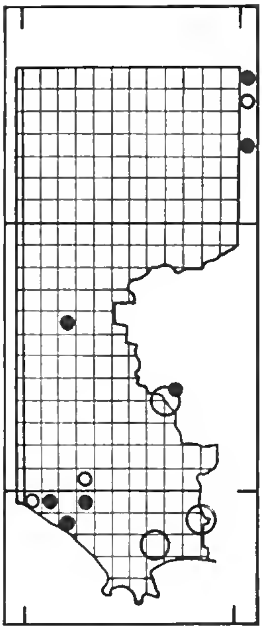
APPENDIX 2

Distribution Maps

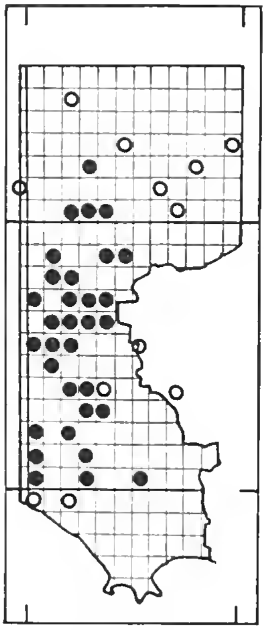
Grid lines are at intervals of 5′ of latitude and longitude. ● – records made during FWD survey. ○ – records prior to October 1974. ◯, ⬤ – general locality record.



