Natural History of the SouthEast

Edited by

M. J. Tyler, C. R. Twidale, J. K. Ling and J. W. Holmes

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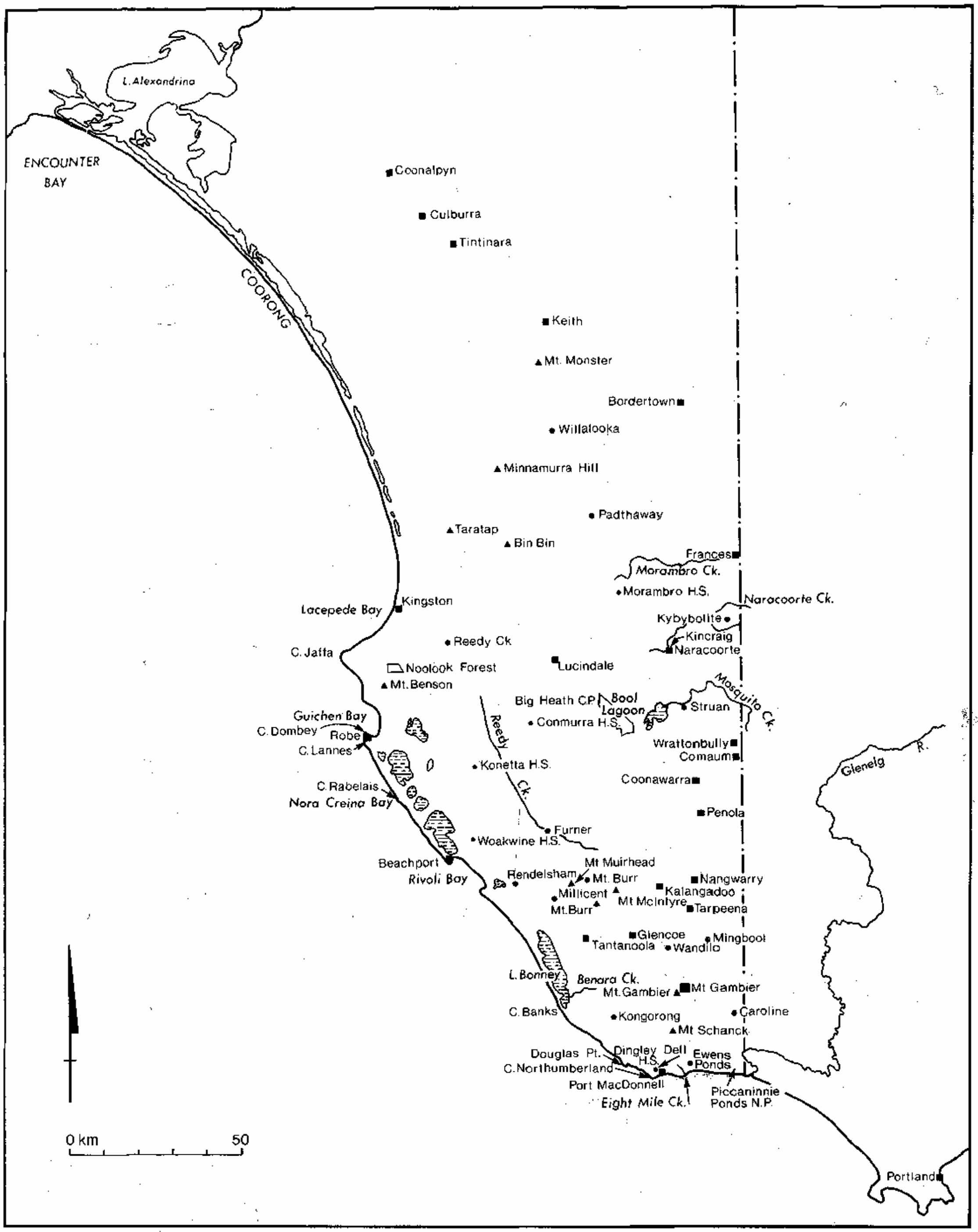

South East of South Australia showing localities mentioned in the text.

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Foreword

The traveller in the South East, with an eye for nature, following any of the main roads leading inland from the coast can find remnants of a succession of different habitats. The variations in habitat are attributable to significant differences in soils every few kilometres. A pattern of dune ridges dominates the landscape with flats between, an ancient granite outcrop here, a recent volcano there. Aboriginal man occupied these dunes for at least 8000 years, exploiting the plants, animals and rocks. White man has drained the flats, introduced plants and animals from overseas and added minerals to the soils. Now after a little over a century of European occupation the South East is producing annually vast quantities of food and fibre.

One of the prices that has been paid for th is increased productivity is the diminution of most native species. Some have become extinct, others are endangered.

Early settlers in the South East, thirsting for an understanding of Nature, sent specimens by the cartload to their homeland museums. Today this desire still motivates naturalists, whether amateur or professional, to learn more about this particular environment and this book will provide some background to understanding the complex relationship between plants, animals, the soils, the climate and man.

In the early 1920's, the Handbooks of the Flora and Fauna of South Australia were issued by the British Science Guild. This marked the beginning of a new era in the spreading of scientific information at extremely low cost, by reason of the authors providing their manuscripts free of charge. Sixty years later the Flora and Fauna of South Australia Handbooks Committee is still publishing this excellent series. In addition, various societies, of which the Royal Society of South Australia is the most active, are publishing naturalist guides. The present volume is the third one the Royal Society has produced. We in South Australia are indebted to the editors and authors who have continued this fine tradition of publication, with this present volume, 'Natural History of the South East'.

Archie McArthur,
'Mt Hope',
Millicent

Introduction

By C. R. Twidale and M. J. Tyler

The naming of areas with reference to local centres can be confusing, so that the district considered here, the South East, so called because it occupies the southeastern corner of the State of South Australia, is nevertheless bordered to the east by the Western Districts of Victoria. The two areas, the South East and the Western Districts have much in common in human terms. The border between them is quite artificial. Sportsmen from both sides of the line compete in activities as diverse as Australian Rules Football and polocrosse; yet if only in political and administrative matters the South Easterners perforce have strong links with Adelaide and the rest of the State. And for the naturalist also there is a schizophrenic quality about the South East. In some respects it is closer to Victoria than it is to the remainder of South Australia. But in other ways the area has affinities with the Mt Lofty Ranges, and in yet others is distinctively itself.

The 'Natural History of the South East' is the third in a series of volumes intended to document the natural history of various parts of South Australia. The Adelaide region (1976) and Kangaroo Island (1979) have already been treated in this fashion and Eyre Peninsula is next in line. In the present publication, as with its companion volumes, the primary purpose of each chapter is to review the present state of knowledge of various facets of the natural environment and also to record the way in which aboriginal man interacted with that environment.

The region under consideration had its origins in the partition of part of the old supercontinent called Gondwanaland, and as is so graphically described by Harris (Chapter 1), in the rifting and pulling apart what became Austral ia and Antarctica, a process which began about 150 million years ago. Rivers deposited sediment in the depression formed between the two masses, but then about 120 million years ago marine influences began to affect the ever-extending basin and much of the present character of the region has its roots in the nature of the strata laid down in the oceanic basin that gradually developed beneath the South East, and indeed extended across what is now south-western Victoria as far as the western shore of Port Phillip Bay. Thus the riverless 'karst' that occupies much of the area near Mt Gambier is due to the pervious nature of the limestone laid down there in the sea that occupied the area some 20-25 million years ago. But the seas that invaded the area lapped around islands of old granite rocks that are related genetically and in age with those that occur within the Mt Lofty Ranges in such areas as Palmer and Monarto, and which like them were emplaced in a molten condition into the pre-existing rocks. Molten rocks, albeit of a very different kind - lavas that poured out at the earth's crust in relatively recent times - are also responsible for the salient features of the Western Districts, and for two major areas of volcanic landforms in the South East, one, the older, near Mount Burr, the other near Mount Gambier; and the full story of these spectacular events, which occurred so recently that they were almost certainly witnessed by the earliest inhabitants of the region, is related in Sheard's Chapter 2.

But for all their dramatic impact the volcanoes are not the South East's best known feature - at least not in a scientific sense. For the region is internationally famed for the series of marvellously preserved coastal dunes or barriers that have been left high and dry partly as a result of the uplift of the Lower South East, partly as a consequence of sea level changes during the past 2 million years or so. These dunes, which with intervening flats, corridors or swales, are the most prominent relief features of the region apart from the earlier mentioned volcanic hills, have long attracted the attention of geologists from Tenison Woods, the Hillside Priest, onwards. Schwebel's analysis (Chapter 3) marks a new beginning to the investigation of the problems posed by these remarkable dunes, which extend northwestward beyond the present area of study, as far as the Murray valley, and the lakes near the Murray mouth.

Like their predecessors, the seas to which the dune ridges are related lapped around islands of crystalline rock, particularly granitic rocks, and especially in the north of the region under consideration. When the sea stood high the landscape must have been rather like that one sees today from The Bluff or Victor Harbor looking towards Encounter Bay. The 'islands' of granite give rise to characteristic landforms as does the chemical attack of the limestones that underlie much of the southern area of the South East; and these land forms, together with lunettes, crescentic dunes that develop at the margins of shallow lakes, are described in Chapter 4. The living soil is vital to the well-being of all organisms and the soils found on various facets of the landscape, and of various parent materials, on dune and swale, on limestone and volcanic ash, are described in Chapter 5, a chapter by Blackburn based on a lifetime's experience of the area.

Lakes, lagoons and swamps are a common feature of the South East, and they are of varied origins. Some, like Bool Lagoon, are famous for the associated bird life. Another, Blue Lake, is famous for its regular colour changes. But well known or not, large or small, several of the lakes are discussed by Allison and Harvey in Chapter 7. The lakes are of course only part of the hydrological system of the region, and the subsurface waters and their importance and content are discussed by Holmes and Waterhouse in Chapter 6. Lastly the offshore waters, the source of the marine life for which the South East is justly famous, are described by Bye in Chapter 8, while the climate that is of such pervasive importance to all is described by Penney (Chapter 9).

In a biological sense the South East is the richest area in number and diversity of species. The western boundary with Victoria is of no biological or physical significance and so the area represents an extension of the flora and fauna of the south-eastern portion of the continent.

The fauna and flora of the South East have to be viewed within the context of broader patterns of distribution of organisms in Australia. Spencer (1896) divided Australia into four zoogeographic provinces: 'Torresian' embracing the wet-dry tropics north of latitude 200S and the eastern seaboard to latitude 30oS; 'Bassian', occupying the south-east of the continent and including Tasmania, 'South-west' being the moist extreme south-west of Western Australia, and finally 'Eyrean' to include the vast arid central portion of the continent.

Spencer's scheme has been modified by many authors, seeking further to subdivide the mainland or to change the nomenclature. The scheme may be an oversimplification but, as demonstrated by the many contributors to the mammoth review of Australian ecology and biogeography edited by Keast (1981). the fundamental accuracy appears indisputable.

Within South Australia Bassian elements occur in the South East and, to a lesser extent, on the Fleurieu Peninsula, Mt Lofty Ranges, Kangaroo Island and the southern tip of Eyre Peninsula. Faunistically the significance of the South East is the preponderance of Bassian species.

Plant distribution patterns appear to be complex, but within South Australia the zoological Bassian pattern, described above, extending to the southern end of Eyre Peninsula, has its plant counterparts.

Because the trend within the southern units listed above is one of decreasing diversity along a western gradient, it follows that the South East is the site of greatest diversity of Bassian species within South Australia.

In the case of mammals (Chapter 12) Aitken documents the massive local extinction associated with land clearance, and demonstrates that many of the remaining populations are known from very few recent sightings. The contribution on birds (Chapter 13 by Parker and Reid) and the invertebrate chapters by Gross and Zeidler (20, 19) emphasise the appall ing state of knowledge of these creatures. In fact it was the proposal to publish this book that led several contibutors to make the first species surveys of creatures such as aquatic crustaceans. The inference is that the preparation of management plans for the various reserves described by Robinson and Rowbury in Chapter 22, requires a better knowledge of the fauna and flora than is currently available.

In the review of the reptiles and amphibians Thompson and Tyler (Chapter 14) have been aided by extremely detailed distribution data assembled by residents over the last decade; comparable data on other groups of animals are not available. Thompson and Tyler analyse species diversity along a north-south transect, and demonstrate a fairly progressive increase at lower latitudes. If this trend is shared by other organisms, it will become possible to quantify the relative significance of different sites.

Wells and Pledge (Chapter 16) review the rich vertebrate fossils of the South East and show that it includes a number of species not found there today, and other species that are extinct. The changes in this component of the vertebrate fauna probably took place before the advent of Aboriginal and European man in the area, and are attributable to direct or indirect effects of periods of climatic deterioration over the past 100 000 years. Nevertheless the destruction over the past century or so has been catastrophic.

We draw attention to the words that close the late Peter Aiken's chapter, so constituting his last published contribution ... "Even some of the supposedly more common species may, in fact, be declining unmonitored at alarming rates. This is not a record of which we should be particularly proud."

REFERENCES

Keast, A. (Ed.) (1981). 'Ecological Biogeography of Australia'. (W. Junk, The Hague).

Spencer, B. (1896). 'Report on the works of the Horn Scientific Expedition to Central Australia.' (Melville, Muller & Slade, Melbourne).

Twidale, C. R., Tyler, M. J. & Webb, B. P. (Eds) (1976). Natural History of the Adelaide Region. (Royal Society of South Australia, Adelaide).

Tyler, M. J, Twidale, C. R. & Ling,J. K. (Eds) (1979). Natural History of Kangaroo Island. (Royal Society of South Australia, Adelaide).

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1: Geology
by W. K. HARRIS

INTRODUCTION

In the South East of South Australia outcrops of rocks predating the later. Cainozoic are few and far between but it is the nature of the older, unseen sedimentary sequences underlying the region that impose on the region several of its more significant characteristics. The lack of surface streams for instance is directly attributable to the sub-surface structure. The nature of the sediments of the basin structure that underlies much of the South East is considered in this Chapter.

GEOLOGICAL EVOLUTION

As is now well-known the Australian and Antarctic Continents were once joined together and formed part of a larger supercontinent called Gondwana (see Craddock, 1979 and Falvey & Mutter, 1981, for a discussion on the evolution and fragmentation of Gondwana). The geological evolution of the South East is closely related to the separation of the two components mentioned, beginning in Late Jurassic time, some 150 million years ago. At that time, Antarctica began to pull away from Southern Australia and sequences of sand and silt were laid down in the elongate depression now known as the Otway Basin which was formed as the two land masses began to fracture and drift apart.

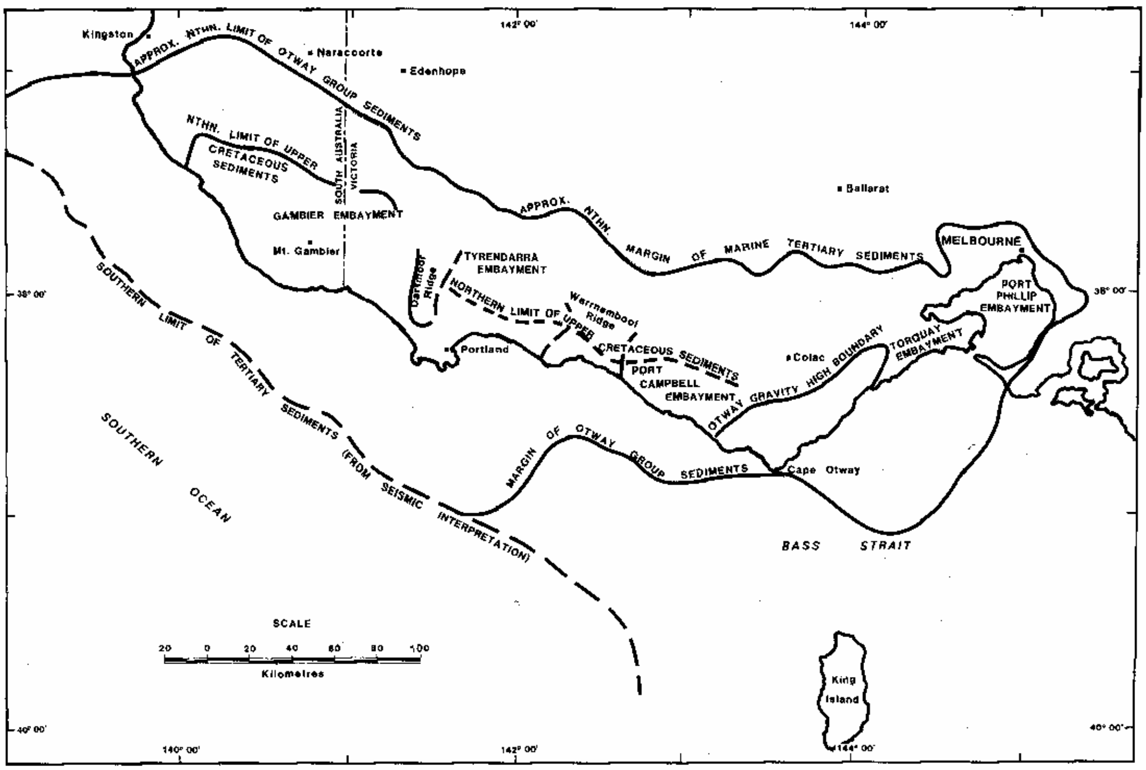


Fig. 1. Location of the Otway Basin in south-eastern Australia. Dashed lines indicate uncertainty of extent of various structural and sedimentation features. Note that only the western most part of the Otway Basin, termed the Gambier Embayment, is represented in South Australia.

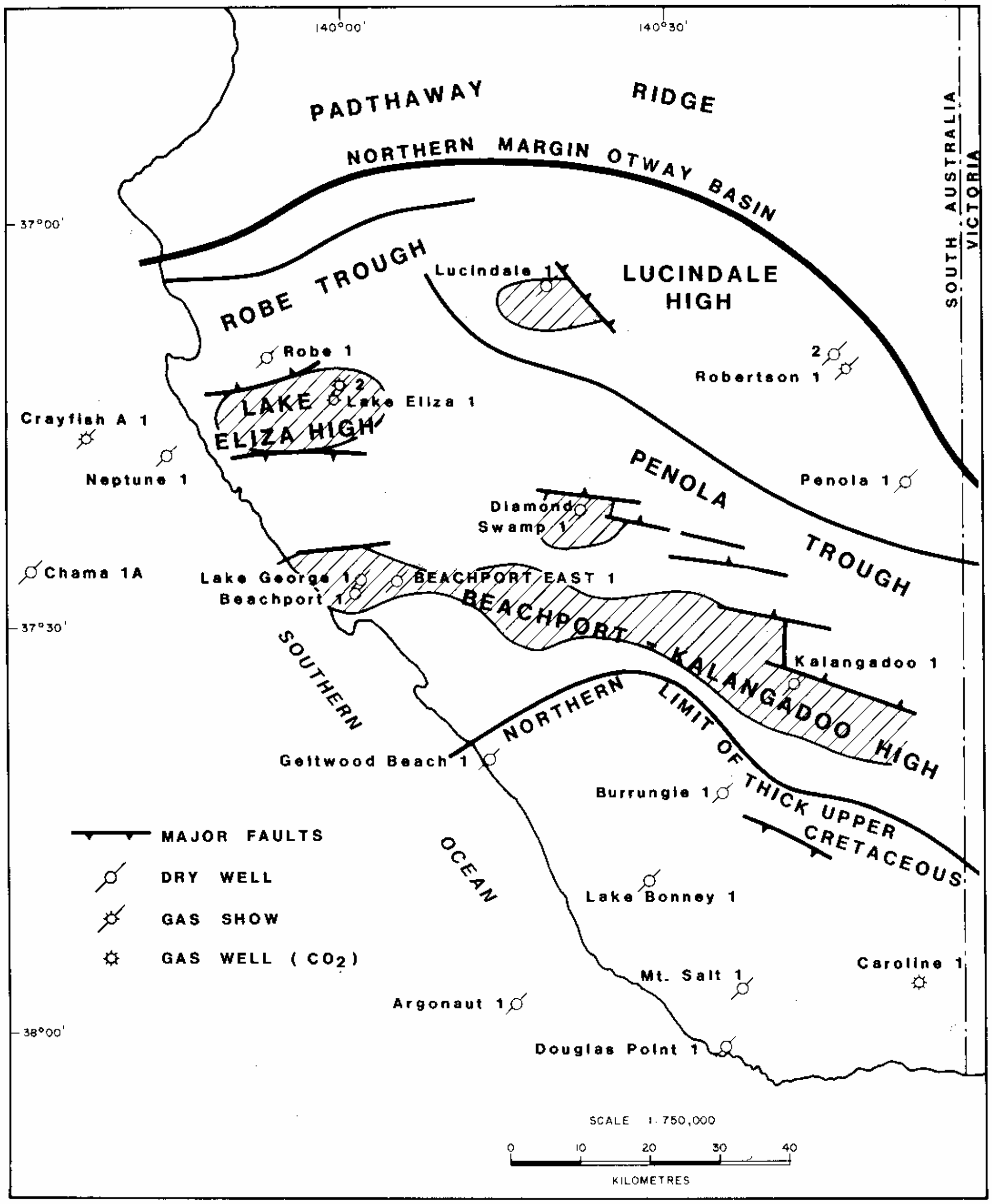
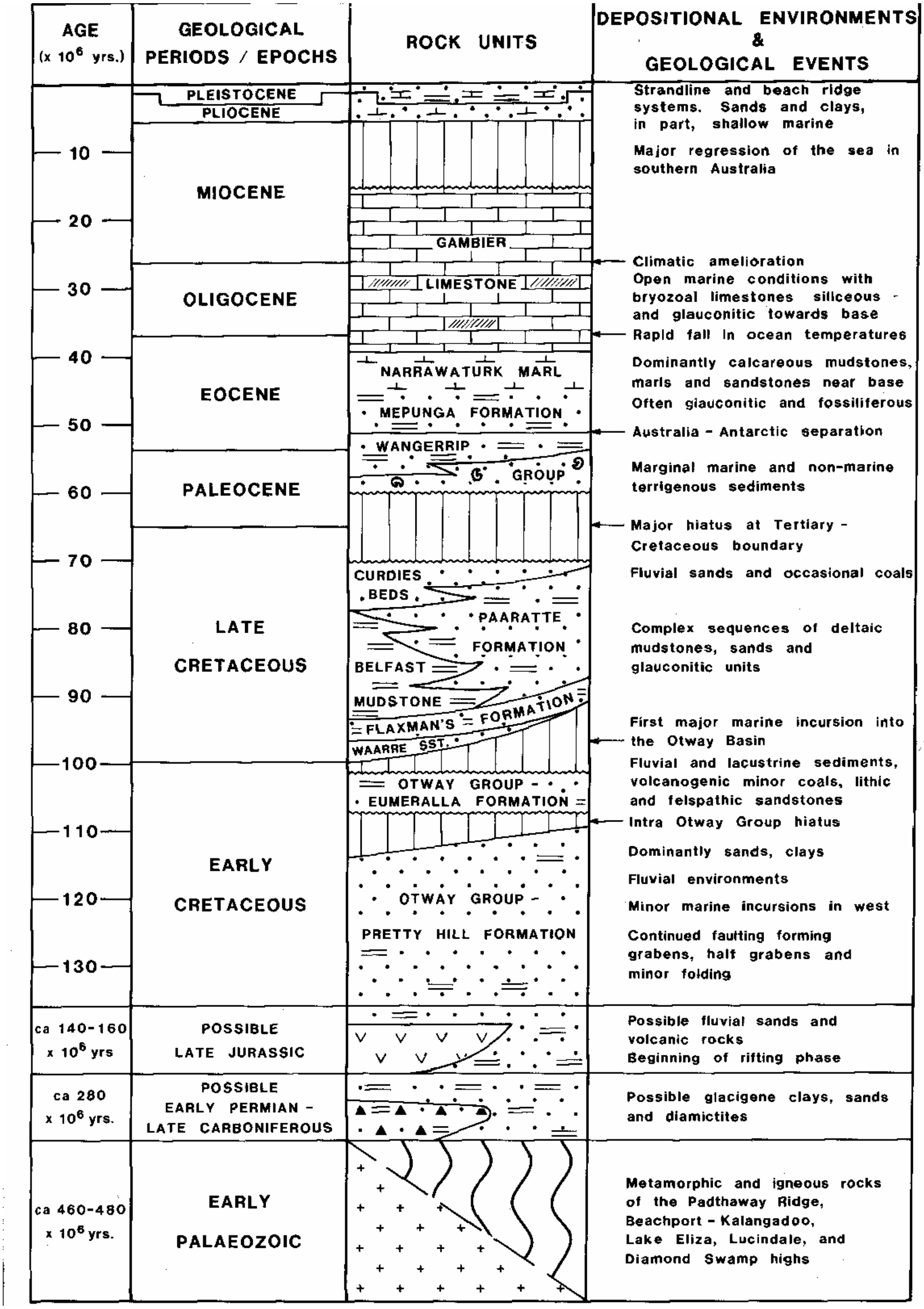


Fig. 2. Major structural and sedimentation features of the western Otway Basin. Major petroleum exploration wells are indicated.

Fig. 3. Stratigraphic column for the Gambier Embayment, Otway Basin. Major rock formations and their lithological types are set against the geological time scale and against major geological events. The nomenclature of the formations is that adopted in Douglas & Ferguson (1976), Rogers (1980), Shepherd (1978) and Wopfner & Douglas (1971). Detailed lithological descriptions and thicknesses can be found in these references.


AGE (x 10^6 yrs.)
GEOLOGICAL PERIODS / EPOCHS
ROCK UNITS
DEPOSITIONAL ENVIRONMENTS & GEOLOGICAL EVENTS
10
20
30
40
50
60
70
80
90
100
110
120
130
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
LATE CRETACEOUS
EARLY CRETACEOUS
GAMBIER
LIMESTONE
NARRAWATURK MARL
MEPUNGA FORMATION
WANGERRIP
GROUP
CURDIES BEDS
PAARATTE FORMATION
BELFAST
MUDSTONE
FLAXMAN'S FORMATION
WAARRE SST.
OTWAY GROUP - EUMERALLA FORMATION
OTWAY GROUP - PRETTY HILL FORMATION
Strandline and beach ridge systems. Sands and clays, in part, shallow marine
Major regression of the sea in southern Australia
Climatic amelioration
Open marine conditions with bryozoal limestones siliceous and glauconitic towards base
Rapid fall in ocean temperatures
Dominantly calcareous mudstones, marls and sandstones near base
Often glauconitic and fossiliferous
Australia - Antarctic separation
Marginal marine and non-marine terrigenous sediments
Major hiatus at Tertiary - Cretaceous boundary
Fluvial sands and occasional coals
Complex sequences of deltaic mudstones, sands and glauconitic units
First major marine incursion into the Otway Basin
Fluvial and lacustrine sediments, volcanogenic minor coals, lithic and felspathic sandstones
Intra Otway Group hiatus
Dominantly sands, clays
Fluvial environments
Minor marine incursions in west
Continued faulting forming grabens, half grabens and minor folding
ca 140-160 x 10^6 yrs
POSSIBLE LATE JURASSIC
Possible fluvial sands and volcanic rocks
Beginning of rifting phase
ca 280 x 10^6 yrs.
POSSIBLE EARLY PERMIAN - LATE CARBONIFEROUS
Possible glacigene clays, sands and diamictites
ca 460-480 x 10^6 yrs.
EARLY PALAEOZOIC
Metamorphic and igneous rocks of the Padthaway Ridge, Beachport - Kalangadoo, Lake Eliza, Lucindale, and Diamond Swamp highs

The Otway Basin covers all the region south of a line running through Kingston and Naracoorte. The Otway Basin itself extends from Kingston as far east as the Mornington Peninsula in Victoria, but the easternmost portion that underlies. the South Australian sector is known as the Gambier Embayment (Fig. 1). Deep exploration wells sunk in the embayment (Fig. 2) show that the early Palaeozoic rocks that form scattered small outcrops in the Kingston-Coonalpyn-Keith-Padthaway areas and which form the surface exposures of the Padthaway Ridge, also underlie the basin structure (Wopfner & Douglas 1971). Although Permian sediments are exposed in the Victorian sector of the Otway Basin (Fig. 3) they are unknown in the Gambier Embayment, but may be present in deeper undrilled sections. During much of Cretaceous and Quaternary times these low but bold rocky outcrops formed islands standing above the surface of the seas. They also formed a major barrier between the Murray Basin to the north and the Otway Basin to the south. The rocks of the Padthaway Ridge are mostly igneous and metamorphic and consist of adamellites, rhyolites and granites (see Chapter 4). The oldest known rocks, the Otway Group, were deposited on a surface of low relief in a subsiding downfaulted valley during the Late Jurassic and Early Cretaceous.

The earliest basin sediments are of terrestrial origin and though exposed in coastal sections in western Victoria are known only in drill holes in the South East.

Initial sedimentation took place in alluvial fans, lacustrine and fluvial floodplain environments. It has been suggested that the climate was cooler than that at present and the vegetation was dominated by coniferous forests dominated by genera such as Podocarpus, "Microcachrys and Araucaria. The first unit laid down in the rift valleys was the Pretty Hill Sandstone, and was followed by sediments of the Eumeralla Formation which is characterised by volcanic clastic material ejected contemporaneously with the deposition of the Formation. The source of this material is open to speculation but the Antarctic region is possible.

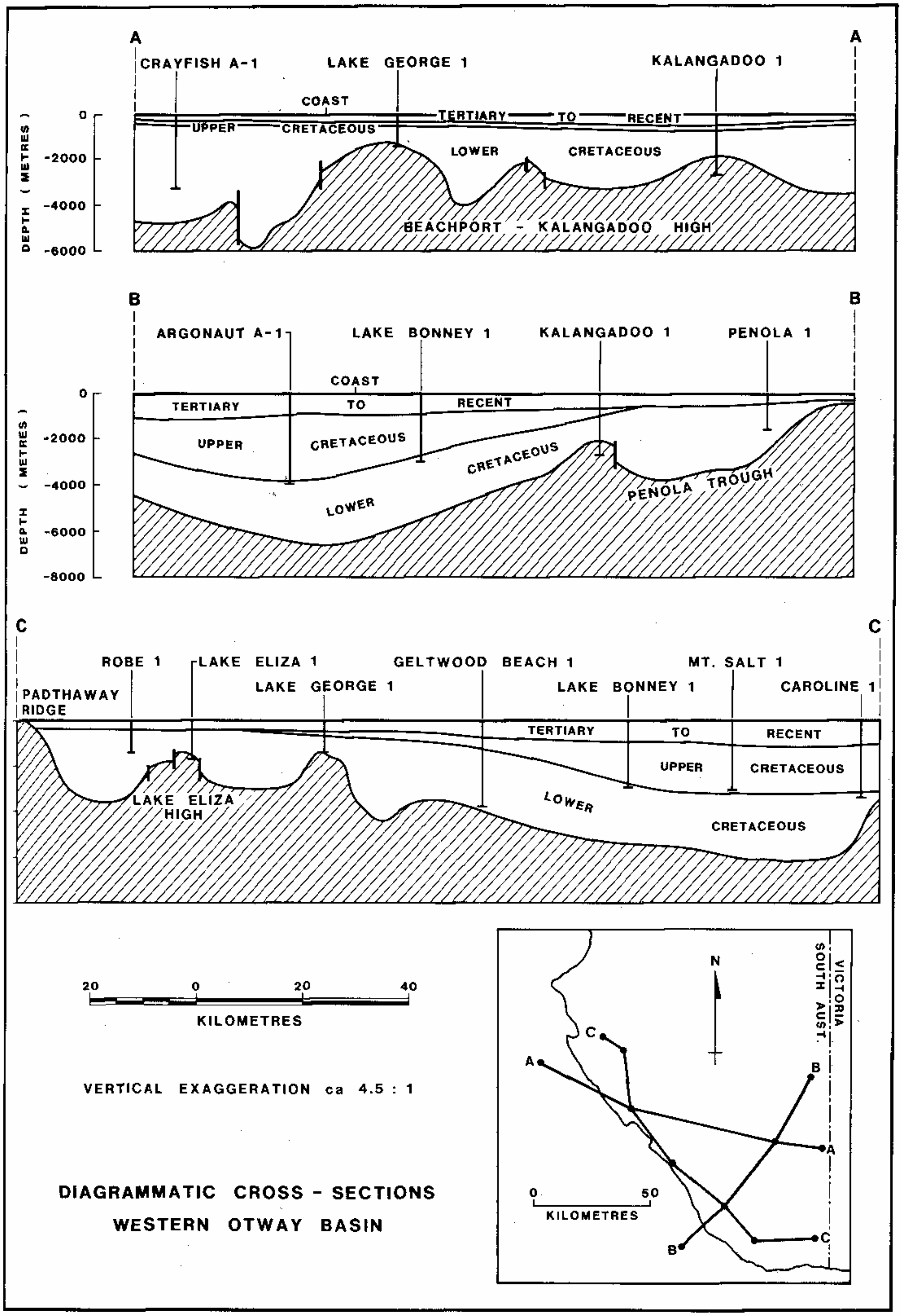
At the time there was considerable crustal stress as Antarctica and Australia began to separate, and these earliest sedimentary sequences are considerably disturbed by faulting. Indeed in Middle Cretaceous times tectonic activity was such that many areas were uplifted and eroded. Subsidence was then renewed du ring the early part of the Late Cretaceous and a thick sequence of riverine-deltaic and shallow marine sediments (the Sherbrook Group) laid down in conditions characterised by a fluctuating sea level. Only the northern zone of this deposit is preserved beneath the Gambier Embayment, the main sequence being located south of the present coastline.

Palaeontological evidence suggests that the climate of this time may have been cooler late in the Cretaceous than during earlier times (Dettmann & Playford 1969). Angiosperms had evolved during the later part of the Early Cretaceous and they became an increasingly important vegetational element. During this time such recent genera as the Southern Beech (Nothofagus) had evolved but the swamps and deltaic plains were still dominated by conifers that now included Oacrydium.

The final unit to be deposited in the Late Cretaceous of the region is the Curdies Formation, a sequence of arenaceous and carbonaceous units formed during a retreat of the sea and the replacement of marine by terrestrial conditions. It is separated by a major hiatus from the early Tertiary rocks of the Wangerrip Group. The oldest unit recognised in the western part of the Otway Basin is the Pebble Point Formation, deposited in Middle to Late Paleocene times, mostly in near-shore environments, though non-marine coals and sands of similar age have been identified near Comaum and west of Naracoorte. The Pebble Point Formation represents a major change in sea level, one of several that affected events during the Tertiary.

For this was a time of change involving marked rises and falls of sea level associated with global tectonic events. Perhaps the most interesting of these was the final separation of Australia from Antarctica, 53-55 million years ago, resulting in the formation of the Southern Ocean and the final breaching of the link that connected Tasmania and Antarctica during the latest Eocene and into the Oligocene (see for example Deighton et al. 1976). The breaching allowed circum-Antarctic Ocean currents to develop in the later Oligocene, and this event is recorded in the sedimentary sequences of the Otway Basin, including the Gambier Embayment.

In broad terms the terrestrial Wangerrip Group is representative of conditions that



DIAGRAMMATIC CROSS - SECTIONS
WESTERN OTWAY BASIN

obtained prior to the separation of Australia and Antarctica. It is followed by sediments of the Mepunga Formation and Narrawaturk Marl which were deposited in environments that were increasingly marine in character as the developing seaway became established. Near Naracoorte lagoonal sediments are recorded bordering the marine embayment, but by the end of the Eocene a limited Southern Ocean existed over much of the South East.

The birth of this great Southern Ocean was accompanied by a world-wide and pronounced drop in water surface temperatures (Shackleton & Kenneth, 1975). This had a pronounced effect on the development of the Australian biota but through the Late Oligocene and into the Miocene conditions once again ameliorated and the southern margin of Australia experienced warm temperate climates. Increasing subsidence and advance of the coastline resulted in the flooding by the sea of the Gambier Embayment and this transgression penetrated far inland along the whole of southern Australia. At this time most of the Padthaway Ridge was inundated and some of the topographic highs probably were loci for reef development. In the Gambier Embayment (Fig. 4) largely bryozoal limestones were deposited in well aerated ocean waters with abundant marine life. These sediments are now quarried for the building stone so common in the South East and for high grade whiting. They form important aquifers and are the site of extensive karst development.' Similar sediments can be seen on parts of the Naracoorte Range.

Towards the close of Miocene time yet another major event occurred with the reg ression of the sea and exposure and erosion of the Gambier Limestone and older sediments in the north of the Embayment. During the earliest Tertiary, deposition was still essentially non-marine for the sediments of the Wangerrip Group, known from borelogs over wide areas of the South East and comprising mainly silts and sands, appear to be of fluvial, lacustrine and marginal-marine origin.

The Tertiary culminated in uplift and deposition of shoreface sands which have now been largely eroded by the Pleistocene seas but are still preserved on parts of the Padthaway Ridge to the north. Elsewhere in the Otway Basin in Western Victoria this uplift was accompanied by widespread volcanism which produced basalt flows and tuffs.

REFERENCES

Craddock, C. (1979). The evolution and fragmentation of Gondwanaland. In Laskal', B. & RajaRao, C. S. (Eds). 'Fourth International Gondwana Symposium: Papers Volume 11'. (Hindustan Publishing Corp., Delhi) pp711-719.

Deighton, I., Falvey, D. A. & Taylor, D. J. (1976). Depositional environmental and geotectonic framework: southern Australian continental margin. *Aust. Pet. Explor. Assoc. J.* **16**, 25-36.

Dettmann, M. E. & Playford, G. (1969). Palynology of the Australian Cretaceous: a review. In Campbell, K. S. W. (Ed.), 'Stratigraphy and Palaeontology; Essays in Honour of Dorothy Hill'. (ANU Press, Canberra.) pp. 174-210.

Douglas, J. G. & Ferguson, J. A. (1976). Geology of Victoria. *Geol. Soc. Aust. Spec. Publ.* **5**.

Falvey, B. A. & Mutter, J. C. (1981). Regional plate tectonics and the evolution of Australia's passive continental margin. *B.M.R. J. Aust. Geol. Geophys.* **6**, 1-29.

Rogers, P. A. (Compiler) (1980). Geology of the South East South Australia. Geol. Surv. S. Aust. 1 :500,000 Map Sheet.

Shackleton, N. J. & Kenneth, J. P. (1979). Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analyses in DSDP Sites 277, 279 and 281. In: Kenneth, J. P., Houtz, R. E., et al. 'Initial Reports of the Deep Sea Drilling Project', Vol. 29. (U.S. Govt Printing Office, Washington). pp. 743-755.

Shepherd, R. G. (1978). Underground water resources of South Australia. *Geol. Surv. S. Aust. Bull.* **48**.

Wopfner, H., & Douglas, J. G. (Eds) (1971). 'The Otway Basin of south-eastern Australia.' *Geol. Surv S. Aust. Vict., Spec. Bull*.

2. Volcanoes

by M. J. SHEARD

INTRODUCTION

The Quaternary-Recent volcanic province of South Australia occupies a small portion of the South East, and constitutes a western extension to the Quaternary Newer Volcanics of central and western Victoria (Fig. 1.). This extension contains about 17 main eruptive centres-many of which have experienced multiple eruptions. The volcanic structures are underlain and surrounded by a karstic terrain of low profile with poorly developed surface drainage and abundant groundwater.

Two distinct groups of volcanics are evident: the northern Mt Burr forms one group, and the more isolated Mt Gambier and Mt Schank the second (Fig. 2). In a temporal sense also the volcanicity occurred in two separate and distinct phases (Fig. 3).

MOUNT BURR RANGE

The Mt Burr Range, northeast of Millicent, includes some 15 major volcanic centres. Most are associated with cracks in the ground-fissure eruptions, and are aligned in three main zones that parallel the Burr/Gambier Lineament and the Burr Platform (Fig. 4) described by Sprigg (1952) and Marker (1975). Seismic profiles indicate that a basement high, possibly an upthrown block (horst structure) underlies the Burr Platform. The magma, rich in silicates of Fe, Mg and Ca and of basaltic type, approached the surface along the fractures that define this horst.

The volcanic structures are varied, ranging from lava flows, scoria domes, composite domes and agglomerate cones to maars or tuff

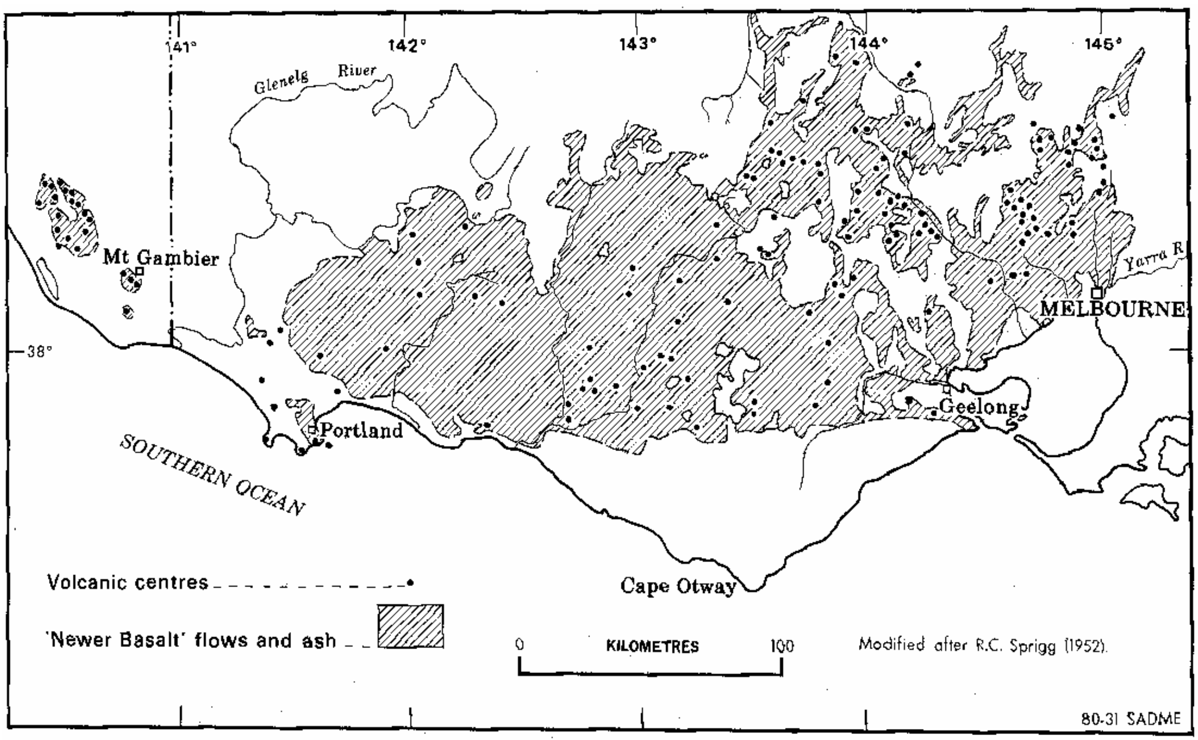


Fig. 1. South East of South Australia and south-western portion of Western and Central Victoria showing Tertiary to Quarternary volcanic deposits.

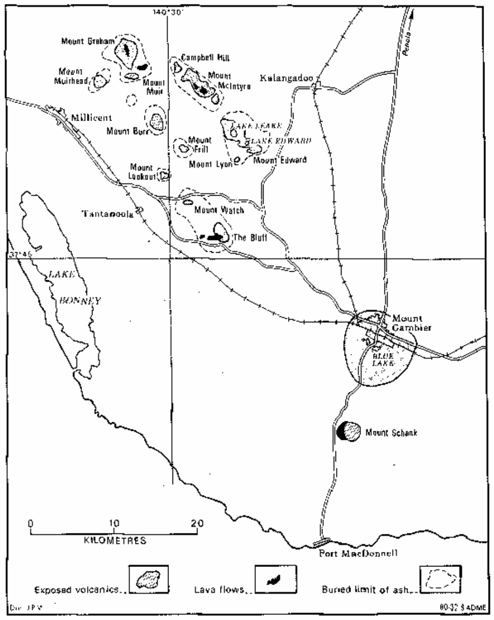


Fig. 2. Quarternary volcanic centres Mt Gambier and Mt Burr regions.

rings. Volcanic products associated with each structure are indicated in Table 1 and an example of a lava bomb is shown in Fig. 5. The ejecta rest on the erosional surface of the Gambier Limestone and are overlain by Pleistocene relict beach sand up to 50 m thick known as the Bridgewater Formation (Fig. 6). The volcanic materials are partly covered by these Pleistocene sands, and the full extent is revealed only by drilling, but the indications are that the field covers an area of about 110 km^2 (Fig. 2). Drilling at The Bluff revealed an alternating sequence of scoria, lava flows, and ash containing a fossil soil located 30 m below its apex and indicating a major time break in its eruptive history. So far as the possible magma sources and the geochemistry of the Mt Burr Range volcanic rocks are concerned, no pattern is apparent, though Irving & Green (1976) suggested that there are some chemical similarities and relationships between adjacent centres.

Pleistocene marine activity has had a marked effect on the shape of the volcanic edifices and on ash distribution. Mt Muirhead and The Bluff are asymmetrical due to the action of onshore winds and coastal erosion by the sea (Fig. 7). Cross-bedding with high angle set, slumping, and ripple marks are

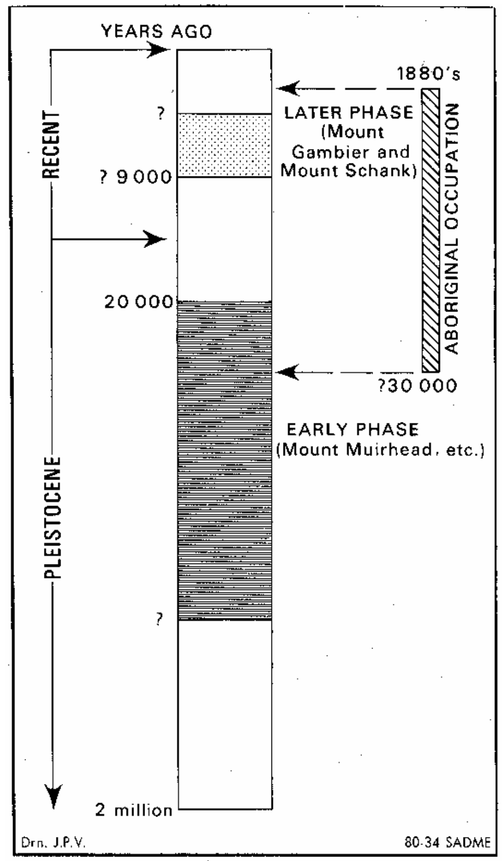


Fig. 3. Phases of volcanic activity in relation to Aboriginal occupation and the geological time scale (after Selby & Sheard, 1979, Fig. 2).

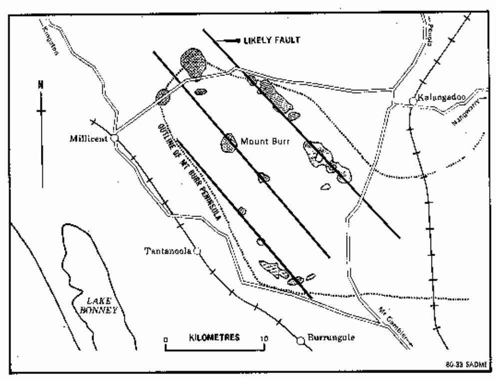


Fig. 4. The older Mt Burr Range volcanics with superimposed outline of the Mt Burr Peninsula and the position of inferred basement faults.

Table 1. VOLCANIC CENTRES IN SOUTH EAST SOUTH AUSTRALIA (MODIFIED AFTER WALKER (1967)

Name of volcano	Height *above m.s.l (m)	Edifice height* above plain (m)	Type of volcano	Volcanic products +olivine bombs present
Mt Graham	181.6	132	Composite	Lava, ash and conglomerate[1]
Mt Muir	172	122	Ash-cone	Ash, lapilli[2] & agglomerate
Campbell Hill	111	50	Ash-dome	Ash & agglomerate
Mt McIntyre	188.7	128	Composite	Lava, scoria[3] & ash (well bedded)
Boyce Hill	139	69	Ash-cone	Lapilli & agglomerate
Lake Leake Hill	127	57	Maar[4]	Well bedded ash & agglomerate
Mt Edward	160	80	Maar	+ Bedded agglomerate
Mt Lyon	150	80	Ash-cone	+ Bedded lapilli & agglomerate
The Bluff	201.5	168	Composite	Lava, scoria, agglomerate & ash
Mt Watch	181.5	121	Scoria-dome	+ Bedded scoria & lava bombs
Mt Lookout	96	66	Ash-cone	Agglomerate in soil below dune sand
Mt Frill	181	101	Ash-dome	Lapilli & agglomerate
Mt Burr	240.5	158	Composite	Lava, scoria & agglomerate
Mt Muirhead	149.7	122	Maar & cones	Bedded agglomerate overlying buried lava flow
Submarine flow near Beachport	-64 (approx) #	5 (approx) #	Flow	Lava? (No samples collected to date)
Mt Gambier	189.3	152	Maars	+ Stratified tuffs[5], agglomerate scoria, lava.
Mt Schank	122.2	82	Maar & cones	Lava, scoria & agglomerate

* from Dept of Lands, S. Aust 1:50000 scsale Topographic Maps: Kalangadoo, Millicent.
# from Sprigg (1959)

1. Agglomerate: An unsorted mass of rock fragments-angular to rounded in shape and ranging in size from dust to boulders, unlayered.
2. Lapilli: Pea shaped and sized droplets formed of solidified lava ejected from a volcanic crater.
3. Scoria: Lava pumice or foam formed by escaping gas invery fluid lava. It chills on contact with cold air-presenting the bubbly texture.
4. Maar: An explosion crater usually less than 5km in diameter, surrounded by a ring of volcanic ash with a low angle outward slopes, the crater floor is generally flat and if below the water table the crater contains a lake.
5. Tuff: Volcanic ash and other fragments that have consolidated into a rock-like massrock

common features of the volcanic layering on the lower seaward flanks of Mt Muirhead (Fig. 8), indicating that the eruptions took place in a coastal setting and produced ash-based beach deposits.

Ages for the Mt Burr Range volcanics based on rock relationships, depth of weathering, and pollen fossils from present deposits, range from two million to 20000 years B.P. (Dodson 1974, Marker 1975). It is possible that local aborigines witnessed volcanic activity in this area (Fig. 3). Tribal legends from the Booandik Tribe describe Mt Muirhead as being the oven of a giant called Craitbul, which is filled with ash that can be seen under the soil today (Smith 1880).

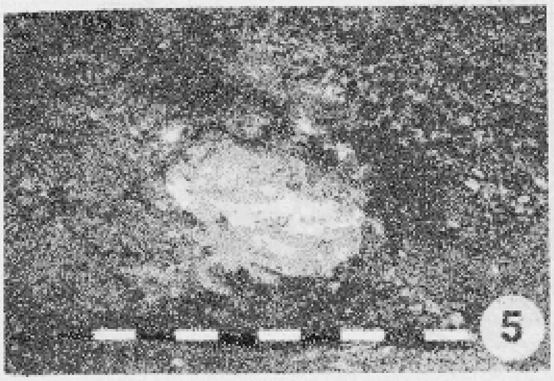
SOUTHERN VOLCANIC GROUP

The southern volcanic group (Fig. 2) consists of the Mt Gambier Volcanic Complex and Mt Schank (Figs. 9,10). Both structures rest on the Bridgewater Formation (drift sands) which appears to have consolidated prior to eruption (Fig. 5). Hence these volcanic structures are stratigraphically younger than those of the Mt Burr Range. Neither structure was subjected to marine erosion. However, Solomon (1951) described quench textures at Mt Schank, indicating the presence of surface water, possibly a swamp. Both Mt Gambier and Mt Schank are complex maar-cone structures. They are dominantly constructive features formed by volcanic explosions (Oilier 1967, Sheard 1978). There is no evidence for the large scale collapse proposed by earlier workers. Large open craters, like those at Mt Gambier are typical of steam-induced volcanic explosions, and are caused by the influx of abundant near-surface groundwater into the active vents and conduits.

Mt Gambier

A detailed geological history of Mt Gambier is set out in Sheard (1978). Briefly, Mt Gambier has undergone two closely spaced periods of eruption, each with a distinctive style.

Carbon-14 dating of charcoal fragments within the basal tuff has recently refined the age of Mt Gambier. Blackburn et al., (1982) indicate the eruptions occurred 4000 to 4300 years B.P. This evidence agrees with the palaeomagnetic results of Barbetti & Sheard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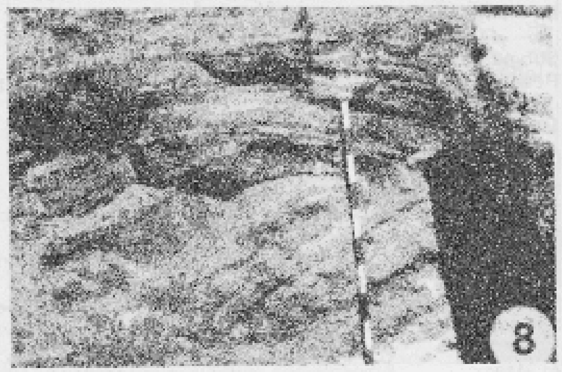
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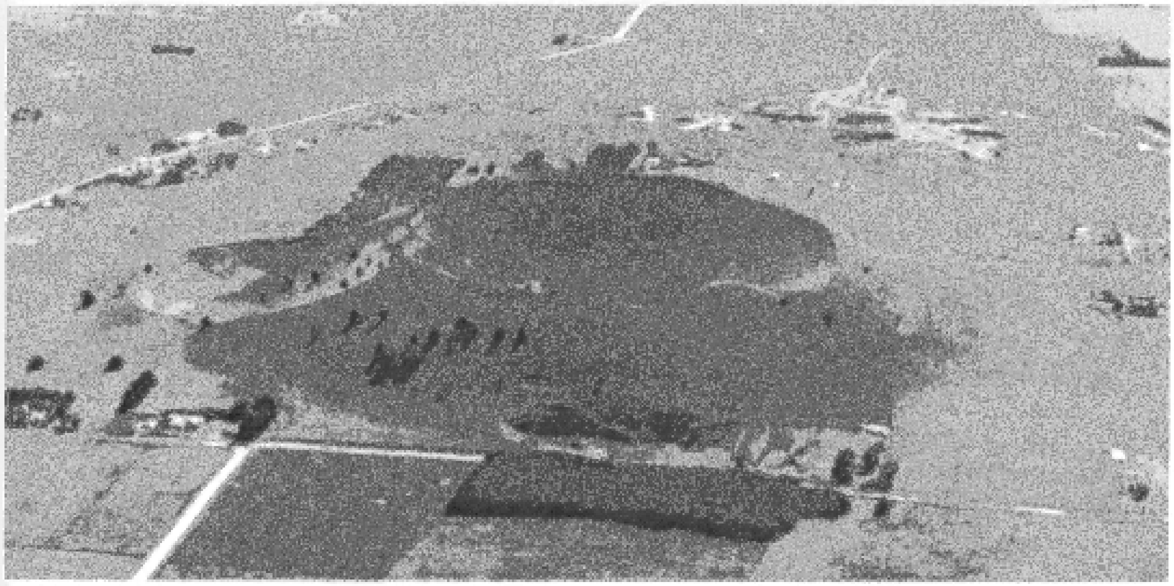


Fig. 10. Aerial view of Mt Schank looking west. Central crater straddles the southern maar crater and partially obscures the lava flow on its western side. (S.A.D.M.E. Transparency No. 14283).

(1981). There is no measurable difference in magnetic orientation between the earliest and latest eruptive materials. This indicates the gap between eruptive periods is small, and probably less than two or three centuries (Barbetti & Sheard 1981). Hence, Mt Gambier is one of the youngest volcanic features on the Australian mainland.

Initial eruptions occurred at the present sites of the Tenison College oval at the western end of the Complex (see Selby & Sheard 1979) and the Leg-of-Mutton Lake crater. Small, low, open explosion craters called maars were produced, covering the surrounding countryside with ash and lapilli. Next, lava flowed from fissures near the present day Brownes Lake and from a vent in the centre of the complex near the present day Leg-of-Mutton Lake. A scoria cone now partly exposed in the crater walls west of Brownes Lake, completed this first phase of eruption. Activity ceased for some time, allowing the lava flows to cool and crystallize, a process that may have taken up to two years.

The second period of eruptive activity was on a much larger scale than the earlier one. Between the two periods groundwater percolated down the existing volcanic conduits to mix with hot and/or molten rocks at depth. The resultant explosive volcanism produced the large craters that are such prominent features of the present landscape (Figs 9, 11). Many closely spaced small vents eventually combined to form the large craters that now contain the Blue, Valley and Brownes Lakes. During these eruptions many large blocks, some weighing many tonnes, were thrown out of the craters (Fig. 12). The Leg-of-Mutton Lake crater is a late-stage feature that formed as activity was waning. Lava fountaining in the Brownes Lake crater was the last magmatic event, and produced lava spatter and ropey lava. Activity ended with steam venting through blow holes such as the Devils Punch Bowl and several others inside and outside the main craters (Fig. 11).

A thick covering of dune sands (light) overlying the bedded scoria (dark) at the Mt Watch Quarry. Mt Muirhead, looking east, showing asymmetrical form due to action of on-shore winds blowing north (right to left). The main vent for this part of the complex is halfway down the slope below the highest point. (S.A.D.M.E. Transparency No. 14284).

Aerial view of Mt Gambier looking south-east. The City on left; from back of foreground-Blue Lake, Valley Lake, Brownes Lake, and Tenison College oval (S.A.D.M.E. Transparency No. 142l7).