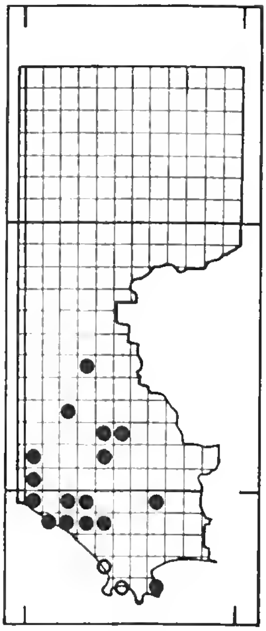
1. *Tachyglossus aculeatus*



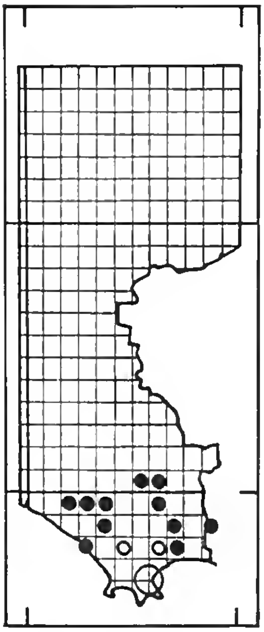
2. *Ornithorhynchus anatinus*



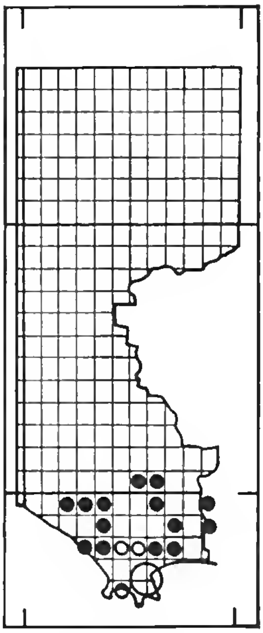
3. *Antechinus flavipes*



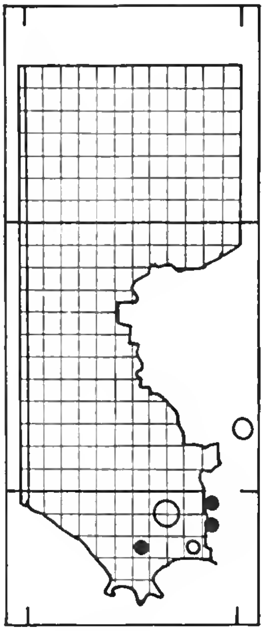
4. *Antechinus minimus*



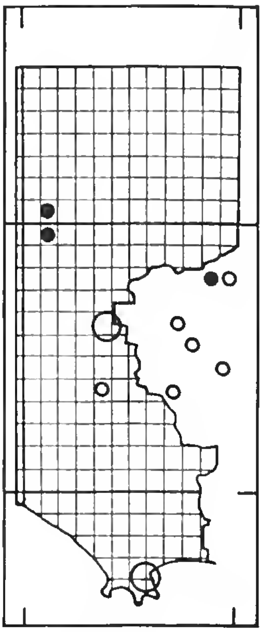
5. *Antechinus stuartii*



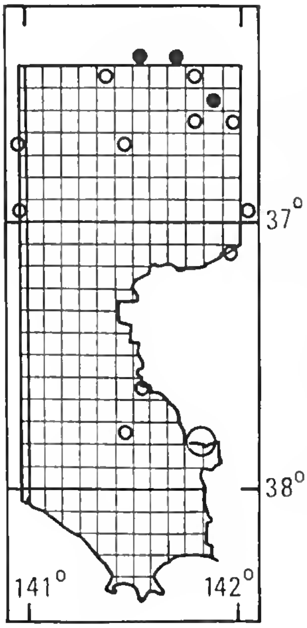
6. *Antechinus swainsonii*



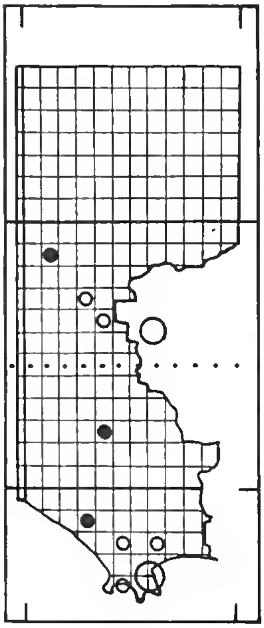
7. *Dasyurus maculatus*



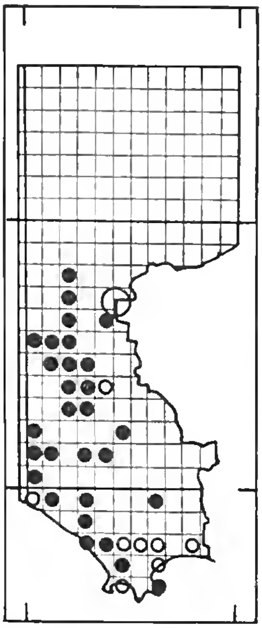
9. *Phascogale tapoatafa*



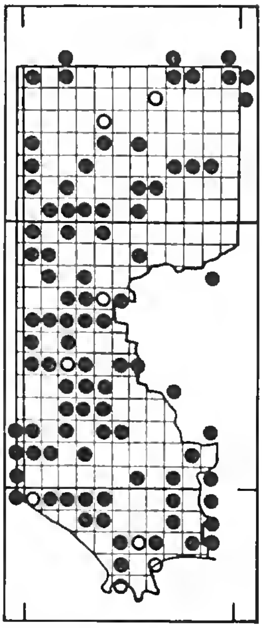
10. *Sminthopsis crassicaudata*



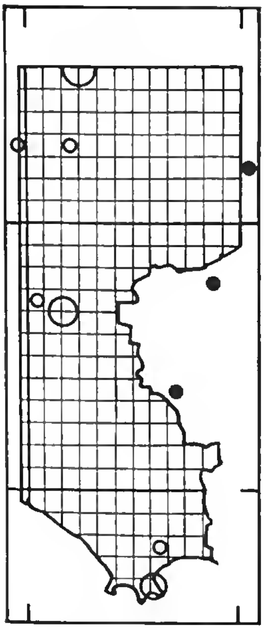
11. *Sminthopsis leucopus* (lower)
12. *S. murina* (upper)