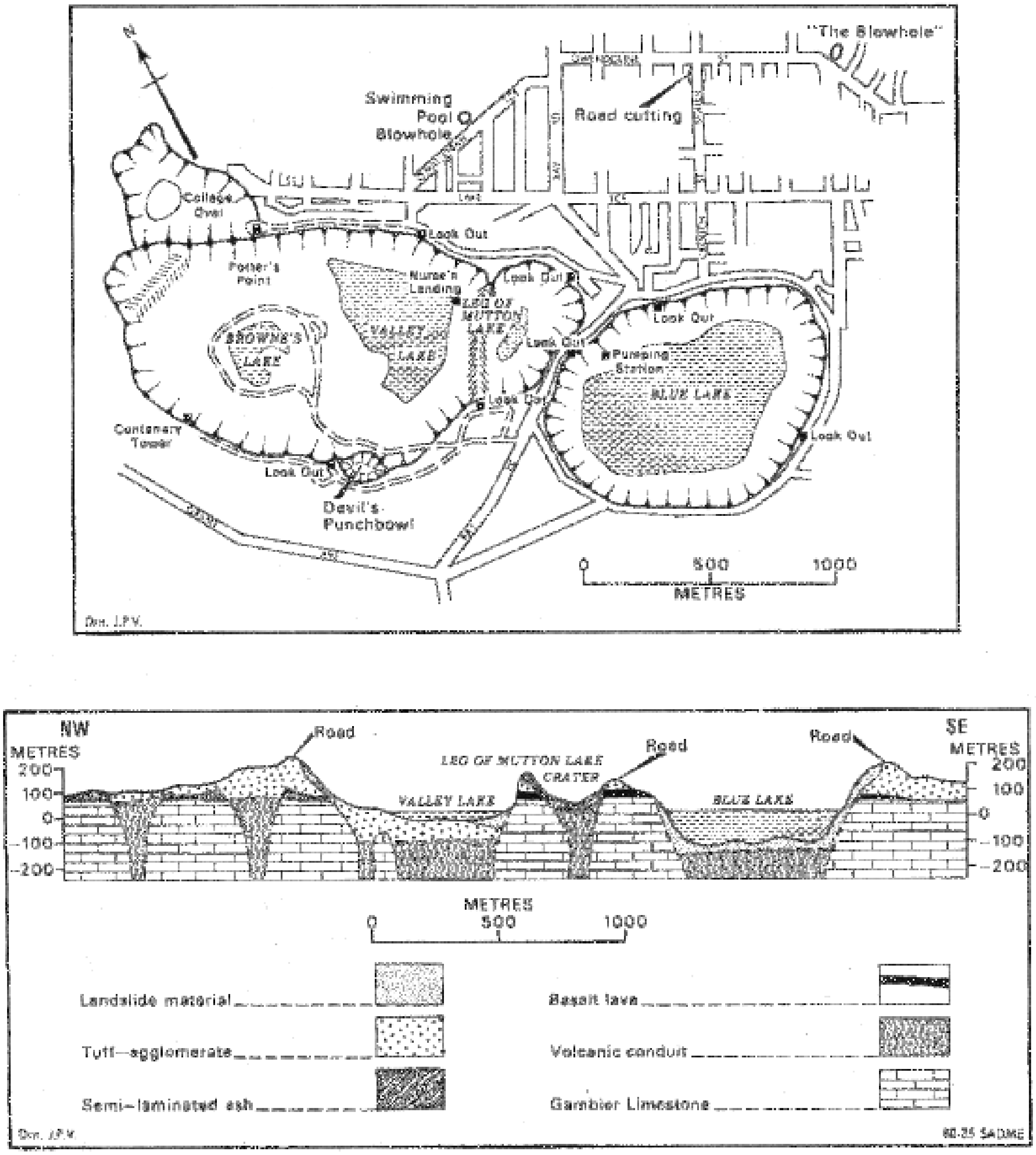


Fig. 11. Mt Gambier craters and a diagramatic cross section.

Mount Schank

The volcanic pile at Mt Schank has not been dated, but carbon-14 dating of charcoal fragments found in sands underlying the tuff deposit has yielded an age of 18 100 ± 350 years (Polach et al., 1978). Palaeo mag netic data obtained by Barbetti & Sheard (1981) indicate Mt Schank is not contemporaneous with Mt Gambier, and that it erupted either prior to 7000 years B.P. or 5000-1000 years B.P. Thermo-luminescent data obtained from lava-baked sands have given a tentative age of 8700 ± 900 years B.P. according to B. Smith (pers. comm.), thus supporting the older possible date.

There appears to have been no break in eruption at Mt Schank as is evident at Mt Gambier, though, exposure of the whole volcanic pile near the craters is incomplete, so

Fig. 12 Impactite or piercement structure at the Crouch St cutting, Mt Gambier, caused by wedge-shaped bomb landing heavily on the ash surface. Bar scale 13 cm long.

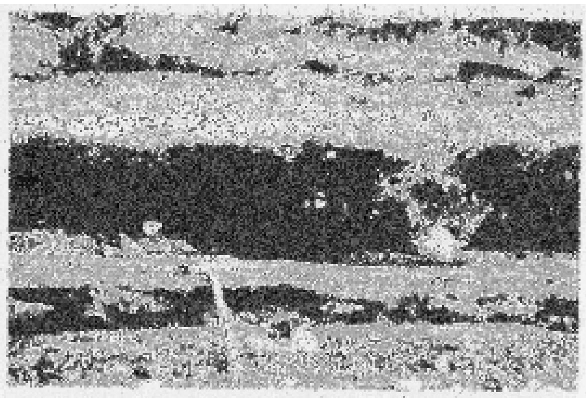


Fig. 14. Bombs in layered agglomerate at Mt Schank. Differential erosion has highlighted sagging in a layer to right of hammer. Hammer is 30 cm long.

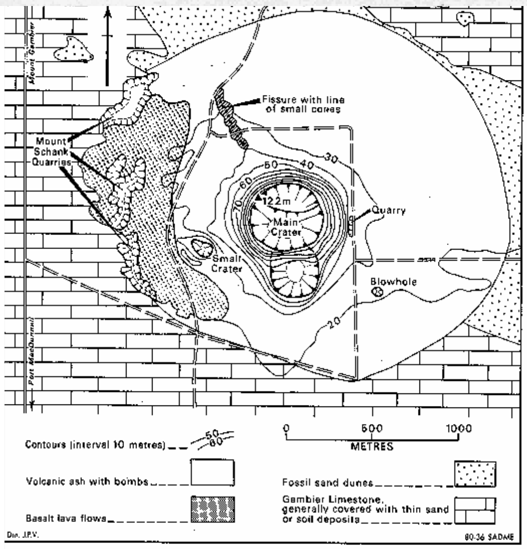


Fig. 13. Volcanic cones forming Mt Schank (after Selby & Sheard, 1979, Fig. 5).

that evidence of a discontinuity may await discovery.

Initially lava flowed westward from a north-west-trending fissure, now marked by a line of small scoria cones (Fig. 13). Explosive activity followed with the development of a large ash-scoria cone at the centre of the fissure and a small maar crater at the southern end. Straddling the small maar and almost obliterating the large cone is a larger hybrid maar-cone structure composed mainly of lapilli and agglomerate (Fig. 14) which completed the eruption at this site.

Strong south-westerly winds influenced the ash distribution during eruption (Fig. 13).

OBSERVED ACTIVITY IN THE PROVINCE

The possibility that aboriginal people witnessed volcanic activity at Mt Muirhead was mentioned earlier. It is even more likely that they saw eruptions from Mt Schank and/or Mt Gambier. Evidence for this is recorded in the Booandik Tribe legend of the giant Craitbul which also tells of him digging ovens at Mt Gambier: four times he dug his oven and lit a fire but each time the underground water rose and put it out (Smith 1880).

Since European settlement tectonic activity in this volcanic province has been restricted to earthquakes. Two of the State's largest recorded earthquakes occurred near Kingston and Robe in May 1897 and August 1948 respectively, just to the north-west of the volcanic province. Sutton. et al. (1977) have demonstrated that these were most likely due to regional tensional releases related to crustal plate tectonics. Sprigg (1959) postulated a link between these two earthquakes and· the existence of three possible submarine lava flows about 17 km WSW of Beachport (Table 1). So far no samples have been collected from these supposed flows. Nor have detailed magnetic surveys been carried out over them, so that their volcanic origin remains conjectural.

Between 1975 and late 1976 several small earth tremors have shaken areas closer to Mt Gambier (Sutton et al., 1977, McCue & Sutton 1979). The distance from the nearest recording stations precluded calculation of the exact epicentres, but a local seismic network set up by the University of Adelaide and presently being calibrated, will provide more accurate data in future. Sutton *et al.* (1977) indicated that the close association of the volcanic province with recent earthquake activity cannot be ignored.

CONCLUSIONS

The Mt Burr Range provides evidence of an extended period of interrupted volcanic activity of many styles, with ash fallout over an area of 110 km^2.

The younger southerly volcanic group on present indications may be following a similar pattern of development.

REFERENCES

Barbetti, M. & Sheard, M. J. (1981). Palaeomagnetic measurements from Mts Gambier and Schank, Southeast, South Australia. *J. geol. Soc. Aust.,* **28**, 4, 385-394

Blackburn, G., Alison, G. B. & Leaney, F. W. J. (1982). Further evidence on the age of tuff at Mt Gambier, South Australia. *Trans. R. Soc. S. Aust.,* **106**,163-167.

Dodson, J. R. (1974). Vegetation history and water fluctuations at Lake Leake, South-eastern South Australia. I. 10000 B.P. to Present. *Aust. J. Bot.,* **22**,719-741.

Irving, A. J. & Green, D. H. (1976). Geochemistry and petrogenesis of the Newer Basalts of Victoria and South Australia. *J. geol. Soc. Aust.*, **23**,45-66.

McCue, K. F. & Sutton, D. J. (1979). South Australian earthquakes during 1976 and 1977. *J. geol. Soc. Aust.,* **26**, 231-236.

Marker, M. E. (1975). The Lower Southeast of South Australia: a Karst Province. *Dept. Geog. Environ. Studies, Univ. Witwatersrand, Johannesburg, Occas. Pap* (13), 1-68.

Oilier, C. D. (1967). Maars: Their characteristics, varieties and definition. *Bull. Volcanol.,* **31**,45-73.

Polach, H. A., Head, M. J. & Gower, J. D. (1978). ANU Radiocarbon date list VI. *Radiocarbon*, **20**, 360-385.

Selby, J. & Sheard, M. J. (1979). Volcanoes of the Mount Gambier Area. Mineral Information Series (pamphlet), *Geol. Surv. S. Aust*. 1-12.

Sheard, M. J. (1978). Geological history of the Mount Gambier Volcanic Complex, Southeast South Australia. *Trans. R. Soc. S. Aust*., **102**, 125-139.

Smith, C. (1880). Booandik tribe of South Australian aborigines; a sketch of their habits, customs, legends and language. (Govt Printer, Adelaide).

Solomon, M. (1951). The volcanic deposits of South East South Australia. S. Aust. Dept Mines & Energy (Unpub. Rept.) 30/3.

Sprigg. R. C. (1952). The geology of the South East province, South Australia, with special reference to Quaternary coast-line migrations and modern beach developments. *Bull. geol. Surv. S. Aust*., **29**, 1-120.

Sprigg, R. C (1959). Presumed submarine volcanic activity near Beachport, Southeast South Australia. *Trans. R. Soc. S. Aust*., **82**, 195-203.

Sutton, D. J., McCue, K. F., & Bugeja, A. (1977). Seismicity of the Southeast of South Australia. *J. geol. Soc. Aust*., **25**, 357-364.

Walker, N. C. (1967). A review of post-Miocene volcanic centres in South Australia. *Min. Rev., Adelaide,* **126**,152-155.

Wall, H. J. (1971). Kalangadoo map sheet, Topographic series of South Australia, 1 :50 000 series (Dept Lands, S. Aust., Adelaide).

Wall, H. J. (1971). Millicent map sheet, Topographic series of South Australia, 1 :50 000 series (Dept Lands, S. Aust., Adelaide).

3: *Quaternary Dune Systems*

by D. A. SCHWEBEL

INTRODUCTION

The broad coastal plain of South East South Australia has preserved across its width a unique record of Quaternary sea level change. Slow tectonic uplift, low coastal plain gradient and eustatic sea level oscillations have combined to produce a series of subparallel depositional shorelines hundreds of kilometres long.

The Quaternary strandlines have been deposited on a coastal plain which stretches from Western Victoria to the Murray River (Fig. 1). Twenty-one stratigraphically separable Quaternary coastal barrier deposits occur in 13 geomorphologically distinct ranges across the coastal plain at its widest point between Robe and Naracoorte. To the south and north of this line of section many of the ranges coalesce and lose their integrity (Fig. 1).

The potential value of these forms and deposits to the eventual understanding of Quaternary sea level change has been recognised by many workers (Hossfeld 1950, Sprigg 1952, Cook et al. 1977, Schwebel 1978). Early studies were hampered by poor outcrop, absence of widespread subsurface control and the lack of dating techniques capable of accurately determining the ages of the sediments forming the stranded shorelines. Geomorphology and subjective geological reasoning were the only criteria on which to base a chronology of depositional events.

Shallow stratigraphic drilling by the Bureau of Mineral Resources during 1974-1975 provided extensive subsurface control across the widest part of the coastal plain. This drilling revealed complexities in the Quaternary sequence which require substantial alteration to existing theories of the relationship between the stratigraphy and eustatic sea level change. Cook et al. (1977) described the gross stratigraphic relationships revealed in 36 drill holes. They referred to work then in progress investigating the detailed relationship between and within the stratigraphic units. This account represents a summary of those investigations which are described more comprehensively by Schwebel (1978).

THE SEQUENCE OF ROCK STRATA

A predominantly carbonate sequence was deposited across the coastal plain during the Quarternary. The stratigraphy is divisible on the basis of lithology and depositional environment into three mappable units which were deposited episodically in association with interglacial high sea levels.

The subdivision into units on the basis of depositional environment is broadly comparable to that established by Cook et al. (1977). The three units described in detail by Schwebel (1978) are:

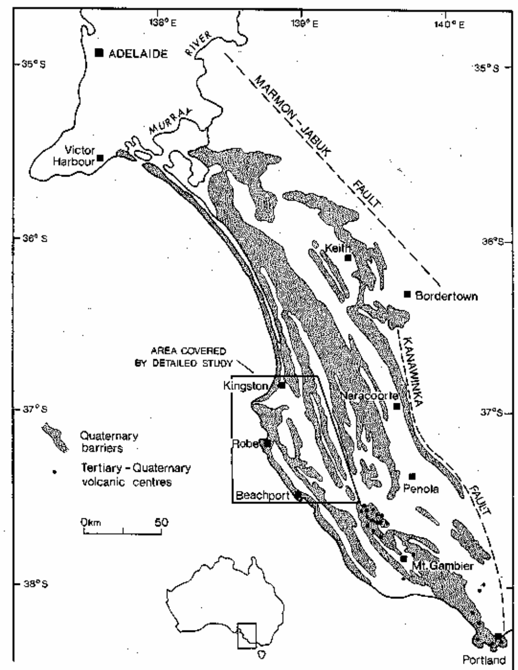


Fig. 1. Location.

(1) A *Beach-Dune Skeletal Grainstone Unit* consisting of grainstones deposited as the beach and dune components of barrier shorelines at the peak of glacio-eustatic sea level transgressions.

(2) A *Lagoonal Skeletal Grainstone, Packstone and Wackestone* Unit consisting of sediments deposited under sheltered marine conditions created on the leeward side of those shorelines which formed as barrier islands when the peak of each transgression was reached.

(3) A *Lacustrine Calcitic and Dolomitic Mudstone Unit* consisting of calcareous mudstones deposited from saline lakes occurring in low-lying areas between the stranded coastal barriers wherever the groundwater table emerged at the surface.

The three units are not uniformly distributed across the coastal plain. The Beach-Dune Unit occurs as shoestrings of sand parallel to the present coastline and separating extensive sheets of finer grained sediments of the Lagoonal Unit and the Lacustrine Unit (Figs. 2, 3)

Deposition of the Beach-Dune Unit occurred at the peak of eustatic sea level oscillations. If suitable conditions were formed by the flooding of an older topography, then the Lagoonal Unit was also deposited at this time. The Lacustrine Unit appears to have been deposited initially as part of a regressive sequence at the stablized interglacial sea level and then continued to accumulate in areas of outcropping watertable as the sea level retreated.

The Beach-Dune Unit has been described by Sprigg (1952), Firman (1973) and Cook et al. (1977) It was deposited as mainland barrier shorelines and barrier islands which have been preserved as conspicuous topographic ranges on an otherwise featureless coastal plain (Schwebel, 1978) Ditches excavated to facilitate the drainage of winter rains (see Chapter 6) expose excellent cross sections through the more prominent topographic ranges.

The unit unconformably overlies Tertiary marine sediments. Calcreted outcrops of the unit generally occur along the crest of the ranges, while on the flanks it may be overlain by onlapping sediments of the interrange Lacustrine and Lagoonal Units. Significant unconformities may exist within deposits of the Beach-Dune Unit. These are identified by conglomerates and shell beds in the case of marine erosion and by soil profiles and calcretes where there has been extended periods of exposure and non-deposition.

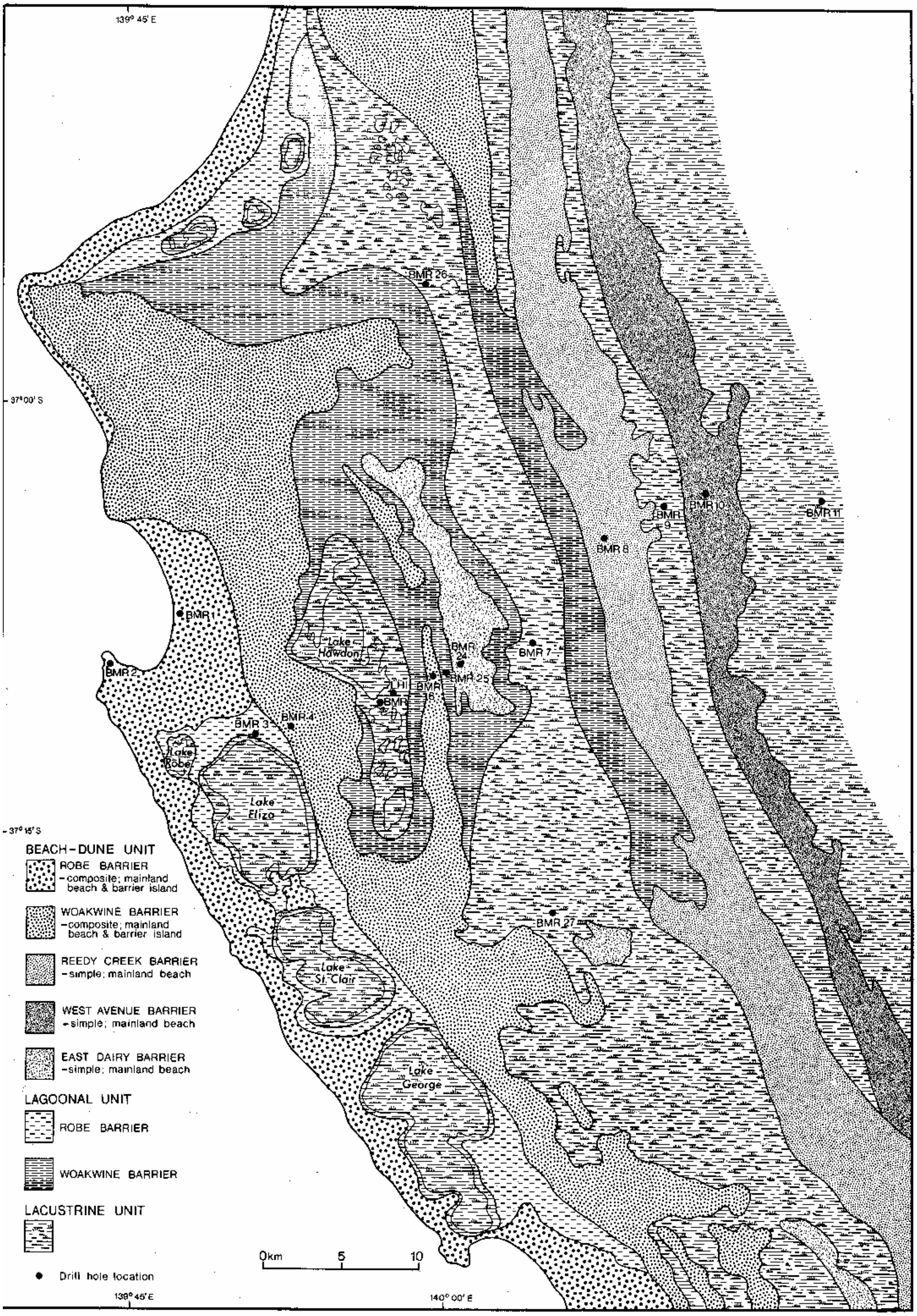
Limestones of the unit are beach and wind deposited sand-sized sediments which range in carbonate content from 3 to 80%. The carbonate fraction is made up principally of molluscan and calcareous algal debris and lithoclasts of older limestone. The non-carbonate fraction is almost entirely quartz, with minor quantities of K-feldspar and traces of plagioclase and heavy minerals, primarily opaque minerals, amphiboles and zircons (Colwell, 1977)

A calcrete of variable form and thickness veneers all the Pleistocene elements of the unit (Blackburn et al. 1965) Calcrete development has prevented redistribution of the sediment and preserved near perfect coastal barrier morphology in each accumulation of Beach-Dune Unit (Schwebel 1978). The one stratigraphically significant episode of calcretization proposed by Firman (1973) is not consistent with this observation. As there is no indication of the development of other soil profiles on the Beach-Dune Unit, it is most likely that calcrete development has occurred either continuously or immediately after each episode of shoreline deposition through the Pleistocene.

The grainstones beneath the calcrete have poorly developed calcite cements which have been deposited in both vadose and phreatic groundwater environments. The zone of maximum cementation coincides with the level of the water table in each simple barrier and with the surficial calcite accumulation.

Sediments of the Beach-Dune Unit have a mineralogy typical of limestones deposited under temperate latitude conditions. The carbonate minerals in the Recent sediments are biogenically derived calcite and Mg-calcite (60-80%) and aragonite (20-40%). The principle sources of the minerals are molluscs (calcite and aragonite) and calcareous red algae (Mg-calcite).

Pleistocene elements of the unit have both calcite and dolomite present as the principal carbonate mineral types. In successively older barrier shoreline sediments, progressive diagenesis reduces the quantity of aragonite and Mg-calcite present. The proportion of


139° 45' E
37°00' S
37° 15' S
BMR 26
BMR 10
BMR 11
BMR 9
BMR 8
BMR 1
BMR 2
BMR 7
BMR 24
BMR 25
BMR 16
LH1
BMR 3
BMR 4
BMR 27
Lake Hawdon
Lake Robe
Lake Eliza
Lake St. Clair
Lake George
BEACH-DUNE UNIT
ROBE BARRIER -composite; mainland beach & barrier island
WOAKWINE BARRIER -composite; mainland beach & barrier island
REEDY CREEK BARRIER -simple; mainland beach
WEST AVENUE BARRIER -simple; mainland beach
EAST DAIRY BARRIER -simple; mainland beach
LAGOONAL UNIT
ROBE BARRIER
WOAKWINE BARRIER
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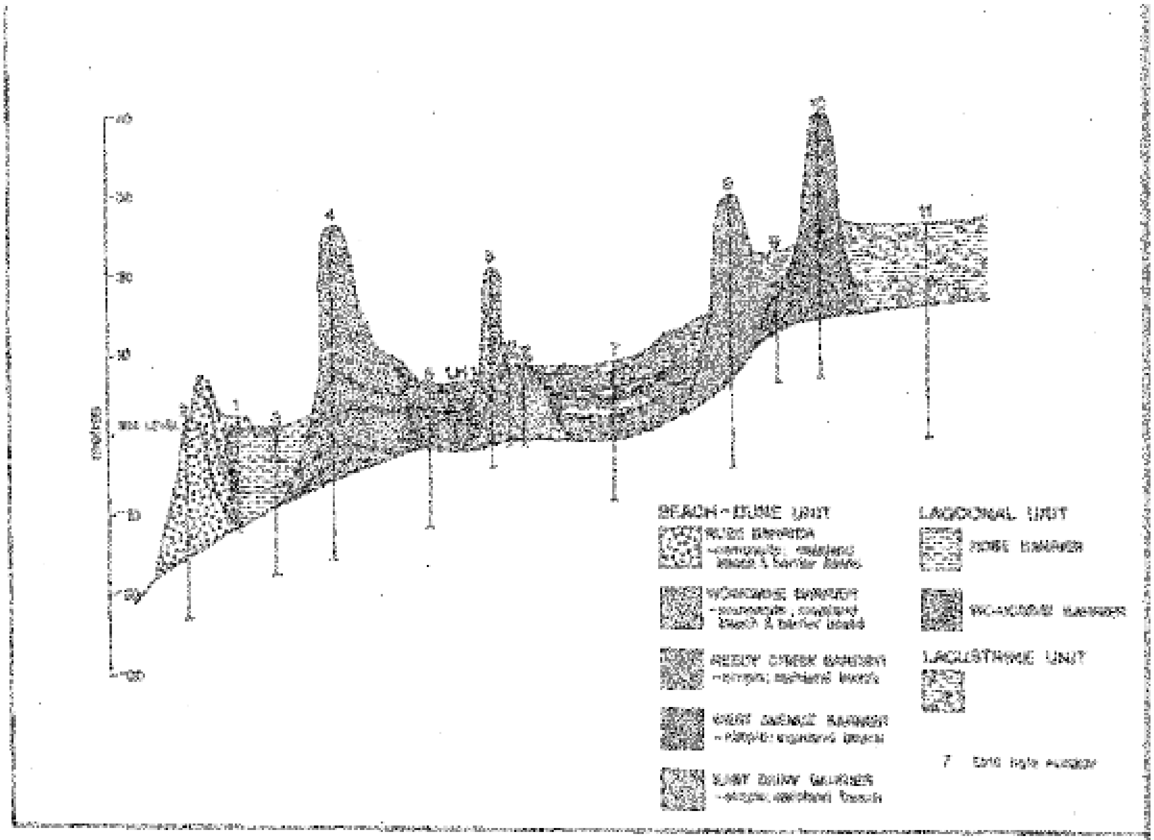


Fig. 3. Geological cross-section through drill holes shown on Fig. 2.

dolomite present in the Pleistocene sediments increases in response to diagenetic processes associated with the mobilization of Mg from the metastable Mg-calcite.

The Lagoonal Unit was deposited under marginal marine conditions where lagoons were created in flooded interdune corridors in the lee of the barrier forming at that particular high sea level. It is present only to the west of the Reedy Creek Barrier and is intimately related to multiple episodes of deposition along the Robe and Woakwine shoreline trends (Figs. 2, 3).

The unit ranges in age from Pleistocene to Recent, occurring as thin sheets of sediment which have complex stratigraphic relationships. It unconformably overlies either Beach-Dune Unit, Lacustrine Unit or Tertiary sediments and is partially overlain by Lacustrine Unit. The Unit is a common surficial sediment and can be shown to be a lateral facies equivalent of the Beach-Dune Unit deposited at the same high sea level stand. The degree of induration is largely dependent on age and proximity of surficial calcrete development. Recent sediments are unconsolidated while their Pleistocene counterparts range from unconsolidated to strongly indurated.

The grainstones have similar composition to the sediments of the Beach-Dune Unit. They were deposited around the margins of the lagoon and represent low energy beach and nearshore conditions. The framework most commonly consists of either whole or fragmentary bivalves and gastropods.

The packstones were deposited in lower energy conditions where mud could not be winnowed from the framework of the sediment. In the most sheltered and deepest parts of the lagoon the wackestones were deposited. In these sediments the coarser grainsize fraction consists entirely of skeletal material derived from organisms (primarily molluscs, ostracods and foraminifera) living in the low energy environments in which deposition took place.

Texture and mineralogy are closely related. The grainstones and packstones have a very uniform mineralogy which is controlled by the skeletal components of the framework, age of the sediment and the degree of diagenesis.

The mineralogy varies in a similar manner to the way in which it does for the Beach-Dune Unit. Grainstones of successively older units progressively change from a calcite-aragonite-Mg calcite composition to a calcite-dolomite composition.

The wackestones also have a mixed calcite-aragonite-dolomite mineralogy. However, there is no corresponding systematic compositional variation correlatable with age. The source of the carbonate minerals is generally biogenic. However, in the finer fractions there is an increase in the proportion of aragonite at the expense of the other minerals. This has been interpreted to indicate that there is a contribution of aragonite from an inorganic source, precipitated directly from lagoonal waters in much the same way the aragonite sediments of the Coorong Lagoon are currently being formed (Alderman & Skinner 1957, Von Der Borch 1965).

The Lacustrine Unit is present in all the interrange areas (Figs. 2, 3). It occurs across the coastal plain as the unconsolidated surface sediment of modern saline lakes. The indurated sediments of Pleistocene lakes crop out in interrange areas to the east of the Woakwine Range. In the same area they underlie most modern lakes.

The Lacustrine Unit unconformably overlies Tertiary sediments. It conformably overlies the Lagoonal Unit where the two combine to form an upward-fining regressive sequence. The unit may also onlap and disconformably overlie the Beach-Dune Unit.

The sediments of the unit are primarily mudstones with occasional wackestones and rare packstones. Sand size grains are derived from molluscs, foraminifera and ostracods. Some wind blown quartz grains are also present. The calcareous mud has a grainsize generally less than 2 microns and is commonly aggregated into pellets.

A systematic distribution of lithologies is controlled by the energy conditions prevalent in the different parts of the lake. Coarser grained, better sorted sediments occur around the leeward margins of the lakes where wind generated waves winnow the sediment in beach environments. Pelletal mudstones tend to occur on those shallow parts of the lakes where currents and waves associated with seiching periodically remove the fine disaggregated mud from the lake surface and promote the formation of laminated pelletal mudstones. Amorphous mudstones (the yoghurt muds described by Von Der Borch 1977) appear to be representative of the more central lacustrine conditions where surface water persists through severe seasonal evaporative periods.

The Coorong Lagoon and ephemeral lake chain are considered to be the present day analogue of the Pleistocene parts of the Lacustrine Unit. However, the complex mixtures of hydromagnesite, magnesite, protodolomite, aragonite, Mg-calcite and calcite present in the modern environments have not been identified in the Lacustrine Unit.

ROCK RELATIONSHIPS

Detailed stratigraphic drilling has shown that the Quaternary sequence was deposited in response to the complex interaction of slow tectonic uplift and eustatic sea level change on a broad, gently dipping coastal plain. The resultant overall regressive sequence is made up of a series of transgressions and regressions. Sediments preserved as linear shorelines represent deposition at the peak of each of these transgressions, and provide a discontinuous record of the depositional environments active throughout the Quaternary.

The Robe and Woakwine barriers have complex internal structure and are the result of three and five separate high sea level stands respectively. The deposits of each high sea level are separated from overlying deposits by conglomerates, soils, calcretes and strong induration. Lagoonal Unit deposits on the inland side of these barriers are lateral equivalents of the upper two and th ree barrier shoreline deposits respectively.

All of the other barriers (except the West Naracoorte Barrier) have been shown by stratigraphic drilling to be simple shoreline deposits. No deposits of Lagoonal Unit have been identified to the east of the Reedy Creek Barrier.

The West Naracoorte Barrier accumulated on the downthrown side of the major north-west-southeast trending fault which marks the inland limit of the coastal plain. Successive episodes of deposition may have accompanied local steepening of gradient as the fault moved during the early Pleistocene. Stratigraphic drilling identified beach sediments at the base of the oldest component of the barrier. The remainder of the sediment pile consists of aeolian accumulations separated by thick soils.

DATING OF STRATA

The sequence consisting of Beach-Dune Unit, Lagoonal Unit and Lacustrine Unit is regarded as Pleistocene and Recent (Sprigg 1952, 1958; Hossfeld 1950; Firman 1969, 1973; Cook et al. 1977). Refinement of this Quaternary age estimate was not possible until the results of uranium series age dating, radiocarbon dating and magnetostratigraphy became available.

All of the Beach-Dune Unit to the west of and including the West Naracoorte Barrier has normal magnetic polarity and is interpreted to have been deposited since the Brunhes-Matayama magnetic reversal 690000 years ago (Cook et al. 1977). The youngest part of the Woakwine Barrier was deposited within the dating range of the uranium series method and age estimates of 100000 ± 30000 and 125000 ± 20000 years respectively were obtained from aragonitic muds and molluscs of the Lagoonal Unit (Schwebel 1978). Both of these results suggest a last interglacial age. The remainder of the Beach-Dune Unit is either outside the range of Th^{230}/U^{234} method or devoid of material suitable for dating.

Recent sedimentation has occurred along the modern coastline and uncemented sediments of the final stage of Robe Barrier deposition are within the range of radiocarbon dating and are estimated to have been deposited since sea level peaked after the last transgression. The maximum measured age of these sediments is 4330 ± 100 years (Blackburn 1966).

Lacustrine Unit sediments are of both Pleistocene and Recent age (Von Der Borch 1977, Cook et al. 1977). The unit exhibits no simple spatial variation through time and appears to be independent of barrier shoreline deposition. There is probably a general trend towards increasing age with greater distance from the present coastline. However, the unit may be deposited at any time and in any place where the water table intersects the land surface. Von Der Borch (1977) described lakes in the vicinity of Naracoorte which are actively precipitating dolomite

The age estimates of the sediments and the preservation of their spatial relationships indicate that calcrete development was an active process throughout the Pleistocene. Uncemented sediments and unaltered sediments are of Recent age.

SEA LEVEL CHANGE

The essential variables from which estimates of Pleistocene palaeosea levels can be made are the age of barrier shoreline deposition, rate of tectonic uplift and present height above sea level.

The ages of the barrier shorelines that have been dated by conventional means are outlined above. The ages of the other deposits have been estimated by comparing the detailed stratigraphy with the deep sea oxygen isotope record (Shackleton & Opdyke 1973, 1976) The measured and estimated ages of the barrier shorelines are presented in Table 1.

The rate of tectonic uplift has been calculated by two separate methods relying on independent age estimates of different barrier shorelines. Using the presently measured heights of the strandline deposits and the 690000 years age estimate for the oldest element of the West Naracoorte Barrier and the 125000 years age estimate for the youngest element of the Woakwine Barrier, uplift rates of between 0.05 mm/year and 0.09 mm/year have been calculated.

Table 1 AGE ESTIMATES, MEASURED PALAEOSEA LEVEL HEIGHTS AND UPLIFT CORRECTED PALAEOSEA LEVEL HEIGHTS FOR EACH BARRIER SHORELINE.

Stratigraphic Event	Age (000's years)		Height (m)	
	Measured	0^{18} Estimate	Measured	Uplift corrected
Robe I	43±01	4	0	0
Robe II	-	83	-6 to +2	-13 to 5
Robe III	-	93	-15 to 8	-23 to 16
Woakwine I	100±30 125±20	120	+12 to +17	+2 to +7
Woakwine II	-	203	0 to +9	-16 to 8
Woakwlne III	-	218	-3 to ?	-20 to ?
Reedy Creek	-	248	+12to+17	-8 to 3
East Dairy	-	309	2 to ?	-27 to ?
West Avenue	-	347	+13 to +14	-12 to 10
Woakwine IV	-	384	- 5 to ?	-36 to ?
Woakwine V	-	?	-7 to ?	?

Table 2. CRITERIA USED TO ESTABLISH RANGE OF PALAEOSEA LEVEL HEIGHTS RESPONSIBLE FOR DEPOSITION OF EACH BARRIER SHORELINE.

Stratigraphic Event	Measured height above MSL (m) (max. & min.)		Criterion by which sea level height defined
Robe I	0		Modern sea level.
Robe II	2	-6	Height of palaeosol between Robe II and Robe III barriers. Presence of Lagoonal Unit in lee of Robe II Barrier.
Robe III	-8	-15	Absence of Lagoonal Unit in lee of Robe III Barrier. Base of Beach-Dune Unit in Robe II Barrier.
Woakwine I	17	12	Palaeosol between Woakwine I and II barriers. Marine erosion surface at base of Woakwine I Barrier.
Woakwine II	9	0	Beach aeolian transition in Woakwine II Barrier. Marine erosion surface at base of Woakwine II Barrier.
Woakwine III	-	-3	Indeterminable. Marine erosion surface at base Woakwine III Barrier.
Reedy Creek	17	12	Absence of Lagoonal Unit in lee of Reedy Creek Barrier. Base of Beach-Dune Unit in Reedy Creek Barrier.
East Dairy	-	-2	Indeterminable. Base of Beach-Dune Unit in East Dairy Barrier.
West Avenue	14	13	Absence of Lagoonal Unit in lee of West Avenue Barrier. Base of Beach-Dune Unit in West Avenue Barrier.
Woakwine IV	-	-5	Indeterminable. Marine erosion surface between Woakwine IV and V Barrier.
Woakwine V	-	-7	Indeterminable. Base of Beach-Dune Unit in Woakwine V Barrier

The present heights at which the former sea levels responsible for the deposition of the barriers are found are shown in Table 2. These are based on a number of stratigraphic criteria which are outlined there.

Combination of the information contained in Tables 1 and 2 and an average uplift rate of 0.07 mm/year leads to the development of a sea level curve which has affected the South East of South Australia (Fig. 4). The most important aspect of the curve is that it agrees well with the existing interpreted history of sea level change for the period up to 125 000years ago For the period of 125 000-400 000 years the inferred sea level is no higher than that of the present time.

DISCUSSION

The stratigraphy has preserved a history of sea level change which when reconstructed presents a picture of oscillations dating back 400 000 years The most recent portion of the reconstruction, up to 125 000 years, is in agreement with the established sea level curves from the upper Pleistocene to the Recent.

The deep sea oxygen isotope record is the only reference with which to compare the remainder of the interpreted sea level history.

The record of oxygen isotope variation has provided a means of estimating the absolute ages for the temporally uncontrolled portion of the stratigraphy 125 000-400 000 years ago Consequently, the sea level curve derived herein and the oxygen isotope curve will have identical periodicity of maxima and minima. The good correspondence between the sea level and the oxygen isotope record over the last 125 000 years suggests that the earlier record for both phenomena should be comparable. The major factor which lends credence to the sea level curve generated from the stratigraphy of the South East of South Australia is that, the last interglacial apart, the absolute heights of the old sea levels are not significantly greater that the present sea level.

An essential adjunct to the derivation of the old sea level curve is the determination of an uplift rate for the coastal plain This has been done using two independent methods of determining ages of different barrier shoreline

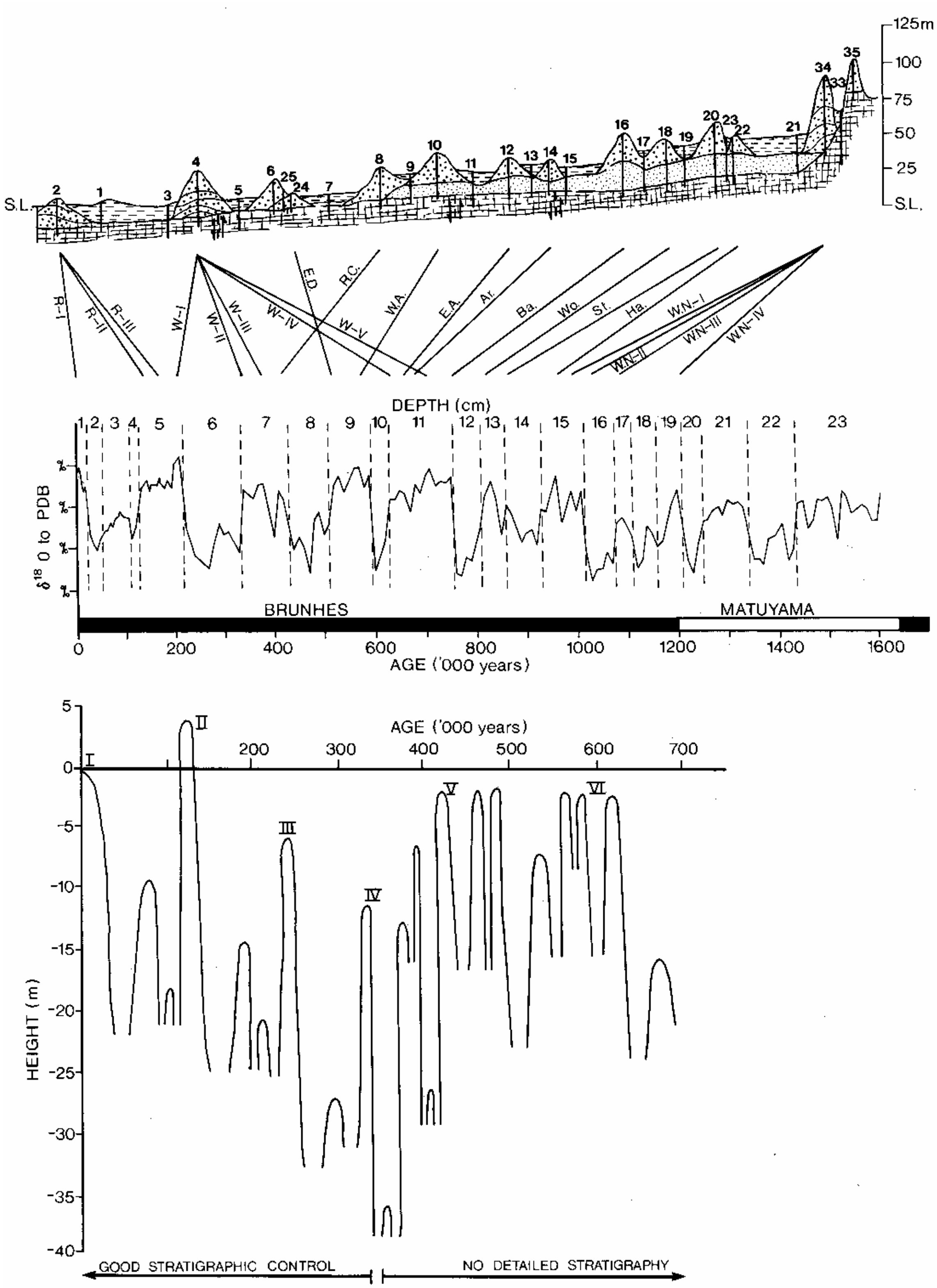


Fig. 4. Correlation between Quaternary stratigraphy, the deep sea oxygen isotope record from Pacific core V28-238 (Shackleton & Opdyke 1976) and the palaeosea level curve for the south-east of South Australia.

deposits. The results indicate an uplift rate of 0.05-0.09 mm/year. There is no detailed understanding of the uplift mechanism, but coincidence of the area of maximum uplift with sites of Tertiary volcanism has been suggested by Cook et at. (1977) as evidence of a causal relationship.

The detailed investigation of the Quaternary stratigraphy has done much to explain the mechanisms of shoreline emplacement along the southern Australian coastline. The most common shoreline type is the simple mainland beach type. This is normally deposited on a gently sloping coastal plain at the peak of the transgressing post-glacial sea level. Barrier shorelines of the Beach-Dune-Lagoon complex type appear to occur only where the peak of the transgressing post-glacial sea level coincides with a local steepening of gradient along a topographic irregularity on the coastal plain. This situation is normally encountered where an older, generally eroded, barrier shoreline coincides with the peak of the transgression This appears to have been the case for the only two barriers having complex internal structure. The Robe and Woakwine barriers are the only Beach-Dune Unit deposits to have Lagoonal Unit sediments preserved on their inland sides. It is from these particular sediments that material suitable for dating by the uranium series method is preserved.

The whole stratigraphy has been preserved in its near perfect condition because of the rapid post-depositional induration of the sediments. This has been a direct consequence of their carbonate composition. Stabilization has not simply been effected by normal vadose and phreatic zone cementation of grainstones. Calcrete formation in association with soil profile development has been the major agent in preserving the spatial relationships between the different lithologic units.

REFERENCES

Alderman, A. R. & Skinner, C. W. (1957). Dolomite sedimentation in the South-East of South Australia. *Am. J. Sci*. **255**,561-567.

Blackburn, G. (1966). Radiocarbon dates relating to soil development, coastline changes and volcanic ash deposition in south-east South Australia. *Aust. J. Sci*. **29**, 50-52.

Blackburn, G., Bond, R. D., & Clarke, A. R. (1965). Soil development associated with stranded beach ridges in south-east of South Australia. *C.S.I.R.O. Soil Publ*. **22**.

Bloom, A. L., Broecker, W. S., Chappell, J., Mathews, R. S. & Mesolella, K. J. (1974). Quaternary sea level fluctuations on a tectonic coast: new Th^{230}/U^{234} dates from Huon Peninsula, New Guinea. *Quatern. Res*. **4**, 185205.

Boutakoff, N. (1963). The geology and geomorphology of the Portland area. *Geol. Surv. Vict. Mem*. 22.

Bretz, J. H. (1960). Bermuda: A partially drowned, late mature, Pleistocene karst. *Geol. Soc. Amer. Bull* **71**, 1729-1754.

Broecker, W. S. & Van Donk, J. (1970). Insolation curves, ice volumes and 0" record in deep sea cores. *Rev. Geophys. Space Phys.* **8**, 169-98

Broecker, W. S., Thurber, D. L., Goddard, J., Ku, T. L., Mathews, R. K. & Mesolella, K. J. (1968). Milankovitch hypothesis supported by precise dating of coral reef and deep-sea sediments. *Science* **159**, 297-300.

Chappell, J. (1974). Geology of coral terraces on Huon Peninsula, New Guinea: A study of Quaternary tectonic movements and sea level changes. *Geo. Soc. Amer. Bull*. **85**, 553-70

Chappell, J. & Veeh, H. H. (1978). Coral terrace on Atayro and Timor *Geol Soc. Amer. Bull*. **89**.

Colwell, J. B. (1977). Heavy minerals in late Cainozoic sediments of south-eastern South Australia. *Bur. Min. Res. Rec*. **1976/89**.

Cook, P. J., Colwell, J. B., Firman, J B, Lindsay, J. M., Schwebel, D. A. & Von Der Borch, C C. (1977). Late Cainozoic sequence of South East of South Australia and Pleistocene sea level changes. *Bur. Min. Res. J. Geol. Geophys*. **2**,8188.

Fairbridge, R. W. & Teichert, C. (1953). Soil horizons and marine bands in coastal limestones of Western Australia. *J. R. Soc. New S. Wales* **86**, 68-86

Firman, J. B. (1969). Quaternary Period. In Parkin, L. W. (Ed.) Handbook of South Australian Geology. *Geol. Surv. S. Aust.* Adelaide.

Firman, J. B. (1973). Regional stratigraphy of surficial deposits in the Murray Basin and the Gambier Embayment. *Geol. Surv. S. Aust. Rep*. **39**.

Hossfeld, P S. (1950). The Late Cainozoic history of the south-east of South Australia. *Trans. R. Soc. S. Aust.* **73**,232-279.

Mathews, R. K. (1973). Relative elevation of late Pleistocene high sea level stands: Barbados uplift rates and their implications. *Quatern. Res*. **3**,147-153

O'Driscoll, E P D. (1960). Hydrology of the Murray Basin province in South Australia. *Geol. Surv. S. Aust. Bull*. **35**.

Schwebel, D. A. (1978). Quaternary stratigraphy of the south-east of South Australia. Unpubl. Ph.D Thesis, Flinders University of S.A.

Shackelton, N. J. & Opdyke, N. D. (1973) Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core U28-239: Oxygen isotope temperature and ice volumes on a 10^5 and 10^6·scale *Quatern. Res*. **3**, 39-55.

Shackelton, N. J. & Opdyke, N. D. (1976). Oxygen isotopes and palaeomagnetic stratigraphy of Pacific core U28-289 late Pliocene to latest Pleistocene. *Geol. Soc. Amer. Mem*. **145**, 449464.

Sprigg. R. C. (1952). Geology of the south-east province South Australia, with special reference to Ouaternary coastline migrations and modern beach developments *Geol. Surv. S. Aust Bull.* **29**.

Veeh. H. H. (1966). Th^{239}/U^{238} and U^{234}/U^{238} ages of Pleistocene high sea level stands. *J Geophys. Res* **71**, 3399-3386.

Von Der Borch, C C. (1965). The distribution and preliminary geochemistry of modern carbonate sediments of the Coorong area, South Australia *Geochem. Cosmochem. Acta* **29**, 781-799.

Von Der Borch, C C (1977) Stratigraphy and formation of Holocene dolomite carbonate sediments of the Coorong area, South Australia *Sedimentology*. **46**, 952-966.

Von Der Borch, C. C, & Jones, J. (1976) Spherular modern dolomite from the Coorong area, South Australia. *Sedimentology*. **23**, 587-591

Ward. W C (1975) Petrology and diagenesis of carbonate eolianites of north-eastern Yucatan Peninsula, *Mexico. Amer. Assoc. Petrol. Geol. Stud. Geol*. **2**, 500-571

Yaalon, D. H. (1976) Factors affecting the lithification of eolianite and interpretation of its environmental significance in the coastal plain of *Israel J Sediment. Petrol*. **37**, 1189-1199

Yaalon. D. H. & Laronne. J. (1977). Internal structure in eolianites and palaeowinds, Mediterranean coast, *Israel J Sediment. Petrol.* **41**,1059-1064

4: Granite Forms, Karst and Lunettes

by C R TWIDALE, ELIZABETH M. CAMPBEll and JENNIFER A BOURNE

INTRODUCTION

Much of the.South East of South Australia is underlain by limestone and the stranded coastal dunes are also built of calcareous material. The dunes impede surface drainage and promote areas of standing water whereas the limestone bedrock tends to 'swallow' water. Solution and collapse features, such as surface depressions and caves, and collectively known as karst topography are widely developed. Nevertheless, swamps, lakes and lagoons, formed where the water table reaches the surface or where clays have accumulated in the interdune corridors, are commonplace, and many are bordered on their eastern side by crescentic dunes called lunettes In addition, although they are not extensive either individually or *in toto,* the numerous small outcrops of granitic rocks that occur in the Padthaway and Coonalpyn areas (and in a few other localities) quite familiar to the residents of the South East, because they are so different from the dunes and flats that surround them, are in several instances set aside as parks and picnic spots, and are sources of road metal and faci ng stone.

GRANITE OUTCROPS

The granitic rocks exposed in the South East are merely the highest projections of the so-called Padthaway Ridge or Horst that underlies much of the entire region and which, from a structural point of view separates the Murray Basin from the Gambier and Otway basins (see Chapter 1, Figure 1) It is composed of early Palaeozoic sediments and metamorphic rocks intruded by granites of various types. The granitic rocks are of Ordovician and Silurian age (see Chapter 1), those of the Coonalpyn area giving radiometric dates of 458-486 ma. (millions of years), that at Taratap 464-474 ma., and those of the Padthaway area 416-471 ma. (Webb 1976).

The two principal areas of granite outcrop (Fig. 1), those around Padthaway and Coonalpyn, display the same range of forms. Borelog data show that in both areas the granite basement between the isolated outcrops is buried beneath Cainozoic marine strata. As was appreciated more than 70 years ago (Brown 1908), there is no doubt that during the Cainozoic the granitic outcrops formed archipelagos and isolated islands (see map in Hossfeld 1950). A considerable relief amplitude was developed on parts of the Padthaway Ridge, so that near Padthaway and Keith the Cainozoic marine sediments are quite thick. Yet in the Coonalpyn area there are extensive areas where the granite is nowhere far beneath the surface. Thus around Cold and Wet, Crotty Nob, and Kangaroo Flat the outcrop is virtually continuous and one has the impression of a granitic terrain comprising isolated hills with bedrock plains between. Apparently the granite hills, surrounded by low boulder-strewn plains, though inundated by the Cainozoic seas, were buried to only shallow depths by the associated marine strata.

The granitic rocks exposed in the South East vary in composition and texture (see Mawson & Parkin 1943; Mawson & Dallwitz 1944; Mawson & Segnit 1945 a, b; Henstridge 1970) and this is to some extent reflected in the landform assemblages developed on the various outcrops. But the patterns and spacing of joints seem overall to be much more important than mineralogy in determining the shapes evolved on the exposures. There are various gradations and mixtures, but a few characteristic landform assemblages can be distinguished.

Some hills, and particularly those formed on quartz keratophyres are composed of angular blocks rather than rounded boulders, presumably because these rocks are more resistant to weathering than are granites. Bin Bin or Easter Rock is a good example of this type; it stands only 20 m or so above the

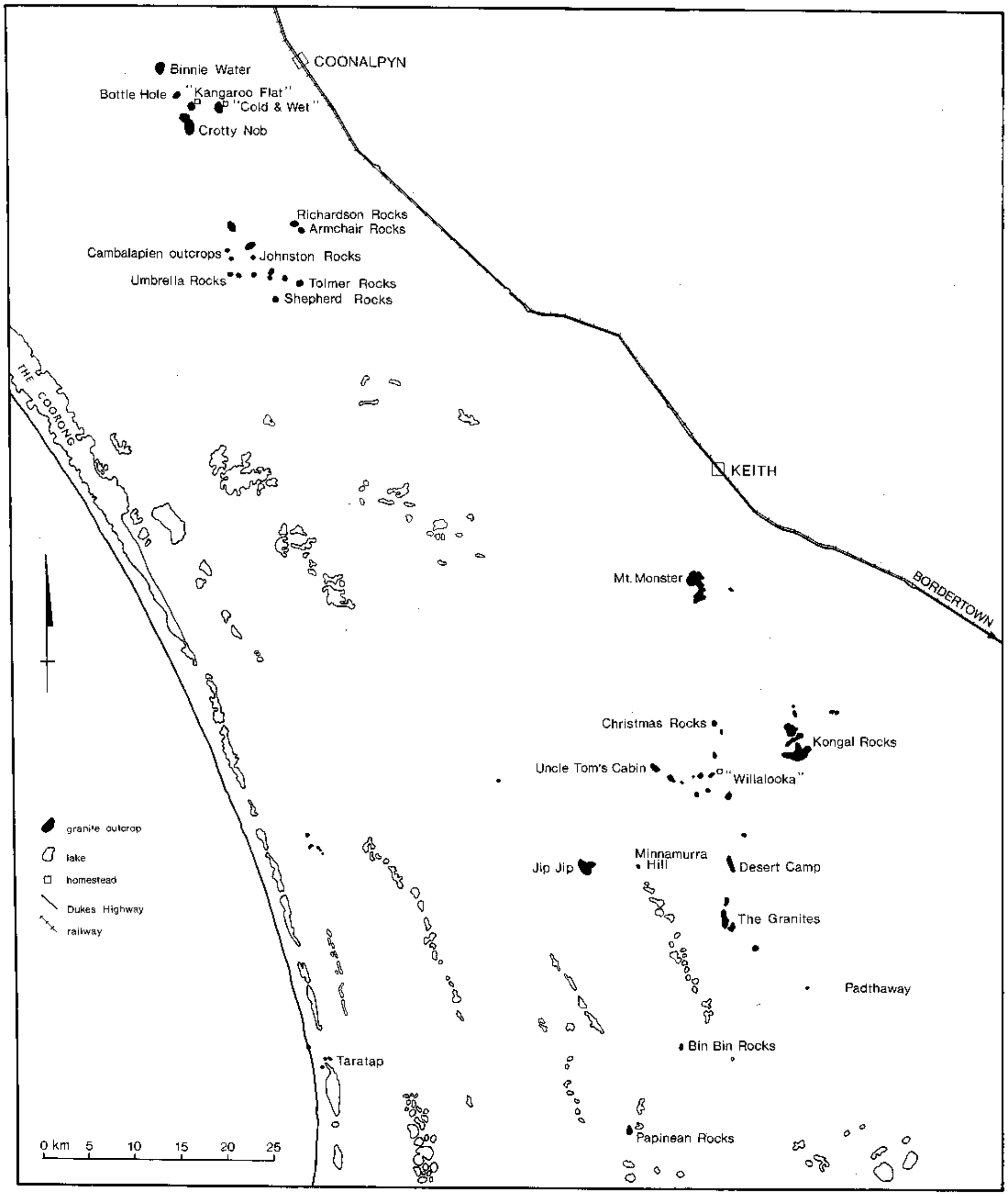


Fig. 1. Major granitic outcrops in the South East.

surrounding plains and in broad view forms a low wooded cone, but in detail its surface is rough and strewn with angular mottled and iron-stained blocks. The country rock is fine grained (though porphyritic) and resistant quartzite also occurs at the site. Minnamurra Hill, near Jip Jip, is much smaller and consists of a smooth cone surmounted by an angular blocky prism of rock.

Other hills are boulder strewn. Some, like Jip Jip and Crotty Nab, are extensive and the boulders are large. Others, like some located east of Willalooka, are of limited extent and comprise' a few boulders perched on top of a rise. Some hills consist of broad sandy rises with a scatter of boulders (e.g. Binnie Water) while others, like the Granites, the Bottle Hole, and the unnamed hill east of Richardson Rocks, consist of large radius domes with a scatter of boulders.

Elsewhere, as at Kongal and Tolmer rocks, the domes of granite are more evident, though again boulders are a prominent feature of the hills. Both of these outcrops also have a stepped appearance with platforms or flattish areas separated by steep scarps in which large blocks are exposed.

Isolated large radius domes occur at Taratap and at Reedy Creek, but large residual boulders, occurring either in isolation or in groups, are characteristic of many outcrops. Thus, such groups or clusters of boulders can be seen at Mt Monster, Mystery Rocks (near the Granites), Armchair Rocks, Shepherd Rocks, Johnston Rocks and in the Reedy Creek area as well as at many sites near Cold and Wet and on Kangaroo Flat.

Many of the boulders are flared, so that their sides are to a greater or lesser extent concave, and in some places, e.g. at Richardson Rocks (Fig. 2), some are so shaped that in profile they look like an elephant's head and trunk (Twidale & Bourne 1976). Some very large residual boulders, only half exposed, are oval in plan and look like the back of a whale protruding from the sea. Such whaleback rocks can beseen in the Reedy Creek area and on the beach near Taratap (Fig. 3).

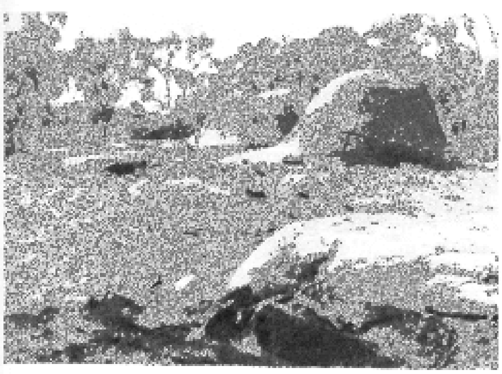


Fig. 2. Elephant heads consist of large residual boulders, the sides of which are slightly flared and which lead down on one side to an exposed platform, the whole assemblage looking (with a little imagination) like an elephant's head and trunk. These examples are from Richardson Rocks, south-west of Culburra. Note the platform in right foreground, the height of which above the ground suggests a recent lowering of the

Though these granite outcrops stand out and are notable in the South East because of their varied forms, they are not at all unusual when viewed in the context of the granitic rocks on which they are developed. They are in fact rather typical of granite outcrops and their evolution has been described elsewhere (see e.g. Twidale 1971, 1976, 1982; Twidale & Foale 1977) so that there is no necessity here to present more than a general outline, and touch upon special or unusual points.

Fig. 3. These whalebacks, or elongate humped boulders, of porphyritic granite are exposed on the beach near Taratap, a few kilometres north-west of Kingston.

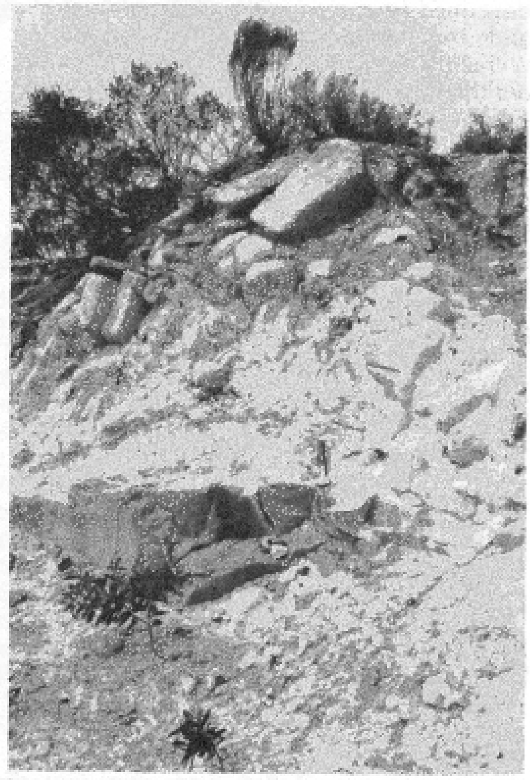


Fig. 4. Corestones or kernels of fresh rock set in a matrix of weathered material and exposed in a quarry at Mt Monster, near Keith.

The key to the understanding of the major granite landforms can be observed in shallow quarries excavated in the local granite bedrock at Cold and Wet, Taratap, Shepherd Rocks, Mt Monster and elsewhere. At these sites the surface is strewn with large boulders, and similar forms can be seen beneath the ground, exposed in the walls of the quarries (Fig. 4) These buried boulders or corestones are set in a matrix of weathered granite (or grus) and are of about the same size range as those exposed at the surface. Similar subsurface corestones or kernels, and associated exposed boulders have been described from many other parts of Australia and indeed throughout the world (see Wilhelmy 1958, Twidale 1971,1976). Boulders are thought to develop in two stages (Fig. 5). First, water percolates down the Joints that subdivide the granite mass, weathering or altering the rock with which it comes into contact. Because there are more (three) exposed faces at the corner of a rock than on an edge (where two faces intersect) or than on a plane face (where there is only one)

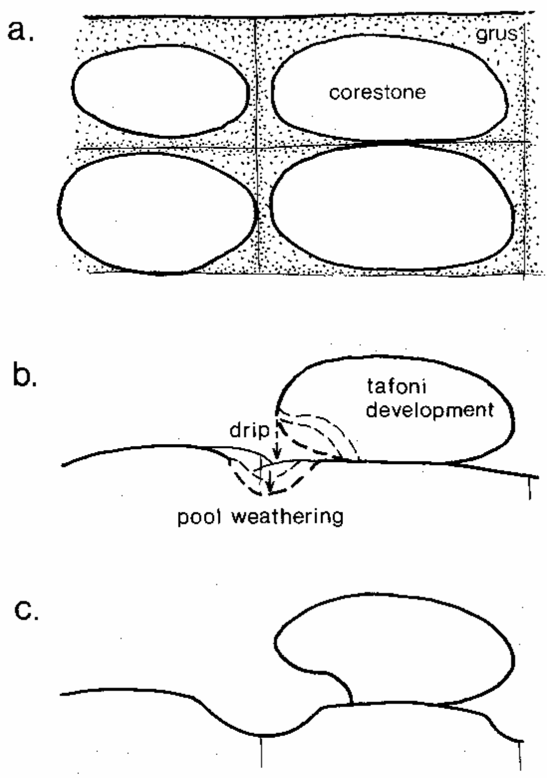


Fig. 5. Suggested stages in the development of corestones, and the concurrent initiation, by subsurface moisture attack, of flared slopes and basal depressions.

weathering takes place more rapidly on the corners and edges than on the planar faces of each joint block and the shape of the still-fresh corestone derived from the cubic joint block gradually becomes spheroidal (Fig. 5). Then, as the land surface is lowered, the weathered granite sand is easily washed away, leaving the corestones, which are too large for streams to transport, as residual boulders (Fig. 5b, c).

The larger hills of granitic rocks are of similar origin, only instead of a single joint block of granite subjected to differential joint controlled weathering and erosion, imagine a large mass or compartment of granite which is poorly Jointed or massive, surrounded by rocks that are well-jointed. These latter are readily penetrated by water, and are rapidly weathered, while the massive compartments remain resistant and fresh. When the land surface is lowered, the latter remain as upstanding hills, while the weathered compartments are worn down to plains.

Thus both of the major landforms, the boulder fields and the residual steep sided hills or inselbergs, are initiated in the subsurface by weathering, and the same is true of some of the minor forms also.

The flared slopes that are typical of so many large boulders are a particular form of weathering front, or limit of weathering, developed as a result of pronounced moisture attack at the base of the boulder or hill (Fig. 5b). The flat benches or platforms seen for example at Richardson Rocks and Tolmer Rocks (Twidale 1962, 1971, 1976-see Figs 6, 7), are merely lateral extensions of these flared or concave weathering fronts (Twidale & Bourne 1976) Both the gnammas or rock basins that can be seen at many sites, and the grooves that score many of the flatter surfaces, begin as localised or linear depressions in the weathering front formed by moisture attack beneath the mantle of weathered rock (Twidale & Bourne 1975a), though they have been modified and extended since the exposure of the rock surface (see Twirlale & Corbin, 1963).

The flared slopes and platforms are of particular interest, for if they form in the scarp foot zone beneath the land surface (and there is ample field evidence as well as general argument to support the suggestion), then it is clear from Fig. 5 that the location of the old land surface can be determined from the shoulder that marks the merging of the convex top of the boulder and the concave flared slope.

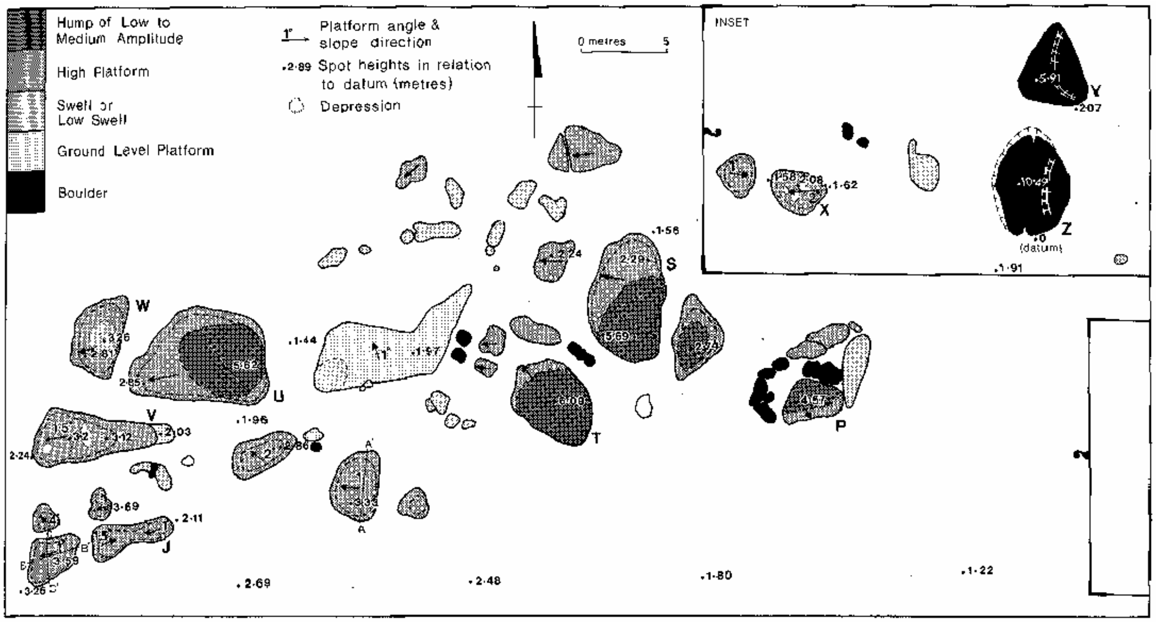


Fig. 6. Morphological map of Richardson Rocks.

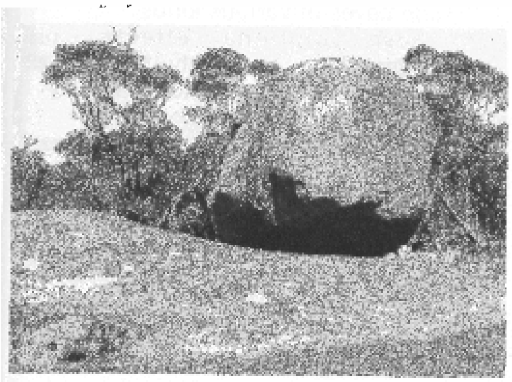


Fig. 7. Large residual boulder at Tolmer Rocks, south-west of Tintinara. It is near an exposed platform but stands at a lower level because of the weathering of the platform adjacent to the boulder by water that has dripped from the latter (see also Fig. 5).

At many sites such shoulders occur at similar elevations so the old plain levels can be reconstructed. It is evident that the fields of large bou lders have been exposed not in one episode, but in a series of phases of lowering of the plains (Fig. 5) And basically this is also the reason some of the larger hills, like Kongal and Tolmer Rocks, are stepped: they have been exposed in distinct phases (see Twidale & Bourne 1975b)

It will have been noted that so far none of the granite forms of the South East has been attributed to marine action. All have been explained in terms of differential subsurface weathering. Yet we know from the many marine sediments that blanket most of the region that the South East was inundated by the sea during the Pleistocene. Judging from the whalebacks exposed on the beach near Taratap, the sea did not greatly modify the hard-rock outcrops and forms. The principal effect of such transgressions was probably to strip away the weathered rock exposed in the tidal zone leaving the forms etched in still fresh granite standing in relief This may well account for the complete exposure of the platforms and other minor weathering features seen at various sites throughout the South East. Similar effects of marine stripping of weathered granite have been noted on the west coast of Eyre Peninsula (Twidale, Bourne & Twidale 1977).

After the exposure of the outcrops, the various depressions were enlarged by weathering and erosion to form gnammas or weather pits, and gutters or grooves, all forming part of a rudimentary drainage network cut in the flatter bare rock surfaces.

However, some depressions or pits are related to the drip of water from the large residual boulders. If such residuals as Tolmer Rocks are visited during rain it can be seen that water running from the convex upper surfaces of boulders, drips off the edge of the rounded forms and that where this water lands on the platforms below, a series of small pools or depressions has formed as a result of the wetting, weathering, and the impact of drops of water splashing on the rock (Fig. 7). The pools are of course so arranged that in plan they together reflect the shape of the boulder above (Fig 5b, c).

Some boulders, as for instance those at Tolmer, Richardson, Kongal, Taratap rocks and elsewhere, have been hollowed out so that mere shells remain. These caverns or tafoni are known from many parts of the world particularly from arid and semiarid lands and from many coastal areas, and are obviously due to differential weathering, usually from the undersides of the boulders. Some are initiated in the subsurface (Boye & Fritsch 1973; Twidale & Bourne 1975a) but they seem basically to involve the development of a toughened outer skin of rock, and simultaneously the enlargement of the initial hollow by flaking or disintegration, possibly under the influence of salt crystallization.

Concentric arcuate scratches on the outer walls of some boulders are due to the regular wafting by the wind of stiff spiky leaves (as of Vacca, or Blackboys) which scratch the hard rock surface (Fig. 8).

KARST

The northwest-southeast trending dune ridges that dominate the topography of the South East are built of limestone, a rock that is peculiar insofar as it 'swallows' water. Moreover limestone of Miocene age, the Gambier limestone, underlies much of the district. They are exposed to any major extent only in the Naracoorte and Mt Gambier areas (Fig. 9). Their physical and chemical characteristics have had a profound influence on geomorphological development over much of the area.

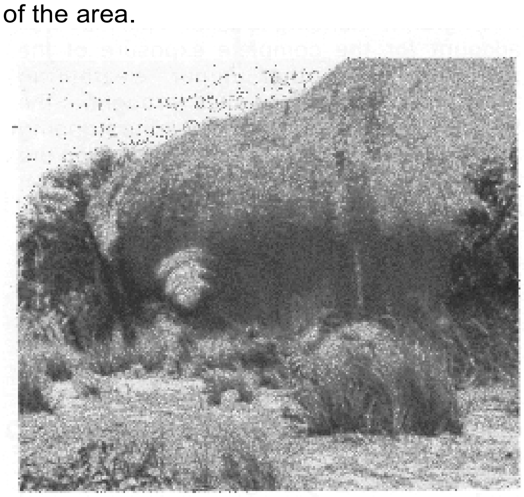


Fig. 8. Arcuate marks on the side of a large granite boulder at Armchair Rocks, caused by the wind blowing the spiky points of grasses and the small branches of trees against the rock surface, so scratching the patina of lichen and algal remains.

Limestone is composed principally of calcite. The Tertiary limestones are crystalline and are well bedded and jointed. In brief they are impermeable because their crystalline structure prevents passage of water through the body of the rock, but they are pervious, for water can readily infiltrate along joints and bedding planes. As it does so the water attacks the calcite. In particular, weakly carbonated waters react with the insoluble calcite to form the highlv soluble bicarbonate:

$$CaC0_3 + H_20 + C0_2 \leftrightarrow Ca (HC0_3)_2$$

Thus in practical terms:-

(a) streams tend to sink below the surface,

(b) the joints and bedding planes are enlarged by solution to form sinkholes and caves of various kinds,

(c) these solutional effects cause undermining and unbuttressing and eventually collapse takes place,

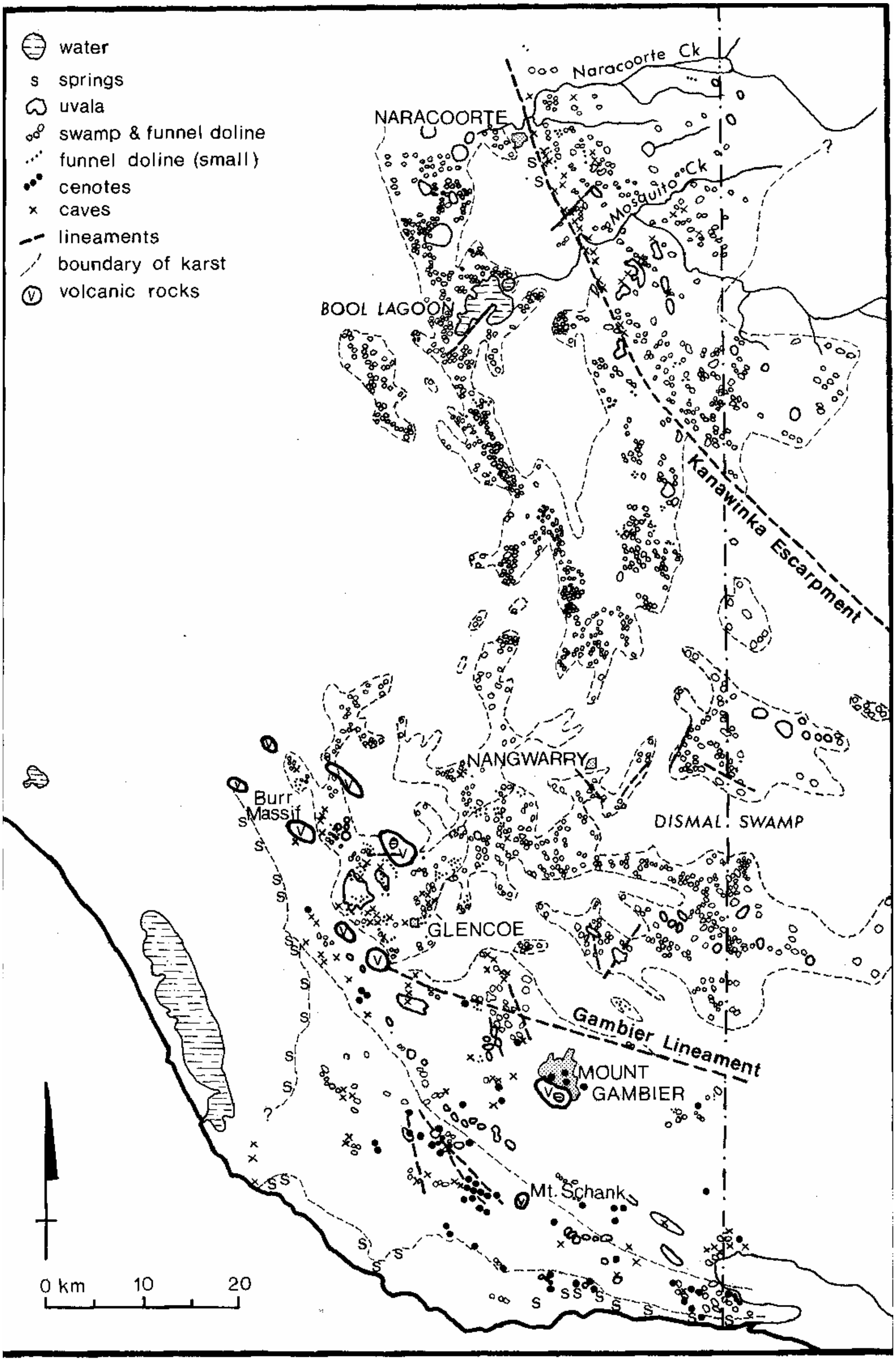
and

(d) in some circumstances the carbonates carried in solution are reprecipitated to form speleothems of which stalactites and stalagmites are well known examples.

This assemblage of forms characterised by a lack ot surface drainage and the dissolution and reprecipitation of lime in the groundwater zone is referred to as karst. Now the limestones of the South East are in the main covered by non-calcareous deposits, Karst forms are scarce or absent east of Nangwarry in the Dismal Swamp area where the limestones have been eroded, west of the Stewart and Cave ranges, and north of Naracoorte where the cover of overlying sediments appears to have inhibited solutional effects, But elsewhere the overburden is relatively thin and the underlying limestones have imposed some of their characteristics on the relief forms, Such covered karst landscapes are widely developed in the South East and enclosed depressions-dolines, or sinkholes, and coalesced groups of these forms called uvalas-in the underlying calcareous rocks show through.

Next page

Fig 9. Karst features of the South East (After Marker, 1975)


water
s springs
uvala
swamp & funnel doline
funnel doline (small)
cenotes
x caves
lineaments
boundary of karst
volcanic rocks
Naracoorte Ck
NARACOORTE
Mosquito Ck
BOOL LAGOON
Kanawinka Escarpment
NANGWARRY
Burr Massif
DISMAL SWAMP
GLENCOE
Gambier Lineament
MOUNT GAMBIER
Mt. Schank
0 km
10
20

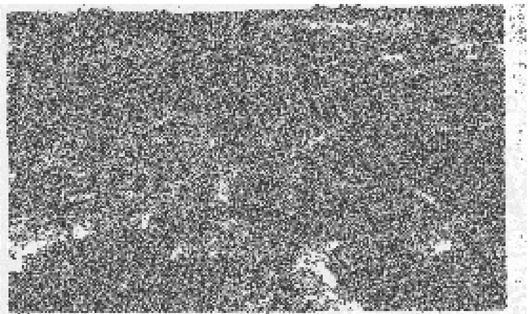


Fig. 10. Limestone plain west of Mt Gambier showing solution cups partly filled with soil, and with minor flutings or Karren on the sidewalls.

The area southwest of Mt Gambier is the only extensive area of bare karst in the region (Fig. 9). The surface solutional features displayed include pavements with flat-floored joint-controlled gutters or *Karren,* solution cups and residual blocks etched by fluting and rainpits (Fig. 10), particularly on the sides facing the main rain-bearing winds, where the rock faces are exposed to the direct impact of raindrops.

The Naracoorte Plateau lies east of the Kanawinka Escarpment and stands relatively high in the landscape (Fig. 9). A deep water table has allowed through drainage and the formation of funnel dolines. These shallow infiltration dolines, locally called 'runaway holes', are developed within shallow uvalas. The shallow circular swamps found along the Morambro, Naracoorte and Mosquito creeks, the only natural stream channels in the region, 'and draining from the laterite-capped plateau to the east, are probably partially infilled dolines.

Cave entrances occur at the bottom of dolines located along the Kanawinka Escarpment. The caves seem to have formed in relation to a shallow water table (they are of phreatic origin) though they have been modified by the rainwaters infiltrating from the surface (vadose waters). They have been enlarged by collapse. Cave passages conform to the joint patterns (Fig. 11) in this area, particularly those trending northwest-south-east (Hawke 1974). Cave decoration includes stalactites, stalagmites, flowstone, and various shaped helictites as well as crystals of aragonite (Fig. 12). A considerable marsupial fossil assemblage has been found in the silts that cover the floor of the Victoria Fossil Cave (see Chapter 16) to a depth of several metres.

West of the Kanawinka Escarpment lies an area of moderate to poor karst development. The limestone has either been eroded or is blanketed by non-calcareous beds. Uvalas and circular shallow depressions called swamp dolines -are formed in ridges of flaggy nodular limestone between Bool Lagoon ana Kalangadoo, and east of Penola. Swamp

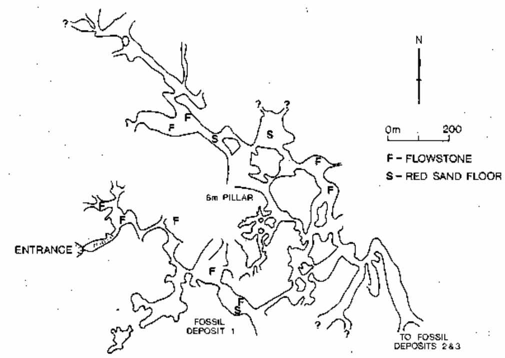


Fig. 11. Plan form of caves influenced by fracture patterns in the limestone (After Marker, 1975).

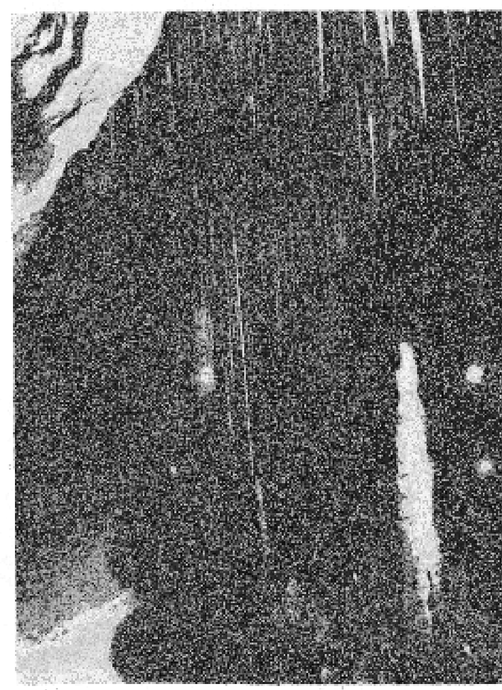


Fig. 12. Thin stalactites and thicker stalagmites in the Alexandra Cave, which is part of the Naracoorte complex (Publicity Branch, Premier's Department, Adelaide).

dolines also occur at the margins of the Dismal Swamp area.

Runoff from the volcanic massifs in the Glencoe area enters deep funnel dolines some of which have been extended to form short dead-end or blind valleys. There are dolines and limestone knolls ridd led with caves to the east, and uvalas of 2 km^2-12 km^2 are common here as elsewhere.

The Gambier Lineament finds surface expression in a series of elongated deep dolines. To the south there occur, in addition to the uvalas, dolines and caves described thus far, numerous cenotes or collapse dolines. These are thought to develop along the trace of major subsurface channels (Marker 1975) The cenotes are dry-floored where the limestone is covered but in the area of bare karst they reach water at about 30 m and nearer the coast they are filled with water and disguised by recent marsh growth, for there the water table has intersected the surface. Springs occur ·along this line, in places well in from the coast. Water resurges on the beach below mean sea level and may also emerge as sea bed springs, for it has been calculated that the volume of emergent water is much less than the aquifer intake (Floeggel 1972 in Marker 1975).

The South East of South Australia is a lowrelief doline and uvala karst area, and, as described above, the solution features are best developed in the essentially crystalline limestones of mid Tertiary age. Poorer karst forms such as shallow depressions occur in the limestones of the Pleistocene dunes, and where the limestones are exposed water has effected micro-fluting and pitting of the surface. However even these poor karst regions display the principal characteristic of limestone country, namely lack of surface drainage. The dune ridges stand in marked contrast with the intervening flats, where water tends to stand at the surface in shallow lakes or lagoons, particularly in the winter wet season.

LUNETTES

The flats that separate the northwest-southeast trending dune ridges are poorly drained, so much so that measures have been taken to hasten the outflow of water by the excavation of artificial drainage channels (see Chapter 6). Indeed there is now a strong feeling that these areas have been overdrained

However, notwithstanding these changes, and certainly before the advent of the European settlers water collected in topographic depressions, many of them dolines related to limestone bedrock at shallow depth, and filled with water to form shallow lagoons or swamps within the flats Some are small; others like Bool Lagoon are extensive; some are occupied by water only in the winter wet season; others carry water through all or most of the year, though obviously this varies from year to year. many of these shallow ephemeral lakes are bordered on their eastern sides (Fig. 13) by low crescentic

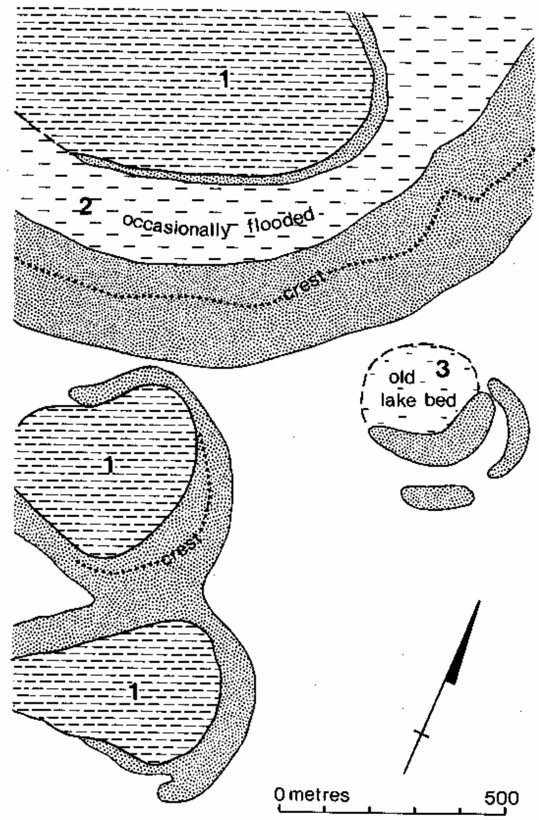


Fig. 13. Many of the lakes, large and small, modern and relic in the Bool Lagoon area are bordered by lunettes on their eastern sides. 1. Modern lake. 2. Seasonally flooded area. 3. Former lake.

ridges called lunettes (Hills 1940).

In addition, inland from the Naracoorte Range, on the Naracoorte Plateau, some of the isolated lagoons and swamps have lunettes on their eastern or southeastern sides.

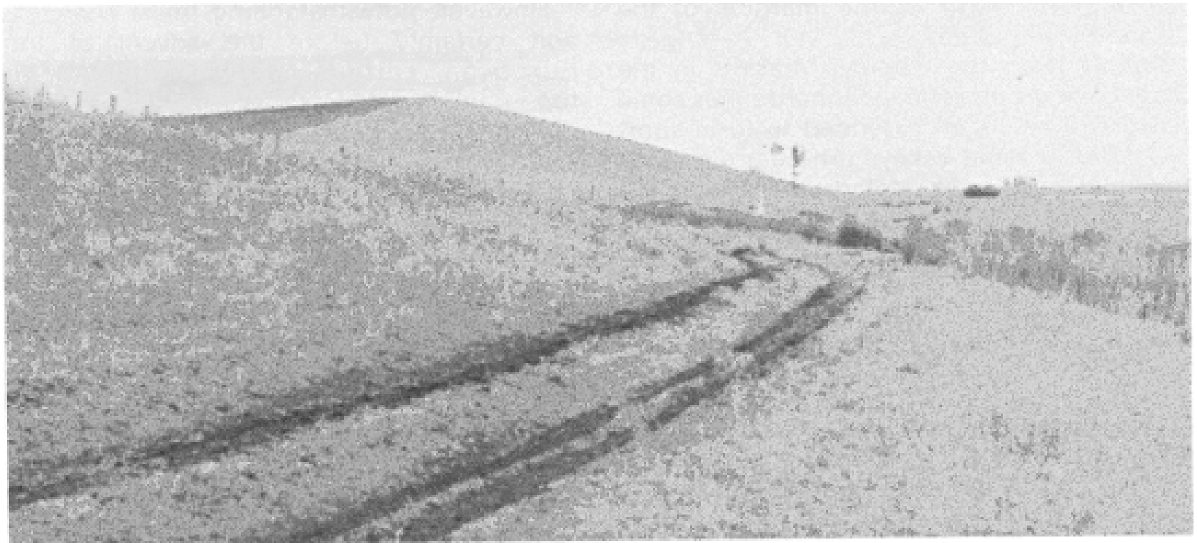


Fig. 14. A lunette located on the southeastern side of Bool Lagoon. It stands about 20 m above the bed of the adjacent lake.

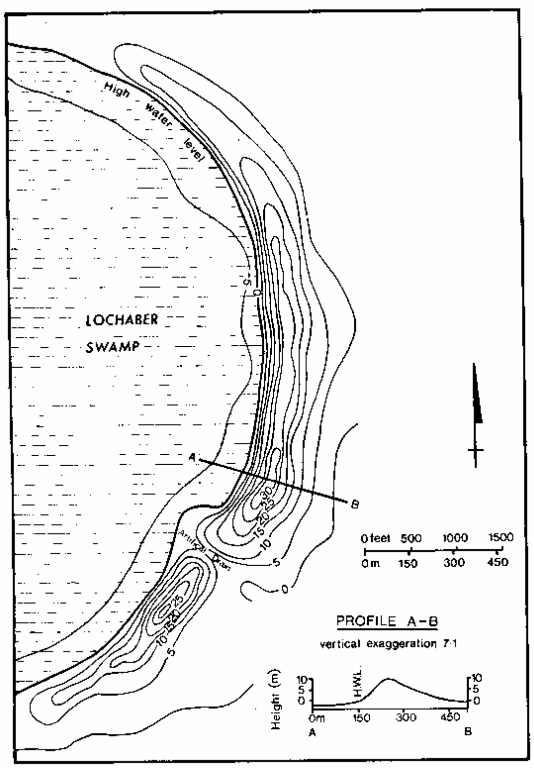


Fig. 15. Plan of Lochaber lunette.

The lunettes of the South East are similar to those described from other parts of southern and eastern Australia (Hills 1940, Stephens & Crocker 1946, Jessup 1960; Bowler & Harford 1967, Bowler 1967, Campbell 1968, Walker 1978). In Texas the forms are called 'clay dunes' (Price & Kornicher, 1961) and in West Africa French workers have referred to them as *bourrelets* (Boulaine 1954, Tricart 1954). Playa bordering mounds described from arid central Australia appear to be of similar origin though their morphology is' less regular (Twidale 1972, see also Dulhunty 1983).

In the South East lunettes range in height from a few centimetres, to 20 m in the ridge bordering Baal Lagoon (Fig. 14). Again, they range in length from a score of metres to 3 km as at Baal Lagoon and in breadth from a few metres to 300 m, again at Bool Lagoon. Whatever their dimensions, lunettes are arcuate or crescentic in plan, and extend round 25%-50% of the eastern, usually the southeastern, perimeter of the lake (Fig. 15).

The lunettes are typically asymmetrical in cross-section with the steeper face adjacent to the shore, i.e. facing the lake. The lake slope, cliffed on some lunettes, generally ranges in inclination from about 1 in 3 (Bool Lagoon) to about 1 in 25 (Cockatoo Lake) whilst the lee slope, further from the lake, ranges from about 1 in 10 (Lochaber Swamp) to 1 in 30 (Bool Lagoon).

The lunettes of the South East are predominantly fine-grained and poorly sorted: the dominant minerals are quartz and "amorphous" material of clay size (Campbell 1968). Some are, however, composed of well· sorted quartz sand, for example those at Lake Cadnite and Moona Flat. The composition, both mechanical (grain-size) and mineralogical, of the lunettes is closely related to that of the associated lake bed, although there are minor though explicable anomalies (see Campbell 1968).

Most lunettes display no detectable sedimentary structures. However aeolian cross-bedding, dipping at angles of 2°-12° to the east, and decreasing in that direction, was observed in the face of a quarry excavated in the Lake Cadnite lunette. At the same site a series of sedimentary layers, separated by soil profiles, suggests that this lunette was built up, not continuously and gradually, but in several phases of deposition separated by periods of weathering and soil formation.

Most lunettes carry a ground cover of grasses though that bordering Lake Cadnite for example carries red gums. The general lack of trees and bushes reflects not the natural situation, but rather clearance by man of areas of fertile soil.

Hills (1940) was the first to describe, explain and name lunettes. He worked in northern and northwestern Victoria, where the lunettes are predominantly fine grained. He related the lunettes to periods when the lake depressions were occupied by water (hence the 'wet' theory). He thought that dust carried in suspension became coagulated by moisture as it passed over the lake. The particles were then deposited on the eastern or leeward side of the lake, where they eventually became fixed by vegetation. However, many lunettes, including some of those in the South East, are composed of sand, which cannot, save in special, rare circumstances, be carried in suspension. Moreover, in these terms the lakes and the lunettes are seen as being genetically unrelated, and Hills offered no explanation for the numerous lakes found in varied geological settings.

Stephens & Crocker (1946) suggested that the material in the lunettes was derived by deflation of the dry bare surface of alluvial flats and, later, from dry lake beds. It was trapped a short distance downwind by vegetation growing around the lake shore. This 'dry' theory accounts for much of the observed evidence That clay particles can be transported as aggregates is supported by observations in southern Texas (Coffey 1909). The cross-bedding observed in some lunettes, is consistent with aeolian deposition. The composition of the lunette and the lake bed are similar, which is rational, for the one is, in these terms, derived from the other. The crest of the lunette being close to the lake margin is better explained by the dry theory, for the lake bed is the source of the dune material.

However, there are still some anomalies. For example if lunettes are due to deflation they ought to be oriented in relation to the dry season winds, but in reality they are most closely correlated with wet season winds (Campbell 1968). In addition, where lunettes border salinas it is difficult to invoke the deflation of silt or sand from a salt-encrusted surface.

It has been suggested (Twidale 1968, Campbell 1968, Bowler 1968, see also Woods 1862) that the work of wind-driven waves in the wet season is significant in transporting material across the bed of the lake and depositing it in a beach on the lee shore. Wind driven waves have been suggested as a possible cause of the consistently curved shape of the eastern shore of the lakes (Campbell 1968), and small beaches of water transported sediments and piles of wood and other debris, are commonly found on the eastern margins of the lakes and swamps. It is suggested that from the beach, wind transports the material to the area beyond the shore, where it is trapped by vegetation to form a lunette.

In this polygenetic theory, the fact that the lake bed when dry is encrusted with salt becomes irrelevant. Moreover this modification of the 'dry' theory does not endow lunettes with any particular climatic significance. They can develop under climatic conditions of marked seasonal rainfall similar to those pertaining in the South East of South Australia today, or in truly arid regions of episodic rains.

However, other difficulties have not been resolved. For example in any given region some lakes are bordered by lunettes, others are not; and there is no consistent relationship between the size of the lake and the lunette.

Aboriginal man saw the advantage of elevated well-drained sites in locating his campsites on lunettes, for example at Moona Flat (Blackburn 1959). European man has also taken advantage of such dry lunette sites in locating farm houses (Bool Lagoon, Neilan Swamp), townships (parts of Hynam and Frances) and roads which skirt Lochaber Swamp, and Groker Swamp.

The soils on lunettes are generally deeper, more loamy, more fertile and better drained than those of surrounding areas and have consequently been chosen as preferred sites for growing cereal crops (Bool Lagoon), summer pastures (Neilan Swamp) and irrigated pastures (Blackburn 1959, 1964) Lunettes are thus valuable as agricultural areas in a predominantly pastoral environment.

In addition, the sandy lunette at Lake Cadnite has been quarried for fill for roadmaking and for sand for concrete, with which the grain storage silos at Frances were constructed.

CONCLUSION

Despite their limited areal extent the granitic and limestone outcrops count amongst those most frequently visited by local people seeking something different, well as by tourists. Lunettes are dry sites with fertile soils, and are also, in some are, sources of building sand, while limestone al granitic rocks are also quarried for various purposes Thus despite their insignificant si and extent, the minor features discussed this chapter are of considerable intrinsic interest and practical importance.

REFERENCES

Blackburn, G. (1959). Soils of the Tatiara District, South Australia. *CSIRO Soils and Land Use Ser.* No. 34.

Blackburn, G. (1964). Soils of Counties MacDonnell and Robe, South Australia *CSIRO Soils and Land Use Ser.* No. 45.

Boulaine, J. (1954) La sebka de Bien Ziane et sa "lunette" ou bourrelet. *Rev. Geomorph. Dynam.* **5**,102-123.

Bowler, J. M. (1967). Quaternary chronology of Goulburn Valley sediments and their correlation in southeastern Australia. J. *geol.* Soc. *Aust.* **14,** 402-404.

Bowler, J. M. (1968). Australian Landform Example N'o 11 Lunette, *Aust. Geogr.* **10**, 402-404.

Bowler, J. M. & Harford, L. B. (1966). Quaternary tectonics and the evolution of the Riverine Plain near Echuca, Victoria. J. *geol. Soc. Aust.* ***13,*** 339-354

Boye, M. & Fritsch, P. (1973). Degagement artificiel d'un d6me cristallin au Sud-Cameroun. *Travaux Documents Geographic Tropicale.* **8**, 33-63.

Brown, H. Y. L. (1908) Record of the Mines of South Australia. S Aust. Mines Dept (4th Ed.).

Campbell, E. M. (1968). Lunettes in southern South Australia. *Trans. R. Soc.* S. *Aust.* **92**,85-109.

Coffey, G. N. (1909). Clay dunes. J. *Geol.* 17,754-755.

Dulhunty, J. (1983). Lunettes of Lake Eyre North, South Australia. *Trans. R. Soc. Aust.* **107** (in press).

Hawke, D. V. (1974). Structural Control of Subsurface Chemical Weathering in Limestones, Southeastern District of South Australia. B.A. Hans thesis, University of Adelaide (Unpublished).

Henstridge, D. A. (1970) The Petrology and Geochemistry of the Upper South East Granites. South Australia, B.Sc. thesis, University of Adelaide (Unpublished).

Hills, E. S (1940) The lunette; a new landform of aeolian origin. *Austr. Geogr.* **3**, 15-21

Hossfeld, P. S (1950). The Late Cainozoic history of the South-east of South Australia *Trans. R. Soc. S. Aust*. **73**, 232-279.

Jessup, R. W. (1960) An introduction to the soil, the south-eastern portion of the Australian arid zone. *J. Soil Sci*. **11**, 92-105.

Marker, M. E. (1975). The Lower Southeast of South Australia: Karst province. *Dept. Geogr Env. Stud. Univ. Wits. Occ Pap*. 13.

Mawson, D. & Dallwitz, W B. (1944). Paleozoic, igneous rocks of lower south-eastern *South Australia Trans. R. Soc. S. Aust.* **68**, 191-20

Mawson, D. & Parkin. L. W (1943). Some granite rocks of south-eastern South *Australia Trans Soc. S. Aust* **67**, 233-243.

Mawson, D. & Segnit, E. R. (1945a) Granites of the Tintinara district. *Trans. R. Soc. S. Aust.* **69**,263 276.

Mawson, D. & Segnit, E. R. (1945b). Porphyritic potash-soda micrograniteS of Mount Monster. *Trans. R. Soc. S. Aust*. **69**, 217-222.

Price, W A. & Kornicher, L S. (1961). Marine and lagoonal deposits in clay dunes, *Gulf Coast, Texas. Sed. Petrol*. **31**, 245-255.

Stephens, C. G. & Crocker, R. L (1946) Composition and genesis of lunettes. *Trans. Soc. S. Aust* **70**, 302-312

Tricart, J (1954). Une forme de relief climatique sebkhas. *Rev. Geomorph Dynam*. **5**,97-101.

Twidale, C. R. (1962) Steepened margins of inselbergs from north-western Eyre Peninsula South Australia. *Z. Geomorph*. **6**,51-69.

Twidale, C R. (1968) 'Geomorphology, with Special Reference to Australia'.(Nelson Melbourne).

Twidale, C R. (1971). 'Structural Landforms (ANU Press, Canberra)

Twidale, C R. (1972). Evolution of sand dunes in the Simpson Desert, Central Australia. *Trans. Pap, Inst. Brit. Geogr*. **56**, 77-109.

Twidale, C. R. (1976). 'Analysis of Landforms (Wiley, Sydney)

Twidale, C. R. (1982) 'Granite Landforms, (Elsevier, Amsterdam)

Twidale, C R. & Bourne, J A. (1975a). T subsurface initiation of some minor granite landforms. *J. geol. Soc. Aust*. **22**,477-484

Twidale, C R. & Bourne, J A. (1975b) The episodic exposure of inselbergs. *Bull Geol Soc. Am.* **86**, 1473-1481

Twidale, C R. & Bourne, J. A. (1976) The shaping and interpretation of large residual granite boulders. *J geol Soc. Aust*. **23**,371-381

Twidale, C R, Bourne, J A. & Twidale, N. (1977) Shore platforms and sealevel changes in the Gulfs regions of South Australia *Trans. R. Soc. S. Aust*.**101**,63-74.

Twidale, C R & Foale, M. (1977) Landforms Illustrated' (Nelson, Melbourne)

Walker, G T. (1978) Origin of the New England lagoons. Unpublished Ms.

Webb, A. W (1976) The use of thepotassium-argon method to date a suite of granitic rocks from South-Eastern South Australia. *Amdel Bull* **21**, 25-35.

Wilhelmy, H (1958). 'Klimamorphologie der Massengesteine'. (Westermann, Braunschweig)

Woods, J. E. T. (1862). 'Geological Observations in South Australia principally in the District southeast of Adelaide' (Longman, London)

5. Soils

By G BLACKBURN

INTRODUCTION

There are three main aspects of interest in the soils of this region: their variety-the principal types and their distribution, the effect of many (how well preserved or otherwise are the soils after years of occupation by human societies), and the relations of soils to other features of the region. Special interest attaches to the occurrence of soil types that do not occur elsewhere in South Australia, the notable deficiencies of trace elements, and the close association of soil types with geological features and particular landforms.

Julian Tenison Woods is memorable for his early attention to the local soils; he was the first scientist to describe their variety and relations (Woods 1862). Like many other natural historians of the 19th century, his interests included biology and geology, but his positive concern with soils was unusual for the times. Burr (1845, 1846), a member of an expedition to the region under the command of Governor George Grey, had already described soils, minerals and rocks along the way from Adelaide to Mt Gambier. His curiosity may have been prompted by the recent valuable discoveries of copper ore in the colony, gained simply through close attention to unusual exposures at the ground surface. Woods certainly watched for valuable minerals but he found no local indications of copper or gold (Woods 1866). His first publication concerning the region refers to seven soil varieties in general terms, with identifications by colour or by distinctive geological or topographical associations. The peats were his only important omission.

A new phase of scientific interest in the soils began with the local development of farming, as distinct from the pastoral industry. Analyses of characteristic arable types were first reported by Perkins (1903); certain physical problems were acknowledged and given early attention at the Kybybol ite Research Centre (Cook 1925). Soil mapping was begun by Spafford (1925) to give information about land to be reclaimed by drainage. Chemical studies scored a notable success when manganese was shown to be seriously deficient for oat production on soils at Mt Gambier and Penola (Samuel & Piper 1928). Gradually the scope of soil studies was widened to include unimproved pastoral land and forest areas. Knowledge came from several lines of investigation.

When an Australian centre for soil research was established in Adelaide at the Waite Agricultural Research Institute, expansion of field and laboratory studies followed and soon affected the region. The inauguration of soil surveys, similar to those initiated much earlier in the U.S.A. and Great Britain, provided information on soil types. These were established by reference to colour, texture, and thickness of different layers in soil profiles examined during the surveys. Soil types were designated informally in the first CSIRO soil survey in the region (Marshall & Hosking 1934), but later there was general use of a binomial name, e.g. Kalangadoo sand. The widely adopted approach of Russian soil science, stressing relations between soil profiles and environmental factors, was introduced to this country by Prescott (1931).

In his distinction of major soil groups or zonal soils of Australia, the characteristic one for this region was named podzolised soils. His scheme encouraged study of various morphological and chemical features of soil horizons and gave special attention to the influence of climate and vegetation in the development of soil profiles in different parent materials. Reconciliation of the binomial soil classification customary for the soil surveys with the new zonal system was achieved by accepting the binomial units as constituents of the major or great soil groups.

The soil survey of softwood forestry areas near Mt Burr, Mt Gambier and Penola (Stephens *et al.* 1941) showed the traditional concern with identification of binomial types and their land-use problems. Considerable attention was also given to the origins of the soils, their relation to the environment, and to comparisons with major types of soil elsewhere. The zonal soils were acknowledged to be podzolised, and other types were classed as intrazonal, meaning that their development was construed as dominated by influences such as parent material (especially if limestone) and drainage conditions, rather than zonal effects, namely vegetation and climate. This survey was important as a basis for later studies of the region. The association it established between the types of vegetation and the soil groups was extended by Crocker (1944) in preparing a tentative soil map of the whole region. This showed the major soil groups already recognized: podzols, rendzinas, and terra rossa, together with the volcanic soils, swamps, coastal complex, and variable heath soils. Although new names had been introduced, the categories compared closely with those presented earlier by Tenison Woods (1862)

The concept of great soil groups helped the exchange of information on widely separated examples The podzolized soils of the region were thus found to be comparable with other sandy soils in coastal parts of southern Australia and Tasmania, and with similar profiles in many other countries. The comparisons may be criticized as facile, but without them the local experience of soils

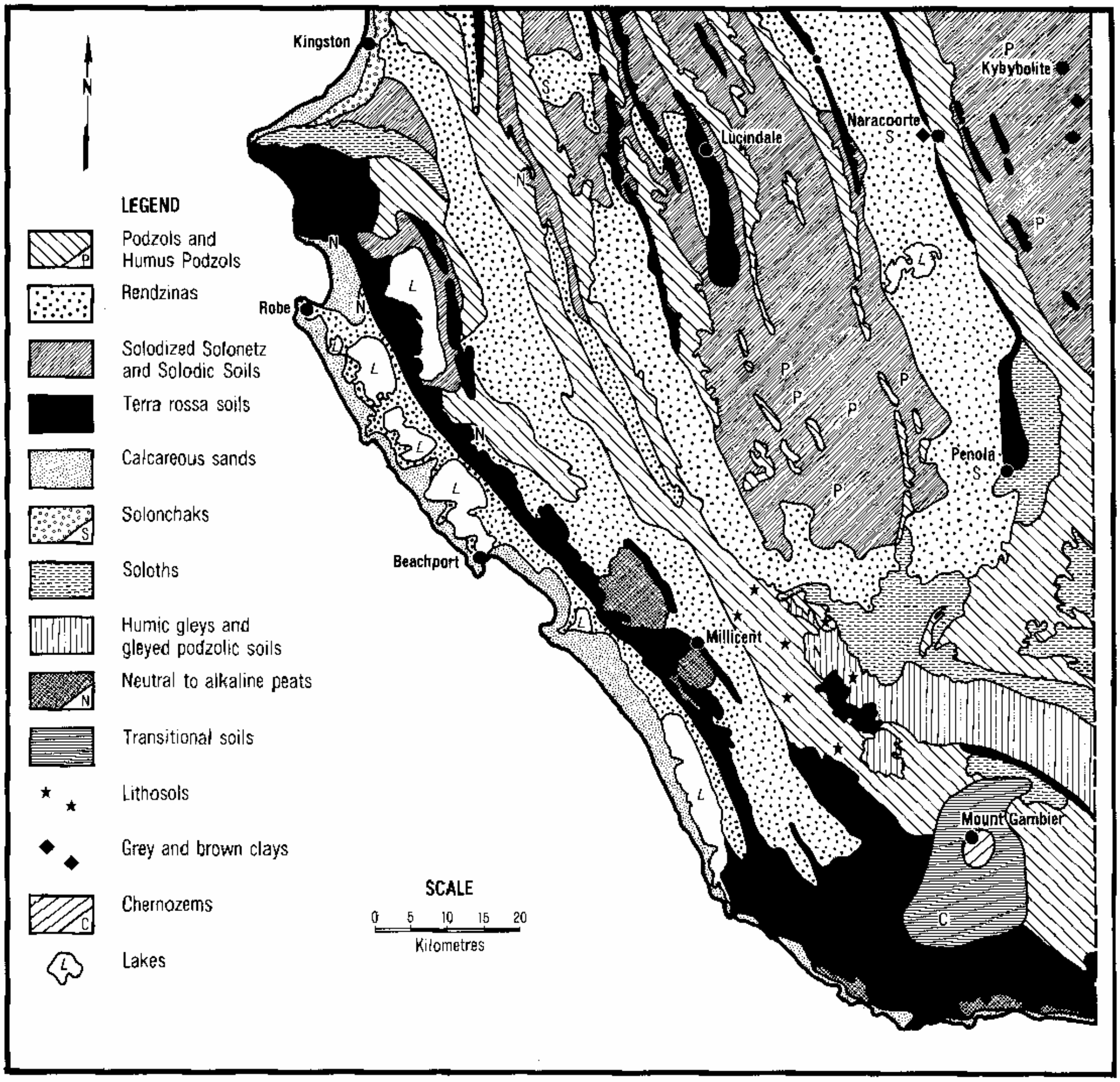


Fig. 1. Generalised soil map of the South East of South Australia.

would not have been readily related to practices elsewhere These distant comparisons are no longer so direct and simple because new systems of soil classification have come into use. One example of these represents a complete departure from the system of great soil groups; it is the scheme used by Northcote (1960,1971) in recent mapping of Australian soils, including those of this region. In the following outline of characteristic soils, they are referred to as soil groups, following the common practice in publications concerning the local soils.

OCCURRENCE AND DISTRIBUTION OF GREAT SOIL GROUPS

Of the 14 great soil groups so far recognized from the region (Stace *et al.* 1968), only six are relatively common and widespread. The distribution of those with significant extent is indicated in Fig. 1, which is based on more detailed maps (Blackburn 1959, 1964). Profile features for the six major soils are sketched in Fig. 2, together with indications of topography, vegetation, and drainage.

PREDOMINANT SOILS

Podzols

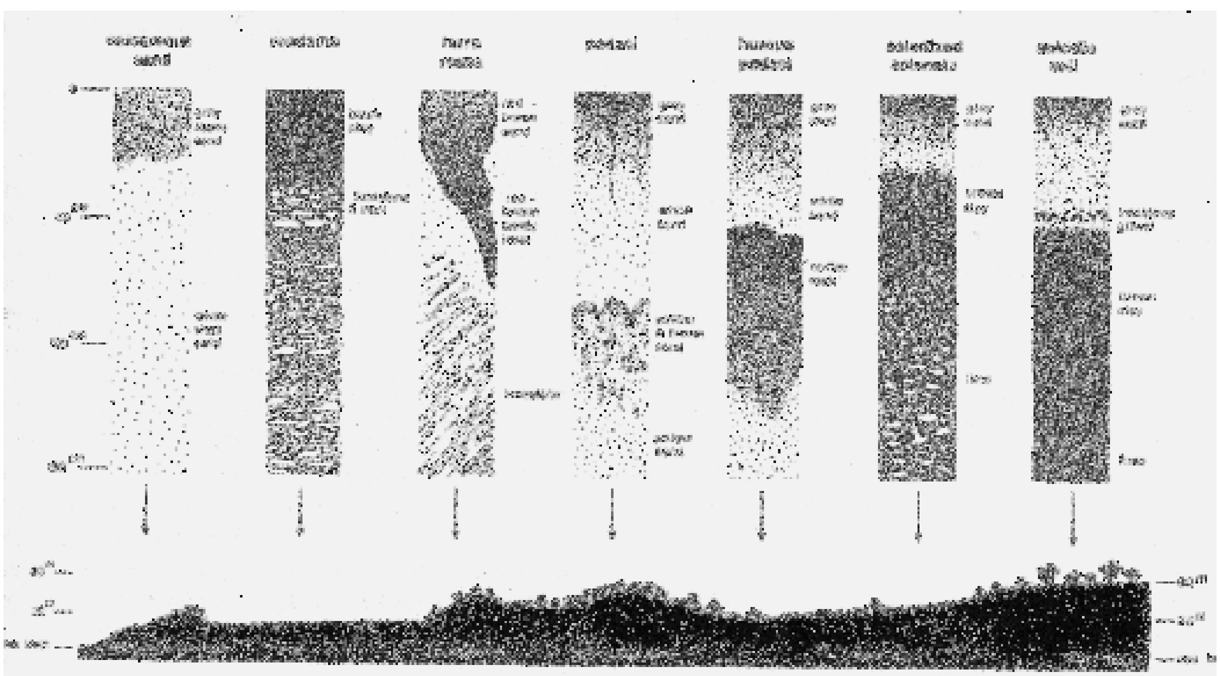
These are distinguished by (a) a substantially acid reaction throughout the profile, (b) an ash-grey or almost white subsurface layer clearly separated from (c) a deeper horizon coloured by accumulation of organic matter and iron oxide. Podzols are found mainly in banks of quartz sand where the native vegetation is dominated by *Eucalyptus* and heath plants, in conditions where organic litter tends to accumulate on the ground. Extensive sandy areas in the southern half of the region are occupied mainly by podzols.

Humus Podzols

These differ from podzols in having subsoils with an organic hardpan coloured very dark brown to black and sometimes referred to as 'coffee rock'. Humus podzols are influenced by a water table which is established seasonally within the soil profile. They generally occupy depressions in undulating areas of quartz sand, with podzols on the higher parts In Fig. 1, humus podzols are indicated as occurring in close association with podzols.

Rendzinas

These dark grey to black soils lacking distinct profile differentiation and overlying highly calcareous substrates were related by Prescott (1931) to rendzina or lime humus soils of Europe. In this part of South Australia they generally have a high content of clay and are alkaline throughout the depth of 10-45 cm occupied by the earthy part of the profile. Rendzina soils occur extensively in low lying parts of the region, where they may be related to deposits of estuarine or lacustrine silts and clays. Before the widespread construction of



ig. 2. Characteristic soil profiles and their positions in the landscape.

surface drains they were subject to annual flooding; even now they are influenced by groundwater lying close to the surface, except on well-drained ridges and lunettes. A shelly type overlying thick deposits of marine shells is restricted to parts of the low lying coastal land.

Solodized Solonetz and Solodic soils

Both these types have profiles with marked differentiation of horizons. A variable depth of sand or loam, generally of neutral or acid reaction, is sharply distinguished from a clay horizon which overlies highly calcareous substrate. The clay subsoil of the solonetz has distinctive columnar structures, but the solodic subsoil is generally massive. Much variation occurs in the depth to the calcareous layer and in the features of the surface soil. Shallow varieties, showing perhaps three distinct horizons within a depth of less than 20 cm, generally have compact surface soil. Deeper varieties, which are more common, usually have 20-40 cm of sandy soil above the dense clay; their sandy top soil may appear similar to that of the podzols. Chemical features of the complete profiles show that the solodized solonetz and solodic soils have certain properties due to the effects of soluble salts.

Terra Rossa soils

Red-brown soil showing no distinctive horizons, except for the crust developed on the highly calcareous substrate, was first reported from the region by Stephens *et al.* (1941), who identified it with terra rossa, a type found particularly in Mediterranean countries. This soil is associated with limestone, and the relationship in this region is often close and complex, judging by the columns of red soil in solution pipes exposed in numerous cuttings. Despite the proximity of limestone the surface layers of this soil group have a neutral rather than an alkaline reaction. In many instances the soils are sandy and occupy elevated sites with frequent outcrops of limestone. loamy types are more common in the south in association with Tertiary limestone. Only near Coonawarra has the soil a notable clay content.

Calcareous Sands

These have profiles with little alteration of the pale yellow loose sand consisting mainly of fragments of marine shells. The upper 2030 cm is coloured grey-brown by organic matter. Quartz sand is generally an important minor constituent of the soil. Alkalinity, low water-holding capacity, and poor supply of plant nutrients are intrinsic features which limit plant growth on these soils. Their proximity to the coast involves high inputs of oceanic salts and exposure to strong winds. After destruction of the native vegetation, these soils are readily moved by wind, with serious results in several places along the coast.

MINOR SOILS

Solonchaks These have high concentrations of soluble salts, usually either common salt or gypsum, but rofile features are otherwise variable. The presence of salt crystals in dry surface soil is a feature confined to the solonchaks. All local examples are in places with impeded drainage, and most occurrences are in the north.

Lithosols This group includes gravelly or stony soils lacking expressions of horizon development other than organic matter accumulation in the surface layer. They are associated with small areas of basalt in the south (see Chapter 2). Some soils classed as podzols or rendzinas have affinities with lithosols because of their high content of flint boulders or chips, as in the Tantanoola and Benara districts.

Grey and Brown Clays

Their profiles have clay texture throughout the depth. Horizon development is inconspicuous and calcium carbonate occurs throughout the profile. The clay is of the expansive type, and the soi I profi Ie therefore cracks markedly when dry. These soils occur only in the northeast of the region and are distinguished in their natural state by the distinctive microrelief known as gilgai. Another term applied to this uneven surface feature is 'crab-hole land'. The bizarre terms, 'Biscay country' and 'dead men's graves' are mentioned by Woods (1862), who reported 'large tracts of this kind of soil are seen to be covered with mounds just like graves in a churchyard, only far more closely packed together…'

Chernozems

Near Mt Gambier and Mt Schank there are dark grey or dark brown loams with remarkably stable granular aggregation or structure. The profiles compare most of all with chernozems- the friable black soils extensive in Europe and North America. In this region the soils are found only in association with volcanic ash deposits; they are not known elsewhere in South Australia. Close to a point of volcanic eruption, the layer of ash is deep enough for soils to be developed entirely from it. The quality of the ash deposit varies according to the balance of basaltic and nonbasaltic components. Fragments of Tertiary limestone are plentiful in the ash deposited close to Crater lake at Mt Gambier, and the soils developed on that material provide the best local examples of chernozem. There is much variation in soil reaction: surface layers range from slightly acid to alkaline, but subsoil layers are generally alkaline.