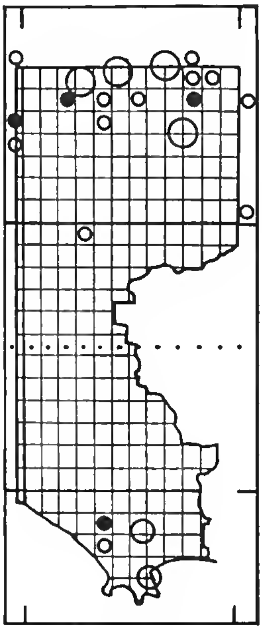
13. *Isoodon obesulus*



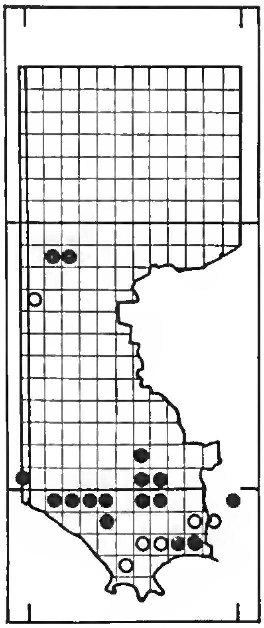
14. *Trichosurus vulpecula*



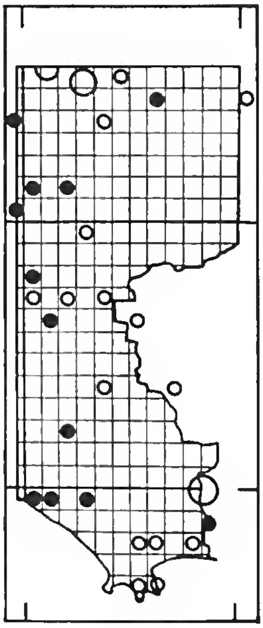
15. *Acrobates pygmaeus*



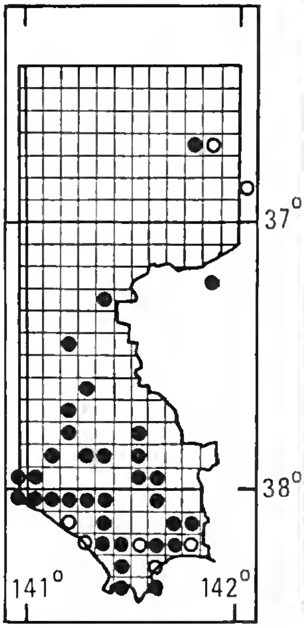
16. *Cercartetus concinnus* (upper)
17. *C. nanus* (lower)



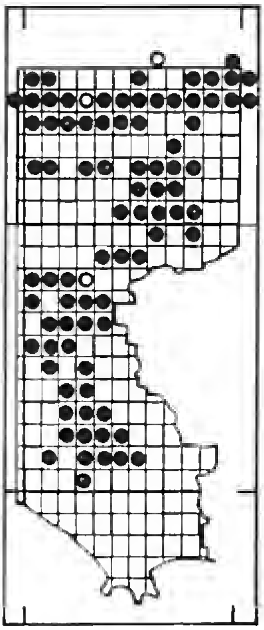
18. *Petaurus australis*



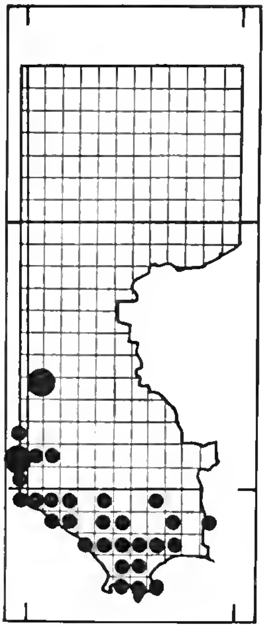
19. *Petaurus breviceps*



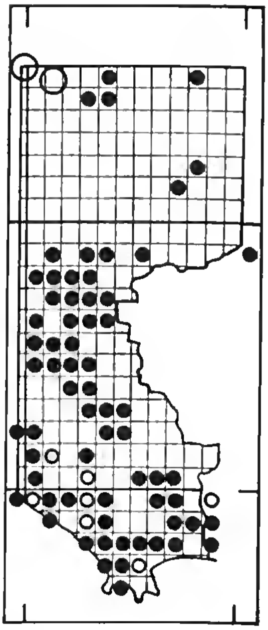
20. *Pseudocheirus peregrinus*



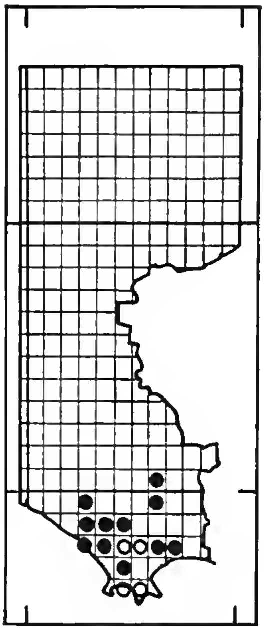
21. *Macropus fuliginosus*



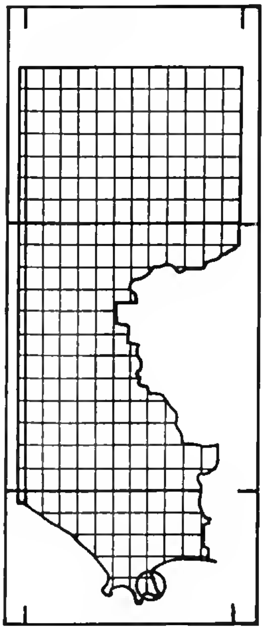
22. *Macropus giganteus*



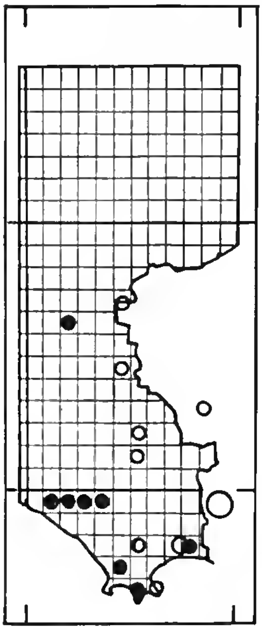
24. *Macropus rufogriseus*



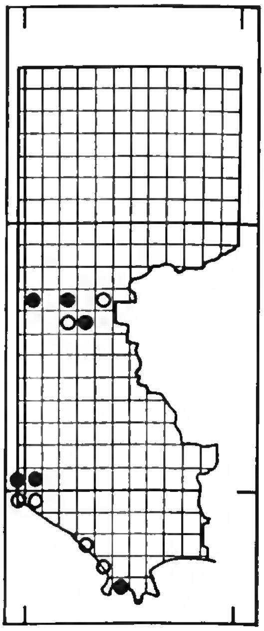
25. *Potorous tridactylus*