Soloths

These are related to the solodic soils but they have an acid reaction throughout the profile. Concretionary nodules with some accumulation of iron oxide may occur just above the dense clay sub-soil. Soloths are found mainly in the southcentral and northeastern parts of the region, in association with the solodized solonetz and solodic soils.

Gleyed Podzolic soils

The clay subsoil of these acid, well differentiated profiles is conspicuously mottled, with red, yellow-grey and grey colours. Their main occurrence is in the east central part of the region. Previously they were referred to as meadow podzols. Gleyed podzolic soils and soloths are two units with some common features. Their similarity indicates a weakness of the great soil group classification.

Humic Gleys

This group comprises many of the soils found in swampy places. The gley feature is represented specifically by distinctive mottling in the subsoil, where rusty streaks and a grey matrix are characteristic in the region and blue or green colours may also occur, as in the deep subsoil. The soil reaction is acid to neutral and the profile has a clay texture throughout.

Neutral to Alkaline Peats

Peat is an accumulation of relatively loose and partly decomposed plant remains. When dry it is combustible. Black, dark brown, and yellow-brown varieties have been described from the region. These soils occur only in low lying parts moist enough to sustain the special peat-forming plants and to preserve their remains. The highly organic soil has distinctive physical properties: low cohesive strength especially when wet and low bulk density. After drainage the material becomes strong enough to support animals and farm equipment. Exposure of bare dry peat entails a risk of wind erosion, and there is also a serious fire hazard for drained peat. The main occurrences of this soil are in several swamps in the south. The peats have generated a wide interest on account of their own unusual features (Stephens 1943), as well as their content of pollen which provides a guide to changes in vegetation (Dodson 1977), and their preservation of aboriginal tools (Luebbers 1975).

RARE, ANOMALOUS, AND TRANSITIONAL SOILS

Types not comparable with any of the great soil groups mentioned above occupy a very small part of the region. Some have profiles representing other groups described by Stace *et al.* (1968). Others correspond to no great soil groups recognized in Australia. lastly there are those, especially around Mt Gambier and Mt Schank, which combine features of two soil groups.

Acid peat has been reported from swamp land between the Mt Burr highland and lake Leake (Crocker & Eardley 1939; Dodson & Wilson 1975). It is associated there with small areas of sphagnum moss.

Red-brown earth occurs sporadically in close association with terra rossa soils, but it is readily distinguished from them by the presence of a clay subsoil and the greater depth of earthy material.

In the Glencoe district there is a red-brown soil which has been referred to as krasnozem (Stephens 1957). The surface has loam texture, the subsoil is clay, and the profiles are commonly 1.5 m deep. This soil lacks the distinctive granular surface structure of krasnozems, as well as their acid reaction and high clay content throughout the profile. Basalt from nearby volcanoes has apparently contributed to the parent material of the soil (Norrish & Tiller 1976).

Soil on the slope of Mt Schank has been referred to as Ando soil by Hamblin & Greenland (1972). Ando soils or andosols are not otherwise recorded for Australia but are important in Japan and other Pacific countries. The profile at Mt Schank is dark brown in colour, slightly acid, highly organic, and is distinguished by the presence of allophane-an amorphous mineral which is a constituent of the clay fraction.

Transitional soils are prevalent near the margins of the volcanic ash zones. The upper part of their profile is influenced by a thin deposit of ash and the lower part is a buried soil-either a podzol or terra rossa soil. Other examples of transitional soils include those with a thin layer of peat over a podzol, solodized solonetz, or humic gley soil. On part of Lake Hawdon there is highly calcareous or dolomitic silt overlying peat

SOIL COMPOSITION

MINERALS

Quartz is the most common mineral in soils of the region. It dominates the sand component of all except the calcareous sands, which are rich in calcite derived from shell fragments. Heavy minerals, e.g. zircon and rutile, are apparently rare: the highest known concentration in the sands is 2% (Blackburn *et al.* 1965). The clay-size particles comprise a variety of minerals. They include phyllosilicates of the clay mineral group, represented in the region mainly by illite and kaolin, and also quartz, geothite, chlorite, and feldspar.

The soils developed from volcanic materials contain the greatest variety of minerals, including readily weathered types such as olivine and volcanic glass. Their presence at some distance from Mt Gambier and Mt Schank may provide a guide to the extent of fallout of the volcanic ash.

The clay mineralogy of several great soil groups in the region is presented by Norrish & Pickering (1977).

ORGANIC MATTER

The content of organic matter in local soils varies from approximately 1 % in some podzols to more than 75% in peats. Rendzinas, chernozems, and humic gleys commonly have 10% of organic matter in their surface layers: other types have less than 5%. Supply of water is the major control of organic matter accumulation-it determines both the growth of vegetation and the preservation of its remains.

SOIL REACTION

The range of pH recorded for thousands of samples taken from different depths varies from slightly less than 5, i.e. strongly acid, to 10, strongly alkaline. Sandy soils other than the calcareous sands are acidic, at least under natural conditions. Most clays, as in the rendzinas, humic gleys, and in the subsoils of solodized solonetz, are neutral to alkaline.

PLANT NUTRIENTS

The most common soils are relatively poor sources of the chemical elements required for plant growth (Stephens & Donald 1958). This became evident after the replacement of the native flora, well adapted to the local soils, by more sensitive species introduced for agriculture and forestry. The siliceous sands of podzols and the solodized solonetz are particularly deficient in nitrogen and phosphorus, and moderately deficient in potassium. Only the limited areas of soils on volcanic materials had sufficient reserves of plant nutrients to make fertilizers unnecessary there, at least for many years after their first use for farming.

There are also serious deficiencies of trace elements, or minor elements, so designated because the concentrations significant for plants are much less than for the other major nutrients. The trace elements most widely significant for plant growth are zinc, copper, and manganese Molybdenum occasionally may be important on acid sands. Cobalt is the other trace element with important deficiencies in the region. Lack of it seriously affects the health of certain types of livestock, including sheep. Cobalt was established from this region as an essential element for plants (Powrie 1960), but its main use is for animals, which are treated directly rather than via the soil

The known deficiencies of nutrients have been under treatment for many years Substantial increases in levels of available phosphorus have been gained by annual applications of superphosphate. The residual effects of applications of other elements are not so well known.

SALINITY

Analyses by Clarke (1966) indicate that 40 to 60% of soluble salts extracted from some local soils is provided by sodium chloride.

with the balance consisting of sulphates and bicarbonates of sodium and calcium. Much salt is brought to earth by the rain, which washes from the atmosphere the salt crystals blown inland from the ocean (Hutton & Leslie 1958). Rainwater analyses indicate that the annual accession of sodium chloride alone probably exceeds 50 000 tonnes in this region. Any such salt not returned to the ocean in surface drainage water must be added to the groundwater or retained in the soils.

Tests on profiles from 310 sites show that excessive salinity, using standards proposed by Northcote & Skene (1972), occu red at 10% of the sites, mostly from low lying places with rendzinas, humic gleys, or peats. Most of the saline profiles occur near the coast, and a considerable proportion came from the Naracoorte plain.

Saline effects are also indicated by the soil alkalinity registered from many clay subsoils by pH values of 9.

PARTICLE-SIZE COMPOSITION

Determinations of particle-size composition on 1000 samples from the region represent the bulk of physical studies on the solid phase of the soils. The proportions of sand, silt, and clay found by these analyses are generally related to the grade of field texture estimated by manipulation of moist soil. Anomalies occur mainly in this region with soils which contain much calcium carbonate or organic matter, and there are some minor complications with soils having sub-plastic properties. Some grains in sub-plastic soil behave as particles of silt or sand although they are actually aggregates of claysize particles. These resist dispersion during the standard treatment for analysis but they yield to stronger measures in the laboratory or to prolonged kneading of moist soil. Sub-plastic soil is known in this region from the Glencoe district, where it is associated with basaltic material (Norrish & Tiller 1976), Coonawarra, and Mt Gambier.

Particle-size composition has been used to estimate the distribution of volcanic ash in the Mt Gambier district (Hutton *et* al. 1959, and see Chapter 2). Soils derived from this material *have* a higher proportion of particles with diameters in the range 2-50 microns than is found in the podzols found below the volcanic ash.

SOIL WATER

The soil water which can be extracted by plant roots has been estimated for a variety of profiles and expressed as a rainfall equivalent. Thus, water equal to 40 mm of rain may be obtained from the upper 60 cm of a podzol that has been saturated and allowed to drain normally. More than double this amount is credited for the same depth in terra rossa and gleyed podzolic soils (Ruiter 1964). As the storage of water in these soils also depends on the depth of porous materials comprising the soil, the terra rossa is generally much inferior to the podzol.

The rate of *movement* of water through and beyond the soil profile has been studied in some southern parts of the region, using special field installations. Variations in soil water content have been determined periodically at different positions in the profile. One method depends on changes in the electrical resistance of porous material, such as a gypsum block, specially placed in the soil. Others involving techniques using radioisotopes have given information on the vertical drainage to the water table. Much of the research on water movement is relevant to the general hydrology of the region.

BIOLOGY

Sporadic attention has been given to elements of the fauna which infest the soils and cause damage to agricultural plants and trees, e.g. the Australian field cricket *(Gryllulus commodus)* investigated by Browning (1954). Generally, however, the problems of collecting and identifying organisms peculiar to soils have hampered the study of their activity. Native plants characteristic for particular soil groups certainly *have* been identified, but little is yet known of their activity and effects on soils.

The relations between soil and the microorganisms, fungi, and algae *have* not yet had much attention. Fungi are held responsible for development of water repellence in siliceous sands. Mycorrhizal fungi *have* special interest for forestry because of their beneficial association with the roots of *Pinus.* Bluegreen algae are often visible on the surface of rendzinas and humic gleys, but their contribution to the nitrogen status of these soils has not been determined.

EVOLUTION OF THE SOIL COVER

Woods (1862) was impressed by the fact that the region had a variety of soils but generally only one type of country rock-limestone. He was satisfied that some of the soil variation was a consequence of different conditions of natural drainage. And where marked variation of soils occurred on well drained sites, as on the limestone ridges with their red soils and white sands, he thought that the differences must be due to variation in the composition of the limestones. Subsequent research has demonstrated the great diversity of limestones in the region, and has also shown that soil variation arises from the effects of two important natural processes, apparently not appreciated by Woods. One is the transport of calcium carbonate in solution: the other is the movement of particulate material by wind.

Evidence of the solution of calcium carbonate is widespread in the region and the major expressions are now collectively known as karst topography (see Chapter 4). The limestone caves are notable examples of the karst development. Other evidence occurs at the surface and in the numerous cuttings and limestone quarries. Solution pipes of different dimensions are noticeable in the limestones: many are made conspicuous by the contrast of the infilling soil with the adjacent rock. The significance of the solution process for soils was first shown by analyses of calcareous sands at Robe, which were made by a geochemist studying the distribution and cause of coast disease (Thomas 1938). Two related features of his results were that the content of quartz was greater at the surface, and that calcium carbonate attained its maximum content in the subsoil layers. These findings were taken as evidence of the solution of calcium carbonate and a corresponding accumulation of quartz, the insoluble residue of the predominantly calcareous sands.

Crocker (1941) extended this proposition, claiming that continued leaching of the calcareous sands yielded exclusively siliceous material, much of which was subsequently transported by wind to provide accumulations of non-calcareous sands. Both these and the leached sands undisturbed by wind develop podzol features under the influence of rainfall and vegetation. The calcium carbonate mobilized by solution in the biologically active layers of the ground is not readily moved far; much of it accumulates after precipitation in a deeper layer. Crocker (1946) argued that there were two important consequences of wind erosion acting on the quartz sands left by solution in the beach ridges. One effect was the movement of this sand to new positions; the other was exposure of the carbonate crusts formed by precipitation from solution. Both would provide distinctive parent materials for development of soils.

The reduction of a beach ridge by solution of its calcium carbonate may proceed so far that the ridge disappears, at least along part of its length. This appears to account for major breaks in the continuity of ridges, notably in the heath lands west of Penola. In these situations the movement of flood waters should reinforce the processes of solution and wind erosion in flattening the land. It might also mean that some of the soil profiles in such tracts have been developed to some extent through the deposition of sand over clay, as claimed by Stephens *et al.* (1941) for their Short sand, commonly associated with heath vegetation. Indeed some evidence of layering has been obtained by chemical analysis of a similar soil in the Penola district (Oertel & Blackburn 1970).

The complication in soil development apparently represented by some of the heath land soils just referred to is repeated in other places where the soil profiles include older soil material under younger. In the Mt Burr highland there are podzols overlying soils formed from the older basaltic tuff of that district (Tiller 1958). Other examples of soil burial have arisen from volcanic processes, as with the above-mentioned transitional soils near Mt Gambier and Mt Schank (see Chapter 2).

The soils buried by volcanic ash are occasionally a source of charcoal which may be used for radiometric determination of its age. This method has been used to estimate the maximum age of the overlying deposit, which for Mt Gambier is currently accepted as approximately 4500 years (Fergusson & Rafter 1957). Similarly, age determinations on shells near the coast, on charcoal, and on peats, have been used in assessing the age of some other soils in the region. Calcareous sand profiles have apparently developed with i n the last 5000-10000 years (Tindale 1957, Blackburn 1966). The organic matter in modern peats also has accumulated mainly within the last 10000 years, but some buried peats are considerably older (Dodson 1977). Age determinations for peats have been used, together with palynological studies of this material, to time the latest changes in vegetation (Dodson & Wilson 1975), and they also have application in archaeology, as with the aboriginal tools found in peat at Wyrie Swamp near Millicent (Luebbers 1975). The scope for application of age determinations in local studies of soil development is still very limited, partly because of uncertainty about the origin of the more complicated profiles, and partly through lack of appropriate sample material and methods for extending the range of age determinations well beyond that now commonly accessible with radiocarbon dating.

One of the major remaining problems of soil development in the region is to account for the development of terra rossa soils on stranded beach ridges. The suggestion by Crocker (1946) that they developed on the calcareous crust of old soil following its truncation by wind erosion is not satisfactory in all major respects. The main body of the underlying limestone is largely isolated from the body of terra rossa soil by a thin band of hard consolidated limestone (Norrish & Rogers 1956), which appears to be a secondary formation, thus indicating that the limestone is being reinforced by precipitation of calcium carbonate, not dissolved to provide soil material from its insoluble residue. Despite this feature, a close relationship between the soil and underlying limestone was found by Norrish & Rogers (1956), using mineralogica'i observations on one terra rossa profile in the region, and by McKenzie (1959), who considered the trace element status of the soils and the limestone below the secondary capping. It may be significant that the terra rossa soils of the beach ridges are generally on their coastal sides and are usually adjacent to a clay plain immediately to the west By analogy with the lunettes built up by aeolian dust movement from a dry lake floor, there is a possibility that the situations now covered by terra rossa have received dressings of dust blown from the flats when they have become bare. This should have occurred frequently in response to fires deliberately lit by aborigines during their long occupation of the region. This period probably included a relatively dry period, corresponding to the last glaciation, when the sea level was much lower and the low lying land less subject to annual inundation. The aeolian transfer of dust from the clay flats to the ridges would explain the presence of silt and clay in the terra rossa, and the anomalous secondary capping on the limestone could be due to calcium carbonate provided in the dust and eventually leached through the soil.

CONCLUSIONS

Studies of soil in this region over the last 50 years have been concerned overwhelmingly with their chemical and physical features. The flow of results has been useful to the primary producer, to the various bodies with official responsibilities in the region, and to students of natural history. Future research may give greater attention to biological aspects of the soil, involving a wider range of specialists than at present Even so, there should continue to be an important place for those like Woods, who relied particularly on careful observation, opportunities presented by personal familiarity with the area, and the ability to enlist the help of specialists The soils still offer considerable scope for valuable observations by naturalists living in the region.

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REFERENCES

Blackburn, G. (1959). The soils of County Grey, South Australia. *CSIRO Divn Soils, Soils and Land Use Ser.* No. 33.

Blackburn. G. (1964) The soils of Counties Macdonnell and Robe, South Australia *CSIRO Divn Soils, Soils and Land Use Ser.* No. 45.

Blackburn, G. (1966) Radiocarbon dates relating to soil development, coast-line changes, and volcanic ash deposition in south-east South Australia *Aust* J. *Sci.* **29**,50-52.

Blackburn, G, Bond, R. D. & Clark, A. R. P. (1965) Soil development associated with stranded beach ridges in south-east South Australia *CSIRO Soil Publ.* No. 22.

Browning, T. O. (1954). Observations on the ecology of the Australian field cricket, *Gryllulus commodus* Walker, in the field. *Aust.* J. *Zool.* **2**, 205-222.

Burr, T. (1845). Account of Governor George Grey's exploratory journey along the south-eastern sea-board of South Australia. J. *R. Geog. Soc.* **15**,160-184.

Burr, T. (1846). 'Remarks on the geology and mineralogy of South Australia.' (Murray, Adelaide)

Clarke, A. R. P (1966). The laboratory examination of soils from Counties Macdonnell and Robe, South Australia *CSIRO Divn Soils, Divnl Rep.* No. 4/65.

Cook, L. J. (1925). Possible correction of certain soils of the south-east of South Australia. J. *Dept. Agr. S. Aust.* **28**,807-813.

Crocker, R. L. (1941). Notes on the geology and physiography of south-east South Australia with reference to late climatic history. *Trans. R. Soc. S. Aust.* **65**,103-107.

Crocker, R. L. (1944). Soil and vegetation relationships in the lower south-east of South Australia. *Trans. R. Soc. S. Aust.* **68**, 144-172.

Crocker, R. L. (1946). Post-Miocene climatic and geologic history and its significance in relation to the genesis of the major soil types of South Australia. *Bull. Coun. Sci. Ind. Res. Melb.* No. 193.

Crocker, R. L. & Eardley, C. M. (1939). A South Australian *Sphagnum* bog. *Trans. R. Soc. S.*

Aust. **63**,210-214.
Dodson, J. (1977). Late Quaternary palaeoecology of Wyrie Swamp, south-eastern South Australia. *Quat. Res.* **8**, 97-114.
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.
Fergusson, G. J., & Rafter, T. A. (1957). New Zealand C^{14} age measurements: 3. *N.Z. J. Sci. Tech. B*. **38**,732-749.
Hamblin, A. P., & Greenland, D. J. (1972). Mineralogy of soils from the Holocene volcanic area of southern Australia. *Aust. J. Soil. Res.* **10***,* 61-80.
Hutton, J. T. & Leslie, T. I. (1958). Accession of non-nitrogenous ions dissolved in rainwater to soils in Victoria. *Aust. J. Agric. Res.* 9,492-507.
Hutton, J. T., Blackburn, G., & Clarke, A. R. P. (1959). Identification of volcanic ash in soils near Mt Gambier, South Australia. *Trans. R. Soc. S. Aust.* **82**, 93-98.
Luebbers, R. A. (1975). Ancient boomerangs discovered in South Australia. *Nature,* 253, 39.
McKenzie, R. M. (1959). Trace elements in some South Australian terra rossa and rendzina soils. *Aust. J. Agric. Res.* **10**,52-57.
Marshall, T. J. & Hosking, J. S. (1934). A soil survey of the area under the control of the Division of Animal Nutrition at 'Dismal Swamp'. *Bull. Coun. Sci. Ind. Res. Melb.* No. **85**, 18-22.
Norrish, K. & Pickering, J. G. (1977). Clay mineralogic properties. Ch. 3 (pp 32-53) *in* 'Soil factors in crop production in a semi-arid environment' *(Ed.* J S Russell and E. L. Greacen) (Univ. Qld Press, St Lucia).
Norrish, K., & Rogers, Lillian E. R. (1956). The mineralogy of some terra rossa and rendzinas of South Australia. *J. Soil Sci.* **7**, 294-301.
Norrish, K., & Tiller, K. G. (1976). Subplasticity in Australian soils. V. Factors involved and techniques of dispersion. *Aust. J. Soil Res.* ***14,*** 273-290.
Northcote, K. H. (1960). Atlas of Australian soils, Sheet 1, Port Augusta-Adelaide-Hamilton area. With explanatory data. (CSIRO and Melb. Univ. Press, Melbourne).
Northcote, K. H. (1971). 'A factual key for the recognition of Australian soils' (Rellim, Glenside).
Northcote, K. H. & Skene, J. K. M. (1972). Australian soils with saline and sodic properties. *CSIRO Soil Publ.* No. 27.
Oertel, A. C. & Blackburn, G. (1970). Pedogenesis of a solodized solonetz, based on duplicate soil profiles. *Aust. J. Soil Res.* **8**,59-70.
Perkins, A. J. (1903). An enquiry into south-eastern conditions. *J. Agric. Ind. S. Aust.* **7**, 304-307, 345-349,376-382,427-429,8,1-10.
Powrie, J. K. (1960). A field response by subterranean clover to cobalt fertilizer. *Aust.* J. *Sci.* **23**, 198.
Prescott, J. A. (1931). The soils of Australia in relation to vegetation and climate. *Bull. Coun. Sci. Ind. Res. Melb.* No. 52.
Ruiter, J. H. (1964). The water relations of *Pinus radiata* (D. Don) in the lower south-east of South Australia. M.Sc. Thesis, University of Adelaide.
Samuel, G. & Piper, C. S. (1928). Grey speck (manganese deficiency) disease of oats. J. *Agric. S. Aust.* **31,** 696-705.
Spafford, W. J. (1925). Classification and report on south-eastern lands. *S. Aust. Pari. Pap.* No. 64 of 1925
Stace, H. C. T., Hubble, G. D., Brewer, R., Northcote, K. H., Sleeman, J. R., Mulcahy, M. J. & Hallsworth, E. G. (1968). 'A handbook of Australian soils'. (Rellim, Glenside).
Stephens, C. G. (1943). The pedology of a South Australian fen. *Trans. R. Soc. S. Aust.* **67**, 191-199
Stephens, C. G. (1957). The soils of South Australia in relation to forestry production. Pp. 21-28 in 'South Australian forestry handbook' (Govt Printer, Adelaide).
Stephens, C. G., Crocker, R. L., Butler, B. & Smith, R. (1941). A soil and land use survey of the Hundreds of Riddoch, Hindmarsh, Grey, Young, and Nangwarry, County Grey, South Australia. *Bull. Coun. Sci. Ind. Res. Melb.* No. 142.
Stephens, C. G. & Donald, C. M. (1958). Australian soils and their responses to fertilizers. *Adv. Agron.* **10**, 167-256.
Thomas, R. G. (1938). The influence of geological conditions and soil composition on the regional distribution of 'coast disease' in sheep in South Australia. Pp. 28-39 in *Bull. Coun. Sci. Ind. Res. Melb.* No. 113.
Tiller, K. G. (1958). The geochemistry of basaltic materials and associated soils of south-eastern South Australia. *J. Soil Sci.* **9**,225-241.
Tindale, N. B. (1957). A dated Tartangan implement site from Cape Martin, south-east of South Australia. *Trans. R. Soc. S. Aust.* **80**, 109-123.
Woods, J. E. (1862). 'Geological observations in South Australia-principally in the district south-east of Adelaide.' (Longman, London).
Woods, J. E. (1866). Report on the geology and mineralogy of the south-eastern district of the Colony of South Australia. (Govt Printer Adelaide).

6: Hydrology

by J. W. HOLMES and J. D. WATERHOUSE

INTRODUCTION

A traveller by road along the Prince's Highway in South Australia could remark, if he were interested in rivers or nature's bounty, that there are none to be crossed in 400 km between the Glenelg River and the mouth of the River Murray. Not that the region is waterless, for there is an abundant rainfall in its southern part, but this singular lack of surface streams is caused by geological factors discussed in Chapters 1, 3 and 4.

The South East possesses many swamps. Some are small and can dry up completely each summer. Others are permanent pools of water, which provide the habitats for waterbirds and hosts of other swamp dwellers. Lagoons and lakes abound too, (see Chapter 8). In fact, at the end of a wet winter some Hundreds (the Hundred of Mingbool is an example) may have 30% of their land surface flooded by temporary extensions of the swamps upon the flats. In his written account of a journey to the South East, Ward (1869) described the extensive areas of land which were flooded by winter rains, and discussed the prospects of opening up some agricultural lands by artificial drainage.

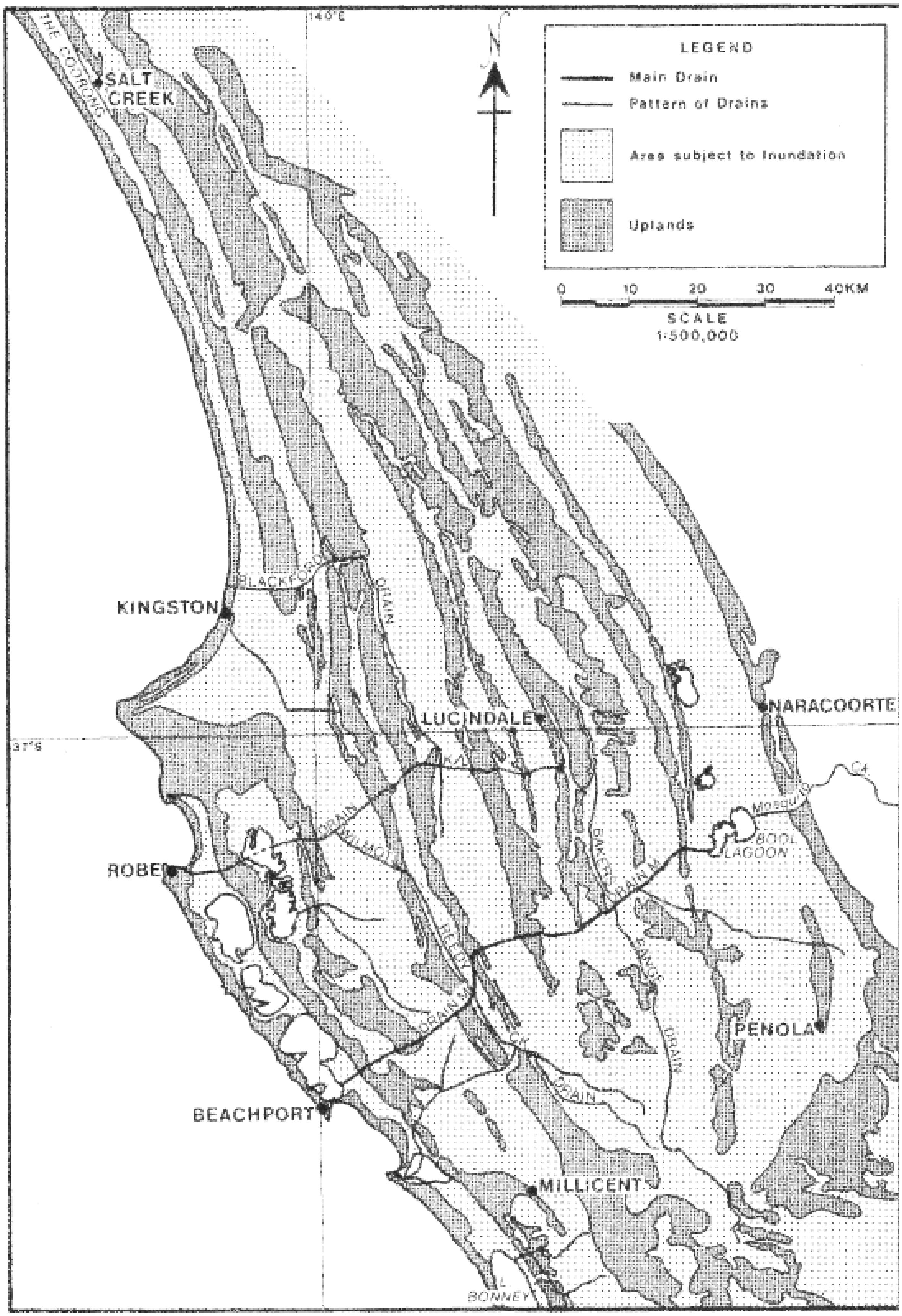
The stranded-beach ridges, the so-called ranges of the South East, have prevented the natural development of streams flowing to the sea. The interdune flats serve as natural collectors of surface water, which used to flow slowly in a north-westerly direction, along the waterways formed by the joining of individual swamps during flood-time.

Drainage of some areas of accumulated water was accomplished during the 19th and early part of the 20th centuries, however it was not until a co-ordinated approach was taken in the 1940's that thorough drainage was achieved in most of the South East. Figure 1 shows the extent of land subject to regular and, in some cases, prolonged inundation, and the drainage system subsequently constructed.

Some drainage has been accomplished by reconstructing natural water courses along the interdune flats, for example the Reedy Creek and Baker's Range Drains, however effective drainage has resulted largely from the construction of systems based on several major drains cut at right angles to the line of the ranges. These big drains, of which drain M is the largest, were cut across the grain of the country to give the shortest distance to the sea from the flooded flats.

Drainage began in the 1860's, according to Williams (1975), whose historical survey of the draining of the land is a valuable source of information. Most of the present extent of the drainage was accomplished, under the administration of the South-eastern Drainage Board, from 1944 to 1970. Many of the swamps and lagoons, with their associated sedges, reeds and ti-tree forests have gone, inevitably, to be replaced by pastures. The disposal of the floods, which formerly rested upon the land to be used up slowly by evaporation in summer, is now accomplished rapidly by discharge in the big drains, of which Drain M has a design (bank-full) discharge about equal to the mean flow of the Murrumbidgee River. Figure 1 shows the drainage works up to 1972, from Williams (1975).

The incorporation of Drain M with the natural overflow of Bool Lagoon and the tributary flow to Bool Lagoon of Mosquito Creek has provided an effective drainage way from the high ground in Victoria west of the Glenelg River, through swamps and flats in South Australia, to the sea. A consequence of this and other drainage works is a flushing of saline water accumulations both from swamp surfaces and from soils and shallow subsurface zones. The process is slow so that the full effects are likely to be noticed only after a hundred years or more but already the unpublished records (of the Engineering and Water Supply Department) of drain water salinity can provide ample evidence of a salt flow borne by the water of the drains to the sea (Table 1). It is a hydrological development that is likely to confer great benefit upon future generations of farmers-the salt drained to


LEGEND
Main Drain
Pattern of Drains
Area subject to Inundation
Uplands
0 10 20 30 40KM
SCALE
1:500,000
140°E
37°S
THE COORONG
SALT CREEK
KINGSTON
LUCINDALE
NARACOORTE
ROBE
BEACHPORT
PENOLA
MILLICENT
BOOL LAGOON
L BONNEY
BLACKFORD
DRAIN
WILMOT
BAKERS RANGE DRAIN
Mosquito
DRAIN

the sea in 1980 by Drain M alone is some 25000 tonnes.

There is abundant water underground as well as upon the ground surface. L. K. Ward made an early assessment of the groundwater resources, when he was Director of the Department of Mines (Ward 1941 a). Although his idea that the underground water comes mainly from Victoria has proved to be incorrect, his recognition that the water is a very valuable resource was an important step, when it was made in the 1930s, in the inventory of South Australia's resources.

In general, the underground water is stored in two aquifer systems. The Gambier Limestone, well known as a building stone, provides a rock stratum that is particularly porous and permeable, so that it is regarded as one of the best aquifers in Australia. Beneath it, the interbedded sands and sandy clays, usually identified with the Dilwyn Formation sediments, form a deeper, confined aquifer It is convenient to describe the underground water of the South East in terms of these two aquifer systems.

THE UPPER AQUIFERS

The upper aquifer system occurs mainly within the coarse-grained, fossiliferous zones of the Gambier Limestone. This aquifer is separated from that underlying it by finer grained marls and clays.

The Gambier Limestone was long regarded as a single aquifer. However it is now known that an upper and lower aquifer should be distinguished in the Millicent-Mt Gambier region, where the limestone is thickest (abou: 300 m). Future study of the hydrogeology probably will show that this zoning occurs more widely than is known at present.

Several relatively thin, geologically younger beds overlie the Gambier Limestone and often form the uppermost, water-table aquifer which is hydraulically continuous within the underlying Limestone. They often occur on the interdune flats in the northern part of the area, where the water table is shallow. Sediments made up of fragments of the Gambier Limestone, reworked in a later geological period by coastal processes, form the dune ranges, the cores of which usually rest upon the Limestone.

The depth to the water table varies considerably, from less than 2 m from the ground surface in low-lying coastal areas, some interdune flats in the inland and the meadow-podsol region of Dismal Swamp and the Hundred of Mingbool, to more than 35 m in elevated areas such as around the Mt Burr volcanic complex and the dune ranges and chaotic aeolianite fields of the Bridgewater Formation. The yield to shallow, pumped boreholes and wells is almost invariably large.

The underground water has provided the main source for supply of farms and towns since the beginning of European settlement. A pumped and reticulated supply for Mt Gambier (Gambiertown) was constructed in 1880, using the water of Blue Lake which is fed from the underground flow (Allison & Harvey, Chapter 7). Despite the early reliance upon the underground water, it has been studied in respect of its annual replenishment and its total usable resource only since about 1960. The upper aquifer is recharged each year by rainwater infiltrating through the soil directly to the water table. Such replenishment begins about the end of May and in a normal year is usually complete by November. The amount of recharge is greatest wherever the land is in annual pasture, but even there it varies widely from 60 mm yr^{-1} to about 150 mm yr^{-1} in the South East, this range being determined by soil conditions (Allison 1975) Further north, where rainfall is less, the annual recharge must be considerably less, but it has not yet been measured except locally in the Padthaway Irrigation Area (Allison & Hughes 1975). The pine forests of the South East appear to prevent any significant recharge to the groundwater beneath the mature

Table 1. WATER SALINITIES AND DISCHARGE RATES FOR DRAIN M

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*July*	*Aug*	*Sep*	*Oc*	*Nov*	*Dec*
1980 Salinity (mg/L)		1240	1130		1010	860	890	855	1010	890	950	1224
1980 discharge (ML/month)	1060	599	484	527	716	961	4950	7250	5860	2920	950	215
1980 Salt discharge (tonnes/month)		740	550		720	830	4400	6200	5900	2600	900	260

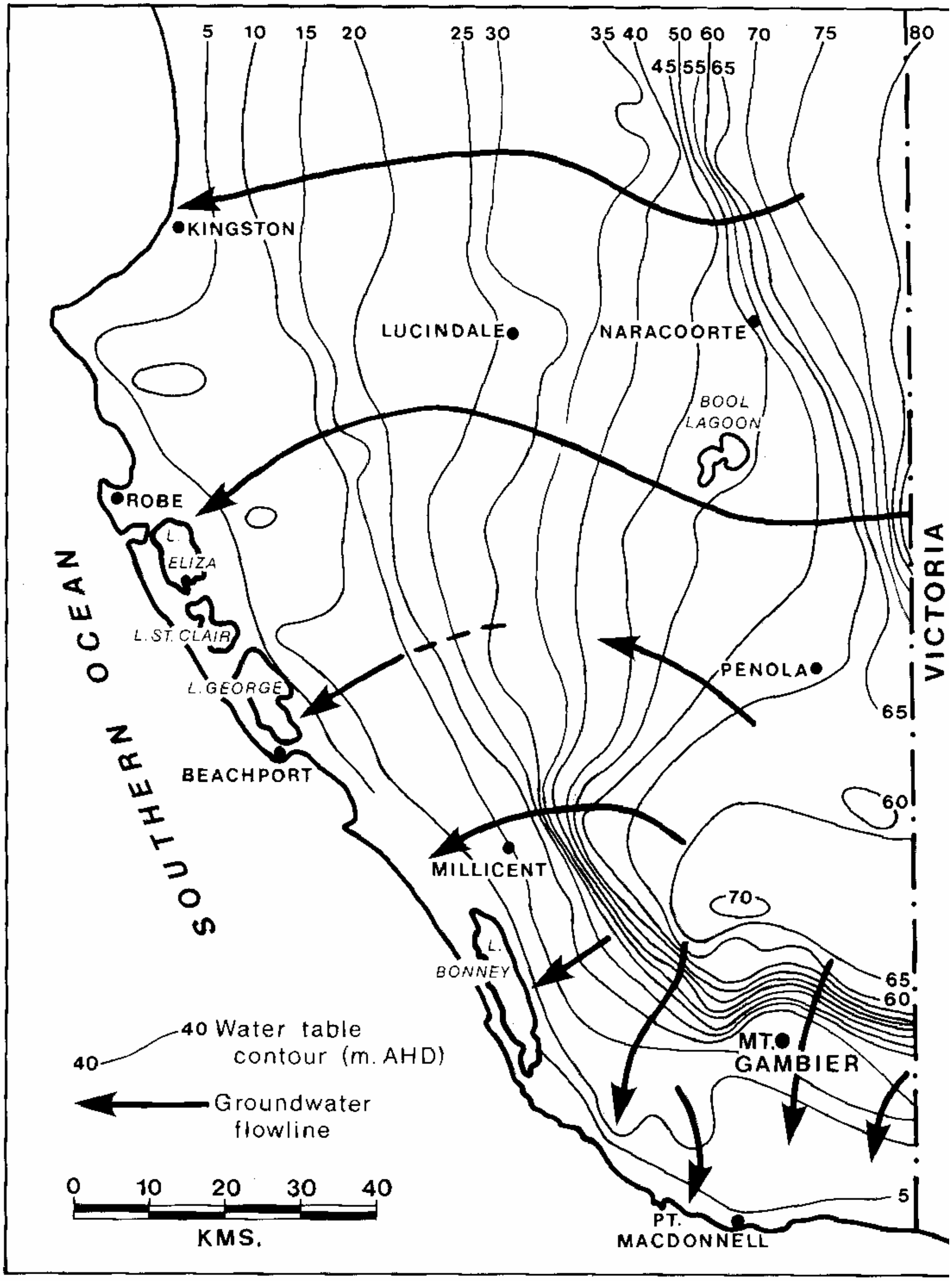


Fig. 2. Water table contours and flow directions for the Gambier Limstone (unconfined) aquifer.

plantations (Holmes & Colville 1970). This rather startling result was verified by Allison & Hughes (1972). using the new and powerful technique of tritium-age dating of the water.

Figure 2 shows a map of the contours of the water table height, based upon observations of water levels in about 600 bore-holes read lor this purpose and established by the Department of Mines and Energy. The direction of the underground flow is everywhere at right ang les to the contours and is closely horizontal except in steep gradient regions. It can be observed, from the map, that the flow generally goes directly towards the sea, therefore passing across and under the dune ranges, which are aligned parallel to the present coast-line. The high ground of Mt Burr perturbs the regular nature of the groundwater flow, presumably because impermeable, volcanic rocks have been emplaced in the relatively shallow subsurface.

The potentiometric surface of the water-table assumes a steep gradient about 5 km north of Mt Gambier, which is a result of the Gambier Limestone thinning out upon the Pleistocene upwarp of the underlying rocks, as proposed by Sprigg (1952). To the south the Limestone becomes very thick and able to conduct the groundwater flow under a small gradient, towards its discharges in springs, concealed submarine seepage and base-flow of the Glenelg River.

The steep gradient near Naracoorte is caused by the groundwater flow descending across the Kannawigara Lineament (probably a deep-seated fault west of Naracoorte Range) to the interdune flat, from its more extensive recharge area upon the elevated plateau of Gambier Limestone reaching into Victoria to the north-east.

South of Penola a groundwater divide occurs in a swampy, poorly drained area, of which Dismal Swamp forms a part. North of this divide the flow is to the north and northwest, in part towards Bool Lagoon, but the maps prove hard to draw there in detail. This groundwater mound at an elevation of about 65 m is caused by thin, relatively less permeable aquifers, which are filled with water nearly to the ground surface. The flow out of this zone southward is facilitated at the steep gradient region as the aquifer rapidly deepens.

Despite the well known karst features that include mainly elongated, joint controlled caves and circular to oval, vertical-sided sinkholes (Marker 1975), underground water flow occurs principally as intergranular flow through the pore spaces between the grains of the limestone. Although these caverns are known to extend many tens of metres below the water table, measurable flow in them is extremely rare, and it seems that they do not form a huge interconnected system as is sometimes suggested. Large spring discharges at the southern coast occur where there is some concentration of flow, but the range of fluctuation of the discharge is far too small for the water to come from a mainly conduit flow system.

The caves do allow ready drainage underground, and have provided a convenient means of water disposal in some areas, to the detriment of water quality.

THE LOWER AQUIFERS

The lower aquifer system occurs within a sequence of interbedded sands and clays generally identified with the Dilwyn Formation. The confining bed that separates it from the overlying Gambier Limestone is mainly the lower portion of the Limestone and a very impermeable, dark-coloured carbonaceous clay at the top of the Dilwyn Formation. A minor confined aquifer, the Kongorong Sand, overlies the Dilwyn Formation, in the south-west of the region.

In the southern part of the region and offshore, the sediments of that part of the Gambier Embayment are thousands of metres thick, as described by Wopfner & Douglas (1971), but little is known about any of the aquifers which must occur in this sequence. It has been drilled for petroleum exploration.

Figure 3 shows the contours of the water levels in boreholes penetrating the confined aquifer (the potentiometric contours) with lines of groundwater flow drawn at right angles. Between Kingston and Beachport and near Port MacDonnell the pressure of the water in the lower aquifer is sufficient to enable bores to flow freely. Elsewhere the aquifer is not artesian although its water level is usually several metres higher than in shallow bores in the coastal regions downstream of the high gradient zones identified in Figure 2. In particular, the head of water in the confined aquifer near Mt Gambier is about 10 m higher than the water level in the Gambier Limestone. It is believed, from rather scanty data, that the flow through the confined aquifer between Millicent and Kingston is small, as can be read from the separation of the flow lines in Figure 3.

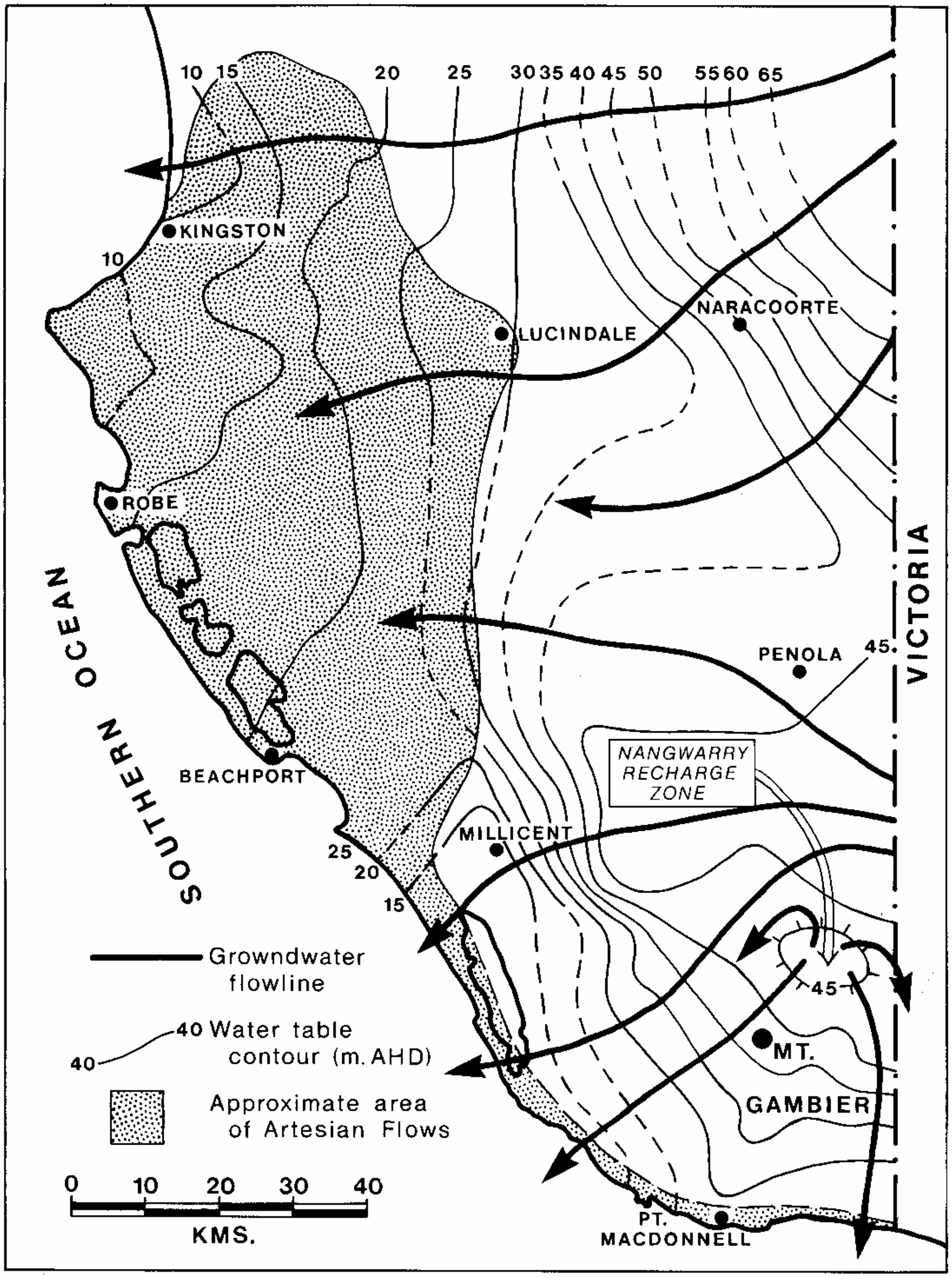


Fig. 3. Contours of water levels and flow directions in the Dilwyn Formation (confined) aquifer.

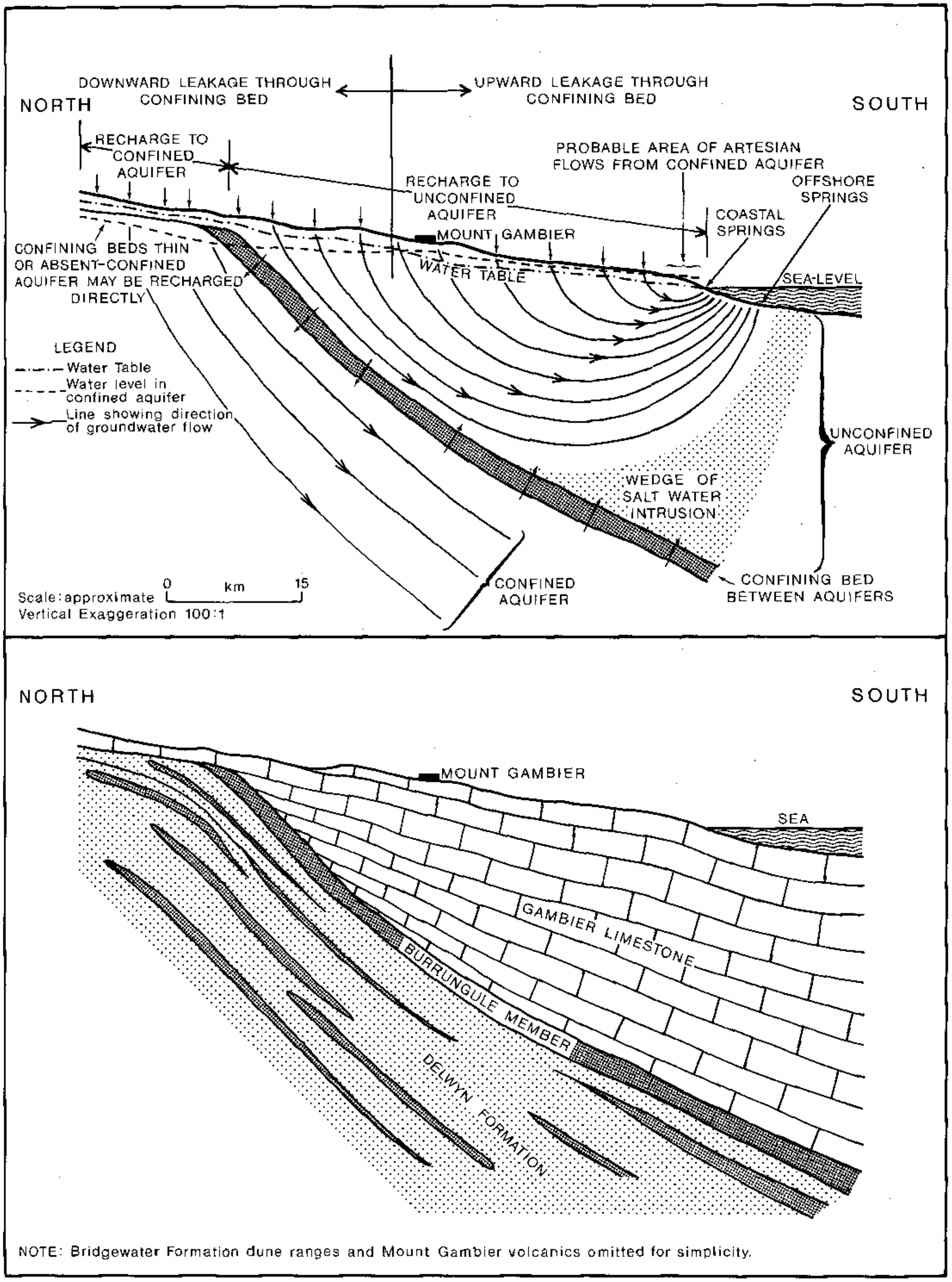


Fig. 4. Diagrammatic north-south section through Mt Gambier to the sea.

In the Nangwarry district, by contrast, the water level in the confined aquifer is up to 15 m lower than in the water table aquifer. This appears to be caused by a small anticline over which the Gambier Limestone thins and the confining bed is absent. In consequence, it is a zone of considerable recharge of the confined aquifer by water from the upper aquifer; it was discovered in the early 1960s (Colville & Hol mes 1972). The effect may be discerned as a near-circular shaped depression of the water table surface (Figure 2). There are probably other local regions of such preferred recharge wherever the head difference of the waters of the two aquifers would allow it, but they have not yet been discovered.

Figure 4 shows a diagrammatic section from the zone of water levels north of Mt Gambier, beginning at the Nangwarry anticline, to the southern coast. It illustrates the varying relationships between the water flows in the two principal aquifers. The unconfined aquifer can be recharged along the entire length of the section, by infiltration of rain water through the soil. The confined aquifer can be recharged only where the head of water in it is lower than in the unconfined aquifer, that is to the north of the region of steep gradient of the water table. South of this zone the heads are reversed so the confined aquifer has a tendency to discharge into the unconfined aquifer, but the amount and nature of that discharge is generally unknown. Recharge of the confined aquifer could occur in western Victoria, where the Dilwyn Formation outcrops over a large area near the margin of the Gambier Embayment of the Otway Basin. The valley of the Glenelg River intersects these sediments but the relationship of this unconfined part of the Oilwyn Formation to its confined and extensive occurrence to the west has not yet been investigated.

WATER QUALITY

The salinity of the groundwaters depends upon their origin, local geological and surface situations and rainfall. The total dissolved salts (T.O.S.) are less than 500 mg L^{-1} in water of the upper aquifer in the lower South East, where recharge is largest. In the northernmost, driest part of the region T.D.S. can reach 5000 mg L^{-1}, in areas of small recharge, where groundwater flow is sluggish, the water table is sometimes close to the surface in the inter-dune corridors, and concentration of salts can be caused by evaporation.

The salinity of water in the confined aquifer shows only a small range of variability. Near Mt Gambier this water possesses 600 mg L^{-1} of T. O.S., near Kingston it has 1000 mg $L^{-1}$and at Naracoorte, where it provides the source for the town water supply it has 1100 mg L^{-1}. The water is much too deep for its salinity to be influenced by any mechanism of evaporative concentration of salts. It does, however, traverse in its flow path a variety of rock types from siliceous sands to clays and sandstones. Floegel (1972) suggested that the systematic change in cation-type from Ca-dominant in the east to Na-dominant in the west could be

Table 2 REPRESENTATIVE ANALYSES OF WATER OF THE SOUTH-EAST

Source	*Main Constituents mgL^{-1}* Na	K	Ca	Mg	*Cl*	*$HC0_3$*	*$S0_4$*	*$N0_3$*	*Total Salinity (mgL^{-1})*	*Remarks*
BLA63-Waterhouse 1977	48	11	74	20	75	295	15	3	380	Unconfined aquifer in south near Mt Gambier
Section 30. Hundred of Marcollat - O'Driscoll 1960	453	Na+K	109	63	674	132	119	Trace	1678	Unconfined aquifer in north near Naracoorte
BLA39-Waterhouse 1977	81	3	113	18	124	75	5	265	690	Polluted unconfined aquifer near Mt Gambier
Ewens Ponds-Waterhouse 1977	46	2	73	20	73	290	15	15	387	Coastal spring south of Mt Gambier
Mt Gambier Standby Town Water Supply Bore 8	115	-	71	30	170	383	21	6	612	Confined aquifer *near* Mt Gambler
Hd. Lacepede Town Lot 2-Floegel1972	312	-	37	13	330	415	17	Trace	924	Confined aquifer at Kingston (west end of flow-path)
Drain M July 1980	192	5	65	38	327	282	73	1.4	855	
Dec. 1980	333	7	45	58	532	230	105	0.01	1224	

caused by ion-exchange as the water contacts the clay sediments (see Table 2).

The water of the upper aquifer shows an abrupt increase in salinity with depth, at locations close to the coast. This well-known phenomenon, sometimes described as the Ghyben-Herzberg lens of fresh water resting upon denser sea water has been studied at the coast south of Mt Gambier, where the transition to salt water occurs at a depth of about 140m. This transition zone rapidly deepens with further distance in an inland direction.

Table 2 shows chemical analyses of waters from several localities chosen to represent the range of conditions found in the South East. In particular, it may be observed that the waters in the south of the region, with lesser TD.S., exhibit a dominance of Ca^{2+} as cation, sometimes also of Mg^{2+}, with HCO_3^- as the dominant anion, but waters in the north, with greater T.D.S., show the usual Na^+ and Cl^- dominance of the dry Australian continent. The effects of prolonged subsurface waste disposal can also be seen in the high nitrate concentration in one analysis from the upper aquifer.

Table 2 also shows analyses of su rface waters sampled from Drain M, to demonstrate the seasonal variation in T.D.S. and to support the opinion that there is a significant salt flux borne by the drain discharges to the sea. The transport of salt in the water of Blackford Drain is very large indeed.

WATER RESOURCES

The South East possesses water resources that are second to the River Murray in their potential importance for South Australia. Barratt (1977) estimated the sustainable yield from underground water to be 0.5×10^6ML yr^{-1} which may be compared with 1.5×10^6ML yr^{-1} allocated to South Australia as entitlement flow of the Murray in a drought year. The amount of water actually provided by the groundwater for irrigation, agriculture, industrial and urban supply probably aggregates about 0.5×10^5M L yr^{-1} at the present time but much of this draft is not lost immediately to the region, only changed in quality. For example, paper making is a process that needs a lot of water but does not consume it. It is released, degraded in quality, from the two mills near Millicent into surface drains that empty into Lake Bonney.

Shallow bore-holes, of which there may be conservatively 30000 in the South East, many pumped by wind power, satisfy rural, domestic and livestock needs. High-yielding bores up to 200L sec^{-1} have been developed for the irrigation of vineyards, lucerne, pastures, sunflowers, potatoes, field peas and vegetables, which benefit from supplementary water in the summer.

Most of the town and city water supplies for a total of about 35000 people are taken from the confined aquifer, which is very satisfactory for the purpose because it remains unpolluted by man's effluents. Water for industry, principally concentrated in the region from Mt Gambier to Millicent comes from both the upper and lower aquifers.

Recent surveys of the deterioration of the quality of underground waters since about 1960 (Waterhouse 1977, Harvey 1979) provide data for understanding and control of the pollution. Since the early settlement of the region, caves, sinkholes and small depressions characteristic of a karst topography, have been employed as convenient dumps for rubbish, including liquid wastes. This practice has continued despite warnings of undesirable consequences to be expected later (o'Driscoll 1960) and known early examples of severe pollution of the unconfined aquifer (Ward 1941b, Dickinson 1947, and Waterhouse & Cobb, 1977 for example).

Wastes disposed upon the ground surface can contribute to pollution of the upper aquifer when their soluble constituents are taken by infiltration of water through the soil to the water table. Such sources include the manures of grazing animals, point sources of concentration such as feed-lots, cheese and butter factories, piggeries and poultry farms. Harvey (1979) conducted a comprehensive study of all available data south of Naracoorte to Kingston, in an attempt to discover the principal sources of pollution of the groundwater. He concluded that agricultural enterprise is the main cause but that point sources, such as those described above, are no more important than widespread and diffuse sources. Pollution is usually detected and specified by the presence of bacteria and increasing concentrations of nitrate. Although it was usually below the level of detection in early analyses, nitrate now frequently exceeds the recommended permissible limit, of 45 mg L^{-1} set by the World Health Organisation, in analyses of waters from surface sources and the upper aquifer. The waters contained in the Gambier

Limestone around Mt Gambier possess about 50 mg L^{-1}, on the average, and local concentrations as large as 500 mg L^{-1} have been detected. It is very fortunate that the natural source of the water in the Blue Lake is from the deep-lying, confined aquifer, which is totally uncontaminated.

Despite the widespread use of poor quality water, particularly by the farming community wherever there is no connection to public water supply, there have been few, if any outbreaks of water-borne disease, either in humans or in livestock. Subclinicareffects do not appear to have been the subject of rigorous study and the possibility should not be dismissed. A high economic cost can someti mes attach to pollution, if towns and industries are forced to treat water before use, or to construct deeper bore-holes to develop the confined aquifer, in order to avoid the shallower water where its quality is unacceptable.

The Water Resources Act (1976) was intended to provide the legislative framework with which to control excessive withdrawal of groundwater, inadequate bore-hole construction and pollution of water resou rces. It applies to the whole of South Australia, of course, not merely to the South East.

Groundwater use is controlled in the Padthaway Irrigation Area, by regulating the area of irrigation permitted to each water user, according to the type of crop. Elsewhere in the South East extraction rates do not appear to present any problems for long-term management of the groundwater, but this situation could change rapidly wherever intensive and widespread irrigation might develop in the future. Even in the wettest parts of the South East the proportion of the land that could be irrigated from local groundwater resources cannot exceed one hectare for every four hectares not irrigated if depletion of the resource and degradation of its quality is to be avoided.