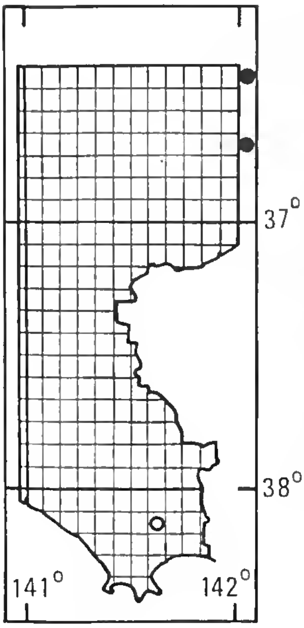
26. *Thylogale billardierii*



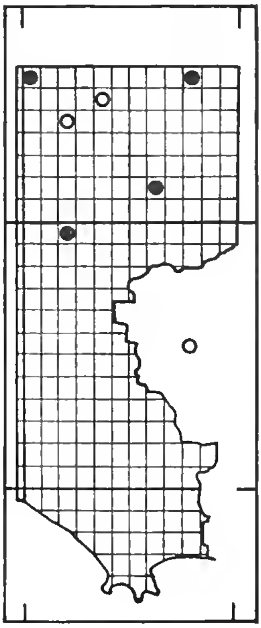
28. *Phascolarctos cinereus*



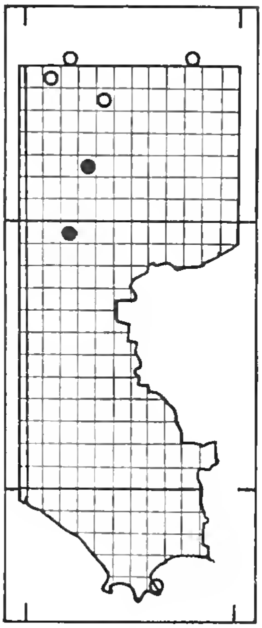
29. *Vombatus ursinus*



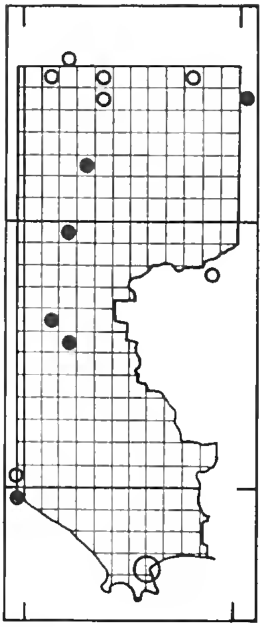
30. *Pteropus scapulatus*



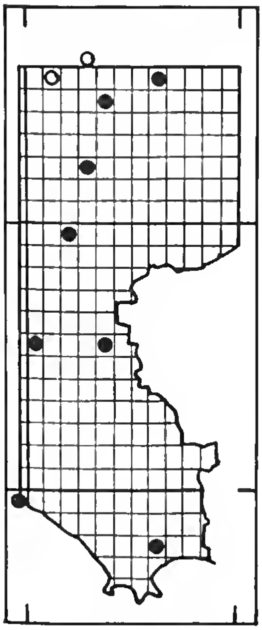
31. *Tadarida australis*



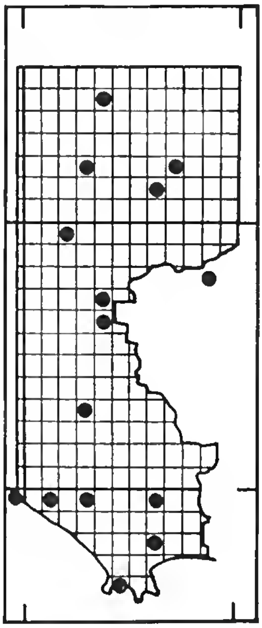
32. *Tadarida planiceps*



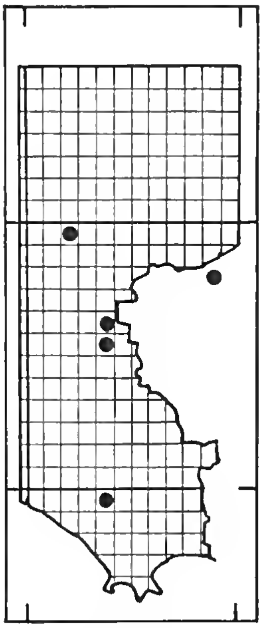
33. *Chalinolobus gouldii*