All water bore-holes are constructed under a permit which specifies the details of construction to minimise pollution of the aquifer from surface waters, to control flowing bores by adequate headworks and to prevent leakage of water from one aquifer to another

Water quality control is less satisfactory than is the control upon quantity of use. By the provisions of the Act, water quality orders can be issued to control major point sources of pollution, such as cheese factory effluents, but they are inadequate to control agricultural pollution, which, by its nature, is diffusely spread across the landscape. Harvey (1979) proposed that local limits to pollution should be agreed upon, appropriate to particular zones of the South East and that diffuse and small point sources of pollution should be controlled in order to maintain the set limitsof groundwater quality.

REFERENCES

Allison, G. B. (1975). Estimation of the water resources of a portion of the Gambier Plain using a new method for evaluating local recharge *Proe. Hydrology Symposium, Armidale, N.S.* W. 1975. (Inst. Eng. Aust. National Conference Publication No. 75/3),1-5.

Allison, G. B. & Hughes, M. W. (1972). Comparison of recharge to groundwater under forest and pasture using environmental tritium. *J. Hydrol.* **17**, 81-95.

Allison, G. B. & Hughes, M. W. (1975). The use of environmental tritium to estimate recharge to a South Australian aquifer. *J. Hydrol.* **26**, 245-254.

Barratt, J. R. (1977) The status of water resources investigations in the Southeast of South Australia-1977. S. Aust. Engineering and Water Supply Dept, unpubl. rept, Library Ref. 75/53.

Colville, J. S & Holmes, J. W. (1972). Water table fluctuations under forest and pasture in a karstic region of southern Australia. *J. Hydrol.* **17**,61-80.

Dickinson, S. B. (1947). Inflammable gas at Mount Schank cheese factory. S. Aust. Dept Mines, unpubl. rept R.B. 23/45.

Floegel, H. (1972). The position of the Lower Tertiary Artesian aquifer within the hydrogeology and hydrochemistry of the Gambier Embayment area (South Australia/ Victoria) Ph.D. thesis, Breslau University, West Germany (unpublished)

Harvey, P D. (1979) Water quality management in the south-east of South Australia. M. Environmental Studies thesis, Centre for Environmental Studies, University of Adelaide, South Australia (unpublished)

Holmes, J. W. and Colville, J. S., (1970). Forest hydrology in a karstic region of southern Australia. J. *Hydrol.* **10**, 59-74**.**

Marker, M. E. (1975). The lower Southeast of South Australia: a karst province. *Dept. Geogr. Environ. Stud. Univ. Witwatersrand, Johannesburg, Occ. Pap,* (13), 68 pp.

O'Driscoll, E. P. D. (1960). The hydrology of the Murray Basin Province in South Australia. *Bull. Geol Surv. S Aust*. **35**, 148 pp.

Sprigg, R. C. (1952). The geology of the Southeast province, South Australia, with special reference to Quaternary coastline migrations and modern beach developments. *Bull. geol. Surv.* S. *Aust.* **29**.

Ward, E. (1869). The south-eastern district of South Australia: its resources and requirements. (Publ ished by the author at the offices of 'The South Australian', Adelaide).

Ward, L. K. (1941 a). The underground water of the south-eastern part of South Australia. *Bull. geol. Surv.* S. *Aust.* **19,**50 pp.

Ward, L. K. (1941b). Report on inflammable gas at Kalangadoo cheese factory. S. *Aust. Dept. Mines unpubl rept.* RB 17/287.

Waterhouse, J. D. & Cobb, M. A. (1977). Geology and hydrogeology of the Southeast province, South Australia-a bibliography. *Geol. Surv.* S. *Aust.*

Waterhouse, J. D. (1977). The hydrogeology of the Mount Gambier area. *Rep. Invest. geol. Surv.* S. *Aust.* **48.**

Williams, M. (1975). Draining the Swamps, Ch. *Sin* 'The making of the South Australian Landscape, (Academic Press, London and New York).

Wopfner, H. & Douglas, J. D. (1971). The Otway Basin of south-eastern Australia. *Spec. bull. geol. Surv*. S. *Aust. Vic.* 464 pp.

7: Freshwater Lakes

by GRAHAM ALLISON AND PAUL HARVEY

INTRODUCTION

The lakes and swamps of the South East form some of the dominant geomorphic features in an otherwise reasonably featureless area. This may be one of the reasons for the considerable interest both by present day inhabitants and early settlers in the lakes and swamps of the region.

Historically an excess of surface water has dominated surface transport and land use in the South East. This was exemplified by a report to a Parliamentary Select Committee in 1866 by G. W. Goyder (then the Surveyor General) which stated that half the area south of Salt Creek was under water every wet season. Ward (1868) quotes a story of a man drowning while travelling on a road in the vicinity of Robe and describes how telegraph lines could not be maintained on the Millicent flats during winter because the swamps were impassable even on horseback.

The South Eastern Drainage Board (1980) consider that of the 665398 ha of rateable land under their Act, 57.3% has benefited from the drainage scheme and only 3.6% of the area is still considered to be disadvantaged by water. Thus the perceived importance of swamps as significant water bodies in the South East has decreased.

In this chapter we discuss the lakes of the South East in five sections as follows. Blue Lake, probably the best known lake of the area and Lake Bonney, the largest freshwater lake in the State, are considered separately because more is known of their hydrology, chemistry and biology than for the other lakes.
Volcanic lakes that have only limited interaction with the groundwater are the next group of lakes considered. This category includes Lake Leake and Valley Lake, both well known as recreational areas.

Several of the lakes of the South East formed as a result of karst activity. Little is known about them although some have gained notoriety because of the activities of cave divers.

The final category discussed is that of swamps. As mentioned above, the area under swamps has decreased markedly as a result of drainage in the last 100 years, but those remaining form an important part of the ecosystem.

The locations of the lakes discussed in this chapter are shown in Fig. 1.

BLUE LAKE

BACKGROUND AND WATER BALANCE

Blue Lake, together with other lakes occupying the present day Mt Gambier volcanic crater, is sited in a complex maar (Sheard 1978). Figure 2 shows a geological section through the lake with stratigraphy as proposed by Sheard (see also Chapter 2).

S. G. Henty in 1839 is recorded as being the first European to view the lake. Since that time the great depth, spectacular setting and annual colour change from grey to blue, have made the lake a focus for local and tourist interest.

The first reported survey of the lake was in 1851 by a Mr Blandowski, but the maps were later lost. Woods (1862) described the geomorphology of the lakes in some detail. He identified the principal materials comprising the crater walls which stand up to 100 m above water level. These materials have been mapped in detail by Sheard (1978) as the Gambier Limestone (which forms the country rock and outcrops to approximately 20 m above the present day water surface); this is overlain by basalt and a tuff agglomerate. These, in turn, are overlain in some places by semi-laminated volcanic ash.

Historically there has been considerable interest in the depth of the lake. Woods (1862) described the lake as deepening almost perpendicularly from the sides being 240 ft (72 m) deep in the centre. Hill (1972) reported soundings taken in 1969 by Capt. French. He found that the depth varied between 180 ft (54 m) and 672 ft (200 m), this latter depth being associated with a small circular hole. No

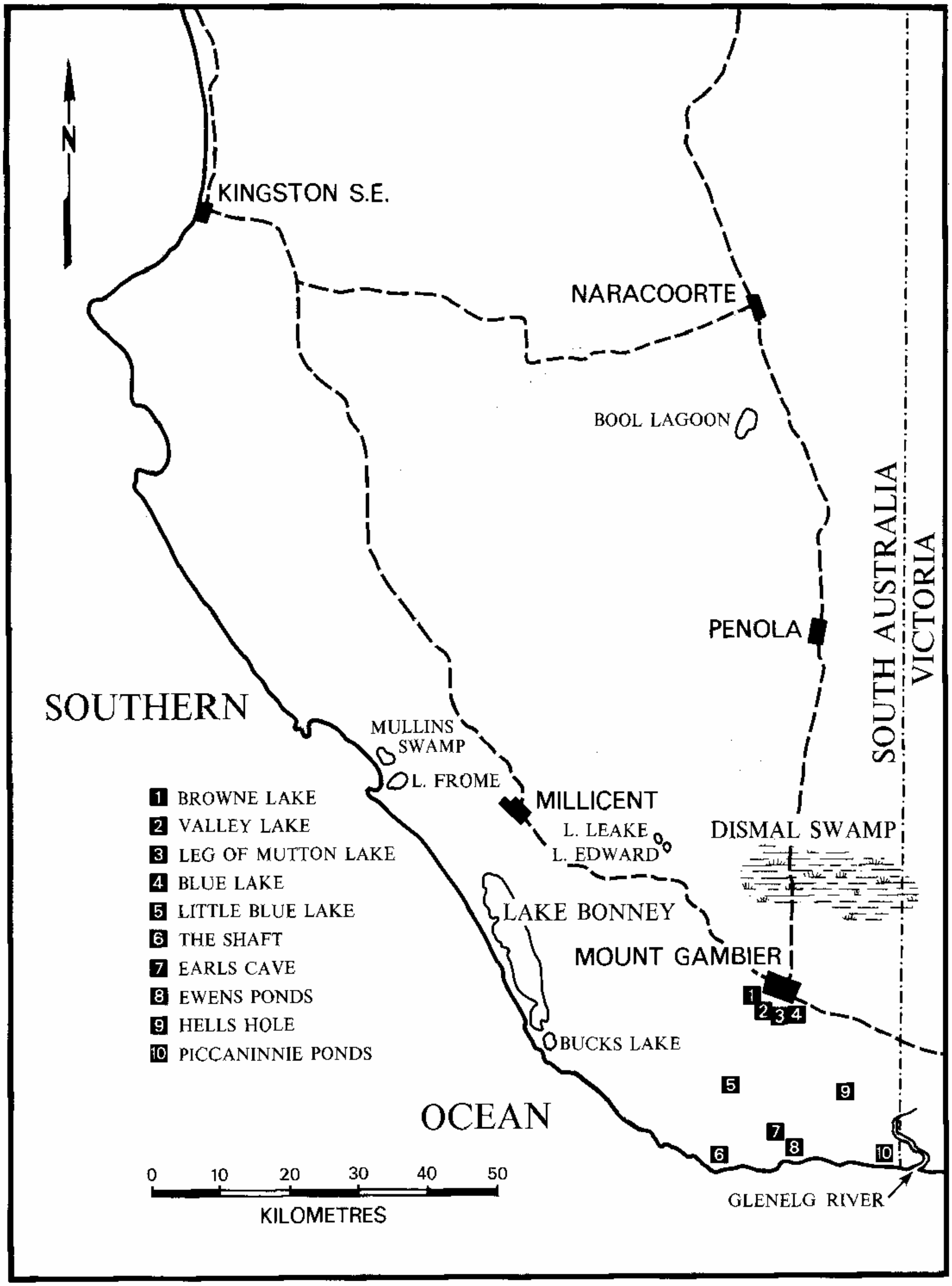


Fig. 1. Location of lakes.

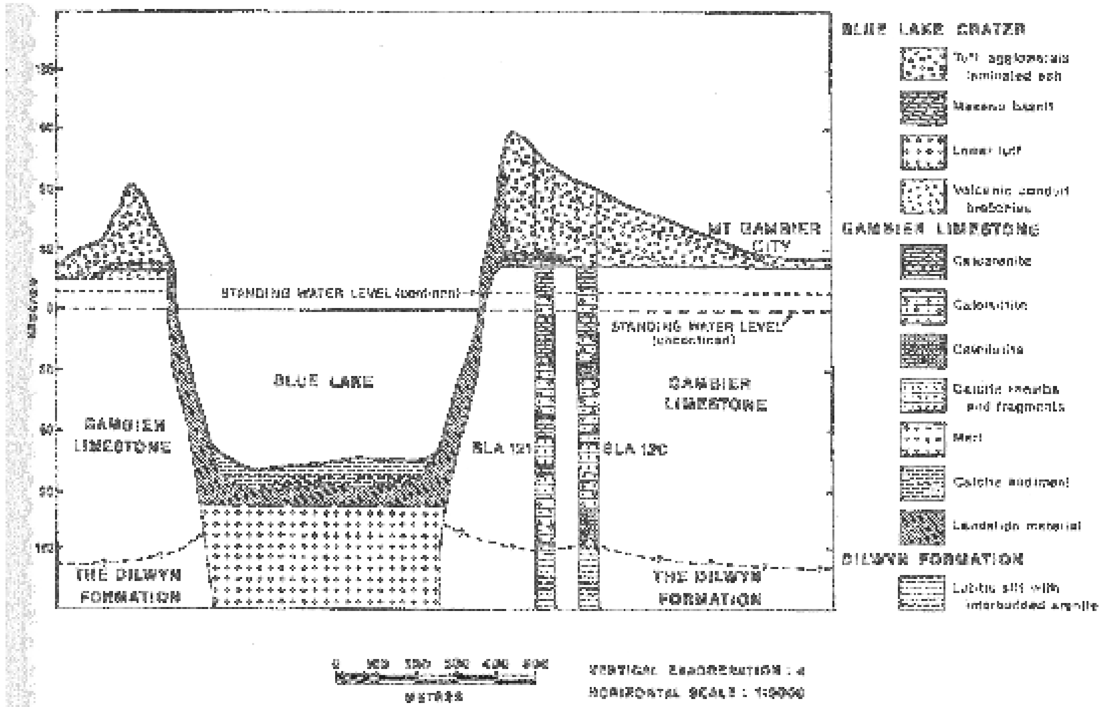


Fig. 2. Geological Section through Blue Lake (after Sheard 1978).

evidence of the hole has been found in subsequent bathymetric surveys including a detailed one carried out by the Department of the Interior and reported by Tamuly (1970). The existence of such an opening would have important implications for the hydrology of Blue Lake.

Many explanations have been proposed for the origin of water in and water level of the lake. Woods (1862) inferred that water in the lake originated from local rainfall when he suggested that the lake would have taken considerable time to fill after cessation of the period of vulcanism. Fenner (1921) recognized that the soil materials in the area around Mt Gambier were very permeable and it seemed likely that a considerable amount of rainfall could recharge the unconfined aquifer in the Gambier Limestone and this groundwater could be a source of lake water. He also recognised the possibility that confined water, found in the deeper sand aquifer (see Figure 2) might find its way into the lake.

Lake water level has varied by 8 m since detailed water level records were first kept in 1885 as shown in Figure 3. Pumping of water for the township of Mt Gambier commenced in 1884 from a shaft dug at the edge of the lake. A fall in water level of the lake since 1912 is one of the reasons for the water supply pumps being shifted several times since that date.

Fenner (1921) showed that there was a strong correlation between cumulative rainfall and lake level. This was interpreted to mean that rainfall determined the level of water in the unconfined aquifer in the Gambier Limestone surrounding the lake, and this in turn determined lake level. This concept was investigated further, with more data, by Ward (1941) who agreed with Fenner'sconclusions

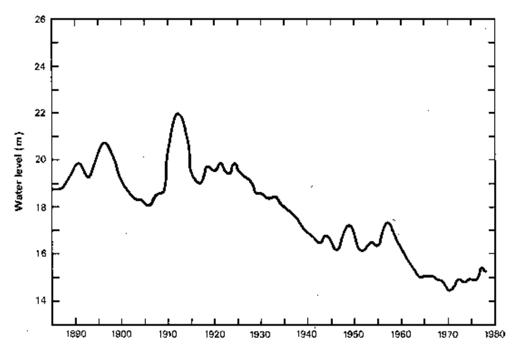


Fig. 3. Variations in Water Level of Blue Lake.

Ward attempted to use this technique to assess the importance of inflow from the unconfined aquifer, but was unable to do so.

The agreement between lake level and cumulative rainfall is not without discrepancies. Beaney (1957) found that the correlation coefficient between these was 0.85 but Ward (1941) suggested that the radical change in land use of the area surrounding Mt Gambier (from native vegetation to pastures and cropping and later to a considerable area of *Pinus radiata* forest) may have altered water loss by transpiration and hence local recharge. This, in turn, may have had an effect on lake level.

From very limited data Ward (1941) estimated the volume of the lake to be 8000 x 10^6 gallons (36 x 10^6 m^3). This estimate was confirmed by Tamuly (1970) who used a Department of the Interior bathymetric map, the survey work for which was carried out in the late 1960s. Tamuly computed that the volume held in the lake at this time was 36.8 x 10^6 m^3

Tamuly (1970) and Turner (1979) obtained detailed temperature and chemical data for the lake. The lake is thermally stratified each summer, with the development of a thermocline commencing in November. The thermocline becomes progressively deeper as stratification develops. In April-May the lake undergoes complete mixing and remains isothermal until the renewal of the stratification.

Tamuly (1970) recognised the possibility of using the difference in temperature between water in the lake and that of surrounding groundwater to determine the amount of water flowing through the lake, a possibility recognised by Fenner (1921) and Ward (1941), but his energy budget measurements were not sufficiently accurate. Waterhouse (1973) showed that nitrate concentrations many times higher than the World Health Organisation limit for drinking water occurred in some portions of the unconfined aquifer surrounding the lake. Recognition that considerable inflow from the unconfined aquifer to the lake could occur led to concern that such groundwater might affect the long term viability of the lake as the sole source of Mt Gambier's water supply and as a tourist attraction.

The water balance of the lake is simplified by the absence of significant surface inflow and the approximate equality of precipitation and evaporation. To estimate the amount of water flowing into the lake from groundwater the tritium budget of the lake was evaluated (Turner 1979; Turner, Allison & Holmes 1984). Tritium is a naturally occurring radioisotope of hydrogen, and measurable differences in its concentration between groundwater and lake water enable estimates of groundwater inflow to be made. These workers showed that total groundwater inflows to the lake fell within the range 5.0-6.5 x 10^6 m^3 per year - about one sixth of the volume of the lake and about equal to the amount withdrawn by pumping each year in the late 1970s. Measurements of other naturally occurring isotopes, deuterium and oxygen-18 were used to semi-independently confirm this estimate of inflow.

Unfortunately these isotope measurements could not be used to differentiate between inflow to the lake from the confined and unconfined aquifers. The confined aquifer was found to have a head 9 m above the lake surface withiN 100 m of the lake, indicating the possibility that much of the groundwater inflow could be from the confined aquifer Although the evidence is somewhat conflicting, a detailed study of various aspects of the chemistry of confined and unconfined groundwater and lake water suggests that much of the groundwater entering the lake originates in the unconfined aquifer (Turner *et al.* 1984). These workers developed a simple model which predicts the changes in nitrate concentration with time in the lake. The water balance parameters which give the best fit to the existing data are:

(i) a natural groundwater inflow of 5.5x10^6 m^3yr^{-1} which has been relatively constant in time and made up of 90% water from the unconfined acquifer and 10% from the confined, and

(ii) an additional groundwater inflow solely from the unconfined aquifer when withdrawals by pumping exceed the natural groundwater inflow. The amount of extra inflow induced by pumping is approximately equal to the difference between the amount pumped and the natural rate of groundwater inflow.

Before the pumping became a significant component of the water balance of the lake, the natural groundwater inflow displaced an approximately equal volume of water into the unconfined aquifer down-gradient of the lake. This is evidenced by oxygen-18 and deuterium concentrations comparable with those in the lake being observed in a bore in the unconfined aquifer downgradient of the lake. Pumping has an insignificant effect on lake level because the high transmissivity of the Gambier Limestone in the vicinity of the lake does not allow a measurable cone of draw-down to develop. Thus lake levels are controlled by water level in the unconfined aquifer.

CHEMISTRY

(i) Nitrate concentration.

Prior to 1970, analyses for nitrate in water samples were unreliable due to poor analytical techniques. Reliable data collected since that time show that mean annual nitrate concentrations have increased from 12 g m^{-3} to 16 g m^{-3}. It is thought that this increase resulted from withdrawals in excess of the natural groundwater inflow rate. This led to increased inflow from the unconfined aquifer, the water of which has relatively high nitrate concentrations. Further withdrawals from the lake will have to be carefully monitored to ensure that nitrate concentrations in the lake do not reach unacceptably high levels. The World Health Organization suggested I i mil for nitrate in reticulated water supplies is 45 g m^{-3}.

(ii) Colour change and carbonate chemistry.

Tamuly (1970) suggested that the blue colouration of the lake was caused by fluorescence of dissolved organic matter. In discounting the more widely held theory that the blue colouration is due to Raleigh scattering of light from small, suspended calcite crystals, Tamuly claimed that the lake was always undersaturated with respect to calcite. However, subsequent calculations have shown that quite the reverse is true-the lake is always supersaturated with respect to calcite (Turner 1979).

The concentration of total dissolved solids in both the confined and unconfined aquifer is greater than 500 g m^{-3} while the lake varies between 360 and 460 gm^{-3}, indicating that some of the dissolved material is coming out of solution in the lake, presumably by exsolution of CO_2 followed by precipitation of calcite.

The concentration of dissolved inorganic carbon is lower in the near surface waters in the summer (Tu rner, 1979), presumably due to enhanced exsolution of CO_2 due to the higher temperature of the surface waters during the period of thermal stratification. This leads to increased precipitation of calcite causing the increased turbidity of the lake during the summer as was observed by Tamuly (1970). Material collected from equipment left suspended in the lake during summer and sediments collected from the lake floor have been identified as low magnesium calcite (Turner, 1979). This finely divided calcite is thought to be of the appropriate particle size to absorb all incident· visible radiation except blue. The reason for the rapidity of the colour change from grey to blue remains something of a mystery, but it may be due to the fact that the change occurs at the time thermal stratification is beginning, leading to a rapid increase in the loss of CO_2 and hence a large increase in supersaturation of calcite. A seeding process of unknown mechanism may initiate rapid precipitation of calcite.

(iii) Mechanism of groundwater inflow.

Water from the confined aquifer may enter the lake through a number of discrete openings in the lake floor (see p. 63) or the input may be widely distributed over the lake floor. The following chemical and isotopic data are included as they provide interesting, albeit conflicting information on the mode of entry of water to the lake.

Depth profiles of the ratio of calcium to magnesium concentrations undergo dramatic change during the year (Turner 1979). During winter, when the lake is fully mixed, little variation of the ratio with depth is observed. However, when the lake is thermally stratified, an easily recognisable peak develops beneath the thermocline.

Both the Ca/Mg ratio and the temperature of water in the confined aquifer are higher than those of the unconfined aquifer. Thus the increase in the Ca/Mg ratio beneath the thermocline may be a result of the warmer, more buoyant water from the confined aquifer rising in a plume from discrete sources in the lake floor and being trapped beneath the thermocline. Some of the tritium profiles of the lake show a small decrease in tritium concentration beneath the thermocline; such a decrease is consistent with the presence of water from the confined aquifer (Turner, 1979).

However, water from the confined aquifer has a low nitrate concentration, thus nitrate concentrations should be lower immediately beneath the thermocline than elsewhere in the lake. Such a decrease has not as yet been found. Also the presence of a narrow layer of water supersaturated with dissolved oxygen which occurs immediately below the thermocline when the lake is stratified does not support the 'rising plume' theory. The source of additional oxygen is not known but as the water in the confined aquifer is anoxic a drop in the concentrations of dissolved oxygen would be expected if a plume of confined aquifer water was trapped below the thermocline. An understanding of these conflicting observations awaits further investigation.

BIOLOGY

Blue Lake is an oligotrophic (non-polluted) lake and as such supports a considerable diversity of aquatic life although individuals of a species are generally only present in very small numbers. Bayly & Williams (1964) state that open water plankton are very scarce and total productivity is low. Biological growth in the lake is probably limited by phosphorus. The total nitrogen to total phosphorus concentration ratio in the lake water (N,:P,) is usually about 50:1. Healey & Hendzel (1980) suggest that a Nt:Pt ratio-greater than 30:1 is indicative of severe phosphorus limitation on phytoplankton growth. Nitrogen and photo reactive light, the main potential growth-limiting factors other than phosphorus, are both available in abundant supply. The lake has a total nitrogen concentration of about 5g m^{-3} and a Secchi depth[1] of between 12 m (summer) and 16 m (winter), (compared with Secchi depth in Mt Bold Reservoir which rarely exceeds 2 munpubl. E. & W.S. Dept data). Data from Golterman (1975) would tend to indicate that whilst algal production should be low, the concentrations of total phosphorus in the lake (0.01-0.15g m^{-3}, unpubl. E. & W.S. data) should support a standing algal crop with a chlorophyll-A concentration of 0.005-0.1g m^{-3}. On the few occasions that chlorophyll concentration has been measured in the lake it has been less than 0.002g m^{-3}. Thus there is some evidence to suggest that there may be other limiting factor(s) affecting algal growth there.

The more common algal genera identified in the lake water are *Closterium, Synedra, Glenodinium* and *Surirella.* Filamentous green algae including *Rhizoclonium* sp, *Ulothrix* sp. and *Zygnema* sp. have been identified growing on rocks at the edge of the lake and a blue-green algal mat is growing on the pontoons of the pumping platform.

[1]A measure of turbidity or clearness of water. A white disc is dropped into the water, and the depth at which it disappears is termed the Secci depth.

The zooplankton consist mainly of calanoid and cyclopoid copepods but the numbers present are generally very low (less than 1000 per m^3). The greatest concentrations of zooplankton in the lake are often found at depth (50-70 m) whereas zooplankton in most Australian waters are usually found at shallower depths (0-20 m) (P. J. Suter-pers. comm.1981).

There are no records of fish in the lake prior to about 1978. Since that time schools of native trout have been sighted on numerous occasions. In 1979 the largest fish sighted was about 50 mm long but by 1981 the largest fish were nearly 200 mm long. This may indicate that a change has occurred in the food chain in the lake to sustain this new population. This theory is supported by further qualitative observations-within the past eight years there has been a noticeable increase in algae growing on the rocks at the water's edge near the pumping pontoon and the algal mat on the pontoons has become established.

The lake also supports populations of yabbies and long necked tortoises. Some species of aquatic birds are known to breed in the lake crater.

LAKE BONNEY

Lake Bonney, located about 8 km southwest of Millicent, is the largest freshwater lake in South Australia - about 23 km long and up to 4 km wide. Although only shallow the lake has a volume of about 10^8 m^3 at the present controlled water level. It is thought to have been discovered by Charles Bonney in 1839 (Sheppard, 1941). It is situated between Woakwine Range, a Pleistocene stranded coastal dune range to the east and a complex of Holocene Semaphore Sand dunes overlying eroded Pleistocene dunes to the west. The lake floor consists of Pleistocene S1 Kilda Formation estuarine and lacustrine clays with areas of bare Gambier Limestone that underlies the St Kilda Formation.

Originally Lake Bonney formed part of a series of shallow coastal lagoons, swamps and lakes that extended from Mullins Swamp (7 km north of Southend) to Bucks Lake (adjacent to Carpenter Rocks). Woods (1862) estimated that in the early 1860's the lake was 40 km long, but in about 1850 much of the lake had dried up. He describes it as surrounded by level flats covered with black mud, limestone and shells, and with only one or two fresh brackish water inflowing streams, He also commented that there appeared to have been a gradual decline in water level since white settlement in the area.

Natural surface inflows to the lake include Benara Creek which drains some areas of swamp to the east of Woakwine Range and at least one spring fed stream to the west of the lake. During very wet periods the lake may have received overflow water from Lake Frome to the north. Lateral seepage from the swamps of the Mt Muirhead flats through the base of Woakwine Range probably helped maintain a relatively stable lake level at this time. Natural outflow from the lake was by overflow to Bucks Lake to the south and eventually to the ocean near Cape Banks. This would have occurred only during very wet periods when the lake level exceeded 2.3 m AHD (Glover 1975), The deepest portion of the floor of the lake is approximately-2.7 m AHD.

Man has significantly altered the hydrology of the lake by a number of actions. In a 20 year period from 1864, the Mt Muirhead Flats drainage scheme was constructed. This included cutting three major drains through the Woakwine Range (Roe, 1969):

Narrowneck, draining to Lake Frome north of Lake Bonney -1864; Milne's Gap, draining to Canunda swamp north of Lake Bonney -1867; and English's Gap, draining to Lake Bonney - 1867

The scheme, which drained about 40000 h of land and also included an outlet from Lake Frome to the sea at Southend, probably had a profound effect of the hydrology of this area though there are few records to show this. Lake levels probably fluctuated more rapidly and between greater extremes, and probably natural outflow from Lake Bonney to the ocean occurred more often than at present.

From 1942 up to 9 X 10^3 m^3 per day of effluent from a pulp mill at Snuggery has been discharged to the lake via English's Gap drain. The volume of effluent has increased with expansion at the original mill and the establishment of a second mill in 1960, from 9 x 10^3 m^3 up to about 40 x 10^3 m^3 per day. The continuous inflow of water to the lake caused the winter levels to increase and in 1958 the Engineering & Water Supply Department cut a channel through the Holocene dune system to replace the natural outlet to the south. This unregulated channel caused a very rapid draining of the lake-the water level dropped about 25 m in only a few days (Glover 1975). This action was taken to facilitate the flow of effluent from the existing and the then proposed pulp mill to the sea and to drain an area of potential pasture land on Canunda Flats. When the 1958 channel was closed by a sandbar there were complaints that the rising lake level was flooding pasture land created by the draining. This led, in 1972, to the Engineering & Water Supply Department constructing a regulated outflow channel. At this time it was announced that whenever possible the level of the lake would be maintained between 0.82 m AHD and 1.72 m AHD. The maximum and minimum recorded levels in the lake prior to 1958 were 1.1 m AHD (1914) and 3.2m AHD. Since 1958 the range of lake levels has been between - 0.1 m AHD (1960) and 2.15m AHD (1972).

The salinity of the lake ranges between 1700 g m^{-3} and 4700 g m^{-3} (unpubl. E. & W.S. Dept data, 1972-80), and varies quite rapidly in response to hydrologic changes, particularly the volume of influent water other than pulp mill effluent. The combined pulp mill effluents have a salinity of approximately 1100 g m^{-3} while the other major natural inflows have salinities of the order of 500 g m^{-3}

An approximate water balance for Lake Bonney during the summer months can be estimated as there are minimal ungauged surface inflows during this period. Evaporation for the period November-April is estimated as 550 mm (Glover 1975). Over the same period, the water level of the lake falls by approximately 700 mm. These approximate data indicate that groundwater does not playa dominant part in the water balance of the lake, although groundwater levels immediately east of the lake show a potential for groundwater inflow. Glover (1975), from limited data, postulated a lateral seepage loss through the coastal sand dune of 40 mm yr^{-1}. As the variations in salinity show, surface water inflows form the dominant component of the water balance of the lake.

Samples taken in January and March 1933 indicate that the salinity of the lake water was considerably lower than it is at present (Average salinity of 1933 samples 1320 g m^{-3}-unpubl. Dept. Mines & Energy analyses; average salinity for January-March 1973-80, 3500g m^{-3}-unpubl. E. & W.S. Dept. results). This increase is almost certainly due to the radical change in the water balance of the lake which occurred following construction of the outlet regulator. It would appear that throughout its history the discharges from the lake both natural and man-induced, have been sufficient to ensure that any salt build-up due to evaporation has not had a significant effect.

Concern was expressed about pollution of the lake by the pulp mill effluents as early as 1945 (Nature Conservation Soc. 1976). Complaints were made that suspended solids in the effluent (mainly wood pulp) were causing the water in the lake to become turbid. A further deterioration occurred when the second pulp mill was established, resulting in the discharge of a highly coloured, turbid and malodorous effluent. The colour resulted from tannins and lignins extracted from the timber by the sodium bisulphite pulping process. By 1970 approximately 22 tonnes per day of suspended solids were being discharged by the mills. The majority of this was fine cellulose fibre which, because of the prevailing south-west winds, was deposited in huge mats on the northeastern shore of the lake in the vicinity of the once popular recreation area, Picnic Point. Public outcry at this pollution led in 1972 to an agreement between the Government and the companies to install effluent treatment facilities to limit the discharge of suspended solids to less than 2 tonnes per day per mill. The average total suspended solids load since that time has been about 2-3 tonnes per day (Nature Conservation Soc. 1976). This has led to a marked improvement in the appearance of the northeastern shore of the lake, but has not affected the main problem which is the intense brown colour of the lake water.

The problem is now essentially one of aesthetics because the lake supports a wide variety of aquatic life, and the water is not toxic to plants (Glover 1975). A large number of aquatic species has been identified as living in the lake (Glover 1975), but only a few of those species occur in large numbers. These include 'blood-worms'-larvae of *Chironomus australis,* molluscs *Coxiella confusa* and *Potamopyrgus pattinsoni.* At least six species of fish have been recorded in the lake in the past decade, as have long necked tortoises and eels. Glover (1975) also lists 34 species of aquatic birds identified on or near the lake between 1971 and 1975. An earlier report (Ey 1944) indicated that huge colonies of white ibis, straw necked ibis and nankeen night-herons nested on islands on the lake. Although Glover (1975) demonstrated that the combined pulp mill effluents are toxic to some aquatic fauna there is no direct evidence that the pollution of the lake water has caused the decline in numbers of some genera or the apparent extinction of the other species such as mullet (Glover 1975). It is likely that the change in the hydrologic characteristics of the lake have had a more profound effect on the flora and fauna than any other factor. These effects could range from the loss of habitat for breeding (by the lake level being controlled) to the new outlet structure preventing migration of fish from the sea into the lake. However, secondary effects of the discharge of effluent to the lake, such as reduction in the depth of the photic zone by the intense colour and high suspended solids content and reduction of the dissolved oxygen content, particularly in calm weather, in the vicinity at the effluent inlet drain, are almost certainly havi ng some effect on the flora and fau na at the lake.

VOLCANIC LAKES WITH LIMITED INTERACTION WITH GROUNDWATER

The lakes in this category are Brownes, Valley and Leg-of-Mutton Lakes in the Mt Gambier complex and Lakes Leake and Edward in the Mt Burr volcanic block east of Millicent (see Figure 1). It is also understood that at times a shallow lake has appeared in the small crater on the western flank of Mt Schank.

Timms (1974) describes Valley Lake and Lakes Leake and Edward as shallow maars with flat floors and steeply shelving littoral zones, although as Fenner (1921) points out, there has been considerable divergence of opinion over the questions of the number, extent and processes of formation of the Mt Gambier craters.

All the lakes of this category, with the exception of Valley Lake, have floors and walls composed entirely of volcanic materials. The northeastern wall of Valley Lake consists of a bare limestone "cliff similar to, but smaller than, those surrounding Blue Lake. Table 1 details the basic physical characteristics at these lakes together with some details of their water chemistry together with the same data for Lake Bonney and Blue Lake for comparison.

LAKES LEAKE & EDWARD

Ward (1917) recognised that these two lakes would have no inflow from regional groundwater as their surface levels were above the potentiometric surface of both the confined and the unconfined aquifers. He concluded that they were formed by local

Table 1 PHYSICAL CHARACTERISTICS OF SEVERAL LAKES

Lake	*Max. depth Zmax (m)*	*Surface area (ha)*	*Catchment to lake area ratio*	*Salinity (gm ^{3})*	*pH*
Lake Leake	4.5*	64	6.3	1150-2210	8.3-88
Lake Edward	7	29	6.7	705-2140	6.7
Valley Lake	16	28	3.6	695-770	8.2-89
Browns Lake	1	1	10	2800	8.9-9.8
Leg-of-Mutton Lake	dry	dry	10	2000-3000	
Lake Bonney	3	6400	8	3040-5200	82-8.5
Blue Lake	72	71	1.5	360-460	81-84

Data derived from Ward 1917, Bayly & Williams 1964, Tamuly 1970, Timms 1974, Glover 1975, and unpublished E. & W.S. Department records. Maximum depth and surface area quoted for 1981.

* Ward (1869) quoted depths of 5, and 11m for Lake Leake and Lake Edward respectively

rainfall run-off from the small drainage basins around each lake. Dodson (1974) found that the floor of Lake Leake consists of peats (up to 4 m thick) overlying blue-grey clay It is considered likely that Lake Edward contains similar sediments. Considering that the two lakes are close together, are both maars composed of similar sediments and have the same source of water, the composition of the water in the lakes is surprisingly different

Bayly & Williams (1966) found that in Lake Leake the relative abundance of both cations and anions matched that of rainwater (i.e. Na^{+}>Mg2^{+}>Ca^{2+}>K^{+}·and Cl^{-}>$HC0_3^{-}$>CO_3^{2-}>SO_4^{2-}). However they found that in Lake Edward the concentration of SO_4^{2-} was greater than that of $HC0_3^{-}$ + CO_3^{2-}. This agreed with earlier data quoted by Ward (1917). Bayly & Williams concluded that this difference is due to the greater proportion of pine forests on the Lake Edward catchment (38% of area; Lake Leake, 13.5%). They' considered that the pine trees acted as a more efficient filter for wind blown salt and dust particles of terrestrial origin than the pasture vegetation that covers much of the Lake Leake catchment These particles contain a greater proportion of sulphur than does rain. However they do suggest that other mechanisms including differential uptake of ions by the pines and differences in the amount of biomass (incorporating sulphur) removed from the catchment may be at least contributing to the apparent anomaly. However, a more plausible explanation may be due to different weathering characteristics of the volcanic materials in each crater.

Solomon (1953) reported that salinities in Lake Leake varied between 700 gm^{-3} and 2150 g m^{-3}. Data from Ward (1917) and Timms (1974) indicate that similar variations are

experienced in Lake Edward. These variations probably are a function of rai nfall, evaporation and seepage to the water table.

Timms (1974) studied the benthic fauna of Lakes Leake and Edward and found that Lake Leake supported 12 benthic species while Lake Edward supported 17. He suggested that the difference in diversity could be due to depth, temperature or salinity or a combination of these Timms considered that while Lake Leake was probably polymictic (fully mixed at all times), Lake Edward probably becomes stratified during summer and therefore has a different temperature regime.

Dodson (1974) studied the water level fluctuations and vegetation history of Lake Leake for the period 10000 years BP to the present by analysing pollen samples from sediment cores. He found that immediately prior to 10000 BP, conditions were drier than at present and that after this time conditions became wetter with the wettest period being 6900 BP to 5000 SP. The period 2000 BP to 1300 BP was marginally wetter than the intervening time and since 1300 BP to present, conditions have been relatively dry.

VALLEY LAKE

Valley Lake is the deepest lake in this category with a maximum depth of 16 m. It has some contact with unconfined groundwater as is evidenced by the water level fluctuations in the lake (see Fig. 4). However, as th is record shows, the annual rainfall-evaporation cycle is superimposed on the more gradual water table level changes as exemplified by the level of Blue Lake. This tends to indicate that the influence of unconfined groundwater on this lake is minimal, possibly due to low transmissivity of the limestone in the wall of

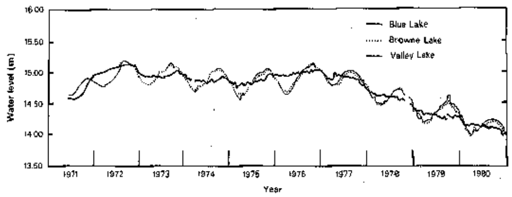


Fig. 4. Comparison of water levels of Valley, Brownes and Blue Lakes.

the lake and the impermeable sediments of the lake floor. This is further supported by the fact that the lake level has been slightly below the level of the water table both to the north and south of the lake during the past 18 months (unpubl. Dept. Mines & Energy data). This indicates that groundwater should be flowing into the lake. However, the relatively low salinity of the lake (about 700-800 g m^{-3}) indicates that both groundwater inflow and outflow are important components of the water balance.

Timms (1974) found that the benthic fauna of Valley Lake was the most diverse of the three lakes he studied with 24 species recorded while Bayly & Williams (1964) found that the planktonic fauna was more similar to that of Blue Lake than either Brownes Lake or Lake Leake. Both Timms and Bayly & Williams concluded that the major differences between the fauna of Valley Lake and Lake Leake are probably due to the difference in salinity.

In recent years problems have been experienced with excessive algal growths in the lake - particularly in the shallow areas. This may be due to a number of factors, including the falling lake level exposing larger areas of the relatively flat crater floor. Nutrients may be leached from these exposed soils creating additional loading on the lake. Also recreational activities carried out in the vicinity of Valley and Brownes Lakes are almost certainly contributing to the nutrient load of these lakes.

When Barton & McElhinny (1980) took core samples from the lake floor sediments they found a 100 mm wide band of creamy white aragonite immediately overlying the volcanic tuff sediments. This aragonite band was overlain by approximately 900 mm of organic muds deposited in a freshwater environment. Although they obtained conflicting radiocarbon dates from the tuff and the aragonite they concluded that the aragonite was deposited quite rapidly at the end of the last eruptive phase about 5000-6000 BP.

The rate of deposition of the organic mud (less than 20 mm per 100 years) appears to be slower than that in Blue Lake where presumably annual bands of carbonate/organic sediments are of the order of 1 to 2 mm wide.

BROWNES LAKE AND LEG-OF-MUTTON LAKE

Brownes Lake, or Crater Lake as it was previously known, is a shallow lake adjacent to Valley Lake. Because of the topography of the crater floor the area of the lake varies greatly with changes in water level. When Europeans first settled in the area (1840) S. G. Henty built stockyards in the area that was later known as Brownes Lake-the area was dry in 1840 as it is now. However, during the intervening period the level in the lake rose to the extent that Brownes and Valley Lakes became one (see Fig. 5). Hill (1972) states that in 1899 the lake was over 6 m deep.

The water level in Brownes Lake closely follows that in Valley Lake. It is not known whether this is due to direct percolation of groundwater through the floor of the lake or by lateral movement of water through permeable materials between these lakes. However, the relatively high salinity and the unusual chemical composition of the water indicate that there is little direct connection of lake water with groundwater.

Bayly & Williams (1964) conclude that the majority of ions in Brownes Lake water have been supplied either from direct rainfall runoff from the catchment or by the weathering of rocks in the surrounding sediments. They claim that the very high levels of potassium and carbonate/bicarbonate ions (123 g m^{-3} and 970 g m^{-3} respectively, compared with 15 g m^{-3} and 310 g m^{-3} respectively, for Valley Lake) are the result of weathering of the volcanic sediments. However, it is difficult to accept this explanation when Valley Lake is surrounded by the similar sediments.

Bayly & Williams (1964) found that Brownes Lake was highly eutrophic with massive blooms of blue-green algae and contained large numbers of planktonic crustaceans. When Bayly & Williams sampled the lake the pH of the water was near the upper limit experienced in natural waters. They considered that pH *per se* probably had little effect on the nature and abundance of flora and fauna in the lake; although there may be

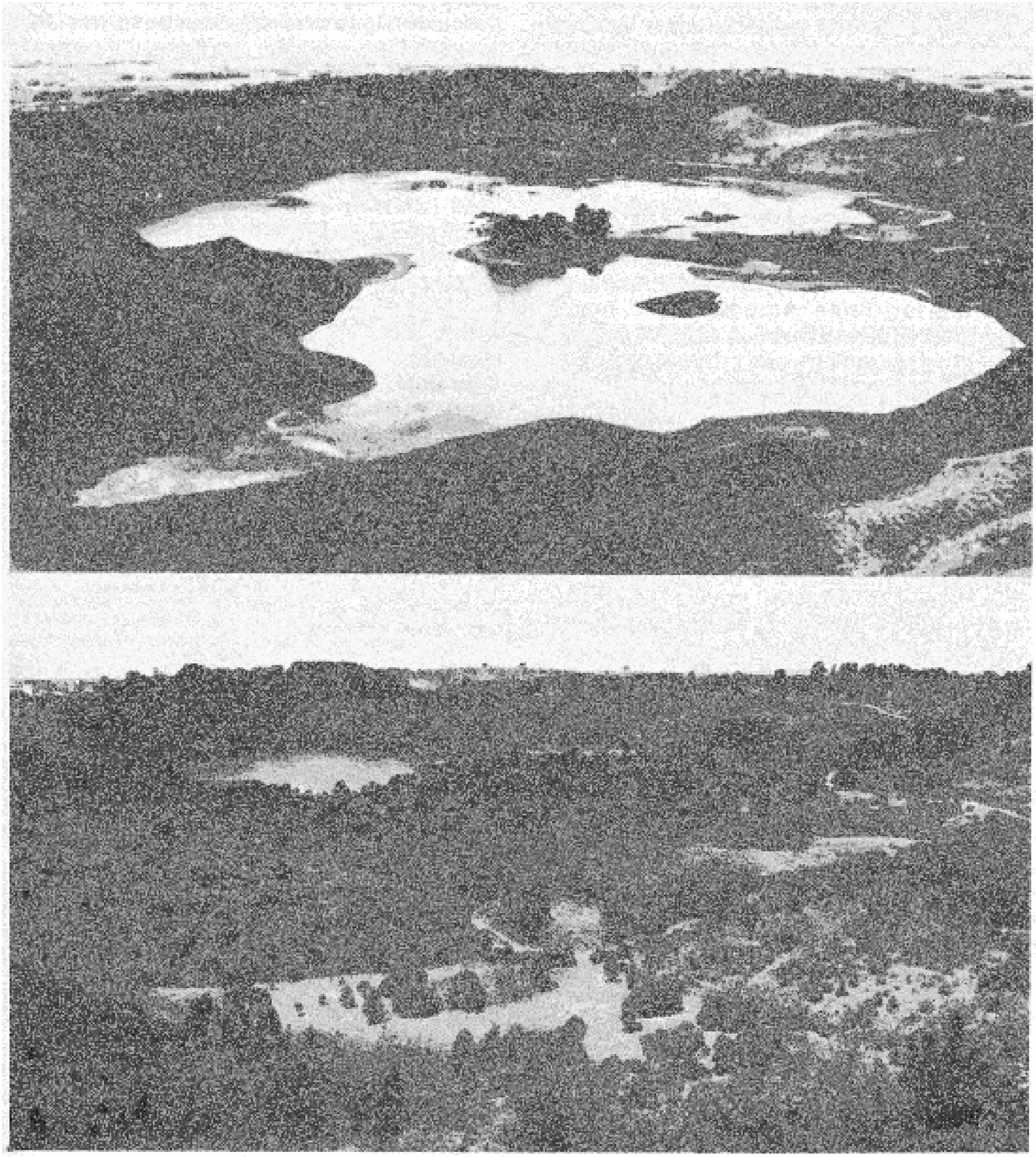


Fig. 5. Comparison of Brownes and Valley Lakes, upper *ca.* 1930; lower 1981.

secondary effects on the phyto- and zooplankton. However it is likely that the high pH was caused by the extensive algal bloom.

Leg-of-Mutton Lake or Middle Lake as it was referred to by Woods (1862), is currently dry because the floor of the lake is above the level of the water table. Presumably it was dry or nearly so when Henty first settled in the Valley Lake-Brownes Lake area. Hill (1972) refers to a report that in 1859 the water level was so low a team of bullocks could not get enough to drink. In the 1890's the lake reached its highest level-then a sizeable lake of the characteristic shape that gave it its name. In 1973 the lake had shrunk to a shallow pond surrounded by reeds.

The water level in Leg-of-Mutton Lake, like that in Valley and Brownes Lakes is controlled by the regional water table and the annual rainfall-evaporation cycle, but, like Brownes Lake, has poor connection with it.

Bayly & Williams (1966) comment that the chemical composition of water in Leg-of-Mutton Lake is principally controlled by the composition of local precipitation with the same order of ionic dominance as rain. However, they did not attempt to explain the differences in composition between Leg-of-Mutton and Brownes Lakes although they acknowledged that they should be similar.

LAKES FORMED AS A RESULT OF KARSTIC ACTIVITY

The South East is one of Australia's more extensive karstic areas (Marker 1975). Enclosed depressions (or dolines) are found over much of the area. Considerable variation of form is observed, ranging from shallow, usually circular, depressions in which swamps occur to depressions having circular sheer walls which extend beneath the water table (Marker 1975). These latter are categorised by Marker as cenotes and it is in these that several of the smaller lakes in the South East are found.

Several workers have recognised that these small lakes, or sinkholes as they are locally known, are associated with structural lineaments running approximately parallel to the coast. They are thought to have formed by collapse of phreatic cave systems. These small lakes are usually deeper around their periphery as collapse normally occurs near the centre, leading to partial infilling with debris in that region (Marker 1975). The walls of these sinkholes often widen beneath the water table. The existing sinkholes show several stages of evolution. The shaft has a very narrow opening <2 m) and bells out to a diameter of greater than 200 m beneath the water table. Further collapse of the walls and roof leads to widening of the opening and the walls become almost vertical as in Little Blue Lake which is almost cylindrical with a diameter of 50 m and a depth of 40 m.

Lewis & Stace (1980) give detailed sketches showing the morphology of twenty sinkholes which are commonly frequented by cave divers. Typically the sinkholes have approximately circular openings with a diameter of 20-65 m. In many of the older sinkholes limestone from collapse of the walls and roof, as well as infill by soil and sand, has made the water quite shallow as in Hell's Hole. Very little is known of the hydrology of these small lakes, apart from the fact that all have their water level controlled by the surrounding groundwater, with the result that it fluctuates 1-2 m seasonally.

It is expected that the sinkholes with openings at the surface of the same diameter as that at the water level shou ld be thermally stratified. This occurs in the case of Little Blue Lake. Allison (1974) found that a strong thermocline developed seasonally at 15-20 m beneath the surface of this lake. Little is known of the thermal regime of lakes which are shallower or have openings at the surface which severely restrict access of solar radiation.

In a study which was a pilot for a more intensive study of Blue Lake, Allison (1974) found that the movement of groundwater into Little Blue Lake was such that the mean residence time of water in the lake was approximately three years. This estimate was made using isotope techniques. Alternatively assessment of groundwater through flow can be made using groundwater gradients and estimates of the regional hydraulic conductivity of the Gambier Limestone (Allison 1974)

Similarities in the groundwater gradients where most of the sinkholes occur, in the diameter of the sinkholes (generally 20-50 m) and in the parent rock *suggest* that there should be considerable throughflow in most of the sinkholes. Such throughflow is important for the maintenance of their water quality as many of them have been used for the disposal of various forms of refuse. For example, many thousand sheep carcases were dumped in Earl's Cave near Allendale following a major bushfire. Fortunately this practice is not as widespread now as it was previously as the public are becoming aware of the possibility of contaminating the groundwater system by such practices.

SWAMPS

The final category of lakes described in this chapter are the ephemeral lakes or swamps for which the South East is well known. During and following wet years, swamps can dominate movement of people, stock and vehicles over the surface, as those who have flown over the Dismal Swamp area in late winter can well believe. However, they usually hold less than 1 m of water and most dry up each summer.

The swamps which occur in the South East are thought to have at least three origins.

Firstly, they may be formed as a result of karst activity with the swamps occurring in shallow, circular depressions (Marker 1975). An example of this type is thought to be the series of swamps known as Marshes Swamp (Dodson & Wilson 1975). Secondly, the swamps of the Dismal Swamp area are thought to have formed in prior channels of the Glenelg River, direction of which was reversed following uplift (Sprigg 1952). After winter, as much as 25% of the area may be covered by water. Thirdly, many swamps have been formed as a result of impaired drainage, being a consequence of the low rei ief of the area. Bool Lagoon, one of the largest swamps in the region, is thought to have formed as a result of the formation of Stewarts Range which impeded the flow of water in Mosquito Creek. Many similar swamps are formed on the western side of the interdunal corridors.

In common with most other lakes of the South East, little detail is known of their hydrology. Shepherd (1958) suggested that enhanced recharge of groundwater would occur if the water level of Bool Lagoon was controlled to maintain 1.2 m of water in the lagoon.

Holmes & Colville (1970) found recharge to groundwater occurred beneath the swamps of Dismal Swamp, but they were unable to make a quantitative estimate of the amount. Most of the swamps dry out each year and, in some cases, considerable cracking of clays forming the base of the swamps occurs. If water flows to swamps following intense rainfall in late summer or autumn, rapid loss of water from the swamps may occur to the underlying groundwater, presumably through the as yet unwetted clay. After the clays become wet, the rate of water movement through the base of the swamps falls to a low level, probably less than 5 mm per day (Holmes & Colville 1970). The fact that a large build-up of salt does not occur in most of the swamps supports the hypothesis that some recharge to groundwater occurs beneath them. A detailed study of the salt concentration of water in the swamps may lead to some insight as to their water balance, but as yet such a study has not been undertaken.

Bool Lagoon is the largest swamp in the South East. Since its level was controlled, the lagoon has become semi-permanent. Together with the surrounding vegetation, it is an important breeding place for approximately 50 species of water birds.

CONCLUSIONS

Although the South East is well endowed with fresh water lakes the ecological balance of these water bodies is very delicate. Most of these waters, unlike many other Australian Lakes, are relatively clear, warm and shallow. These factors make them very susceptible to external impacts, particularly those caused by man. Actions which affect the hydrology or chemistry of these lakes could have profound effects, such as causing a lake to diminish or dry up, cause massive algal blooms or change the whole ecology of an area through habitat modification.

Mistakes have been made in the past in management of some of these lakes and through failing to recognise the full extent of planned actions, and it is to be hoped that recognition of these errors will lead to a better understanding and management of freshwater lakes in the South East in the future.

REFERENCES

Allison, G. B. (1974) Estimation of Groundwater Accession to and Evaporation from a South Australian Lake using Environmental Tritium. *Aust.* J. *Soil Res.* **12**, 119-131.

Barton, G. E. & McElhinny, M. W. (1980). Ages and Ashes in Lake Floor Sediment Cores from Valley Lake, Mt Gambier, South Australia. *Trans. R. Soc.* S. *Aust.,* **104**, 161-165.

Bayly, I. A. E. & Williams, W. D. (1964). Chemical and Biological Observations on Some Volcanic Lakes in the South East of South Australia. *Aust. J. Mar. Freshw. Res.* **15**,123-132.

Bayley, I. A. E. & Williams, W. D. (1966). Further chemical observations on some volcanic lakes in the south-east of South Australia. *Aust.* J. *Mar. Freshw. Res.* **17**, 229-237.

Beaney, H. L. (1957). Mt Gambier Water Supply.

Engineering & Water Supply Dept, South Australia, Report P.O. 7.

Dodson, J. R. (1974). Vegetation History and Water Fluctuations at Lake Leake, South-eastern South Australia. 1-10000 BP to Present. *Aust. J. Bot.,* **22**, 719-741

Ey, A. E. (1944). Birds Breeding in the Millicent District. *Aust.* Om. **17**, 32-37.

Fenner, C (1921). The Craters and Lakes of Mt Gambier, South Austral ia *Trans. R. Soc.* S. *A ust.,* **45,** 169-205.

Glover, B. (1975). Lake Bonney (S.E.) Ecological Study. Engineering & Water Supply Department Report Ref. 75/7 (restricted).

Golterman, H. L. (1975). 'Developments in Water Science - Il Physiological Limnology.' (Elsevier, Netherlands).

Goyder, G. W. (1866). Evidence presented to a Parliamentary Standing Committee. South Australian Parliamentary Papers 86 and 126 of 1865/66

Healey, F. P. & Hendzel, L. L. (1980) Physiological Indicators of Nutrient Deficiency in Lake Phytoplankton. *Can. J. Fish. Aquat. Sci.* **37**,442-453.

Hill, L. R. (1972). Mt Gambier. The City Around a Cave: A Regional History. (Investigator Press, Adelaide)

Holmes, J W. & Colville, J. S. (1970) Grassland Hydrology in a Karstic Region of Southern Australia *J. Hydrol.,* **10,** 38-58.

Lewis, I. & Stace, P. (1980) Cave Diving in Australia. (I. Lewis, Adelaide).

Marker, M. E. (1975). Lower South East of South Austral ia A Karst Province. *Dept. Geogr. & Environ. Stud. Univ. Wittwatersrand. Occ. Pap.* (13)

Nature Conservation Society of South Australia (1976). Lake Bonney. Second Report and Recommendations of a Committee Established to Examine the Pollution of Lake Bonney, South East, S. Aust. January 1976. (Mimeo)

Roe, G. P (1969). Artificial Drainage. Paper presented to Symposium on Water Resources of the South East of South Australia.

Sheard, M. J (1978). Geological History of the Mt Gambier Volcanic Complex South Eastern South Australia. *Trans. R. Soc.* S. *Aust.,* **102***, 125***-**139.

Shepherd, R. G. (1958). Report on the Hydrology of the Bool Lagoon Area. S. Aust. Dept. Mines unpubl. Rep. *58/67*

Sheppard, J. H. (1941). History of Mt Gambier and the South East District. (Manuscript in Archives of State Library of South Australia).

South Eastern Drainage Board (1980) Environmental Impact Study on the Effect of Drainage in the South East of South Australia, June 1980.

Tamuly, A. (1970) Physical and Chemical Limnology of the Blue Lake of Mt Gambier, South Australia. *Trans. R. Soc.* S. *Aust.,* **94**, 71-86.

Timms, B. V (1974). Morphology and Benthos of Three Volcanic Lakes in the Mt Gambier District, South Australia. *Aust. J. Mar. Freshw. Res.,* **25***,* 287-297.

Turner, J. V (1979). The Hydrologic Regime of Blue Lake, South Eastern Australia. Unpubl. Ph.D. . Thesis, Flinders University, S. Aust.

Turner, J. V, Allison, G. B. & Holmes, J W. (1984) The water balance of a small lake usinq stable isotopes and tritium. *Hydrology* (in press).

Ward, E. (1869). The South Eastern District of South Australia: Its Resources and Requirements. (The South Australian, Adelaide).

Ward, L. K. (1918). The Quality and Source of the Water in Lakes Leake and Edward. Rept. Govt. Geologist, S Aust., 1917, 10-16.

Ward, L. K. (1941) The Underground Water of the South East Part of South Australia. *Geol. Surv.* S. *Aust. Bull. (19).*

Waterhouse, J. D. (1973). The Hydrogeology of the Mt Gambier Area, South Eastern South Australia. Unpubl. M.Sc. Thesis, Flinders University, S Aust.

Waterhouse, J D. (1977). The hydrogeology of the Mt Gambier area. Rep. Invest. geol. Surv. S Aust., 48.

Woods, J. E. Tenison (1862). Geological Observations in South Australia. (Green, Longman Roberts & Green, London).

8: Physical Oceanography

by JOHN. A. T. BYE

INTRODUCTION

The first recorded sighting of the coast of South East South Australia was on 3rd December 1800, when Lt James Grant in H.M. Brig Lady Nelson charted Cape Northumberland and Cape Banks (more probably Cape Douglas according to Cooper, 1953), and outlined the adjacent coastline. The first major survey was led by Nicolas Baudin in Le Geographe during the week 2nd8th April 1802, who travell ing north-westward, observed the major coastal features, which subsequently were named in the first publications of the work of the expedition (Peron 1807, Freycinet 1811). Shortly after this survey, during the week 12th-18th April 1802, Matthew Flinders in HMS The Investigator travelled south-eastward (following his celebrated meeting with Baudin in Encounter Bay) and retained the French nomenclature.