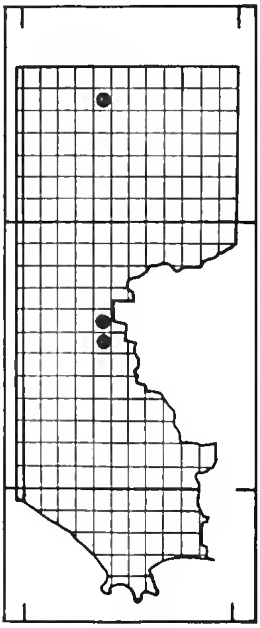
34. *Chalinolobus morio*



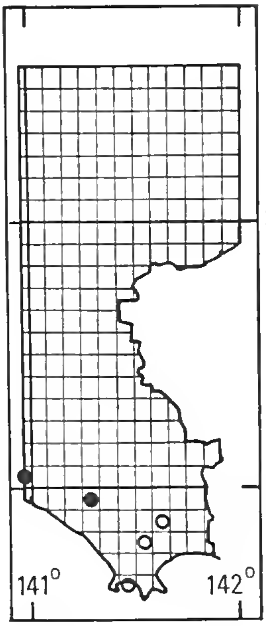
35. *Eptesicus vulturnus*



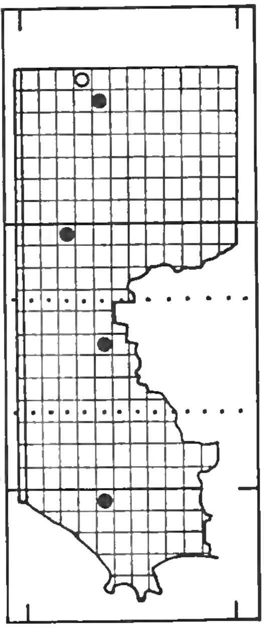
36. *Eptesicus sagittula*



37. *Eptesicus regulus*



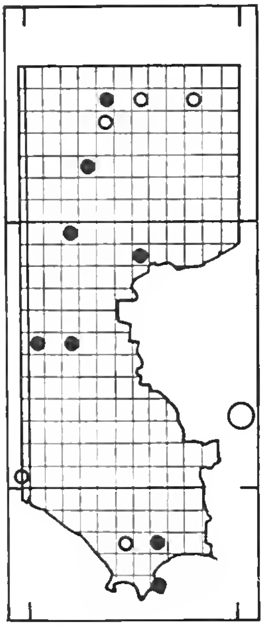
38. *Miniopteris schreibersii*



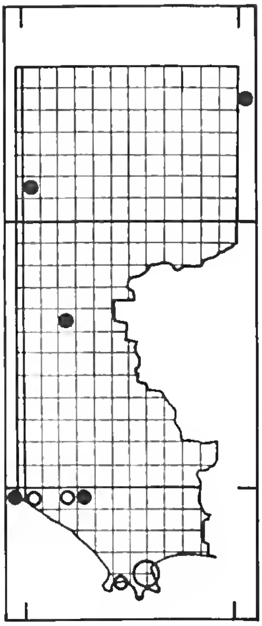
39. *Myotis adversus* (middle)

40. *Nycticeius balstoni* (upper)

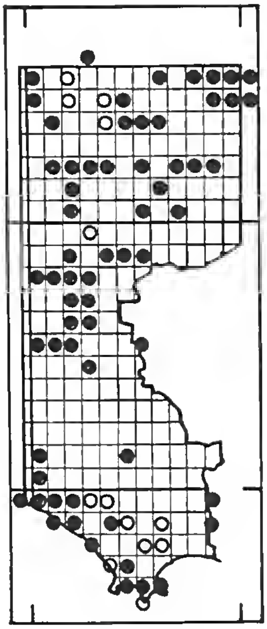
42. *Pipistrellus tasmaniensis* (lower)



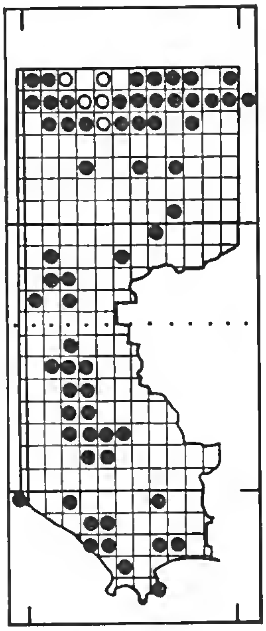
41. *Nyctophilus geoffroyi*



44. *Hydromys chrysogaster*

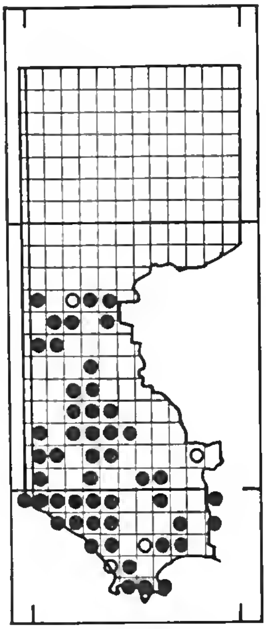


45. *Mus musculus*

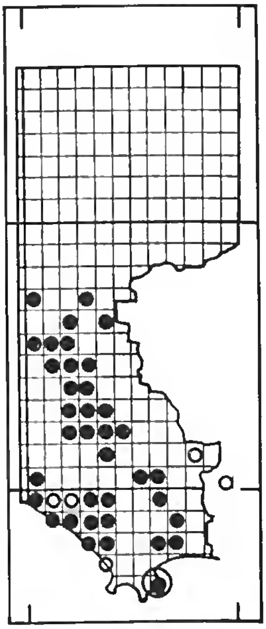


47. *Pseudomys apodemoides* (upper)

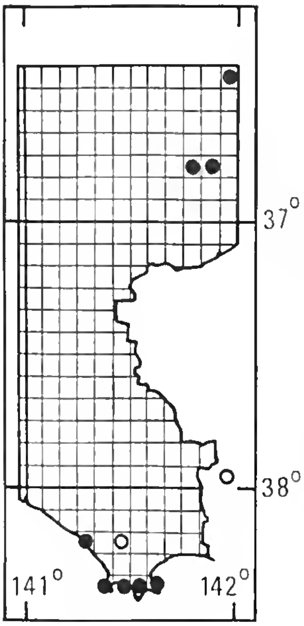
48. *P. shortridgei* (lower)