The account of the French expedition (Peron 1807) available to Flinders only contained an abbreviated list of the named features, and he also mistakenly designated an insignificant cape as Cape Bernouilli. Thus no features were given their original correct names on Flinders' chart (Flinders 1814a) and some important features were not named. The Flinders (with Grant) nomenclature however remains on contemporary charts with the notable exceptions that Rivoli Bay is now as originally designated, and Cape Bernouilli has evanesced. Four of the original French names (Guichen Bay, Lacepede Bay, C. Dombey, and C. Rabelais) also gained common usage (Cooper 1953). The only original name conferred along the coast by Flinders was Baudin's Rocks in reference to a cluster of rocks now known as The Black Pigs in Guichen Bay which Le Geographe peremptorally avoided (Cornell 1974)

Observations in coastal oceanography began with these voyages. Baudin on 3rd April 1802, remarked on the strength of the current towards the west in the vicinity of Cape Northumberland (Cornell 1974), and Flinders noted that a small current favored his passage southwards until 14th April, Whereupon near Cape Lannes an opposing northward current was encountered (Flinders 1814b). On the evening of 4th April, a sea surface temperature of 14° Reaumur (17.5°C) was measured in the region of Cape Banks (Peron 1807), and an extended discussion on sea temperatures is included in the expedition records (Peron 1816).

Scientific exploration of the adjacent ocean was probably first carried out from HMS Beagle in 1836. Charles Darwin in his diary for 6th March, on arrival in King George's Sound from Tasmania records "Our passage has been a tolerable one; and what is surprising, we had not a single encounter with a gale of wind. Yet to me, from the long Westerly swell, the time passed with no little misery" (Barlow 1969). HMS Beagle visited South Australia on a later expedition in November-December 1840, and again in January-February 1842. On the former occasion on leaving Backstairs Passage en route for Bass Strait, Commander Stokes observes "On the morning of the 8th, we were obliged to shorten all sail to a very heavy squall from W.S.W., which announced its appearance by a distant roaring, some time before it was seen on the water. These squalls generally succeed the hot winds that prevail at this season in South Australia, coming from the interior" (Stokes 1846).

COASTAL CIRCULATION

The bathymetry off the coast of South East South Australia (Fig. 1) indicates a wide continental shelf to the north, and a narrow continental shelf to the south of Cape Jaffa. The ocean floor slopes downwards from the edge of the continental shelf (the 100 m isobath) to the abyssal plain of the South Australian Basin. The region of wide continental shelf lies within the South Australian Sea (Bye 1976), while the narrow shelf borders the Southern Ocean. Notable

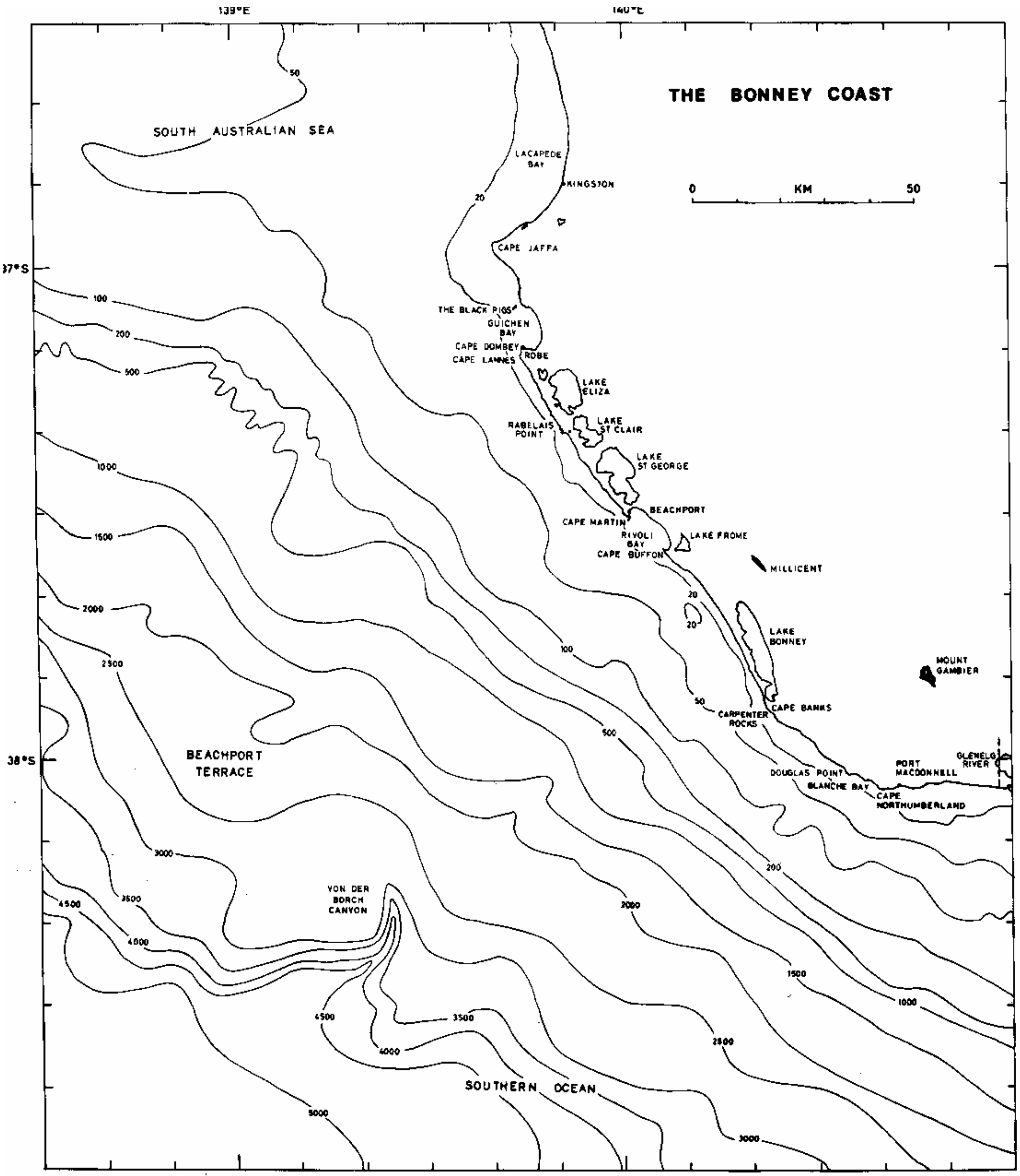


Fig. 1. Bathymetry of Bonney coast. Contours in m. (Contours>200 m courtesy of C. C. von der Borch).

features are a large canyon in the deep ocean which has been called the Von Der Borch Canyon (38° 25'S, 138° 25'E), that lies southeast of the Beachport Terrace (28° S, 139° E), and a series of small identations beyond the continental shelf at 37° 20'S, 139°0'E which was first discovered during the maiden voyage of USGS Oceanographer in 1967 (Von Der Borch, Connoly and Dietz 1970). The shelf edge itself also shows some small scale topography.

This chapter primarily concerns the oceanographic outreach of the South East of South Australia which is the region characterised by the narrow continental shelf, and will be referred to as the Bonney Coast

Early in the history of South Australia, in consideration of the enterprise of the first

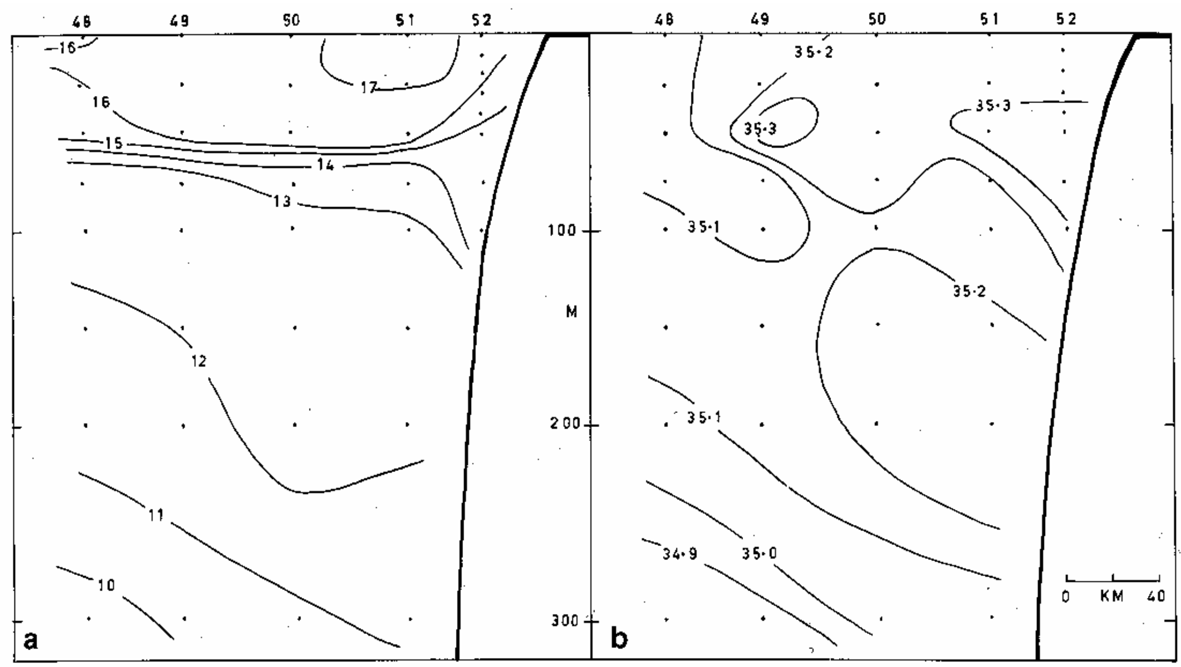


Fig. 2. An oceanographic section normal to the Bonney coast in April 1972 (CSIRO Aust. 1982). (a) Temperature, contours in °C. (b) Salinity, contours in ‰.

explorers, four great coast divisions were proclaimed (S. Aust. 1839) as follows:

Bonneia, Sturtia, Yorke's Peninsula and Eyria, the first referring to the "territory included between the southern part of the eastern boundary of the Province, the Murray, Lake Alexandrina, and the sea" and commemorating Charles Bonney. Lake Bonney also lies approximately midway along the coast of the South East of South Australia.

An oceanographic section (Fig. 2) made by HMAS Diamantina in April 1972 (CSIRO Aust. 1982) normal to the Bonney coast, in which stations for sampling water properties at various depths were occupied about every 40 km, illustrates some important features of the coastal circulation. Firstly, it is clear that there exists a well mixed layer of approximately 50 m depth in which the temperature and salinity values vertically are almost constant. Secondly, the salinity section suggests that the properties found on the shelf extend into the ocean a distance of at least 50 km. Thirdly, the temperature section shows a structure on the continental shelf which can be interpreted as due to vertical motions occu rri ng close to the coast.

The aim of this analysis is to predict the monthly mean temperature and salinity of the coastal waters (which are determined by the circulation in the Southern Ocean), processes within the adjacent coastal regions, and local conditions, and also to understand the evolution of the thermohaline structure of the water column. The primary data are:

(a) meteorological parameters-mean air temperature, rainfall, evaporation rate, and longshore wind stress for all coastal regions which significantly affect the Bonney Coast, and
(b) open sea temperature and salinity distributions adjacent to these coastal regions. These data, in principle, allow temperature, salinity and current distributions to be inferred and compared with observations. For the Bonney Coast, we have monthly values of temperatu re and salinity at a reference station off Port Macdonnell (CSIRO Aust. 1982), results of drift bottle and drift card releases (CSIRO Aust. 1968, Marshallsay and Radok 1972), and also deep sea data (Wyrtki 1971, Bye 1971, 1972, CSIRO Aust. 1982).

THE ANALYSIS

Consider first the coastal currents. The primary generating mechanism is probably the longshore component of the wind stress. The southern coastline of Australia forms an approximate arc with many smaller scale changes of orientation especially along the coast of South Australia. Thus a smoothly varying large scale mean wind field such as is-

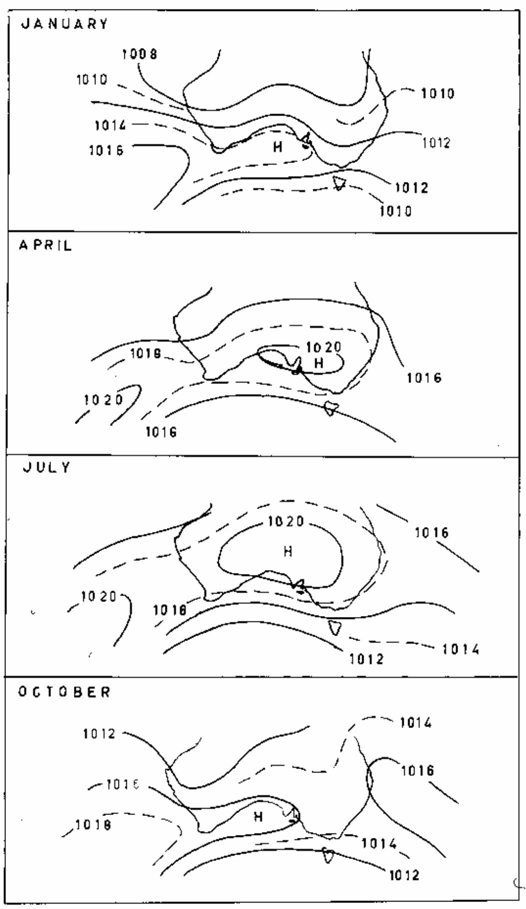


Fig. 3. Mean surface atmospheric pressure for January, April, July and October (Taljaard et al 1969).

depicted by the monthly mean pressure charts (Fig. 3) nevertheless gives rise to significant regional differences in the longshore wind stress. The monthly mean values in general indicate an eastward trending longshore wind stress in winter, and a westward trending longshore wind stress in summer. The Victorian and Kangaroo Island coasts, however, experience longshore wind regimes significantly different from the Bonney coast, owing mainly to their different orientations (Table 1). Thus on the assumption that the water transport of the coastal current is approximately proportional to the longshore stress, the oceanographic implications are that in order to maintain the coastal circulation there must be transports offshore from the continental shelf in the region of eastern Kangaroo Island and the Murray Mouth, and onshore trarolsports across the remaining continental shelf as far as western Tasmania. The remarkable circumstance is that the coastline geography and the prevailing winds combine to make these flows perennial.

The evidence for these transports in the deep ocean has been recorded previously in a programme of classical oceanographic observations south of Australia during the period 1967-1971. This programme led to the

Contours in mb.

Table 1. MEAN MONTHLY AIR TEMPERATURE AT PORT MACDONNELL, AND MONTHLY LONGSHORE STRESS ALONG THE BONNEY COAST (ROBE), THE COAST OF KANGAROO ISLAND (VIVONNE BAY) AND THE VICTORIAN COAST (CAPE OTWAY).

	Mean monthly air temperature for Port Macdonnell[1] °C	*Monthly longshore wind stress*[2] *(positive for eastward trending) N/m*[2]		
		Vivonne Bay	*Robe*	*Cape Otway*
January	18.2	-.032	-.080	-.030
February	18.6	-.034	-.083	-.045
March	17.7	-.021	-.060	-.025
April	14.5	.002	-.017	0
May	12.1	.031	.016	.027
June	10.3	.057	.043	.050
July	9.6	.071	.047	.065
August	10.3	.071	.040	.063
September	11.6	.056	.035	.050
October	13.4	.031	.023	.025
November	14.9	.004	-.004	.007
December	16.7	-.019	-.041	-.022

[1]Estimated from Gentilli (1971).
[2]Estimated from Eyre (1972) and Taljaard et al. (1969).

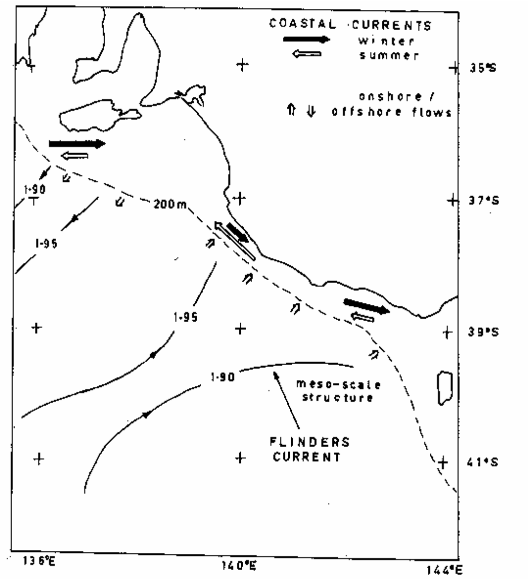


Fig. 4. The surface dynamic topography, relative to 2000 db, for the Flinders Current adapted from Bye (1971) and associated coastal currents in January and July. Contours in dyn. m.

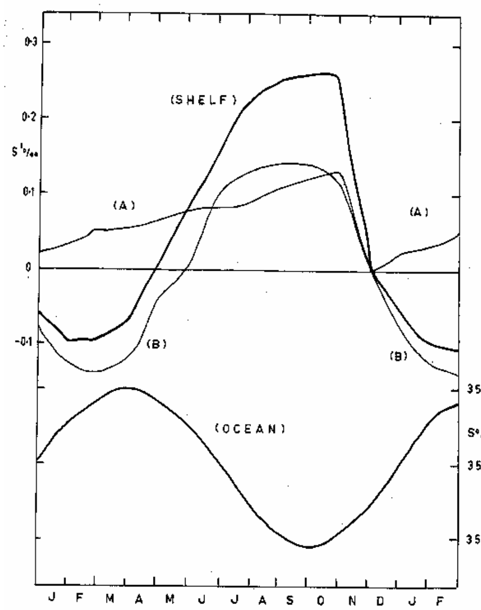


Fig. 5. The annual ocean salinity cycle off Port Macdonnell and the simulated anomaly signal on the continental shelf, which consists of two parts, (A) due to shelf processes, and (B) due to the oceanic salinity distribution.

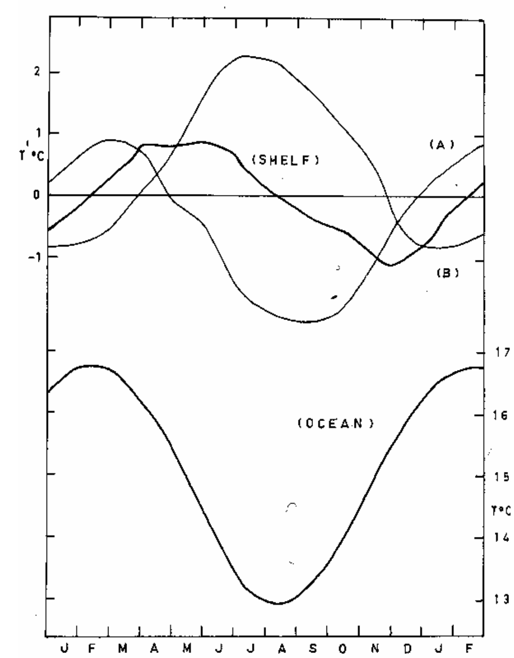


Fig. 6. The annual oceanic temperature cycle off Port Macdonnell, and the simulated anomaly signal on the continental shelf, which consists of two parts (A) due to shelf processes, and (B) due to the oceanic temperature distribution.

mapping of the structure of the Flinders Current which flows westward in the deep ocean. The meso-scale structure of the Flinders Current (Fig. 4) appears to be intimately related to the coastally induced onshore and offshore transports.

This current structure is the basis for the advective changes of water properties on the Bonney coast. Exchange also occurs by horizontal turbulent mixing due to smaller scale gyral circulations, but probably this is of lesser importance. A detailed understanding of the physical oceanography of our region can be obtained from a mathematical simulation of these processes. The calculated anomalies of salinity and temperature on the continental shelf, relative to the adjacent ocean are shown for Port Macdonnell in Figs. 5 and 6

The salinity cycle (Fig. 5) may be interpreted primarily in terms of the mean monthly coastal currents which, in winter flow south-eastwards, and in summer flow northwestwards (Table 1). Thus the positive winter salinity anomaly arises from processes to the north. The two water masses contribute almost equally-water mass (A) which originates in the eastern Great Australian Bight and the South Australian Sea as suggested by Rochford (1957) and Newell (1961), and water mass (B) which is due to on-shelf water transports. In summer, on the other hand, the negative salinity anomaly is due mainly to on-shelf transports to the south (water mass B).

The water temperature is also determined by these processes, together with the exchange of heat with the atmosphere for which the time constant in water of depth 50 m is approximately 50 days. The simulated temperatures (Fig. 6) indicate that the passage of water mass A results in a negative winter temperature anomaly of about 1.5 K, and a positive summer temperature anomaly of about 1 K. Reverse anomalies occur however due to water mass B, and the net shelf anomaly is about + 0.5 K in autumn and about -0.5 K in spring.

Consider now the structure in the water column shown in Fig. 2. Suppose that there are small currents which move water onshore and offshore. Then, along a uniform coast in equilibrium this internal circulation cannot induce any net water or heat transport towards the coast, which acts as a barrier. Fundamental theoretical reasoning (Proudman 1953) however indicates that a stress acting on the surface or the bottom of the ocean gives rise to a transport (the Ekman Transport) which in the southern hemisphere is directed 90° to its left hand side. As a consequence, the no net transport conditions lead to a circulation pattern normal to the coast which would have either of the forms shown in Fig. 7, in which there are three stresses operating,-the bottom stress which is important over the continental shelf where tidal currents are strong (Proud man 1953), the wind stress and an understress by which the atmosphere significantly retards the mean flow in a meandering current (Bye 1980).

Along the Bonney coast, the longshore wind distribution (Table 1) tends to induce a downwelling circulation in winter and an upwelling circulation in summer *(ct.* Fig. 2) as first suggested by Hynd & Robins (1967) and discussed in Rochford (1975, 1977).

Finally, one may ask what effects are produced by events, e.g. storms which occur on time scales much less than that for adjustment of the mean current system (typically about five days in water of depth 50 m). On these shorter time scales, the

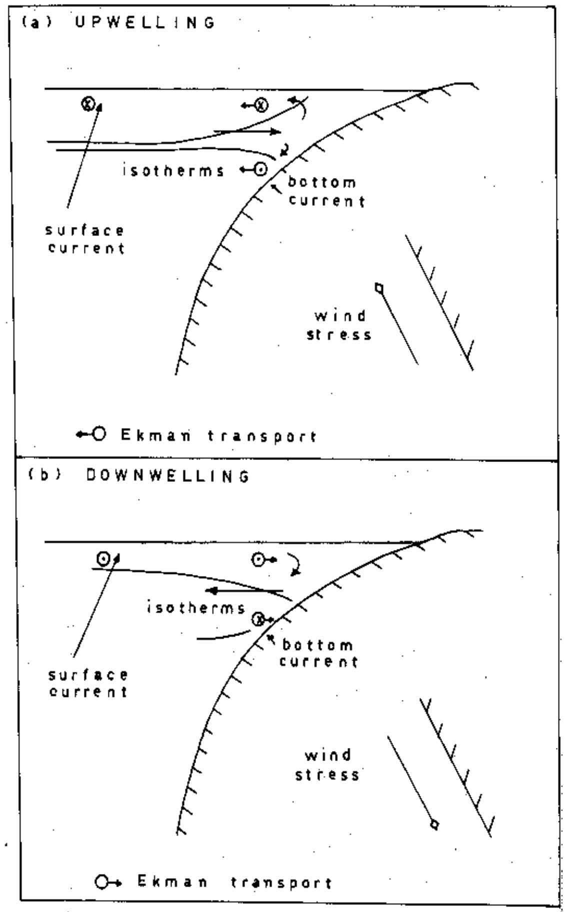


Fig. 7. The vertical circulation for (a) upwelling and (b) downwelling adjacent to a coast in the southern hemisphere.

main response is an oscillation of the isotherms about their mean position. Thus a south-east gale would transiently move colder deep water onshore, and warmer surface water offshore, however these movements would be relaxed after the passage of the gale (Johnson 1977).

DATA

The Port Macdonnell reference station was first used as a release point in a fundamental investigation of surface currents (CSIRO Aust. 1968). During the period September 1958-May 1962 batches of 50 weighted drift bottles were released by passing ships at approximately 38° 12'S, 140° 40'E. The recovery positions and travel times of the drift bottles allowed the direction and minimum current speed (immediate recovery cannot be unequivocably guaranteed on our sparsely populated shores) to be assessed. Travel

Table 2. SURFACE CURRENT DIRECTION DEDUCED FROM WEIGHTED DRIFT BOTTLE RELEASES OFF PORT MACDONNELL'

	1958	1959	1960	1961	1962
January		-	+	-	-
February		-	-	-	-
March		+		-	-
April		+	0	0	+
May		+	+	+	+
June		+	+		
July		+	+	0	
August		+	+		
September	+		-	+	
October	+	0	+	+	
November	-	-	+	-	
December	0	+	-	+	

'Based on records of releases and recoveries of weighted drift bottles given in CSIRO Aust. (1968). Positive indicates an eastward trending current, zero an onshore current, and negative a westward trending current

times for the drift bottles were often 1-2 months, and Table 2 shows the observed surface current directions-clearly there is a strong coherence with the longshore wind stress on the Bonney coast (Table 1). Typical speeds were - 10 cis. which for two months travel time, implies landfalls as far away as Kangaroo Island or the northern coast of east Bass Strait.

In addition, there have been some deep sea releases of drift cards also designed to follow the surface current, for example, a card released at 41 ° S, 132° E was subsequently recovered at Port Macdonnell (Marshallsay & Radok 1972). This observation and other similar card trajectories is consistent with the meso-scale structure of the Flinders Current (Fig. 4).

Monthly hydrographic data off Port Macdonnell have been collected at the reference station (38°10'S, $140^0$41'E) at 10 m sampling intervals in a water depth of 59 m for the period May 1973 and onwards (CSI RO Aust. 1982). The temperature and salinity profiles until April 1978 are presented in Figs3 and 4 of Lewis (1981), and represent an interesting sequence of the annual oceanographic cycles. Notable features are that, (a) the temperature/salinity extrema usually occur in winter and in summer with the approximate values 14°C/35.6%0 and 18°C/35.2%o, ct. the simulated cycles (Figs. 5 & 6), (b) in the summer months the water column is more stratified than in winter, probably reflecting the upwelling circulation, and (c) there is significant supra-annual variability similar to that for the current measurements (Table 2). Some of this variability however may be due to transient events.

Observations of salinity from Robe jetty during the period 1949-1951 (Thomas & Edmonds 1956), where the extreme salinity values were 34.4%0 (August 1950) and 36.2%0 (January 1950), appear to be unrepresentative of conditions in the coastal waters. Surveys of the inshore physical oceanography in Blanche Bay have also been carried out (E & WS 1976, 1977) for the purposes of assessing dispersion from an outfall.

In summary, the general circulation of the Bonney coast is characterised by an oceanographic regime of austere beauty. There appear to be at least three directions for further study. Firstly, it would be of interest to supplement the valuable monthly hydrographic data sets being collected off Port Macdonnell with data of higher temporal resolution so that transient processes can be monitored. Secondly, although the coastal circulation may be essentially homogeneous in structure along the coast, survey programmes would delineate any local anomalies of topographic origin, or possibly due to freshwater outflows.

Pioneering cruises have already been carried out (CSIRO Aust. 1951, Wyllie 1969, Lewis 1982), but an extensive data coverage is necessary before an assessment can be made. Thirdly, the analysis outlined above gives encouragement that the supra-annual variability of the circulation to some extent can be predicted using meteorological data, which in particular indicate a teleconnection between events on the Bonney coast and in the Great Australian Bight.

Table 3. MAJOR TIDAL CONSTITUENTS AT PORTS ON BONNEY COAST								
PORT	M_2		S_2		K_1		O_1	
	g^o	*Am*	g^o	*Am*	g^o	*Am*	g^o	*Am*
Port Macdonnell	326	.13	040	.14	037	.18	010	.12
Beachport	342	.12	049	.13	038	.17	013	.12
Robe	334	.14	039	.15	036	.17	009	.13
Kingston	338	.14	043	.17	040	.19	009	.13
Am = Ampitude in metre: g^o = Phase in degrees Data from NTT (1980)								

TIDES AND WAVES

The major tidal constituents (Table 3) are similar for all ports on the Bonney Coast along the length of which no clear trends are discernible. Thus each tidal constituent travels rapidly along the coast and high water occurs almost simultaneously everywhere. The main local perturbation appears to occur in Rivoli Bay where a delay of about 15 mins is observed. This pattern suggests that tidal waves are reflected by the narrow continental shelf of the Bonney Coast during their propagation along the south coast of Australia, the diurnal tide travelling towards the east, and, east of the South Australian sea, the semi-diurnal tide travelling towards the west (Irish & Snodgrass 1972).

At each port, the amplitudes of the major tidal constituents are similar, and in particular the S2 constituent has an amplitude just greater than the M_2 constituent. This leads to the phenomenon of the dodge tide (Chapman 1892, Easton 1970) wh ich occu rs over much of the South Austral ian coastal waters.

The monthly mean sea level at Port Macdonnell (Fig. 8) has a range of 0.44 m, wh ich is about 2/3 that of the tidal range (Table 2). The cause of this mean sea level variability which is particularly well marked along the south coast of Australia lies with the general circulation over the Southern Ocean. The main conclusion of various studies (Krause & Radok 1976, Provis & Radok 1979) is that mean sea level anomalies occur which are highly coherent over the length of the coast. Provis & Radok (1979) partition the anomalies into storm surges with periods 1-20 days that propagate eastwards at approximately the speed of the meteorological systems, and global surges of longer period which occur simultaneously everywhere. No defi n itive theoretical interpretation is yet available, however it is probable that the global surges reflect changes in the strength of the main oceanic gyre in the I ndian Ocean (of which the Flinders Current forms part), which in turn is responding to changes in the zonal pressure gradient of the sub-tropical anticyclonic belt (Bye & Gordon 1982). The storm surges accompany the individual storms, whose frequency and intensity are also functions of the sub-tropical pressure gradient. The transient changes in the water column (Section 2) complement the storm surges.

There appears to be no instrumental wave data available for the Bonney Coast, although the lighthouse keeper at Cape Northumerland has made a series of visual observations in the period 1957-1978 which are reported in Short & Hesp (1980). The main characteristic is a persistent south-west swell of which the annual height distribution was estimated to be: Calm (1%),0-2 m (31%), 2-4 m (62%),>4 m (6%). The interaction of this swell with the coastal morphology is of fundamental importance to beach processes (Short & Hesp 1980), and new data would be welcome.

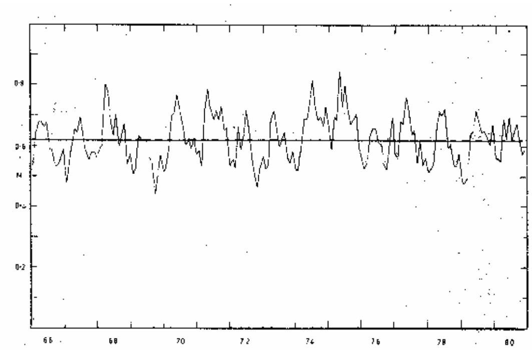


Fig. 8. Monthly mean sea level anomalies for Port Macdonnell for the period 1966-1980 (FUSA 1982).

CONCLUSION

The challenge in coastal oceanography is to assess which factors are importnat to the drama which unfolds on the local opceanographic stage. Such an understanding applied judiciously, yeilds benefits for the fishing industry and opther commercial iffshire enterprises.

The Bonnney coast offers a fine setting for this purpose, being almost equally influenced by continental and oceanic factors. From an historical perspective, the oceaninc influence is symbolized by the French expedition and the continental influence by the British expedition. The true richness of the region lies in the entente between these two imperatives.

REFERENCES

ANTT (1980). Australian National Tide Tables 1981 Australian Hydrog. Pub. **11** (Aust Govt Publ. Serv, Canberra)

8arlow, N. (Ed.) (1969). Charles Darwin's Diary of the voyage of H.M.S. Beagle (Cambridge University Press, Cambridge).

8ye, J. A. T. (1971). Variability south of Australia. *Proc. Inti Mar. Sci. Symp.* 16-17 Aug. 1971, Sydney. pp. 119-135.

Bye, J A. T. (1972). Oceanic circulation south of Austral ia. Antarctic Oceanology II. *Ant. Res. Ser.* **19***, Am. Geop. Un., 95-100.*

Bye, J. A. T. (1976). Physical oceanography of Gulf St Vincent and Investigator Strait *In* C. R. Twidale, M. J. Tyler and B. P Webb (Eds) "Natural History of the Adelaide Region" (Royal Society of South Australia, Adelaide).

Bye, J. A. T. (1980). Energy dissipation by the large scale circulation *Ocean Modelling*, **31**, 12-13.

Bye, J A. T, & Gordon, A. H. (1982). Speculated cause of interhemispheric oceanic oscillation *Nature* **296**, 52-58.

Chapman, R. W. (1892) The tides of the coast of South Australia. *Aust. Assoc Adv. Sci., Rep of Comm. 2.*

Cooper, H. M. (1953). The unknown coast (A supplement) (McAlister, Adelaide).

Cornell, C. (1974). The Journal of Nicholas Baudin (English Translation) (Griffin, Adelaide).

CSIRO Aust (1951). Hydrological and planktological observations by F. R. V. Wareen in south-eastern Australian waters, 1938-39. *CSIRO Aust. Oceanogr. Sta.* List **1**. (CSIRO, Melbourne).

CSIRO Aust (1968). Drift bottle. releases and recoveries in Bass Strait and adjacent waters, *1958-1962. CSIRO Aust. Oceanogr. Stn.* List **78** (CSIRO, Melbourne).

CSIRO Aust. (1982). Hydrographic data bank. (CSIRO, Cronulla N.SW.).

Easton, A. K. (1970). The tides of the continent of Austral ia. *Horace Lamb Centre Oceanograph. Res., Res. Pap. (37)*

E & W.S. (1976). Mount Gambier sewage outfall physical oceanographic studies. November 1974-0ctober 1975 **1**, Surv. Br, E. & W.S. Dept, S. Aust.

E & WS. (1977) Disposal of wastewaters from Mount Gambier. Feasibility studies. E. & W.S. Dept, S. Aust.

Eyre, W. S. (1972). The spherical harmonic analysis of global wind stress field and atmospheric angular momentum. Res. report **6**, Flinders Institute for Atmospheric and Marine Sciences (Flinders University of South Australia).

Flinders, M. (1814a). 'A voyage to Terra Australis'.Charts (Nicol, London).

Flinders, M. (1814b). 'A voyage to Terra Australis **1**,' (Nicol, London).

Freycinet, L. (1811). 'Voyage de decouvertes aux Terres Australes.' Historique (Atlas **II)** (L'imprimerie Royale, Paris).

FUSA (1982). Mean sea level data bank Tidal Laboratory. (Flinders University of South Australia).

Gentilli, J. (Ed.) (1971). Climates of Australia and New Zealand. World Survey of Climatology **13** (Elsevier, Amsterdam).

Hynd. J S., & Robins, J. P (1967). Tasmanian tuna survey report of first operational period *CSIRO Tech. Pap. (22).*

Irish, J. D., & Snodgrass, F. E. (1972). AustralianAntarctic tides. Antarct. Oceano!. II, Antarct. Res. Ser. **19**, *Am. Geop. Un. 101-116.*

Johnson, D. R. (1977). Determining vertical velocities during upwelling off the Oregon Coast. *Deep Sea Res.* **24**, 171-180.

Krause, G., & Radok, R. (1976). Long waves on the Southern Ocean. *In* D. G. Provis and R. Radok (Eds). 'Waves on water of variable depth' (Springer-Verlag, Berlin).

Lewis, R. K. (1981). Seasonal upwelling along the south-eastern coastline of South Australia. *Aust.* J. *Mar. Freshw. Res.* **32**, 843-854.

Marshallsay, P. G. & Radok, R. (1972). Drift cards In the Southern and adjacent oceans. Horace Lamb Centre for Oceanographical Research *Res. Pap* (52), (Flinders University of South Australia).

Newell, B. S. (1961) Hydrology of south-east Australian waters: Bass Strait and New South Wales tuna fishing area. *CSIRO Tech. pap. (10).*

Peron, F. (1807) 'Voyage de decouvertes aux Terres Australes. I' (L'imprimerie Royale, Paris).

Peron, F. (1816). 'Memoire sur la temperature de la mer, soit a sa surface, soit a de grandes profondeurs. L. Freycinet (Ed.) Voyage de decouvertes aux Terres Australes. II Historique', (L'imprimerie Royale, Paris)

Proudman, J. (1953). 'Dynamical oceanography'. (Methuen, London).

Provis, D. G. & Radok, R. (1979). Sea-level oscillations along the Australian coast. *Aust. J. Mar. Freshw. Res.* **30,** 295-301.

Rochford, D. J. (1957). The identification and nomenclature of surface water masses in the Tasman (data to the end of 1954). *Aust. J. Mar. Freshw. Res.* **8,** 369-413**.**

Rochford, D. J. (1975). Oceanography and its role in the management of aquatic ecosystems. *Proc. Ecol. Soc. Aust.* **8,** 67-83.

Rochford, D. J. (1977). A review of a possible upwelling situation off Port Macdonnell, S.A. Rep. (81), Div. Fish. Oceanogr. C.S.I.R.O.

Short, A. D., & Hesp, P. A. (1980). Coastal engineering and morphodynamic assessment of the coast within the south-east coast protection district South Australia. Final rep., Coast Protection Board, Dept Env., S. Aust.

Stokes, J. L. (1846). 'Discoveries in Australia II' (Boone, London).

S. Aust. (1839). S. Aust. Gazette (93) (Adelaide).

Taljaard, J. J., Van Loon, H., Crutcher, H. L. &Jenne, R. L. (1969). Climate of the upper air. Part 1 Southern Hemisphere National Cen. (N.C.A.R., Washington, D.C.).

Thomas, I. M. & Edmonds, S. J. (1956). Chlorinities of coastal waters in South Australia. *Trans. R. Sac.* S. *Aust.,* **79,** 152-166.

Van Der Barch, C. C., Connolly, J. R. & Dietz, R. S. (1970). Sedimentation and structure of the continental margin in the vicinity of the Otway Basin, southern Australia. *Mar. Geol.* **8,** 59-63.

Wyllie, D. V. (1969). Preliminary investigation of offshore ground water seepages in the southeastern part of South Australia. Horace Lamb Centre for Oceanographical Research. *Res.* paper **32,** (Flinders University of South Austral ia).

Wyrtki, K. (Ed.) (1971). 'Oceanographic atlas of the international Indian Ocean Expedition'. (National Science Foundation, Washington).

9: Climate

by C. L. PENNEY

INTRODUCTION

The expansion of agriculture and pastoral production in the South East during the nineteenth century promoted the establishment of the regional centres of Bordertown, Keith, Kincraig-Naracoorte, Penola and Mt Gambier. Winter flooding, however, circumscribed both town and farmland development. The amount and distribution of rainfall through the year helped to determine the pattern of settlement. This chapter examines these and other aspects of the climate of the region.

RAINFALL AND EVAPORATION

The winter track of the cyclonic belt passes, in its eastward movement, over the northern part of the South East. Conversely, the summer track is located further south in the area. This provides the South East at all times of the year with relatively higher rainfalls than other areas in South Australia, except for regions influenced by the topography of the Mt Lofty Ranges (Gentilli 1947; Schwerdtfeger 1976).

Essentially the rainfall characteristics are Mediterranean in that the summers are dry and the winters wet. There is a strong latitudinal variation in the annual distribution of rainfall (Fig. 1), with higher rainfalls being recorded in the south, resulting from the increasing oceanic origin of the rain-bearing winds as their passage becomes less affected by the Yorke and Eyre peninsulas. Typical of the continental situation, rainfall decreases with distance from the coast as the rainbearing winds become drier (Bureau of Meteorology 1974, 1979). In addition to these two major influences, there are more localised effects which are topographically induced. The most important is caused by the Mt Burr Range which dominates the rainfall pattern in the southern region, producing a regional maximum in the mean yearly rainfall of 851 mm at Glencoe Station. A lesser distortion to the pattern is due to the Naracoorte Range, which causes some uplift of the moisture-laden clouds and increases precipitation. Even though the dune ranges are low, they can all cause a rain shadow (Penney, 1980).

The occurrence of rainfall on a seasonal basis (Table 1) follows a latitudinal variation increasing to the south as well as with proximity to the coast. Using this occurrence information and the mean seasonal rainfall totals, it is possible to derive seasonal rainfall intensities. As the largest variances in both rainfall incidence and yearly totals are due to

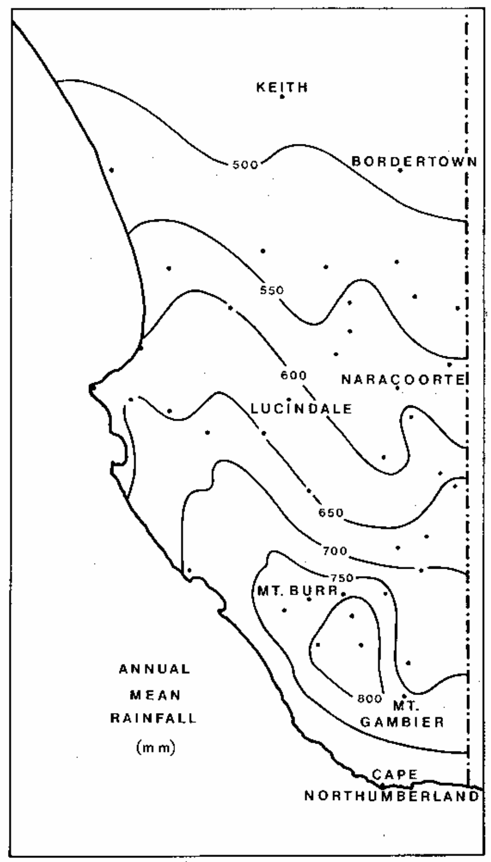


Fig. 1. Mean annual rainfall. (Commonwealth Bureau of Meteorology data: C.B.M.).

Table 1. NUMBER OF RAIN DAYS AND PRECIPITATION EFFECTIVENESS AT VARIOUS STATIONS IN THE SOUTH EAST

Station	Number of rain days	Precipitation effectiveness
Keith	110	32.21
Bordertown	129	34.09
Kybybolite	137	41.28
Naracoorte	130	42.61
Lucindale	126	45.45
Robe	151	45.54
Mt Burr Forest Reserve	176	61.76
Mt Gambier Aerodrome	185	54.98
Cape Northumberland	171	53.46

Table 2. SEASONAL RAINFALL INTENSITY (mm/day)*

Latitude	Station	Summer (D-J-F)	Autumn (M-A-M)	Winter (J-J-A)	Spring (S-O-N)
36°06'S	Keith	4.9	4.5	3.8	4.1
36° 58'S	Naracoorte	4.9	4.6	4.5	4.2
37° 49'S	Mt Gambier Aerodrome	3.4	3.7	4.4	3.6

Data from Bureau of Meteorology, S.A. Tabs elements.

*Seasonal rainfall intensity = Mean seasonal rainfall/mean seasonal number of rain days.

latitudinal change, the seasonal rainfall intensities for Keith, Naracoorte and Mt Gambier Aerodrome have been calculated (Table 2) to demonstrate that influence.

The seasonal rainfall intensities at 'each of these places change primarily because of the different sources of the rainfall at their latitudes. In the north at Keith, rainfall intensities are higher in the summer and lower in the winter. This is consistent with its inland position, which is characterised by summer thunderstorm activity and drier winter rains. Further south at Naracoorte, which is situated in the centre of the South East, rainfall intensity varies little over the year, reflecting milder summer thunderstorm activity and wetter winter rains. Summer thunderstorm activity produces only light rainfalls in the south at Mt Gambier, whilst the winter rainfalls are much heavier than those to the north.

To the agriculturalist of the South East, knowledge of the seasonal rainfall intensity does not provide enough information on the availability of water to decide on the suitability of a particular crop for the area, especially if that crop should need a supplementary water supply by irrigation. They need to know the effectiveness of the rainfall. Thornthwaite (1933) suggested that the 'Monthly Precipitation Effectiveness' could be calculated by:

Monthly Precipitation Effectiveness $= 165\ (r/(t+12.2))^{10/9}$ where r is the mean monthly rainfall in mm, and t is the mean monthly temperature in degrees C. Then monthly values could be summed to produce a yearly value. It was further suggested that these could be used to classify the rainfall climate for a particular region, which may be tabulated as follows:

Code	PE	Climate Type
A	PE > 128	Super-humid climate
B	PE 64 - 128	Humid climate
C	PE 32 - 64	Sub-humid climate
D	PE16-32	Semi-arid climate
E	PE < 16	Arid climate

(after Gentilli, 1972).

The values of the Precipitation Effectiveness for selected rainfall stations are shown in Table 1. Although graziers who have experienced the recent 1981 floods may not agree, Keith is classified as having a "near" semi-arid climate. The rest of the region fits into the sub-humid climate classification, though areas near Mt Burr can almost be classified as humid.

Such a classification system is far too general for the agriculturalist who needs to know how much of the rainfall is lost due to evaporation and how much is therefore avai lable to g row his crops. As each vegetative

Table 3. MEAN TOTAL YEARLY (mm)

Station	*Rainfall Length of**Record*	*Rainfall From Long Term Records*	*Rainfall*	*Pan Evap**	*Rainfall Deficit*	*Wind Run*
				For the Length of Record		
Keith	1975-1976	472	453	1479	1025	60973
Western Flat	1974-1976	n/a	536	1190	653	n/a
Morambro Ck.	1974-1976	574	570	1529	959	n/a
Kybybolite	1967-1976	553	573	1450	877	74224
Noolook	1975-1976	652	704	1489	785	72477
Struan	1975-1976	*n/a*	579	1351	771	n/a
Conmurra	1972-1976	693	593	1398	805	n/a
Konetla	1971-1976	n/a	694	1486	792	n/a
Wattle Range	1974-1976	n/a	686	1287	601	n/a
Mt Gambier	1966-1976	709	686	1490	804	103398

*Measured by US. Class A Pan (Schrale 1977)

**Data from Bureau of Meteorology Tabs.

Table 4. FINDING THE START AND END OF THE GROWING SEASON USING TRUMBLE'S ASSUMPTION THAT MEAN MONTHLY RAINFALL/MEAN MONTHLY PAN EVAPORATION IS >03

Month	Mt Gambier	Kybybolite	Keith
March	0.19	0.16	0.10
April	0.61	0.52	0.25*
October	0.55	0.52	*
November	0.32	0.28	0.21
December	0.22	0.14	0.08

* Due to only 2 years of records, seasonal; variation

covering will have its own evapotranspiration rate, the best indicator of the 'evaporative power' of the air is the pan evaporation. This is measured using a U.S. 'Class A' Evaporation Pan. Since pan evaporation is a function of wind speed, saturation humidity deficit, and energy available for heating, the measured value can show localised effects, though these can be minimised by effective siting. Due to an extensive instrumentation programme initiated by the Department of Agriculture and Fisheries in 1974 (Schrale 1977) much more information is available for this area than for most other settled areas in the state (Table 3).

Since the length of record of the evaporation measurements is fairly short for most of the stations, a high degree of confidence cannot be placed in these data. For this reason, the long term mean-yearly rainfalls have also been presented, to give an indication of the 'typicality' of the length of record. Most prove to be typical, with the notable exception of Conmurra with a variance of 100 mm. The resultant pan evaporations appear to vary randomly across the region and highlight the localness of the measurement. As most of the rainfall deficit occurs during the summer months, crops grown during this period require a supplementary water supply, especially in areas in the north where potential evaporation far exceeds the natural rainfall.

Trumble (1939) has shown that a monthly ratio of rainfall to potential evaporation of 0.3 is a minimum requirement for the growing of agricultural crops in southern Australia. The period for which this ratio exceeds 0.3 was shown to correspond almost exactly to the length of the agricultural growth season. These ratios have been calculated for Mt Gambier, Kybybolite and Keith, to observe how the length of the growing season varies with latitude (Table 4). The data presented for Keith are for only two years and may therefore be affected by a seasonal variation. The growing season as defined by the Precipitation Effectiveness extends from late March-early April to late October-early November, after which crop growth could only be achieved if the ratio could be made greater than 03 by the addition of a supplementary water supply. Areas to the south have a longer growing season, if only natural rainfall is relied upon, than those to the north.

SOLAR RADIATION

The availability of solar radiation data of reasonable quality within South Australia is meagre. Accordingly, there is a lack of long term records and reliance must be placed on sunshine hours data collected from Campbell-Stokes Sunshine Recorders. The sunshine recorder monitors the length of time during the day, when direct radiation exceeds between 0.2 to 0.4 cal/cm^2/min depending upon the particular recorder (Met. Off. 1969). During the summer months, the number of sunshine hours more closely represents the total incoming radiation, while the winter value does not have a simple direct relationship.

Even if sunshine hours data are used, there are only two recording stations in the South East, Kybybolite and Mt Gambier. The Mt Gambier station is slightly better endowed because it is also the sole recording station of global and diffuse radiation. Using the number of sunshine hours recorded at Adelaide as an example of a lower latitude station (Table 5) it can be seen that the number of sunshine hours decreased with increasing latitude. Since the length of the day varies little in this small latitudinal variation from that in Table 5, then the decrease in the number of sunshine hours must be attributable to an increase in cloud cover, as a decrease in incident intensity could not cause the observed differences. Since the number of rain days increases with increasing latitude this reason seems acceptable.

If the Kybybolite records are taken as a mean for the region, direct radiation only exceeds the threshold range of the Campbell-Stokes Recorder for 53% of the available number of hours of the day for the year. From this estimate it is possible to judge the suitability of a certain crop for the area. It must be remembered that this is only an estimate and that full measurement of the radiation fluxes as done at Mt Gambier is needed to give the full solar radiation pattern. The Mt Gambier measurements naturally show Similar characteristics to the number of sunshine hours but also give further information. As the Campbell-Stokes Recorder only measures direct radiation nothing can be inferred about diffuse radiation, the other component of global radiation. Diffuse radiation becomes most important in winter, when at Mt Gambier it is as large as 56% of the direct rad iation. I n such circumstances, the number of sunshine hours cannot be used to predict the amount of energy available for plant growth.

WIND DIRECTION

Despite the climatic importance of wind data, most meteorological observing stations In the South East do not take continuous

Table 5. SOLAR TABLES.

Station		*Mean Daily* *Adelaide RO*	*Kybybolite*		*Mt Gambier (Aero)*	
Length of Record		1882-1976	1966-1978	1966-1979	1969-1978	1976-I978
Month	*Length of** day in hours*	**of sun-shine hours #*	**of sun-shine hours #*	**of sun-shine hours#*	*Global rad-iation (MJm-^{2}) ##*	*Diffuse radiation (MJm-^{2})##*
January	14.4	10.0	9.4	9.2	24.04	8.33
February	3.4	9.2	93	80	2187	651
March	12.2	7.3	75	71	1593	684
April	110	60	55	5.1	10.72	576
May	10.0	4.8	4.6	4.4	777	4.14
June	96	4.2	40	4.1	6.31	3.53
July	10.0	43	4.4	42	6.87	3.67
August	11.0	5.3	5.3	51	9.48	524
September	12.1	62	55	55	12.89	6.87
October	13.4	7.2	6.9	67	1728	850
November	143	8.6	7.8	71	2023	981
December	14.8	9.5	8.5	80	23.59	10.0
Yearly Total	4437.8	2518.5	2372.5	2299.5	5380.1	2409.0

**Data from Gentilli (1971) # Data from Bureau of Met. SA Tabs Elements.
##Data from Bureau of Met. Catalogue of Solar radiation data.

measurements. Instead, estimates of the wind's speed and direction by visual observation are made at the standard observing hours of 0900 hrs (C.S.T.) and 1500 hrs (C.S.T.). As a statistical representation of the daily wind regime this small amount of data is inadequate. The wind speed is unreliable and will not be quantitatively discussed, but it is certain that the coastal regions of the South East experience the strongest winds and the speed of these winds is reduced on their passage inland.

The two times of daily observation coincide with the two major contributing factors to the daily wind regime. The 0900 hrs (C.ST) records tend to emphasize the synoptic pattern, whereas the 1500 hrs (C.S.T.) records tend to reflect the surface generated effects, e.g., sea breezes, superimposed on the basic synoptic situation.

During the summer months (i.e., December, January, February) high pressure cells move eastward along the sub-tropical high pressure ridges which exist to the north of the region. These systems produce a predominance of southerly winds, as illustrated by January 0900 hrs (C.S.T.) in Fig. 2. The persistence varies over the region, being affected by local topographic influences. The Naracoorte Range shelters that portion of the region near its base from easterly-southeasterly winds, inducing a higher number of morning calms. Naracoorte which is nestled within the Range is very protected, resulting in 30% of the mornings in January being classified as calm. Of particular interest is the higher than average percentage of calms at Keith, presumably caused by its position relative to the centre of the high pressure cell.

By 1500 hrs (C.S.T.). the surface generated winds (e.g., sea breezes) are adding to and, in

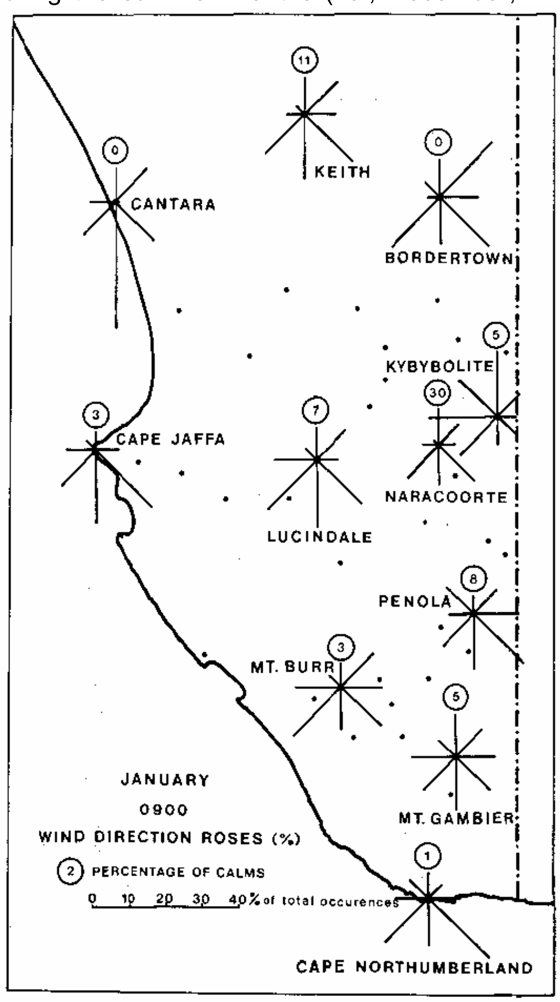


Fig. 2. Wind direction recorded at 0900 hr at climatic stations in January (C.B.M.).

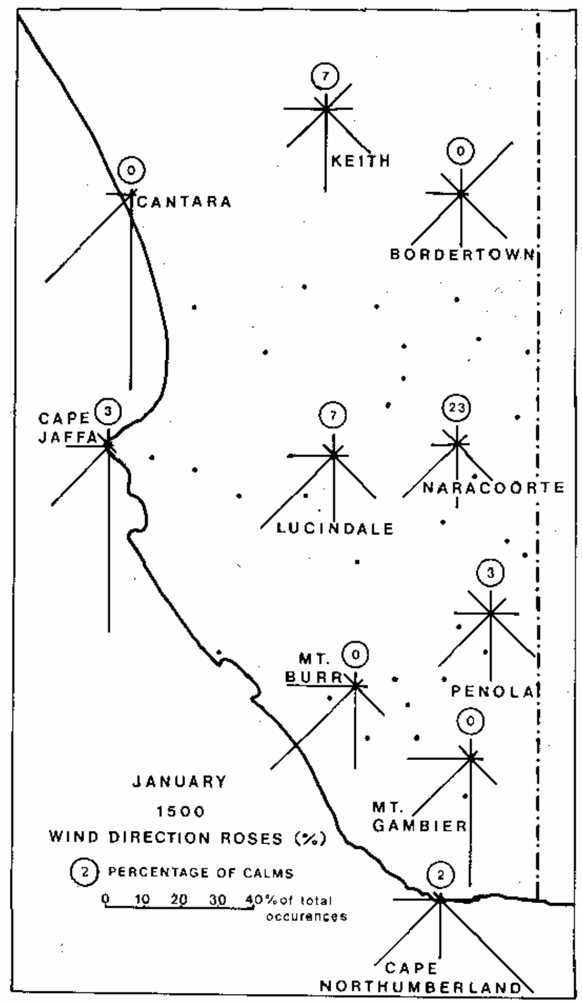


Fig. 3. Wind direction recorded at 1500 hr at climatic stations in January (C.B.M.).

the cases of coastal stations, swamping the synoptic driven wind patterns (Fig. 3). In simplistic terms, a sea breeze is generated by a land-sea temperature differential and its magnitude is determined by this differential. Its initial direction is perpendicular to the line of the coast (W-SW in the case of the South East) but this direction may vary within a few kilometres (SW-S) because of the influence of the continental frictional cross isobaric flow (Troup 1974). At coastal stations such as Cape Jaffa, the influence of both continental and local sea breezes can be observed with the strengthening of the southerly and southwesterly winds and the near elimination of easterl ies The local sea breeze is the stronger as demonstrated by its affect on stations further inland such as Lucindale. Naracoorte still remains protected by the Range and has a high percentage of calms (23%). By 1500 hrs (C.S.T) the sea breeze front has not yet reached Bordertown.

During the winter months (ie, May, June, July) the synoptic pattern produces predominantly north-west to north-east winds (Fig. 4). The 1500 hrs (CST) data show a reduction in the north and north-east winds and a general strengthening of the westerlies (Fig. 5). At both observation hours there is a large proportion of observed calms, with both Naracoorte and Penola registering more than 20% occurrence at both times.

The annual mean temperature shows a decrease towards the south and ranges from 15.5°C at Keith to 13.2°C at Mt Gambier Aerodrome. Besides this latitudinal variation the contours of the annual mean temperature (Fig, 6) show that the ocean exerts a strong influence over the region. Coastal areas such as Robe and Cape Northumberland have

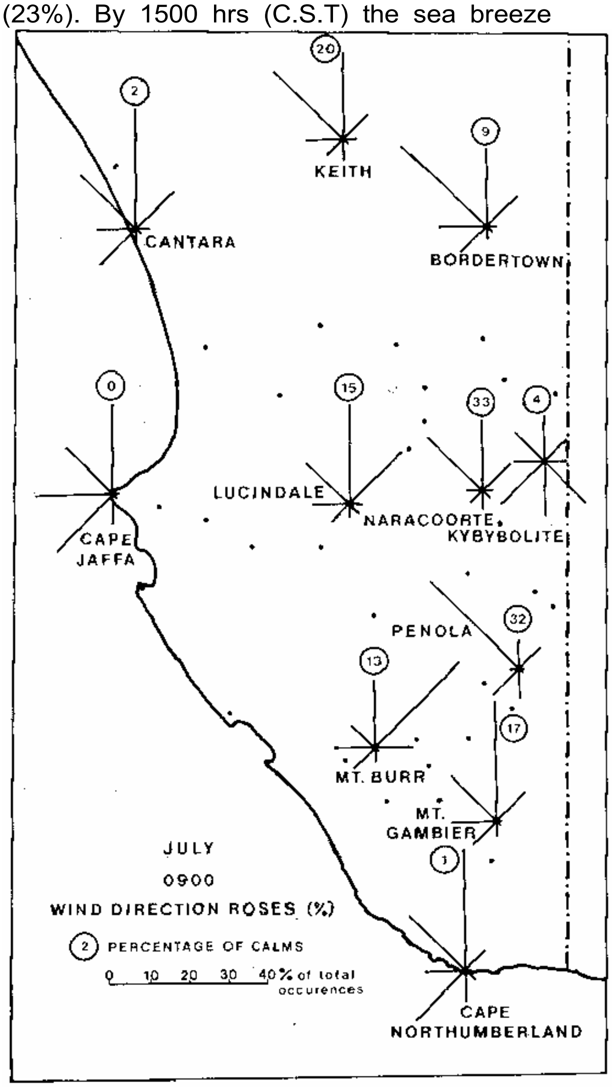


Fig. 4. Wind direction recorded at 0900 hr at climatic stations in July (C.B.M.).

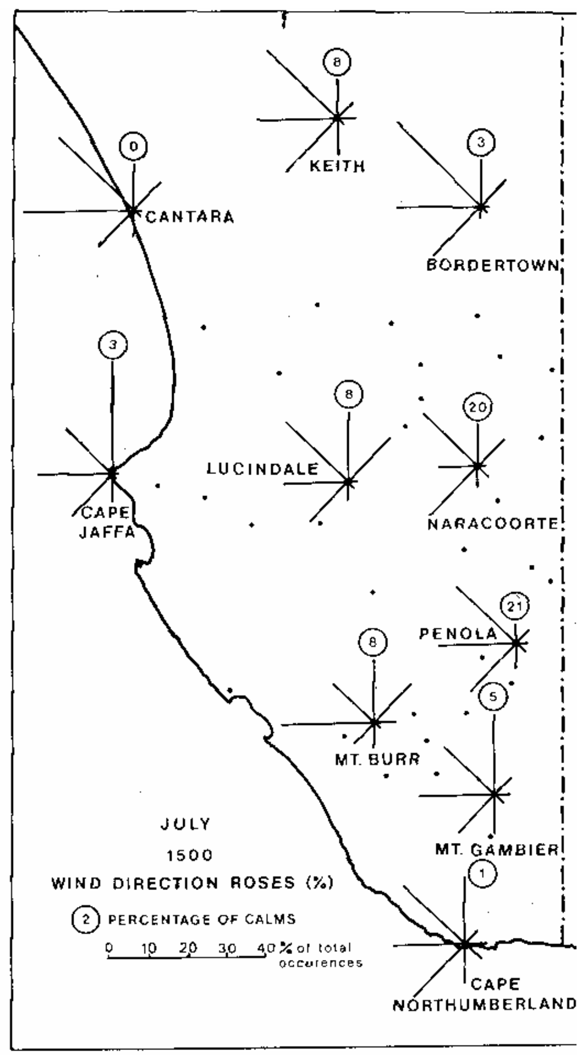


Fig. 5. Wind direction recorded at 1500 hr climatic stations in July (C.B.M.).

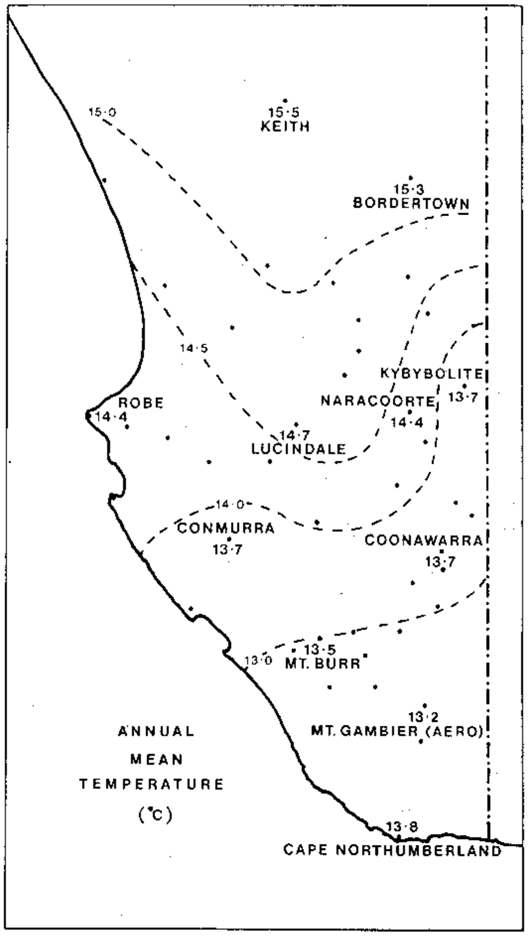


Fig. 6. Mean air temperature in degrees centigrade (C.B.M.).

higher annual mean temperatures than their neighbouring inland areas due to the thermal lag of the ocean. This thermal lag is reflected in the annual mean temperature ranges (Table 6), where the range is least to the south and on the coast. The ranges at Robe and Cape Northumberland, which vary from 7.1°C to 7.2° C are examples of the southern coastal region and are amongst the lowest for South Australia (Taylor 1932). On several occasions during the year maximum temperatures will probably exceed 38.0°C and this is usually accompanied by a hot northerly wind. As Table 6 shows, some quite high temperatures have been recorded in the South East. The highest was 45.8°C at Kybybolite in January, 1939, which incidentally also recorded the lowest minimum of -4.3°C in June, 1964. The extreme maximum at Robe is only 39.1°C, showing the effective cooling of the sea breeze . Kybybolite, which has already been mentioned and Keith, are examples of a continental area which, as a contrast to Robe, have much higher extreme maximum temperatures and lower minimum temperatures.

Fig. 7 shows the temperature and relative humidity throughout the year, for 0900 hrs (C.S.T.) and 1500 hrs (CST) for Keith, Naracoorte and Mt Gambier. These areas have once again been cited to illustrate a variation with latitude. If both the 0900 hrs and 1500 hrs observations are considered together, temperature decreases and relative humidity increases with increasing latitude.

Table 6. TEMPERATURE

	Extreme temperature recorded (O C)		Yearly	
Station	Max (^{0}C)	Min (^{0}C)	*Mean Temp. recorded* (^{0}C)	*Mean Temp. range* ()
Keith	45.6 Jan 1959	*-4.3 June 1964*	15.5	13.3
Bordertown	*n/a*	*n/a*	15.3	10.9
Kybybolite	45.8 Jan. 1959	-5.5 July. 1959	13.7	13.0
Naracoorte	42.7 Dee 1975	-4.1 July 1974	14.4	13.0
Lucindale	44.4 Dee 1975	-4.0 July 1974	14.7	12.8
Robe	39.1 Feb. 1898	-2.8 June. 1964	14.4	7.2
Conmorra	*n/a*	*n/a*	13.7	11.9
Coonwarra	*n/a*	*n/a*	13.7	12.9
MtBurr	42.9 Feb. 1970	-2.9 July. 1945	13.5	10.1
Mt Gambier	43.3 Jan. 1955	-3.9 June 1950/July 1960	13.2	10.8
Cape Northumberland	43.8 Feb 1912	-2.2 July 1960	134.8	7.1

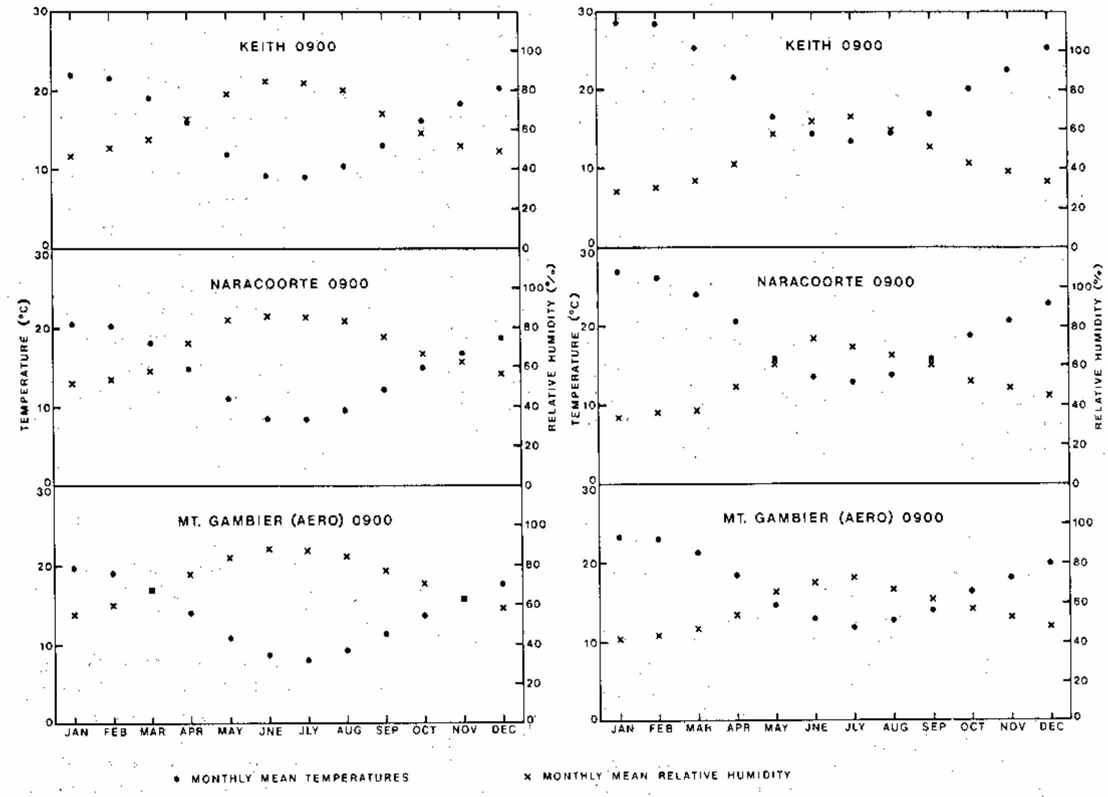


Fig. 7. Temperature and relative humidity recorded at three stations at 0900 hr and 1500 hr (C.B.M.).

Table 7. FROST.

*Mean Number of Frost Days**

Station	*Keith*		*Mt Gambier*	
Record length	1962	1976	1941	1979
Month		*(As % of month)*		*(As % of month)*
January	0.0	(0.0)	0.1	(03)
February	0.0	(0.0)	0.0	(00)
March	0.1	(03)	02	(06)
April	1.1	(3.7)	1.1	(3.7)
May	3.1	(10.0)	29	(9.4)
June	6.5	(21.7)	4.7	(12.3)
July	3.9	(12.6)	5.1	(16.5)
August	3.6	(11.6)	5.2	(16.8)
September	2.7	(9.0)	3.5	(11.7)
October	2.4	(7.7)	2.5	(8.1)
November	0.4	(1.3)	1.2	(4.0)
December	0.0	(00)	0.3	(1.0)
Mean Yearly Total	23.8		26.8	

Data from Bureau of Met. Tabs Elements.
*Frost occurrence estimated from Frequency analysIs of minimum temperature (days 2.5°C Screen minimum temperature).

That is, the air is colder and moister in the south than in the north, matching both the mean temperature and rainfall observations. In all three examples cited, the temperature at 1500 hrs was higher than at 0900 hrs and the relative humidity decreased.

FROSTS AND SNOW

The colder temperatures in the south produce a greater number of frost days than are recorded in the north (Table 7). Ward (1869) claimed this to be the downfall of Mt Gambier's otherwise favourable climate. He considered that the frosts would prevent the cultivation of potatoes, a commodity for which the region is now renowned. In August, 1951 it was reported that snow fell in and around Mt Gambier, a rare phenomenon in South Australia at that altitude of about 50-100 m.

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REFERENCES

Bureau of Meteorology (1975). Climatic Averages Sth. Australia and Northern Territory. (Aust. Gov. Publishing Service, Canberra).

Bureau of Meteorology (1978). Tabs Elements: S.A.

Region. Bureau of Meteorology, Melbourne. Bureau of Meteorology (1974, 1979). Climatic Atlas of Australia. Map sets 1-8, Bureau of Meteorology, Melbourne.

Gentilli, J. (1947). 'Australian Climates and Resources.' (Whitcombe & Tombs, Melbourne).

Gentilli, J. (1971). Climates of Australia and New Zealand *In* World Survey of Climatology 13. (Elsevier, Amsterdam).

Gentilli, J. (1972). 'Australian Climate Patterns'. Nelson, Melbourne).

Meteorological Office (1969). Hand Book of Meteorological Instruments. Part 1: Instruments for Surface Observations. (H.M.S.O., London).

Penney, C. L. (1980). A Study of Evapotranspiration from Irrigated Crops in the South East of South Australia. M.Sc. Thesis, Flinders Univ. (unpublished).

Schrale, G. (1977). Hydro-Meteorological Data for the S.E. of South Aust. and the S.W. of Victoria. Soil Conservation Branch Report S9/77. Dept Agric. & Fisheries, SA

Schwerdtfeger, P. (1976). Climate, in C. R. Twidale, M. J. Tyler and B. P. Webb (Eds) 'Natural History of the Adelaide Region'. (Royal Society of South Australia, Adelaide).

Taylor, G. (1932). 'Handbuch der Klimatologie in funf Banden. Australien und Neuseeland. 1. Climatology of Australia.' (Verlag von Gebruder Borntraeger, Berlin).

Thornthwaite, C. W. (1933). The Climates of the Earth. *Georqr. Rev.,* **23**, 433-440.

Troup, A. J. (1974). The Mean Flow at the Boundary of the Australian Continent. *Aust. Met. Mag.* ***22,*** (3),61-66.

Trumble, H. C. (1939). Climatic Factors in Relation to the Agricultural Regions of South AustTrans. *R. Soc.* S. *Aust.* **63**, 36-43.

Ward, E. (1869). South Eastern District of Sth. Aust.: Its Resources and Requirements.

10: Native Vegetation
by R. T. LANGE

Native vegetation continues to be destroyed in the South East, in a critical and controversial way'. To its early explorers such as Eyre, who was defeated by it in 1838, the then-unbroken mantle of native vegetation was an inhospitable impediment in the way of progress. Woods (1862) declared parts of it

" totally unfit for any purpose" and its landscape-effect gloomy, lonely, sad and dismal. Except for scattered remnants now protected and for many that are not, that primeval mantle is gone (SAD.E. 1980), cleared to make way for agriculture in far less than the lifespan of its trees.

On the mantle's historical timescale, its destruction is instantaneous. Palynology shows that just its most recent pre-settlement adjustments took 100 times longer than all subsequent settlement history (Dodson 1974, 1975a, b). Fossils like coastal mallee *(E. diversifolia)* and tea-tree *(Leptospermum, Melaleuca).* date back 200000 times longer than the settlement span (Lange 1978). Most clearing is less than 50 years old. In 1944, Crocker wrote: 'Land development is now proceeding at such a rate that before long it will be impossible to piece together a picture of the flora of the region as a whole' (see Eardley 1943, Litchfield 1956, Blackburn 1959 for related comments).

The bulk of this clearing was part of the building of the present State of South Australia with the inevitables simply to be borne, but the same cannot be said about unbridled terminal landclearing today, which is an unreasonable excess. It will more than halve the scarce representation of irreplaceable wildlife in the South East with all its scientific, heritage and other values, to add negligibly to a vast impermanent form of agriculture. It will destroy the last benchmarks against which ongoing landcare might be judged. In science that is the abandonment of reason, an 'experiment' without control.

The native mantle was as intimately adjusted to South East landscape as is skin to a body, and no more inconsequentially to be stripped. Certainly people had to be fed, by agriculture, but it is delusory to imagine that any motives immunize excessive land clearing from disastrous consequences. South Australian agriculture, already with world classic disasters in its record (Meinig 1962), knows that salinization already is in train in the South East, along with enormous nutrient drain. 'There is no doubt that super phosphate is essential to Australian farming success. Unfortunately, like oil, it is a dwindling and increasingly precious resource. Over the last decade the price of superphosphate has been increasing at an annual rate of approximately 20%' (Ralph 1981). Thus Australian agriculture, like oil burning industry, runs its land on the philosophy of the non-renewable resource and, like it, must have a bleak, short future in its present form. That ought to concern agricultural science a great deal, and gives the industry not the slightest excuse for terminal land-clearing. For negligible expansion of a transient, troubled way of food production, it would throw into extinction the last of an instructive life-fabric as old as the South East, and everything that might be learned from it.

Not all South East pioneers were insensitive to the plain fact that unbridled total land clearing is against commonsense. The Ellis's of 'Maroona' near Keith and the McLarens of 'Bernarra' near Kingston, long ago committed blocks of their land to bushland preservation, as did Kathleen Birmingham at Robe. About 1950, government reacted with a remarkable bushland rescue episode. Through two decades 1950-1970, the hectare rate of increase in dedicated bushland reserves was exponential at 28% yr-" hence the scatter of National and Conservation Parks now in the South East.

The critical situation now concerns those precious remnants that were not dedicated, and which still give some continuity between the widely-separated, vulnerable parks. These, recognized by wildlife conservationists as invaluable and irreplaceable, are still seen as potential plough land by freeholders. Thus is engendered a situation which, in the wider Australian context, produces some very hostile stupid attitudes. 'The preservationist movement has become worldwide, but so has hippiedom, with which it has much in common. Taken in isolation, it casts a blight on progress and is a cancer in the nation's economy.' (Woods 1970, see also Ellis 1970). In a young nation so ecologically primitive that it has already worn out and abandoned much farmland, and seeks simply to clear more, such criticisms merely indict their authors. There is no solution for the problems of agriculture in land clearing. Agriculture must learn to care for what it already holds. To clear the native remnants in the South East is as barbarous as using the Bayeaux tapestry for oil-rags.

While wildlife conservationists and some scientists protest to governments and committees of enquiry, land clearers are settling the matter with the pre-emptive logic of no more bushland, no more argument. That is obvious both from aerial photographic and space-satellite reconnaissance. Land clearing is rapidly proceeding in a process which, incredibly, is immune from the Impact Statement laws that moderate all other agencies. Over the Kingston coalfield, for example, potential miners were obliged to spend much money on concern for the very same wildlife that agriculture was simultaneously ploughing-in, protected species and all. The prospect in the South East, a century after Woods (1862) is still gloomy, lonely, sad and dismal but for the opposite reasons-far too little bushland, and that little vanishing, not too much of it.

SOME BOTANICAL NOTIONS

Each adult native plant in the South East displays a life-form (tree, shrub, herb and so on; see Raunkiaer 1934) and, in its flowers or reproductive parts, its genetic stock (family, tribe, genus) and breeding-line (species), by which it is named (Porter 1967, Jones & Luchsinger, 1979). The name-list of all the species, usually sorted according to ancestry, is called the flora (Black's Flora of SA). The different life-forms reflect different successful means of coping with the challenges of life in the region, and differences in their blends from place to place define vegetation-types (heath, reed-swamp and so on).

Most botanists believe that over the great timespans of pre-history, the species and the vegetation-types into which they were assembled, represent the outcome of processes called adaptation through natural selection (Wallace & Srb 1961). Part of this belief is that the particular history of demands worked on the available stock, over many generations, to yield flora and vegetation characterized by special fitness. Thus native heath copes more or less in perpetuity on low-phosphate sands, without phosphate loss from the system, whereas most non-adapted introductions have to be sustained with imported phosphates. Another part of the belief is that the landscape and its soils are in part the product of the vegetation, most obvious in the case of peat soils (Stephens 1943) but nonetheless true generally. When the bush is cleared, salting-up often begins immediately, for example.

The South East encompasses a very limited sample of global situations (Walter 1979) so the vegetation-types there similarly are limited to those successful in low altitude, mid-latitude, dry summer, wet winter temperate conditions, on flat, immature landscape with very little hard rock, very low nutrient sandy, clayey, and calcareous soils, often poorly drained (Chapter 5). The stock available to meet these challenges also was limited. Australian flora as a whole lacked many stocks, possessing only those which originally joined the emerging continent on its immensely-long drift in isolation (Ludbrook 1980, Lange 1981), stock which managed to get in after isolation ended (Smith 1981) and various adept world-travellers. For this reason so many of our trees are eucalypts and none are maples, for example; family (F.) Myrtaceae, the eucalypt stock, has been in Australia for ages; F. Aceraceae, the maple stock, never got here spontaneously. For the same reason our heaths feature F. Epacridaceae, not F. Ericaceae as in Europe. Natural selection met the same challenge with the same life-form from the alternative stock on hand.

Then, since the South East emerged from the sea only 'yesterday', geologically, there have been the difficulties of recruiting from distant parts of Australia. *Agonis flexuosa,* the Swan River myrtle of Western Australia, might have done well in the South East, but did not cross the inhospitable hinterland. Much of the immediate flora seems to have come from inland Australia, judging from fossils of eucalypts and tea-trees near Woomera (Lange 1981) and from left-overs such as the little broom bush, *Baeckia behrii,* of which relict patches still live in such otherwise-unlikely places as the Uno and Gawler Ranges, the centre of the Great Victoria desert, and the Everard Ranges.

Nonetheless the South East contained far too much to describe here in full. The following representative selection illustrates the variety of life-forms and the stocks and breeding-lines that occupy them. The divisions are arbitrary and not mutually exclusive. Thus mal lees, which technically might be shrubs, are given a category of their own. These usually-low eucalypts have many woody stems arising separately from a lignotuber (mallee-root). a condition said to reflect adaptation to bushfire. Similarly the distinction between trees and shrubs is, in practice, not clear-cut.

REPRESENTATIVE LIFE-FORMS AND SPECIES

Trees

Big trees

By the standards of Australian mountain ash and karri, which can exceed 90 m and are the world's tallest hardwoods, there are no really tall trees in the South East. There are however trees of big stature, over 20 m tall and sometimes with butt-diameters over 2 m. Most are old rivergums *(E. camaldulensis),* bluegums *(E. leucoxylon),* swampgums *(E. ovata)* and manna gums *(E. viminalis)* of woodland form, and occasional big snowgums *(E. pauciflora)*, here in their westernmost distribution. These species display confusing taxonomic intergrades and are represented in the South East by special forms or subspecies (Boomsma 1981) of taxa that extend further afield (Chippendale & Wolf 1981). In a few places, forest-form stringybarks *(E. baxteri, E. obliqua)* grow well over 20 m tall.

Mid-stature trees

This group, from about 10-18 m tall and up to about 0.8 m butt-diameter, is represented widely by lesser specimens of the foregoing species and introduces more than just eucalypts, for instance wattles *(Acacia mearnsii,* black wattle; *A. melanoxylon,* blackwood, and the tallest *A. pycnantha,* golden wattle), sheoaks *(Casuarina stricta,* drooping sheoak; C. *leuhmannii,* bulloak) and tall specimens of tea-trees *(Melaleuca lanceolata,* dryland tea-tree; M. *halmaturorum,* saltwater tea-tree). It includes exceptionally-tall specimens of usually shorter species such as *Banksia marginata* (silver banksia) and several further eucalypts. One of these. *E. fasciculosa* (pink gum) is one of the most characteristic trees of the South East. *E. nitida* (a snowgum relative) and *E. microcarpa* (grey box) are other eucalypts in this mid-stature group.

Small trees

As well as lesser specimens of the foregoing, this category introduces various species which grow often as shrubs but sometimes as trees *(Bursaria spinosa, Exocarpus cupressiformis,* native cherry, and *Dodonaea attenuata,* hop bush), and plants like *Santalum acuminatum* (quondong) and *Callitris rhomboides* (Oyster Bay pine), of perfect tree-form but only 2 m tall.

Mallees

The main species of this exceedingly successful life-form in the South East are *E. anceps* (Kangaroo Island white mallee), *E. calycogona* (square-fruited mallee). *E. diversifolia* (coastal mallee), *E. dum*osa (white mallee). *E. foecunda* (slender-leaved red mallee), *E. incrassata* (ridge fruited mallee), *E. odorata* (peppermint box), *E. porosa* (mallee box) and *E. rugosa* (Kingscote mallee). Boomsma (1981) illustrates and discusses all of them. They range from the height of mid stature trees to low shrubs and create the scrubs so characteristic of South East limestone areas. Some other eucalypts like *E. leucoxylon* occasionally grow malleeform, but the stunted form of others, such as of stringybarks, is more a depauperate tree than a mallee.

Shrubs

Tall shrubs

Leaving aside the mallees, these include the regionally-important boobyalla *(Myoporum insulare)* and coastal wattle *(Acacia longifolia* var. *sophorae).* as well as the common shrubby forms of both inland and saltwater tea-tree and their tall dense thicket-forming relatives *Leptospermum pubescens* and *Melalauca squarrosa* up to 5 m tall. This lifeform, like the mallees, generates scrubs in the South East, but in these cases, of the coastal calcareous sands and of the swamps.

Other tall shrubs include wattles *(Acacia stricta,* hop wattle, *A. leiophylla; A. dodonaeifolia,* sticky wattle) and sheoaks *(Casuarina striata).* At the lower limit but still taller than the average observer are some *Leucopogon parviflorus, Melaleuca uncinata* (broombush), *Beyeria leschenaultii, Olearia axillaris* (sandhill daisy) and *Hakea nodosa* (needlebush), for example. In favoured places spared by bushfire, normally-shorter species such as *Banksia ornata, Leptospermum juniperinum, Casuarina muelleriana* and many others grow taller than the average observer.

Mid-shrubs

Most of the shrub flora of the South East falls in the approximate range 0.2-2.0 m tall, features pronounced sclerophylly, and involves a wide range of stock. Its richest development is in sand-heath, much studied by Specht and his colleagues (Specht 1957, 1972; Specht & Rayson 1957; Specht, Rayson & Jackman 1958; Rayson 1957).

Many species live there intermingled, repeatedly restoring their same rich mixture after the bushfires to which the heath is very prone. Arbitrary examples are F. Proteaceae *(Adenanthos terminalis, Banksia marginata, B. ornata, Grevillea ilicifolia, G. lavandulacea, Hakea rostrata, H. vittata, Isopogon ceratophyllus, Persoonia juniperina);* F. Rutaceae *(Correa reflexa, Boronia filifolia);* F. Dilleniaceae *(Hibbertia sericea, H. stricta, H. virgata);* F. Santalaceae *(Choretrum glomeratum, Leptomeria aphylla);* F. Sterculiaceae *(Thomasia petalocalyx);* F. Thymeliaceae *(Pimelia glauca, P. stricta);* F. Labiatae *(Westringia eremicola);* F. Epacridaceae *(Astraloma conostephioides; Brachyloma ericoides, Epacris impressa, Leucopogon clelandii; Styphelia exarrhena);* F. Leguminosae *(Acacia verticillata, A. myrtifolia, Daviesia brevifolia, Dillwynia hispidula, Phyllota remota, Pultenaea vestita)* and F. Myrtaceae *(Lhotzkya alpestris, Melaleuca neglecta, Oarwinia micropetala).* Many of these have very small, stiff, crowded leaves with needle tips.

Ground-cover shrubs

Various South East perennials do not ascend but grow flat, either spreading like the important *Kunzea pomifera* (muntree) and the scarlet runner *(Kennedia prostrata)* or in com pact mats, like the cranberries, *Acratriche serrulata* and *Astroloma humifusum.*

Woody Twiners

Devil's twine *(Cassytha,* F. Lauraceae) ranges in the South East from the slender C. *glabella,* often seen in heath, through the intermediate *C. pubescens* to the ropey *C. melantha* which can envelop trees in yellowish tangle. Old man's beard *(Clematis micraphylla,* F. Ranunculaceae) is very widespread, as are *Muehlenbeckia adpressa* and M. *gunnii. Billardiera cymosa* is less conspicuous.

Hard and Wiry Perennial Tussocks and Blades

This arbitrary but very important category deals mainly with the sedges (F. Cyperaceae), rushes (F. Juncaceae) and twine-rushes (F. Restionaceae) and with similar growth produced by unrelated stock (F. Liliaceae). All has the same effect, viz.-longlived straplike or wire-like leaves or stems, produced either in tussocks, fans or separately, emerging from underground rootstocks to vegetate the land with what looks, at a distance, like grassland, but at close hand is hard, leathery, unpalatable and often sharp. Cutting-grass, which is not a true grass but a sedge, is an example. Growth of this sort can stand 2 m or more tall, like *Typha,* or may be minute, like *Tetraria,* but size aside, this form has been immensely successful in the South East, dominating not only swamp and stream localities expected of it, but also taking the structural role of grass in places far from swamps. In heaths, it took over the grass-role entirely. Eardley (1943), who discussed Eight Mile Creek as it was before draining, emphasized the world-wide occurrence of numerous species present. *Gahnia filum* and G. *trifida* were well known to the pioneers as thatching grass and cutting grass, respectively. Many parts of the South East are carpeted with swards and meadows of *Lepidosperma, Chorizandra* and *Scirpus* while in the heath, *Hypolaena fastigiata* and *Lepidobolus drapetocoleus* bind the sand, their comb-like rhizomes littering new ploughing. The unrelated F. Liliaceae also has capitalized on this life-form, with numerous iron-grasses *(Lomandra), Oianella revoluta* and the ubiquitous yakka *(Xanthorrhoea australis),* a sort of dryland equivalent to swampland *Gahnia,* and a character-plant of the entire South East.

Grasses

True grasses (F. Gramineae), first of the herbaceous groups, are so important generally that they command a life-form category of their own. There are about 30 native genera in the South East but they do not produce savannah; usually they grow sparsely. Commonly-known examples include kangaroo grass *(Themeda australis)* and wallaby grass *(Oanthonia)* which, with speargrass *(Stipa)* made up the main original pasture, but many others contributed. They include *Agropyron* (wheat grass), *Agrostis* (blown grass), *Amphibromus* (swamp wallaby grass), *Amphipogon* (greybeard grass), *Bothriochloa* (redleg), *Chloris* (windmill grass), *Deyeuxia* (bent grass), *Dichelachne, Digitaria* (crab grass), *Echinopogon* (hedgehog grass), *Eragrostis* (lovegrass), *Glyceria* (sweet grass), *Hemarthria* (mat grass), *Imperata* (blady grass), *Microlaena* (weeping grass), *Neurachne, Panicum* (panic), *Poa* (coast tussock) *Setaria* (pigeon grass), *Tragus* (burr grass) and *Zoysia* (manila grass). Others, commonly noted because of distinctive appearance or place, include *Triodia* (porcupine grass), which forms needlepointed hummocks and rings, *Spinifex hirsutus,* which binds coastal foredunes, *Paspalum distichum* (saltwater couch) which forms rough lawns, *Oistichlis* (saltgrass), with distinctive flat fans and *Phragmites,* the common reed.

Annual and Perennial Forbs from Seed

Herbaceous plants other than grass sometimes are called forbs, and their variety in the South East is far too great to review here. Those arising from seed commonly are annual; others live into a second year (biennial) or longer (perennial), and they range from scarcely a cm tall to a metre or more. Many shift about on the landscape with the conditions that favour them, like *Ixodia achillaeoides* (fireweed) on recently-burnt sites. Here are a few of the annuals to illustrate their variety: *Stellaria multiflora* (starwort, F. Caryophyllaceae), *Ranunculus parviflorus* (buttercup, F. Ranunculaceae), *Cardamine hirsuta* and *Blennodia cardaminoides* (F. Cruciferae), *Poranthera microphylla* (F. Euphorbiaceae), *Hydrocotyle callicarpa, H. rugulosa, Didiscus pusillus* and native carrot, *Daucus glochidiatus* (F. Umbelliferae), and *Brachycome iberidifolia* and *Senecio minimus,* daisies (F. Compositae).

Geophytes with herbaceous, seasonal shoots

This life-form of herbaceous plants has shoots which arise each year from perennial underground storage organs such as tubers or bulbs. Orchids are typical. As discussed by Weber & Bates (1978), perhaps 80 different sorts in over 20 genera occur in the South East. Known popularly by their common names, they include mosquito, spider, duck, bird, helmet, tongue, donkey, potato, waxlip, hare, blackbeak, onion, horned, leek, sunhood and green orchids, as well as parson's bands and copper-beards, for example. Also in this life-form are numerous Liliaceae, for instance *Anguilleria* (early nancy), *Bulbine* (leek lily), *Burchardia* (milkmaids), *Calectasia* (blue tinsel lily) and *Thysanotus* (fringed lily). Numerous other families contribute too, such as F. Hypoxidaceae with *Hypoxis glabella* (yellow star), F. Iridaceae with *Patersonia* (purple flag) and F. Droseraceae with insectivorous sundews.

Succulents and Special forms

Due to the prevalence of salty places, with which this feature often is associated, succulence is well expressed in the South East. Succulents have insubstantially-fleshy structure, engorged with sap, usually articulated stems or thick leaves. Most obvious are samphires (F. Chenopodiaceae) such as *Sarcocornia blackiana,* S. *quinquefolia* and *Halosarcia halocnemoides* (Wilson 1980). Others include *Crassula* (F. Crassulaceae), *Wilsonia backhousei* (F. Convolvulaceae) and *Carpobrotus* (F. Aizoaceae), pig-face. Of the totally independent forms, probably the most important in the South East is the xerophytic fern, bracken *(Pteridium aquilinum).* Technically an herbaceous geophyte, it performs underground like the most vigorous sedge, and above ground like a wiry shrub. In various areas it so dominates the land as to show up on satellite imagery. Fossil bracken fronds underlie Mt Gambier volcanic ash, so it definitely is native, despite its European distribution.

HABITATS: THE VARIETY OF CHALLENGES

The variety of environmental challenges to plants in the South East, and the blends and patterns in which these are laid out, result

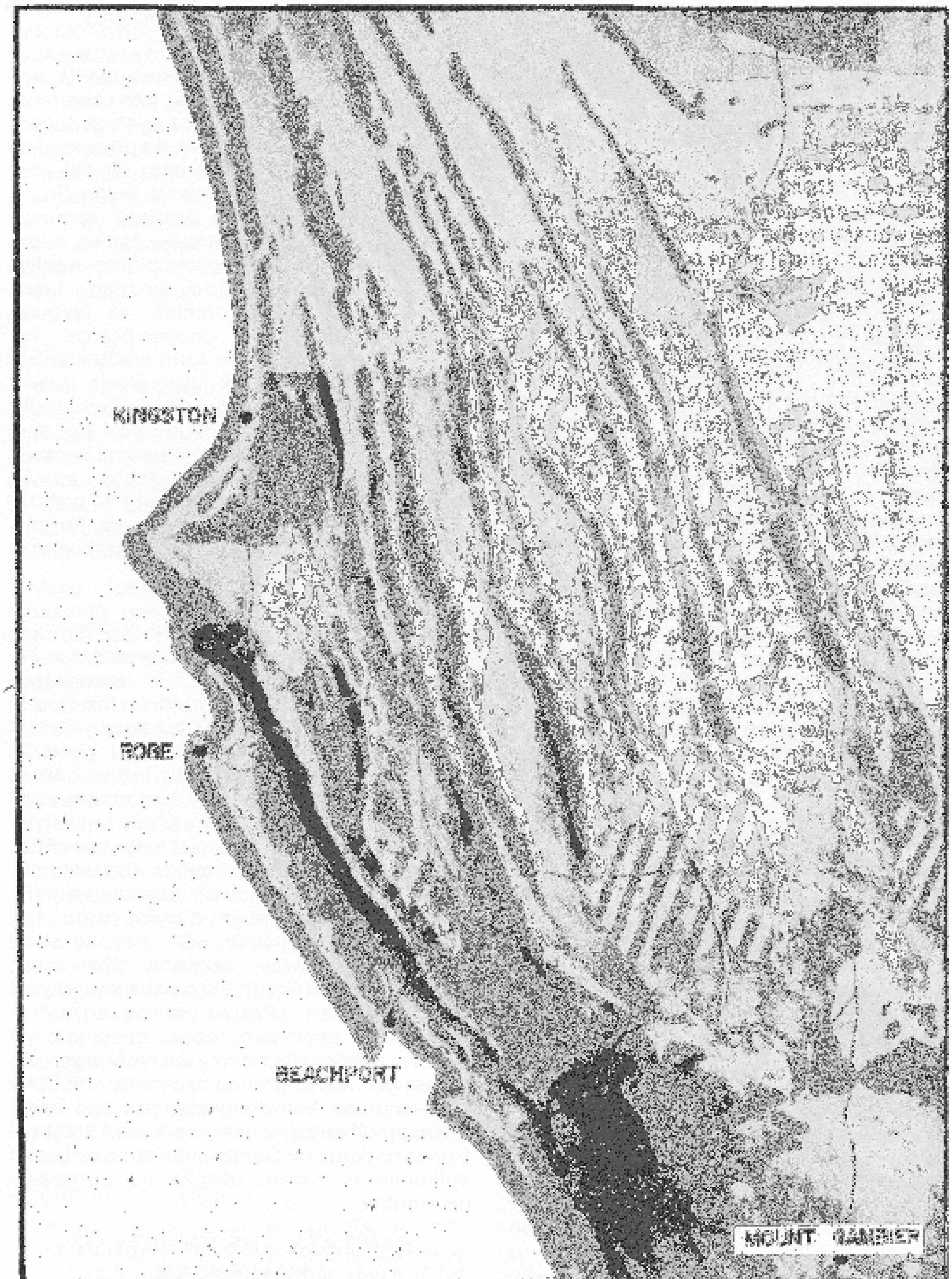


Fig. 1. Photograph of original South East landform model from Crocker's 1944 study which is on permanent display in the east foyer, Benham Building, University of Adelaide. Vertical scale is grossly exaggerated. Note system of parallel ridges.

primarily from two very recent episodes in geological history, cross-cut by only minor climatic gradients. First was withdrawal of the sea from the limestone-sedimented Murravian Gulf and the emergence of the South East as low, flat land, ridged in a remarkable way (Figure 1). Second was extensive mantling with windblown siliceous sand.

Not long ago, geologically, sea stretched from the Mt Lofty peninsula to the Dundas peninsula in Victoria. The South East was a great bay with only monadnocks like Mt Monster as small islands. As regional uplift shed the sea westwards and exposed flat land for colonization, parallel ridging was developed by global sea level rises, counteracting uplift, causing temporary halts in the westward coastline migration, each marked by coastal dune range building. Sea level rises, caused by periodic global ice melting, are thought to have occurred regularly every 100000 years (Milankovitch periodicity), so that each range is 0.1 Myr younger than the next east, i.e. the Woakine is 0.1 Myr younger than the Dairy, and so on inland (Idnurm & Cook, 1980).

This history has been enormously influential on the layout of vegetation challenges, since the repetitive ranges all have the one form of genesis, from shell grit sands, ageing eastwards. The landlocked flats between them likewise offer a repetition of poorly-drained but not identical habitats, differing in substrate more than the ranges according to the vagaries of sediments laid down by steams and lakes pursuing the retreating coastline. Sometimes these were sands, sometimes clays, sometimes carbonates apparently by chemical deposition from ephemeral playalakes. Nonetheless the whole system has a repetitive grain running NNW-SSE with the topography.

The main independent complicating feature is the extensive mantle of silica sand blown across this landscape. Crocker & Wood (1947) believed this resulted from windstripped sandsources during a 'Great Australian Arid Period' 3000-9000 years ago but Dodson (1974) using palynological data from Lake Leake, rejected those dates as too recent. The dune-building seems more likely at the height of the last glacial 18000 years ago.

One might expect, from the foregoing history, that a single eastwards traverse from the coast, about the latitude of Robe, should intersect most vegetation-types of the South East. With a few exceptions, that is more or less true. The exceptions are fen, or freshwater alkaline peatswamp, volcanic soil vegetation (gone before botanists described it) and features due mainly to deteriorating climate from south to north. In the following outline coastal scrub, fen, siliceous dunefield and calcrete vegetation are first treated separately, and used to illustrate certain ideas, then other vegetation is described simply, by reference to eastwards traverse across a couple of corridors and ranges just inland from Kingston.

REPRESENTATIVE VEGETATION TYPES AND THEIR LAYOUT

Coastal Scrub

South East shorelines are backed either with very calcareous sand-dunes or, in places, with limestone headland and cliff. Dunefront beaches carry sea-rocket *(Cakile maritima)* backed by *Spinifex hirsutus,* rushes and sedges, *Tetragonia implexicoma, Threlkeldia diffusa* and *Pelargonium,* with abrupt transition into densely-tangled scrubs of *Leucopogon parviflorus, Myoporum insulare* (boobyalla), *Scaevola nitida, Olearia axillaris* (sandhill daisy) and *Acacia longifolia* var. *sophorae* (coastal wattle), often bound with twiners such as *Muehlenbeckia adpressa.* Lesser plants in these scrubs include *Apium australe, Anagallis arvensis, Swainsona lessertiifolia, Calocephalus brownii, Pimelia serpyllifolia* and grasses such as *Agrostis billardieri* (blown grass) and *Festuca littoralis* (coast fescue). According to analyses by Correll (1963), pattern in such vegetation is a mozaic of about five community-types, not an orderly inland succession. Limestone carries some species much closer to the foreshore than does sand, for instance *E. rugosa, E. diversifolia, Alyxia buxifolia, Frankenia pauciflora, Kunzea pomifera, Melaleuca halmaturorum* and *Casuarina stricta.*

Fen

Some habitat-vegetation combinations are very distinctive and invariable, with the one structure and partly-shared flora worldwide. One such is fen, or alkaline freshwater peatswamp, of which much formerly existed in the South East but little remains, due to drainage and clearing. Its best documentation was by Eardley (1943) Eight Mile Swamp lay in the extreme South East, in a trough parallel to and just inland from the seacoast. It was fed not only by local rainfall and runoff but from springs which delivered great quantities of underground water from Victoria, calcareous and alkaline from its passage through limestone. Overflow ran to the sea. Its wet, impenetrable vegetation involved four communities in a concentric series from those of permanent ponds and streams outwards to those of swamp margins. Peats, the damp-decay product of the plants, averaged over 1.5 m deep.

Eardley found the ponds and streams choked with masses of submerged growth, prinipally water-cress (introduced). and watermat of a *Nasturtium ofiicanale Potamogeton pectinatus* Association, including aquatics like *Lepilaena elatinoides* (water milfoil), *Hydrocotyle verticillata* (marsh pennywort), *Chara* and *Nitella* (stonewort) and freshwater algae. Open waters were surrounded by reed-swamp, a *Phragmites australis* (common reed)- *Typha angustifolia* (bullrush) Association, with some growth submerged *(Triglochin procerum,* water ribbons) but most standing clear *(Gahnia clarkei,* giant sword rush; *Scirpus pungens,* bayonet rush; *Juncus pallidus,* pale rush and *J. caespitocius).* A small-leaved daisy shrub, *Olearia,* grew on banks and covered over small waterways.

Progressing outwards to shallower phases, vegetation changed to a *Machaerina juncea,-M. rubiginosa* sedge-meadow Association. This was even, densely-grown meadow 0.3-0.7 m tall, almost entirely of M. *juncea* (blue wire-rush), the coarse, fibrous peat beneath produced almost totally from its roots and rhizomes. Next came a transition-zone or ecotone, intermediate between the meadow and subsequent tea-tree thicket, called the *Leptospermum pubescens-M. juncea* ecotone. Finally came the most extensive of the fen communities, the *Leptospermum pubescens-Melaleuca squarrosa* Association. This tea-tree thicket was exceedingly dense, impenetrable growth solely of those two shrubs, growing as thin, unbranched vertical stems to carry a closed, level canopy at their tips about 4.5 m above the ground. Fallen litter generated a fine black peat on the perpetually sunless ground below.

Mallee and Heath

Broadscale

A frequent outcome of the region's geological history is limestone or calcrete abutting deep aeolian siliceous sands. Figure 2 illustrates such a situation along a traverse from Bridgewater Formation limestones of the Stirling Hills (a stranded coast-range Just north of Keith) into Molineaux sand dunefields near Gosse Hill trig. Figures 3 and 4 are contour and soil maps of the actual transition. This strip begins in the south on a calcrete hilltop with a pocket of deep sand.

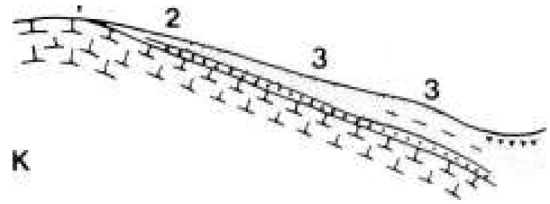


Fig. 2. Generalized section indicating soil-types from Bridewater to Molineaux geological formations near Gosse Hill trig, Mt. Rescue Conservation Park, S.A.

1 = calcrete outcropping or close to surface, calcrete fragments on very shallow sand about 10YR 5/3 (Munsell wet), the surface sometimes crusted, setting, about 10YR 6/4 to 7.5YR 5/6.

2 = calcrete fragments on surface sand about 2.5Y 4/2 over sand about 10YR 6/4 without texture change to 3 dm max., slight chroma increase with depth, then abrupt band of clayey sand and marl over limestone.

3 = sand devoid of calcrete fragments to 6 dm with no texture shift, 10YR 6/2 rising in chroma with depth to 10YR 6/6, then abrupt transition into clay about 5YR 5/6 over marl and limestone. There is sand-clay alternation in some profiles.

4 = deep sand with no texture change, about 1 OYR 6/3 rising to 10YR 6/6 or 7.5YR at 1 m.

As the hill slopes downwards to the north so does the limestone, trending deeper under the mantling sands until 30 m lower, it disappears just before the lowest point is reached. The strip then rises up a steep dunal slip-face and terminates in elevated dunefield.

This gross contrast in soil-type is matched by gross contrasts in native vegetation. On the limestone soils, the observer is in dense mallee thicket about 3 m tall, unable to see far in any direction due to dense eucalypt foliage, and must force a way through the close, slender mallee-stems. Although a variety of species are present, the bulk is of just three eucalypts *(E. incrassata, E. foecunda, E. diversifolia)*, very closely similar. On the sands, the situation from the observer's viewpoint is very different. Vegetation is only knee to waist high and view is unobstructed to the horizon. This is sand-heath vegetation, a rich blend of crowded low shrubs, many with small, prickly leaves, extending away in a more or less level surface. The role of grass is taken by twine-rushes. Broadscale contrast of this sort, between calcrete mallee and

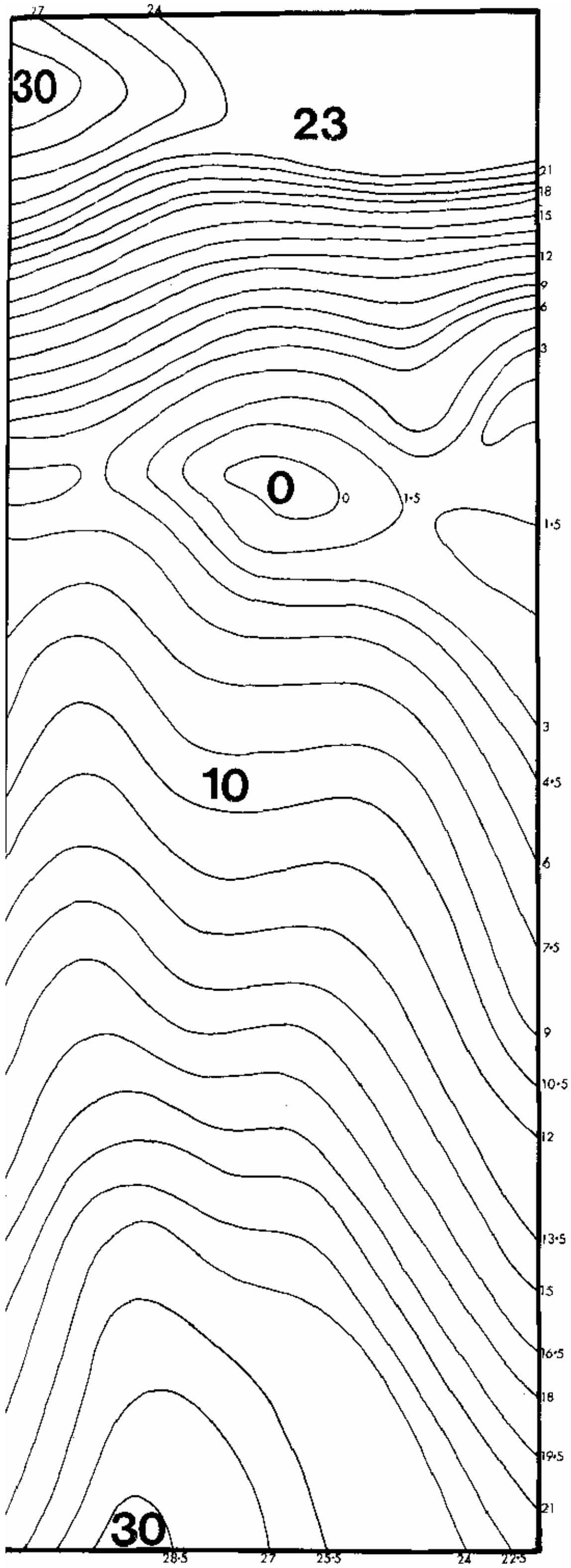


Fig. 3. Contour map (1.5 m intervals) of 0.16 × 0.75 km strip corresponding to Fig. 2. K = Bridgewater formation, M= Molineaux formation. Altitudes are metres above lowest point = 0.

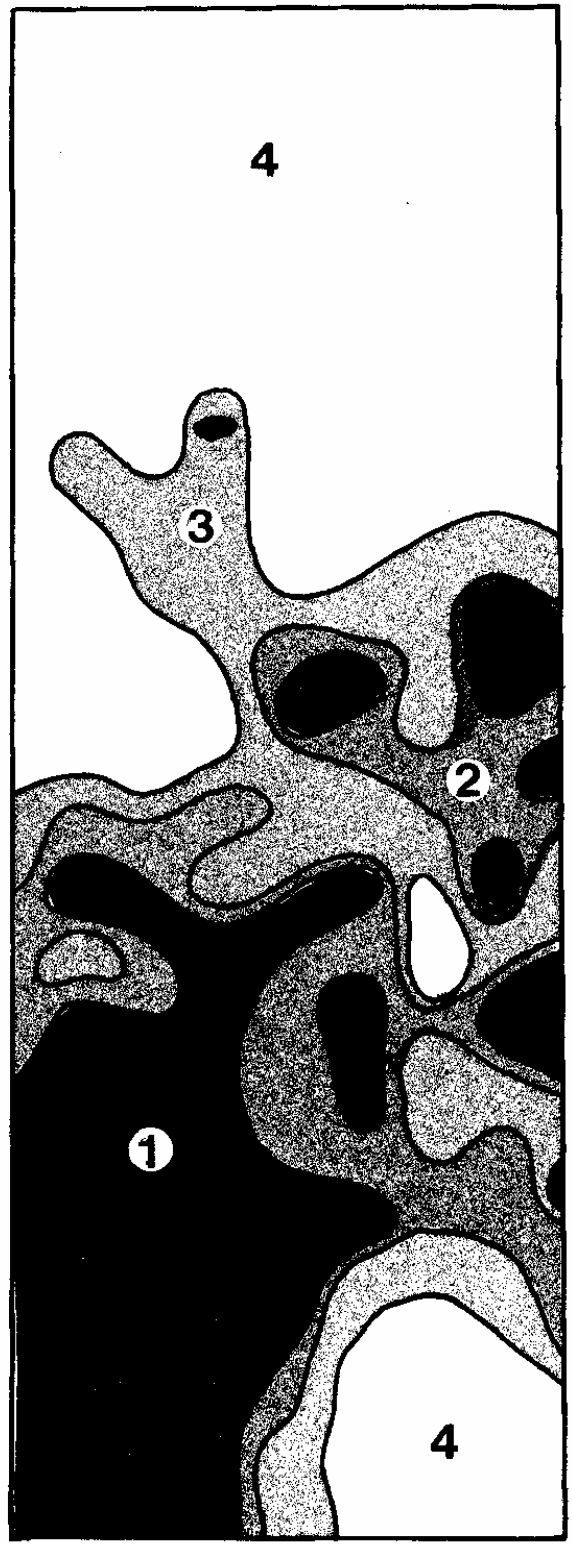


Fig. 4. Soils map corresponding to Fig. 3. 1-4 as in Fig. 2 legend.

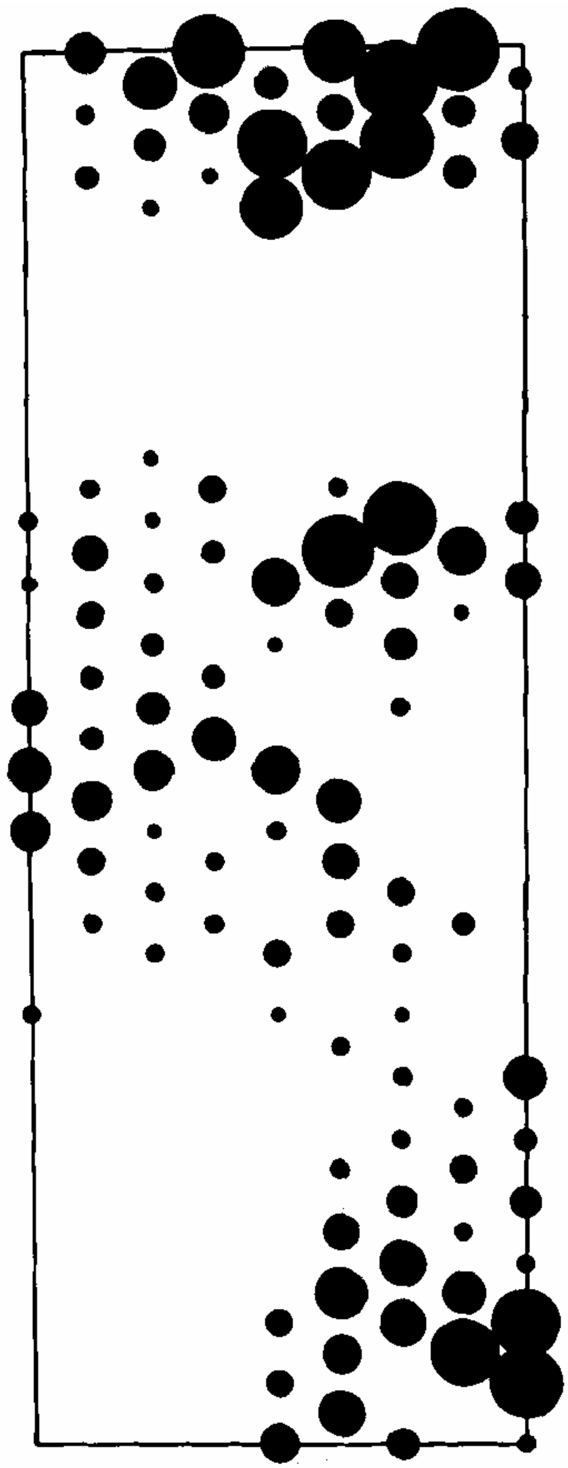


Fig. 5 Relative abundance in 207 1.5 x 20 m quadrats on the Figs. 3, 4 strip of 7 plant species, *Baeckia behrii*.

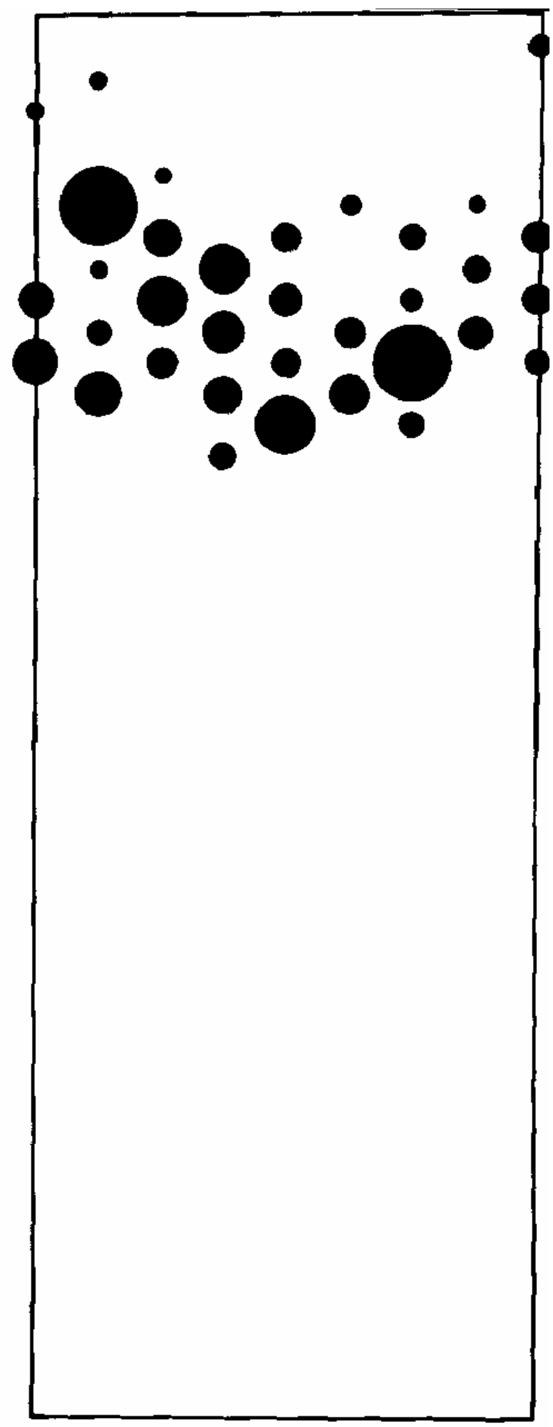


Fig. 6 Relative abundance in 207 1.5 x 20 quadrats on the Figs. 3, 4 strip of 7 pl species, *Banksia marginata*.