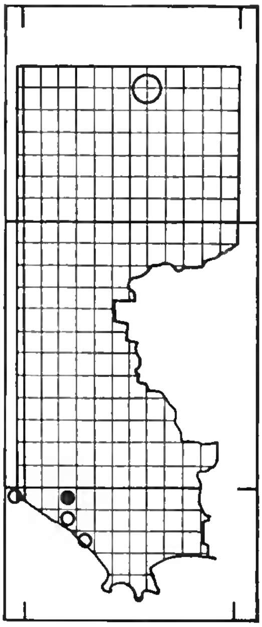
49. *Rattus fuscipes*



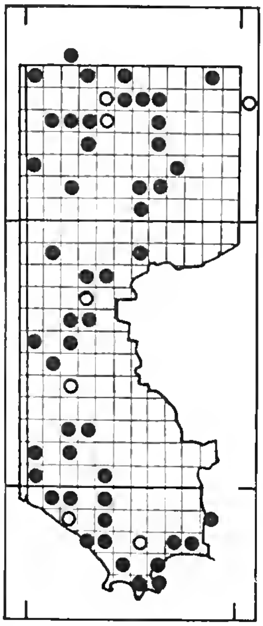
50. *Rattus lutreolus*



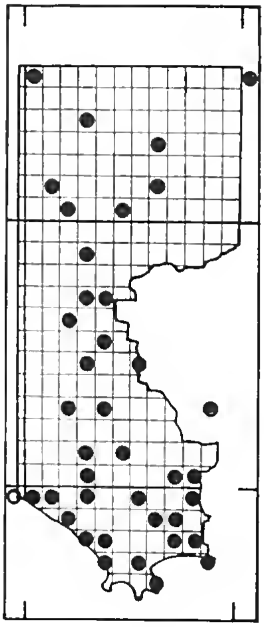
51. *Rattus rattus*



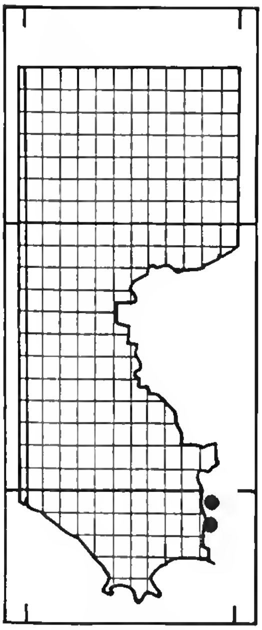
52. *Canis familiaris*



53. *Vulpes vulpes*

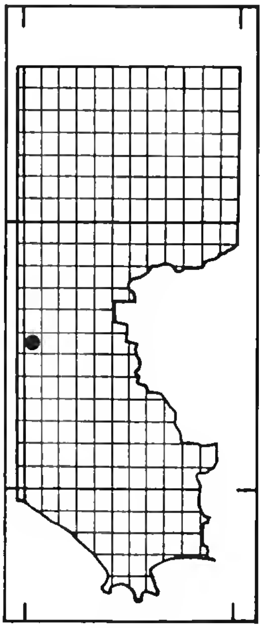


54. *Felis catus*

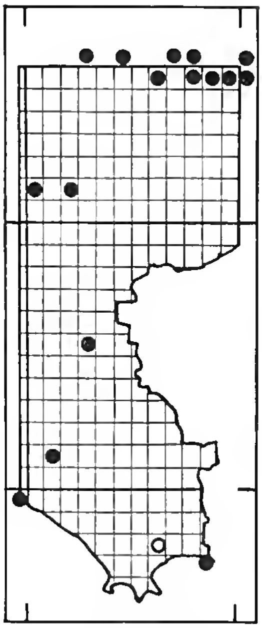


55. *Capra hircus*

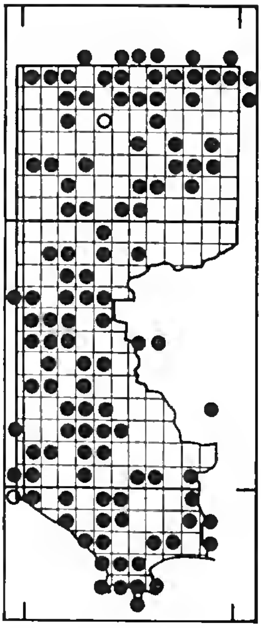
56. *Ovis aries*



57. *Dama dama*



58. *Lepus capensis*



59. *Oryctolagus cuniculus*

ROYAL SOCIETY OF VICTORIA

1982

Patron:	His Excellency Sir Henry Winneke, KCMG, OBE, QC, KStJ, Governor of Victoria.
President:	G. D. Aitchison, ME, PhD.
Vice-Presidents:	D. M. Churchill, BSc, BA, PhD. Professor J. W. Warren, MA, PhD.
Immediate Past President:	Professor L. L. Stubbs, DAgrSc.
Hon. Secretary:	T. A. Darragh, MSc, DipEd.
Hon. Treasurer:	H. G. Stevens, FCA.
Hon. Librarian:	J. G. Douglas, MSc, PhD.
Hon. Editor:	L. A. Frakes, MA, PhD.
Hon. Research Secretary:	I. A. Staff, MSc, PhD, DipEd.
Hon. Development Manager:	Professor G. Seddon, BA, MSc, PhD.
Hon. Assistant Secretary:	P. A. Jell, BSc, PhD.

The above Office-bearers are *ex officio* members of the Council of the Society.

Other members of the Council are:
J. K. Aitken, LLM.
Sir Robert Blackwood, MCE, BEE.
Professor M. J. Canny, MA, PhD.
M. G. Lay, BCE, MEngSc, PhD.
M. J. Littlejohn, PhD.
Professor J. F. Lovering, MSc, PhD.
Professor J. D. Morrison, PhD, DSc, FAA.
A. E. Perriman, BSc.
Mrs. Delys B. Sargeant, BSc, MEd.
G. A. Sklovsky, IngChem, ESCIL, LiciSci, IngDoc.
J. H. Thompson, B.Com.

Executive Officer:
R. R. Garran, MSc, PhD.

Honorary Architect:	F. Suendermann, FRAIA, MRAPI.
Honorary Financial Adviser:	D. S. Clarebrough.
Honorary Solicitors:	Phillips, Fox and Masel.
Honorary Auditor:	I. J. Curry, AASA.
Trustees:	D. M. Churchill, BSc, MA, PhD. Professor J. S. Turner, OBE, MA, PhD, MSc, FAA. Professor J. W. Warren, MA, PhD. The Hon. Mr. Justice A. E. Woodward, LLM, QC, OBE.