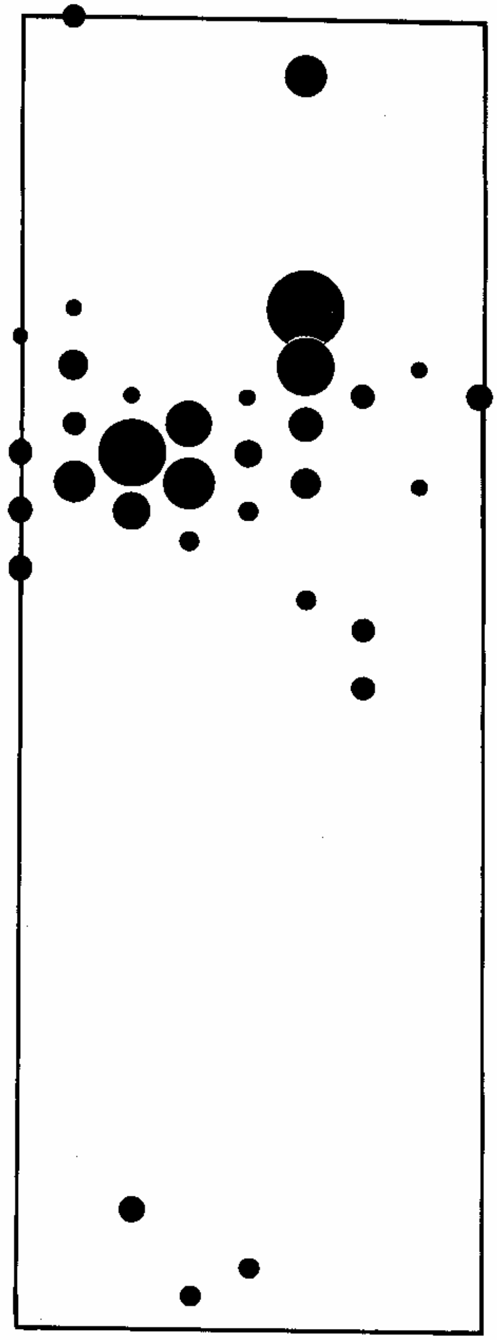


Fig. 7 Relative abundance in 207 1.5 x 20 m quadrats on the Figs. 3, 4 strip of 7 plant species, *Triodia pungens.*

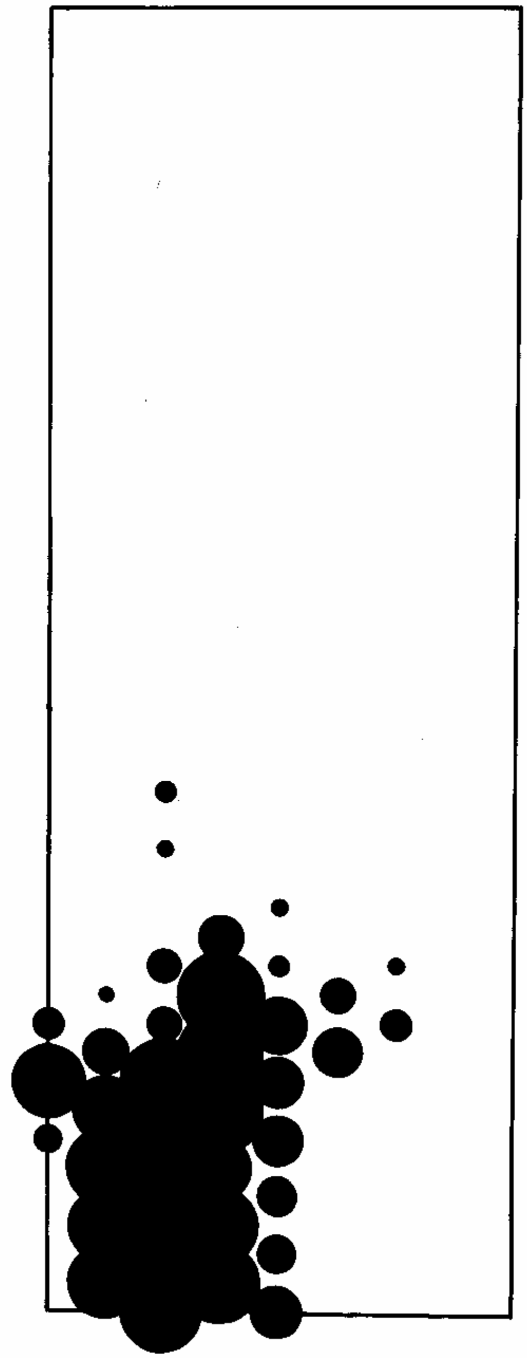


Fig. 8 Relative abundance in 207 1.5 x 20 m quadrats on the Figs. 3, 4 strip of 7 plant species, *Pomaderris obcordata.*

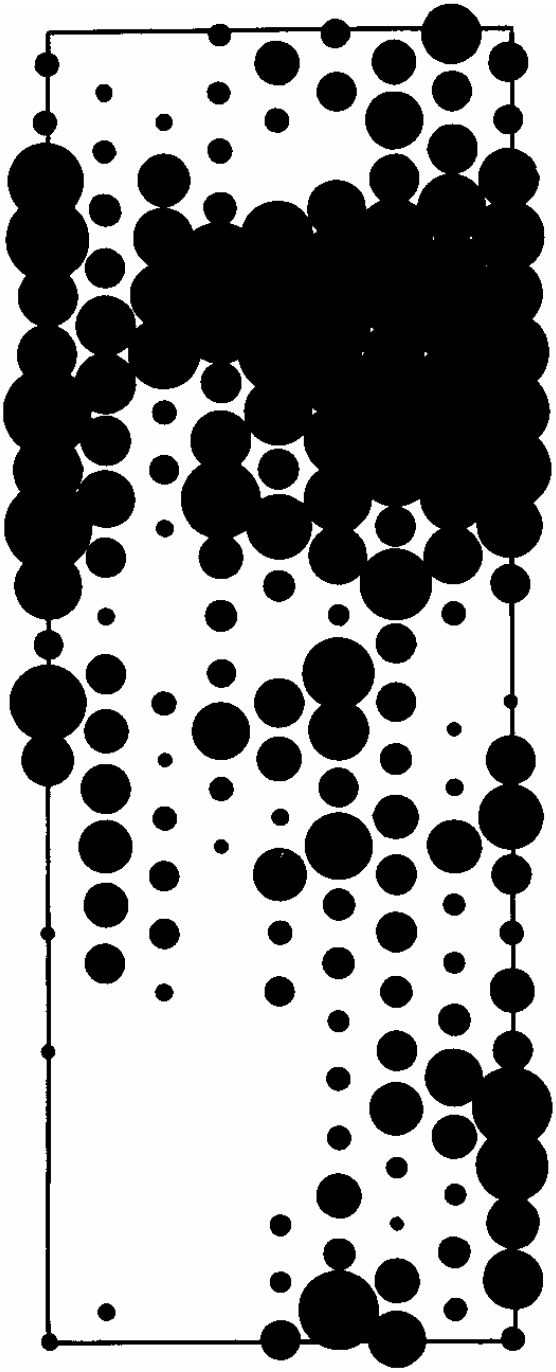


Fig. 9 Relative abundance in 207 1.5 x 20 m quadrats on the Figs. 3, 4 strip of 7 plant species, *Drosera whittakeri*.

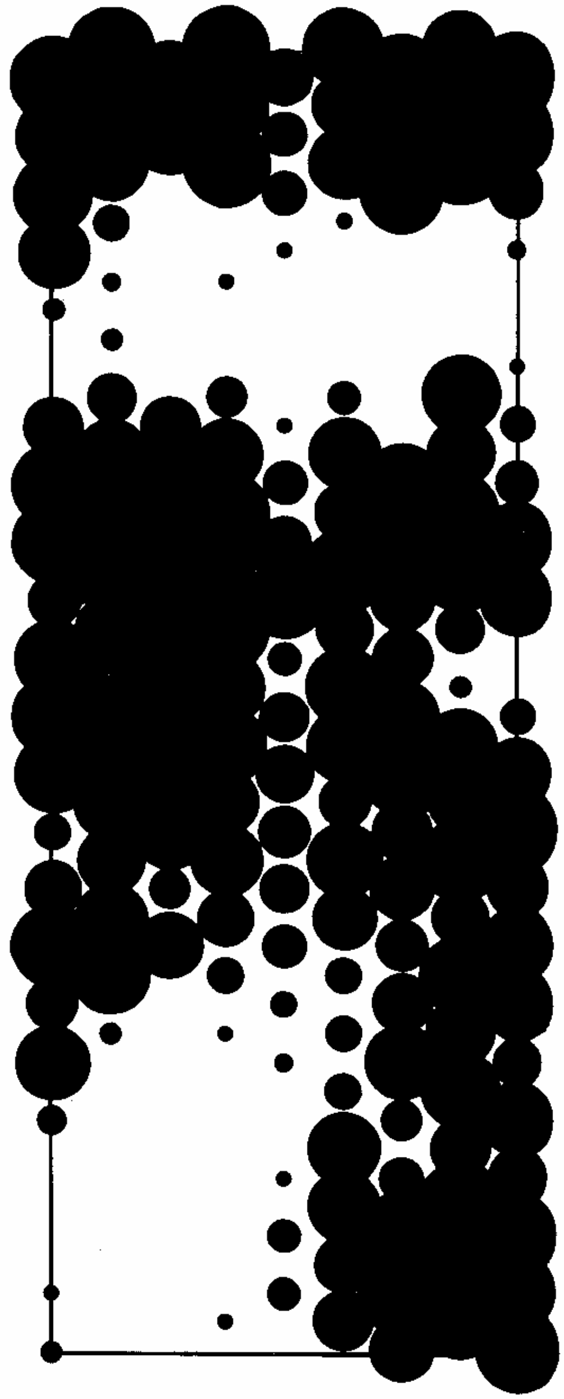


Fig. 10 Relative abundance in 207 1.5 x 20 m quadrats on the Figs. 3, 4 strip of 7 plant species, *Baeckia crassifolia*.

sandheath, is a reoccurring theme in the South East, and epitomizes that which underlies much vegetation-mapping (Crocker 1944, Coaldrake, 1951, Specht, 1972). Both within and between such mapping units, however, the concept of native plant habitat is much more complicated, as the next sections explain.

Finescale

When the precise distributions of all native species on the previously described strip are examined (in this case by measurements over a surveyed grid of 207 samples), it remains true that most are found to live either on sand (e.g. *Leptospermum myrsinoides, Lepidobolus drapetoleus)* or on limestone (e.g. *Pomaderris obcordata, Lasiopetalum baueri).* Figures 5-10 show this as general, by reference to six arbitrari ly chosen species distributions. However, no two have exactly the same distribution-patterns.

Consider the five species *Hypolaena lastigiata, Leptospermum myrsinoides, Lepidobolus drapetocoleus, Lasiopetalum baueri* and *Acacia spinscens.* On the strip, the first three tend to go together, the last two tend to go together, and the two groups tend to avoid each other. Thus places with the first three and without the last two, represent one sort of habitat-occupancy (Fig. 11, rating 1) and the reverse combination represents another (Fig. 11, rating 6). Other combinations represent intergradational outcomes (Fig. 11, ratings 2-5). Figure 11 is the map of the overall pattern produced on the strip by these species.
Comparison of Figure 11 with the soil map shows a close match. Apparently all five species respond to the soil gradation in different ways which, taken collectively, reflect the soil gradation so faithfully as to predict what cannot be seen without drilling, viz.-the tongue of subsoil limestone extending under the toe of the dunal slip-face. On the other hand there is no match with the contour map, suggesting that these species distributions are relatively insensitive to the topography.

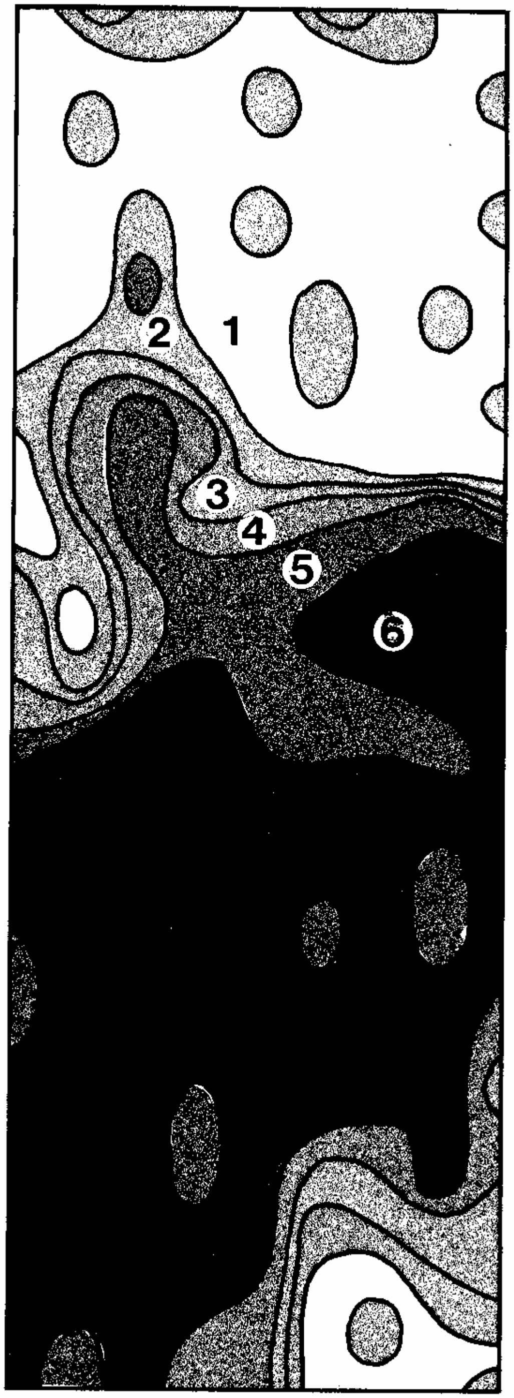
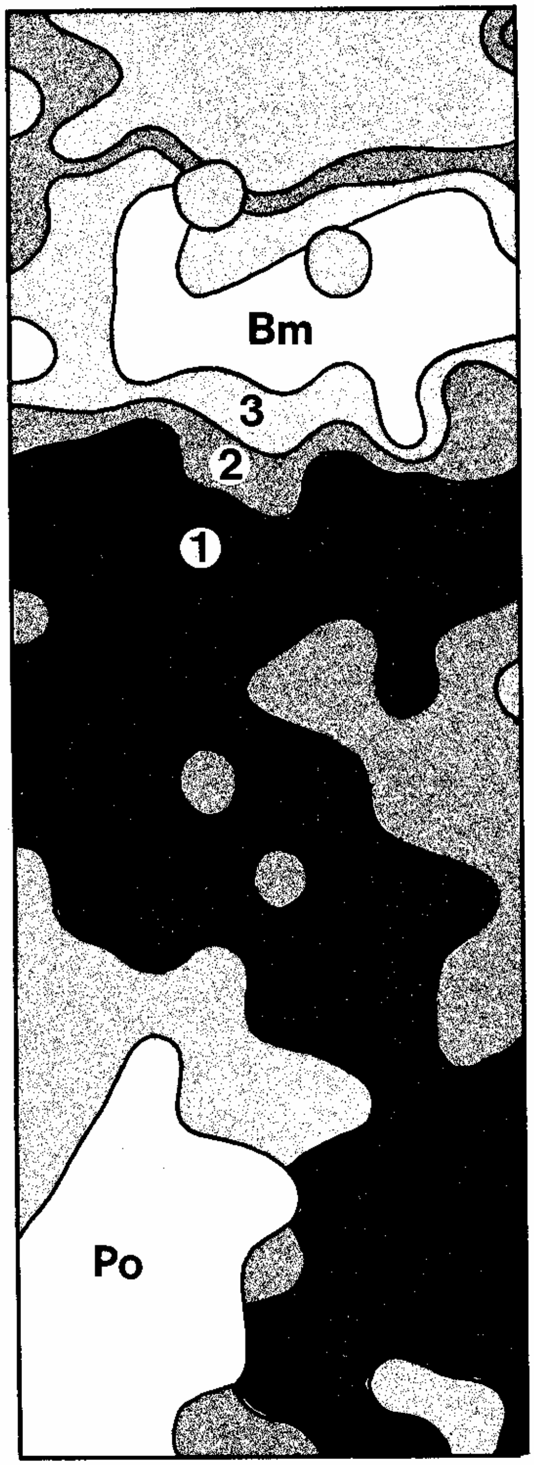


Fig. 11. Vegetation map of the Figs. 3,4 strip based on distribution of the plant species *Hypolaena fastigiata, Leptospermum myrsinoides, Lepidobolus drapetocoleus, Lasiopetalum baueri* and *Acacia spinescens.* Rating 1 = only *Hypolaena* associates, rating 6 = only *Lasiopetalum* associates, ratings 2-5 = graded intermediate mixtures.



Vegetation map of the Figs. 3, 4 strip based on distribution of the plant species *Baeckia behrii, Baeckia crassifolia, Banksia marginata* and *Pomaderris obcordata.* 8m = area to which B. *marginata* is restricted. *Po* = area to which *P. obcordata* is restricted. 1-3; both, one only and neither *Baeckia* species, respectively.

When attention is turned to another set of species on the same strip, a strikingly different map results (Figure 12). This map results from considering *Baeckia behrii,* B. *crassifolia, Banksia marginata* and *Pomaderris obcordata.* The first two go together (Fig. 12, rating 1) and mutually avoid the last two, which avoid each other. There is correspondence with the contour map. The two *Baeckia* species are insensitive to the subsoil gradation but are sensitive to the dunal slip-slope, avoiding that place to which B. *marginata* (Fig. 12, 8m) is confined, and the hilltop calcrete, which *Pomaderris* occupies (Fig. 12, Po).

Figures 11 and 12 together illustrate a general truth, that the conditions for plant life are set by numerous factors, not one or a few, and that the layouts of these factors do not necessarily correspond. Accordingly, the distributions of the variously-reactive species do not correspond, either, and there is no possibility of producing a single map which summarizes all salient information about the distributions of all species present. How can Figures 11 and 12 be blended into a single, clear map that loses sight of no information? They cannot be so blended. Fifty further species on the strip remain unconsidered. Habitat and the vegetation it elicits are multivariate. A simple map helps to comprehend the general layout of vegetation, but no single map can cope with all the details.

Shift

A further complication, not as widely appreciated as it should be, is that even within the one sort of landscape such as dunefield, species may drift from one set of apparent habitat-preferences to another. In dunefields near Keith, for instance, there is a repetitive landform of windward slope, lee slope and swale, in response to which heath always stratifies into corresponding community types. However, comparisons between different places show that some species sometimes shift their occupancy-patterns from one of these communities to another, although some are stable. Thus in Table 1, *E. baxteri* remains a lee-slope species at both

Table 1. COMPARISON OF PERCENTAGE FREQUENCIES OF PLANT SPECIES IN EQUIVALENTLY LOCATED SITUATIONS AT GOSSE HILL (G.H.) AND DARK ISLAND (0.1.) IN MOLINEAUX FORMATION DUNEFIELD

Species	Lee slope Community		Windard slope Community		Swale Community	
	D.I.	G.H.	D.I.	G.H.	D.I.	G.H.
Eucalyptus baxteri	100	100	16	0	15	2
Calythrix tetragona	43	35	21	37	24	53
Triodia irritans	0	0	6	17	8	36
Phyllota remota	0	100	10	100	65	0

.

Gosse Hill and Dark Island, *Calythrix tetragona* performs about the same in both places and so does *Triodia irritans,* but *Phyllota remota* practically reverses its distribution, from a strict swale species at Dark Island to a strictly slope species at Gosse Hill.

This shifting-about in local living-space characterizes probably all species throughout their ranges, up to distributional limits where the species runs out of tolerable options. *Baeckia behrii,* for example, can be traced far away from the swales of the Gosse Hill region, into the Great Victoria desert, where its associates and surroundings are completely different. Th is em phasizes that apparent habitat-relationships in anyone place reflect just the particular habitat-context found there, which is probably unique. There is no basis to assume that the species will be restricted in the same ways in other contexts, i.e.-that it will always be found with the one set of associates on the one range of soil types, for example.

A SHORT INLAND TRAVERSE INTERSECTING MAIN TYPES

Blackburn (1964) provides an excellent explanatory landform-diagram and soils map against which to describe and follow the layout of native vegetation now discussed from an inland traverse just north of Kingston, starting in the first Bridgewater Formation 'range' west of the Reedy Creek corridor (Fig. 13, A). This traverse retains sufficient native vegetation to carry the story, (about one-sixth on average, zig-zagging between relict blocks).

This starting point, mapped by Blackburn as Lacepede Soil Association, is a low lying field of crowded calcrete ridges alternating with shallow troughs, nowhere much elevated above the flat, seasonally-inundated corridors

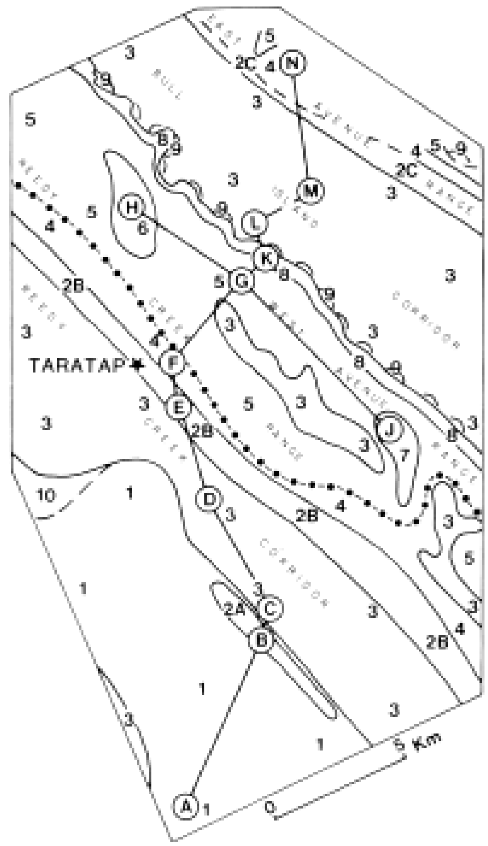


Fig. 13. Map of the Taratap region. For description of vegetation types 1-9, see text. Points A-N on traverse line locate sites discussed in the text. Dotted line is western distributional boundary of *Eucalyptus baxteri.*

on either side. Botanically, its most obvious features are, first, lack of much flora typical of the subsequent inland ranges, particularly stringybark *(E. baxteri)* and many of its distributional associates such as *Phyllota, Adenanthos, Epacris, Lhotzkya, Pomaderris* and *Baeckia,* and second, the prevalence or greater expression of some flora less common with inland traverse, such as *Melaleuca gibbosa, Olearia ciliata* and the coastal elements *Leucopogon parviflorus, Olearia axillaris* and *Acacia longifolia* var. *sophorae.* Its heaths are less rich, its vegetational diversity less and its mid-trees, such as *E. fasciculosa, Casuarina stricta, Acacia pycnantha, Bursaria spinosa* and *Dodonaea attenuata* are smaller.

Its typical situation (Fig. 13, 1) is a repetition of *E. diversifolia* thickets along the calcrete ridges and *Banksia ornata* heath between, from which sparse *E. fasciculosa, E. viminalis* ssp. *cygnetensis* and *E. leucoxylon* ssp. *pruinosa* emerge. Variations include *Casuarina pusilla* heath on siliceous sand and swampy pockets with salt-indicating *Melaleuca neglecta* low teatree and associates, such as *Hakea nodosa, Gahnia trifida, Darwinia micropetala* and D*istichlis.*

At the system's eastern margin along the Lacepede-Kennion Soil Association boundary, a distinctive kind of *E. fasciculosa* woodland occurs (Fig. 13 B, type 2A). Its key features are tall pink gum, a stratum of A. *pycnantha,* C. *stricta,* O. *attenuata* and *B. spinosa,* spasmodic coastal wattle below that and open glades beneath, practicaly bare, except for bracken.

Next east is the Reedy Creek corridor, flat and now cleared, but with a string-line woodland of *E. viminalis* at its extreme western margin (Fig. 13, C), a few low limestone 'islands' with *E. leucoxylon,* and evidence of its former *Melaleuca halmaturorum-Gahnia trifida* swamp scrub, to be described in more detail from the next corridor inland (Fig. 13 D, type 3).

The western margin of the Reedy Creek range, with terra-rossas of Blackburn's Ardune Soil Association, is occupied by a fully-developed version of the previously mentioned pink gum glade woodlands with small variations introduced by limestone outcrop and sandy pockets (Fig. 13 E, type 2 B). On calcrete outcrop large *Melaleuca lanceolata* (dry land tea tree) and C. *stricta* locally supplant pink gum, but the bare ground persists, with only occasional *B. spinosa* and *Acacia ligulata,* often enveloped in *Meuhlenbeckia* and *Clematis,* and some X. *australis* and bracken. Sandy pockets lack trees and feature coastal wattle, X. *australis, Kunzea* and rushes, with occasional blue gums nearby.

Further traverse into the range, onto Landseer Soil Association, adds heath understorey to the *E. fasciculosa* woodland, particularly *Leptospermum myrsinoides Hakea-B. ornata* heath, but not yet the *Phyllota-Adenanthos* group (Fig. 13 F, type 4). *E. diversifolia* thickets replace dryland teatree on the calcrete ridges, sometimes tall without undershrubs, sometimes low with heath, including *Acacia myrtifolia,* A. *leiophylla,* A. *verticillata, Hibbertia stricta* and *H. sericea, Hakea vittata, Correa reflexa, Astroloma conostephioides* and X. *australis.* Lowlying pockets carry *Melaleuca neglecta* low teatree with salt-indicator associates and fringing *E. viminalis* ssp. *cygnetensis.*

Occasionally, landlocked freshwater sandy pockets are encountered. These carry tall B. *marginata* woodland over mossy ground with sparse *Kunzea,* a rare vegetation-type.

About one-third of the way through the range, the western distributional boundary of *E. baxteri* is encountered, running NNW-SSE in the trend of the range (Fig. 13, dotted line). This important line marks the western boundary of much other flora, for instance the mal lees *E. foecunda* and *E. incrassata* (Fig. 13 H, type 6), which occupy some elevated sandy slopes over limestone, many heath species such as *Westringia eremicola, Boronia filifolia, Hibbertia virgata, Adenanthos terminalis* and *Choretrum glomeratum* which occur with them, others such as *Baeckia behrii, Epacris impressa* and *Caustis,* which occur in special places (Fig. 13 J, type 7), and unusual shrubs such as *Beyeria leschenaultii,* in fringe vegetation of M. *neglecta* flats. Where intrarange flats are wide enough and salty, bare crusted pans may be found, carrying only small *Wilsonia backhousei, Samolus repens* and *Sarcocornia blackiana;* these seasonally inundated pans usually are fringed with *Gahnia-Machaerina* sedgeland and salt water teatree. The eastern margin of the range, sloping abruptly to the Bull Island corridor, is occupied mainly by an *E. fasciculosa-E. baxteri* woodland relatively bare beneath, except for occasional coastal wattle, much bracken and some *E. diversifolia* (Fig. 13 K, type 8).

At the precise boundary of the range and corridor is a stringline wood land with some of the biggest trees in the region, mainly old rivergums *(E. camaldulensis)* but also *E. ovata* and very occasionally, *E. pauciflora* (snowgum), the most westerly in Australia and now very rare in this part of the South East (Fig. 13 L, type 9)

The corridor generally is inundated solodic flat under M. *halmaturorum-Gahnia* swampscrub, the vast bulk of the vegetation just these two species, but with *Machaerina juncea, Hakea nodosa, Bursaria spinosa* and a few *Pimelia* scattered sparsely (Fig. 13, type 3). Main variation has to do with 'islands' or slight calcrete rises (Fig. 13, M), which alter the vegetation dramatically. They carry woodland of *E. leucoxylon, E. fasciculosa, E. diversifolia,* C. *stricta* and B. *spinosa,* as well as coastal wattle, with a shrub layer including X. *australis, H. rostrata, Hibbertia* and *Cassytha,* surrounded by *Melaleuca neglecta.* low teatree and its associates such as *Darwima micropetala*

Further inland traverse onto the East Avenue range, tends to repeat the Reedy Creek range sequence (Fig. 13, N), but with subtle differences The west side of the range carries *E. fasciculosa* glade woodland as did the Reedy Creek range; that is succeeded by woodland with heath understorey, as before, and *E. baxteri* and associates such as *Phyllota* and *Leucopogon costatus* are first encountered about the middle of the range. The east face runs down to saltflats carrying stringline forest of *E. camaldulensis* as before. While the theme is the same, the details differ, reflecting probably the increasing maturity of the range and the tendency of species to shift about accordingly.

SOURCES OF DETAILED INFORMATION

Only one major work by a botanist dealing comprehensively and solely with the vegetation of the South East, ever has been written, viz: Crocker (1944), and it contains a large format vegetation-map. This map, or at least Crocker's work, is acknowledged by the South Eastern Drainage Board to underly their 1 500000 map: Pre-Settlement Vegetation, beautifully presented as Map V in their published study of 1980

It is to this map by the South Eastern Drainage Board, and to their corresponding map VI: Remaining Vegetation, that general readers should turn Fourteen mapping categories are shown in coloured printing, accompanied by a clear legend, a book section headed: Vegetation, and an Appendix VI with floristic lists.

The only comparable map-coverage is a specialized treatment by Welbourn and Lange (1968). None of this is very useful in local instances, being too generalized. Those interested in particular localities would do better to consult the literature, to which the following is a general guide, and to extract what is relevant.

Of the major sources, the first is J M. Black's 'Flora of South Australia', in four parts of which the first was recently revised. This is authoritative, treats all vascular flora in the South East, with keys to their identification, and is unequalled Many books and papers deal with special sections of the flora, for instance Whibly's Acacias of South Australia' (1980) with keys, illustrations and distribution maps, Carrick and Chorney's equivalent treatment of teatrees (1979), Wilson's equivalent treatment of samphires (1980), and so on down to particular species (kangaroo grass, Hayman 1960; pink gum, White 1970). Specialised floristic information may be obtained from the Information Officer of the South Australian Botanic Gardens, Adelaide.

Turning to vegetation, indispensible references are Specht's 'Vegetation of South Austral ia' (1972) and Boomsma & Lewis' 'Native forest and woodland vegetation of South Australia' (1981). Otherwise, the literature deals with particular localities (e.g. Correll 1963; Gilbertson & Foale 1977: southern Coorong and Younghusband Peninsula, Coaldrake 1951, Ninety-Mile Plain) or vegetation-types, e.g Eardley (1943) on fen, Crocker & Eardley (1939) on bog, Tiver & Crocker (1951) on grassland, Specht (1957) on heath) Works dealing with particular lifeforms and their distributions include Boomsma (1981) on trees, Chippendale & Wolf (1981) on eucalypts and Litchfield (1956) on numerous species.

An important ancillary source is botanical reference in soil studies (Blackburn 1964; Blackburn, Litchfield, Jackson & Loveday 1953; Jackson & Litchfield 1954), conservation literature (Mowling & Barritt 1980) and some general works (Costermans 1981)

REFERENCES

Black, J. M. Flora of South Australia. Part 1 (3rd edn.) revised and edited by J. P. Jessop (1978) Parts 2, 3 (2nd edn.) photolitho reprint (1977). Part 4 (2nd edn.) revised by E. L. Robertson Facsimile reprint (1980). (Govt Printer, Adelaide).

Blackburn, G. (1959). The soils of the Tatiara district, South Australia. *C.S.I.R.O. Divn. Soils. Soils and Land Use Ser. (34).*

Blackburn, G. (1964). The soils of Counties Macdonnell & Robe, South Australia. *C.S.I.R.O Divn. Soils. Soils and Land Use Ser. (45).*

Blackburn, G., Litchfield, W H, Jackson, E. A. & Loveday, J. (1953). A survey of soils and land use in part of the Coonalpyn Downs, South Australia. *C.S.I.R.O. Divn. Soils. Soils and Land Use Ser.* (18).

Boomsma, C. D. (1981). 'Native trees of South Australia'. *Woods* & *Forests Dept.,* S. *Aust., Bull.* (19) (2nd edn.).

Boomsma, C D. & Lewis, N. B. (1980) The native forest and woodland vegetation of South Australia. *Woods* & *Forests Dept.,* S. *Aust., Bull.* (25).

Carrick, J. & Chorney, K. (1979). A review of *Melalauca* L. (Myrtaceae) in South Australia. *J. Adelaide Bot. Gard.* **15**, 281-319.

Chippendale, G. M. & Wolf, L. (1981). The natural distribution of *Eucalyptus* in Australia. *Aust. Nat. Parks Wildlife Serv., Spec. publ. (6).*

Coaldrake, J. E. (1981). The climate, geology, soils and plant ecology of portion of the County of Buckingham (Ninety-Mile Plain), South Australia. *C.S.I.R.O. Bull. (266).*

Correll, R. L. (1963). The application of phytosociological techniques to the vegetation of the Younghusband Peninsula. B. Sc. (Hons) thesis, Dept. of Botany, University of Adelaide.

Costermans, L. (1981). 'Native trees and shrubs of South Eastern Australia' (Rigby, Adelaide).

Crocker, R. L. (1944). Soil and vegetation relationships in the lower South East of South Australia. A study in ecology. *Trans. R. Soc.* S. *Aust.* **68**, 144-172.

Crocker, R. L. & Eardley, C. M. (1939). A South Australian *Sphagnum* bog. *Trans. R. Soc.* S. *Aust.* **63**, 210-214.

Crocker, R. L. & Wood, J. G. (1947). Some historical influences on the development of the South Australian vegetation communities and their bearing on concepts and classification in ecology. *Trans. R. Soc.* S. *Aust.* **71**, 91-136.

Dodson, J. R. (1974). Vegetation history and water level fluctuations at Lake Leake, south-eastern South Australia. I. 10 000 B.P. to Present. *Aust. J. Bot.* **22**, 719-741

Dodson, J R. (1975a) Vegetation history and water fluctuations at Lake Leake, South-eastern South Australia II. 50000B.P. to 10000B.P. *Aust. J. Bot.* **23**, 815-831

Dodson, J. R. (1975b). The pre-settlement vegetation of the Mt. Gambier area, South Australia. *Trans R. Soc.* S. *Aust* **99**, 89-92.

Eardley, C. M. (1943). An ecological study of the vegetation of Eight Mile Creek Swamp. A natural South Australian coastal fen. *Trans. R. Soc.* S. *Aust.* **67**, 200-223

Ellis, P. L. (1970). Conservation. A geological rationale Supp. to Aust. Inst. Mining Metallurgy. Bull. No. 335.

Gilbertson, D. D. & Foale, M. R. (eds.) (1977). The southern Coorong and lower Younghusband Peninsula of South Australia. Nat. Conserv. Soc. S. Aust. (mimeo).

Hayman, D. L. (1960). The distribution and cytology of the chromosome races of *Themeda australis* in southern Australia. *Aust. J. Bot.* **8**, 58-68

Idnurm, M. & Cook, P. J. (1980). Palaeomagnetism of beach ridges in South Australia and the Milankovitch theory of ice ages. *Nature.* **286**, 699-702

Jackson, E. A. & Litchfield, W H. (1954). The soils and potential land use of part of County Cardwell (Hundreds of Coombe and Richards) in the Coonalpyn Downs, South Australia. *C.S.I.R.O. Divn Soils. Soils and Land Use Ser. (14).*

Jones, S. B. & Luchsinger, A. E. (1979). 'Plant Systematics'. (McGraw-Hili, New York).

Lange, R. T. (1966). Sampling for association analysis. *Aust. J. Bot.* **14**, 373-378.

Lange, R. T. (1978). Carpological evidence for fossil *Eucalyptus* and other Leptospermeae (subfamily Leptospermoideae of Myrtaceae) from a tertiary deposit in the South Australian arid zone. *Aust. J. Bot.* **26**, 221-233.

Lange. R. T (1981). Australian Tertiary Vegetation: evidence and interpretation. Ch. 3 *In* J. Smith *(ed.)* 'A History of Australasian Vegetation'. (McGraw-Hili, Sydney).

Litchfield, H. W. (1956) Species distribution over part 0f the Coonalpyn Downs, South Australia. *Aust. J. Bot.***4***, 86-115.*

Ludbrook, N. H. (1980). 'A guide to the geology and mineral resources of South Australia.' (Govt. Printer, Adelaide).

Meinig, D. W. (1962). 'On the margins of the good earth.' (John Murray, London).

Mowling, F. A. & Barritt, M. K. (1980). The natural vegetation of the south east, 1980. Nat. Conserv. Soc. S. Aust. (mimeo).

Peck, A. J. (1980). Salinity-Man's oldest environmental problem. C.S.I.R.O. Inf. Service Leaflets. sheet No. 1-32.

Porter, C L. (1967). 'Taxonomy of Flowering Plants'. (Freeman, New York).

Ralph, W. (1981). Towards more efficient use of superphosphate. *Rural Res.* **112**, 22-25.

Raunkiaer, (1934) 'The life form of plants and statistical plant geography'. (Oxford Univ. Press, Oxford).

Rayson, P. (1957). Dark Island Heath (Ninety-Mile Plain, South Australia). II. The effects of microtopography on climate, soils and vegetation. *Aust. J. Bot. 5*, 86-102.

Smith, J. (1981). An introduction to the history of Australasian vegetation. Ch. 1 pp. 1-31 *In* J. Smith (Ed.) 'A History of Australiasian Vegetation' (McGraw-Hill, Sydney).

Specht, R. L. (1957). Dark Island Heath (Ninety-Mile Plain, South Australia). V. The water relationships in heath vegetation and pastures on the Makin Sand. *Aust J. Bot.* **5**, 151-172.

Specht, R. L. (1972). 'The vegetation of South Australia' (Gov!. Printer, Adelaide).

Specht, R. L. & Rayson, P (1957). Dark Island Heath (Ninety-Mile Plain, South Australia) I Definition of the ecosystem. *Aust. J. Bot.* **5**, 52-85.

Specht, R. L, Rayson, P & Jackman, M. E. (1958).
Dark Island Heath (Ninety-Mile Plain, South Australia). VI. Pyric succession: changes in composition, coverage, dry weight and mineral nutrient status. *Aust. J. Bot.* **6**, 59-88.

South Australia. Dept. for the Environment (1980).Vegetation Clearance. Agricultural Regions of South Australia. (2nd edn.)

South Eastern Drainage Board (1980) Environmental impact study on the effects of drainage in the south east of South Australia.

Stephens, C. G (1943). The pedology of a South Australian fen *Trans R. Soc.* S. *Aust* **67***,* 191-197

Tiver, N. S. & Crocker, R. L. (1951). The grasslands of south-eastern South Australia in relation to climate, soils and developmental history. *J. Brit. Grassl. Soc.,* **6**, 29-80.

Wallace, B. & Srb, A. (1961) Adaptation. (Prentice Hall).

Walter, H. (1979). Vegetationszonen und Klima. (Springer, New York).

Welbourn, R. M. E. & Lange, R. T. (1968) An analysis of the vegetation on stranded coastal dunes between Robe and Naracoorte, South Australia. *Trans. R. Soc.* S. *Aust* **92**, 19-24.

Whibley, D. J. E. (1980). Acacias of South Australia (Govt. Printer, Adelaide)

White, T. C R. (1970). The distribution and abundance of pink gum in Australia. *Aust. For.* **34**,11-18.

Wilson, P. G. (1980). A revision of the Australian species of Salicornieae (Chenopodiaceae) *Nuytsia* **3**,1-154

Woods, J E. T. (1862). Geological observations in South Australia, principally in the district south east of Adelaide. (Long, Longman, Green).

Woods, J. T. (1970) Some facts of life. Suppl. to Aust. Inst. Mining Metallurgy Bull. (335).

Weber, J Z & Bates, R. (1978). Orchidaceae Pp. *383-462 In.* 'Flora of South Australia'. Part I., 3rd edn. (Govt. Printer, Adelaide)

11: Tribal Man

by GRAEME L. PRETTY, ROBERT C. PATON and RODNEY D.J.WEATHERBEE

INTRODUCTION

For our discussion of tribal man we have used the biogeographical boundaries proposed by Laut et al. (1977). This has established a broad perimeter for the province and subdivided it into its major ecological zones These reflect long established responses of living forms to climate and soils and also bear a recognisable relationship to defined Aboriginal territories. Established biogeographical boundaries were widely recognised by aborigines as territorial margins.

CULTURAL GEOGRAPHY

According to Smith (1880), 'the aborigines of the South East were divided into five tribes each occupying its own territory, and using different dialects of the same language. Their names were 'Booandik', 'Pinjunga', 'Mootatunga', 'Wichintunga', and 'Palinjunga'. Tindale's (1940) reassessment of the region's tribal territories based upon archival sources and aboriginal knowledge, principally from Milerum (Clarence Long) (1870-1942), distinguished three groups: the BunganditJ, the Potaruwutj and the Meintangk. In his (1974) revision of this work, he reports the early accounts as presenting conflicting and intractable evidence for distinguishing between tribes and smaller territorial units called hordes within those tribes. Consequently, listed tribes often show up as a mixture of actual tribes and hordes. For example, the 'PalinJunga', cited by Smith as a tribe, was actually a horde of the PotaruwutJ.

Figure 1 shows Tindale's (1974) assessment of the boundaries of the three South East tribes. Collectively, they cover the area from Salt Creek to the Glenelg River, inland to Wartook in Western Victoria, and north to Bordertown. It reflects the broad area outlined by Smith's five tribes, the principal discrepancy being her fixing of the eastern boundary for the Bunganditj as '30 miles inland' from the coast. Recent linguistic evidence (Dixon 1980) tends to support this and suggests that the people of Western Victoria, described as Bunganditj by Tindale, may have belonged to another group occupying the Western Victorian mallee.

SOCIAL ORGANISATION, CEREMONIES AND CUSTOMS

Only scanty information survives for reconstructing the historic daily existence of these people. There is no doubt considerable detail still to be won from records of early travellers and settlers but it will be difficult to work with as the destabilising of tribal life by the settlers quickly blurred regional distinctions of culture. These are unlikely to have been picked up by outside observers, who were already in difficulty at even comprehending and empathising with the broader make-up of these societies.

The most useful sources to date, are the accounts of early Government sponsored expeditions (Angas 1847; Bull 1885; Tolmer

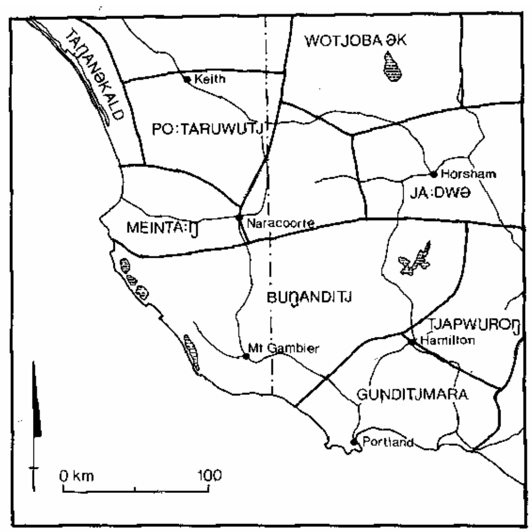


Fig. 1. Hypothesised major biogeographic regions (after Laut *et al.*, 1977) and tribal boundaries delimited by Tindale (1974).

Fig. 1. Hypothesised major biogeographic regions (after Laut *ef al.,* 1977) and tribal boundaries delimited by Tindale (1974).

1882), and the oral and written accounts left by the few settlers who had close association with the Aborigines (Smith 1880; Stewart in McCourt and Mincham, 1977). These sources have permitted excellent analyses by Campbell (1934, 1939). Donovan and Rowney (1977), but the most valuable is Howitt's (1904) classic work.

The three tribes of the South East stand forth as a broadly defined cultural confederation of people, having discernible similarities of language and social organisation, and occupying a coastal and temperate inland region which cradled the dry parched mal lee heartland.

The most basic unit of social organisation was the family, a number of which, grouped together formed a horde. A set of hordes, sharing a common language and with members considering themselves as one people, made a tribe. The Bunganditj had five hordes, the Meintangk seven, and the Potaruwutj eight or more (Tindale 1974). Wallis, a resident born in the district in 1859, recalled that the groups of the Bunganditj tribe numbered 60-100 individuals (Campbell 1934). These figures seem high, contrasting with Tindale's 1974 estimated Australian average of 25 and maximum of 60, and it may be that they were a result of white settlement forcing aborigines to congregate on land unsuitable for pastoralism. Campbell (1939) reaffirms however that the area supported an unusually large population, perhaps numbering 2000. This may have generated large hordes. The point should be clarified.

A second form of social differentiation within the hierarchy of family, horde and tribe, was the system of classes and totems which governed marriage and other social relationships. Every person belonged to one of two classes, and these classes were subdivided into totem and subtotem groups. The class and totem system for the Bunganditj tribe has been set forth by Howitt (1904) as Table 1.

The totemic groups of the South East tribes were poorly understood, even by those Europeans who had prolonged contact with the aborigines. Duncan Stewart, Mrs Smith's son, stated 'All this appears very arbitrary. I have tried to find some reason for the arrangement'. All that could be recorded with certainty was that a person would not kill or use for food any of the animals in their totemic group 'excepting when compelled by hunger, and then he expressed sorrow for having to eat his "singong" (friend) or "tomung" (his flesh)' (Howitt 1904).

The division of hordes into classes was fundamental to marriage arrangements. A person was required to marry someone from a class other than their own; for example, in the Bunganditj tribe a man of the Kumite class to take Kroki woman as wife.

There were other customs governing marriage and the breaking of them often resulted in violent disputes. In addition to marrying outside their class a person was expected to marry within their tribe, but into a different horde. Moreover this horde should not be directly adjacent to their own. In addition, men were forbidden to marry from the horde of thei r mother.

Marriages were thus generally arranged, often at corroborees by the male relatives of unmarried children. Smith (1880) states 'infants are betrothed to one another by their parents. Girls are betrothed by their fathers, with the concurrence of his brothers, into some family which has a daughter to give in exchange'. There were other avenues

Table 1. CLASS AND TOTEM SYSTEM FOR THE BUNGANDITZ TRIBE (AFTER HOWITT, 1904)

Classes	Totems	Sub-Totems
Kroki	*wereo (ti-tree)*	duck, wallaby, owl, crayfish. etc.
	wirmal (an owl)	not known
	murna (an edible root)	bustard. quail, small kangaroo etc.
	karaal (white crestless cockatoo)	kangaroo. sheoak. summer, sun. autumn, wind. etc
Kumite	*mula* (fish-hawk)	snake. *Banksia,* etc.
	parangal (pelican)	dog. *Acacia melanoxylon.* fire. frost, etc.
	waa (crow)	lightning, thunder, rain. clouds. hail. winter, etc.
	wila (black cockatoo)	moon. stars. etc.
	karato (a harmless snake)	fish. eels, seals. stringy bark, tree. etc.

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however. For example, young men and women who were not promised in marriage might court in public and, if their union was acceptable to their relatives, marry. Notwithstanding the formalism of marriage rules, polygamy was widespread. It was quite common for a man to have two wives, and possible to have as many as five (Smith 1880).

The marriage ceremony of the Bunganditj tribe is described by Smith (1880). 'A company, consisting of all the males and the bride, proceed to the bridegroom's wurla, where he is lying on the ground, every limb and nerve in motion at the idea of the approaching ceremony. The company approach the wurla and halt; all eyes are fixed on the bridegroom lying on the ground. One of the honoured men of the tribe takes his seat beside him; the father takes the bride by the hand, and says to the bridesmen, "You give my daughter with the consent of all her males you see standing around". The young men turn to the bridegroom, and say "Here is your wife". She then places herself beside him, and the bridesmen politely walk away. The whole company then return to their wurlas, and leave the young couple to themselves. For five nights she sleeps about two yards from her husband; the fifth night her father goes to her, and persuades her to give up all her bashfulness. The ceremony is ended.'

After marriage, a woman left her home and went to live with her husband's horde, where she was expected to speak its dialect. Any children born from the marriage took their class and totem from their mother, but lived with their father's horde and spoke its language.

As children grew to adulthood, they might be given further totemic names, but as far as can be ascertained, they were not subjected to initiation ceremonies. Campbell (1934) is insistent on this point, stating that 'my informant (Wallis) expressed no knowledge of initiation ceremonies' and refers to Stahle, who was acquainted with the neighbouring Gournditch-Mara tribe, and confirmed that it possessed no initiation ceremonies. We should be skeptical of this, as it is based upon accounts dating from a period when tribal life was in its last stages of disintegration, and such ceremonies would not be made known to the whites. On the other hand, where ceremonial initiations did take place in Aboriginal Australia, their existence was known to all the tribe's members (the details being confined to the initiates), and quickly became known to the whites. It is therefore perplexing that no record of even the existence of such ceremonies comes from this area.

Despite similarities of social organisation and language, the people of the South East were clearly divided into landholding units. Each horde owned an area which they regarded as theirs and which was passed down from generation to generation. Smith (1880) states 'It appears from the statements of the blacks themselves that the land belonging to the Booandik tribe (Bunganditj) was handed down from father to son. They were wont to speak very proudly of their land, and of their forefathers, remarking what splendid hunters they were, and how they taught their children to love their country. I have often heard my faithful Jemmy Mcintyre say with great affection "The Schanck was my father's land, which he seldom left, except to act as chief in quarrel and disputes, to prevent bloodshed. My uncle and my father and mother lie buried there. I buried my wife and children there. My heart was sorry when I left my land-I loved it dearly".'

The land 'owned' by a horde was carefully marked out and jealously guarded. Any trespass upon it without prior agreement led to violent disputes. Howitt (1904) states 'No individual of any neighbouring family or tribe could hunt or walk over the land of another without permission from the head of the family group which owned it, and a stranger on it might legally be put to death'. Certain resources such as water springs were shared on a regular basis, and during hard seasons transgressions were sometimes permitted. There were also times when hordes or groups of tribes, would come together for a corroboree, during which acquaintances were renewed, some trade was carried out, disputes were settled (or begun) and marriages arranged. These gatherings would take place around abundant food resources, or unexpected provisions such as stranded whales, capable of supporting large groups for a limited priod.

SUBSISTENCE ECONOMY

FOOD

Lists of all edible resources available at the time of white occupation have been compiled for the South East (Campbell et al. 1946; Luebbers 1978) These show the richness of the region's biomass and the range of plant and animal species available in areas known to have been exploited by aborigines, but little direct evidence is available on the range of foodstuffs actually consumed.

Smith (1880) observed that their food consisted chiefly of kangaroo, fish, emu, opossum, fine roots, candant-seed, 'meenatt', and honeysuckle. Angas (1847) noted foods found in the aboriginal camps which his party came upon. These included wombat and several 'choices' of root. Other foodstuffs can be inferred from descriptions of hunting and gathering methods and habits. Angas (1847) mentions native techniques for catching birds and small swamp fish, and the method used to make a sweet beverage from banksia cones Smith (1880) reported seeing groups collecting crayfish and crabs, and small parties of shellfish gatherers were frequently seen combing the beaches for stranded seals or whales. Smith (1880) also reported foraging parties on the cliffs collecting eggs and young sea birds.

Food remains in middens and campsites show a preference for the exploitation of shellfish, fish, and the larger land mammals including kangaroo, wallaby and wombat. However, studies to date have concentrated on the coastal and interridge swamp districts, and do not cover the fu ll spectra of ecolog ical zones which the aborigines exploited.

TECHNOLOGY

Historical sources supplemented by collections show the people of the South East to have used a wide range of material objects (Figs. 2-4).

Wooden implements included boomerangs, digging sticks, clubs, shields, spears and spear throwers. All of these except the spears were manufactured from sheoak. The spears were made from ti-tree *(Melaleuca)* which is still abundant in certain swamp areas of the South East.

Baskets and mats were used extensively throughout the area and were woven from grass, reeds and rushes by several different methods.

Stone implements included ground edge axeheads which would have been hafted·to wooden handles (Fig. 2). The rock from which these axeheads were made occurs in western Victoria and was obtained by trade. Its presence in South Australia is largely confined to the South East, suggesting that the tribes of this region were socially remote from their immediate neighbours, and perhaps more powerful. A number of small

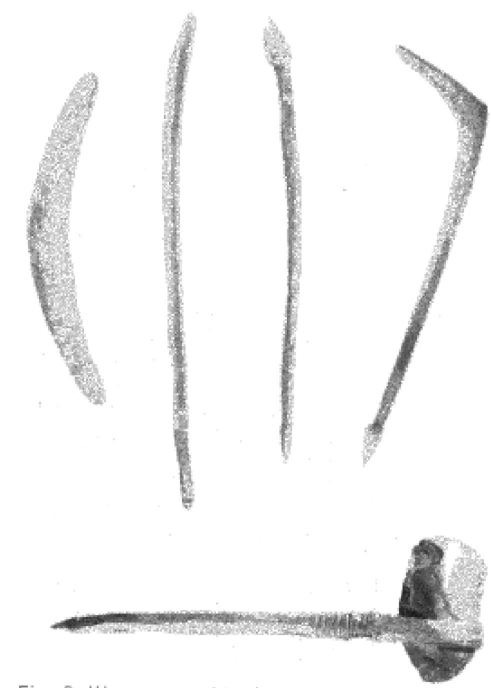

Fig. 2. Weapons and tools.

Fig. 3. Weapons.

stone tools including flakes and backed blades were also used during historic times. Angas (1846) illustrates a spear from the South East which has a number of small stone pieces set in resin as barbs.

In addition to these implements, the aborigines constructed mud weirs to trap fish and wicker work h ides for conceal ment when snaring birds. The fish weirs were made 'like a dam wall, extending across from side to side, for the purpose of taking the very small mucilagenous fish that abound in the water when the swamps are flooded' (Angas 1847) Angas also reported a bird hide about four feet high erected on the flats. It was 'just large enough for one person to squat in; the native, concealing himself in this ambush with his snaring rod protruding from a small aperture in the side, imitates the voice of the birds, and, as they alight upon the wicker work, dextrously slips

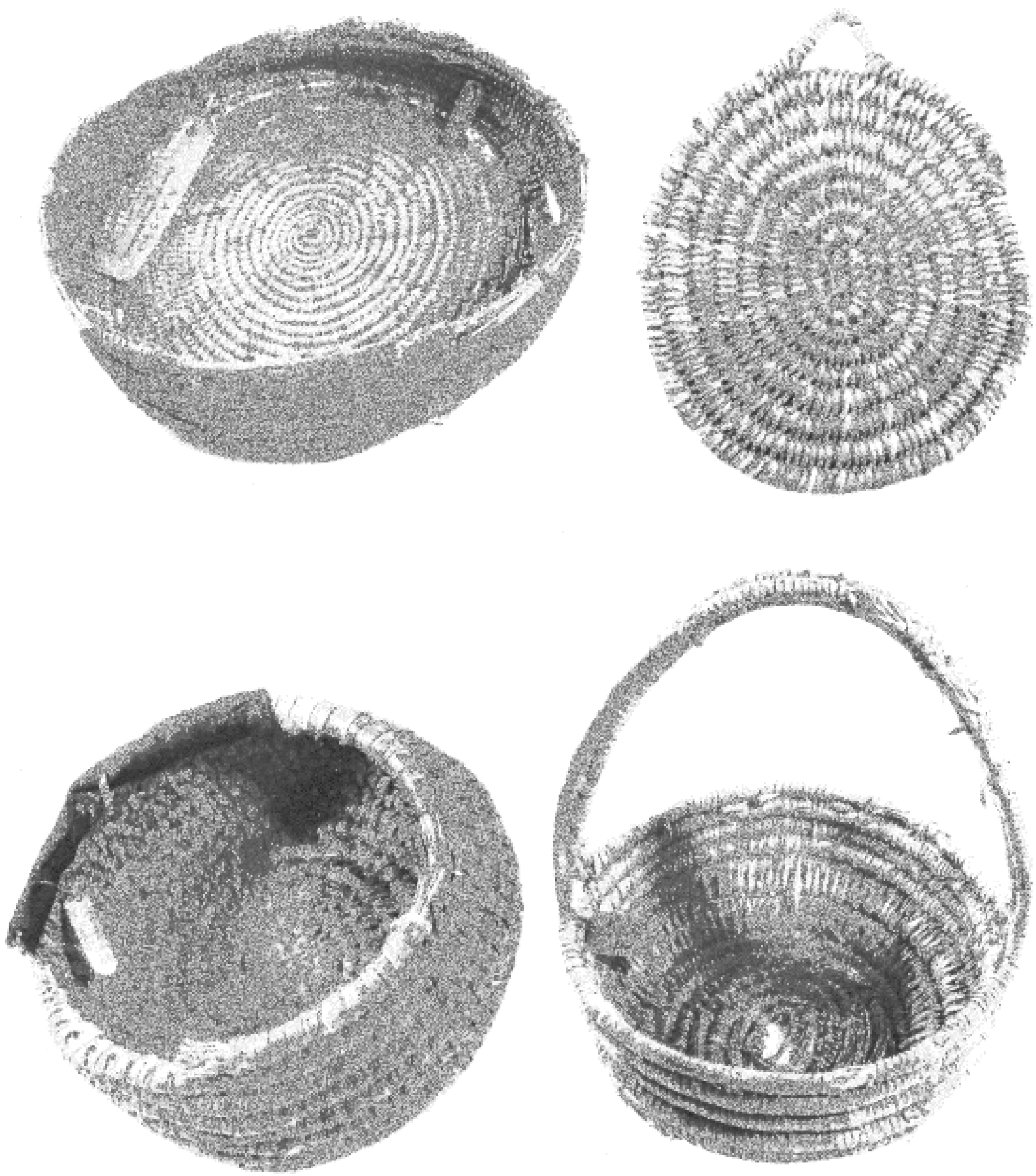

Fig. 4. Plaitwork.

the noose around their necks, and snares them into his retreat'. The snaring rod consisted of a stick up to eight feet long, probably made of ti-tree, with a running noose of kangaroo sinew attached to one end.

COLONISATION

From the beginning of the 1840s when settlement began in the South East, the number of aborigines living in the area is estimated to have declined by 50% every five years until the turn of the century when the last of the full blood aborigines died (Campbell 1939).

The causes of this rapid decline are probably complex. In the early stages of settlement violent confrontations between aborigines and settlers contributed to the demise of the former. Early settlers feared that aborigines were a threat to their personal safety, but above all regarded them as a menace to their livestock. When Mrs Smith (1880) spent a night in the bush with some aboriginal friends, they 'talked much about the treatment the blacks received from the early settlers; how when they killed a sheep which was merely lawful game in their eyes, just the same as kangaroos or emus or any other animal fit for food-they were hunted down and shot like dogs' (Smith 1880). She also heard from an aborigine of the murder of eleven members of a nearby horde by a party of white men in retaliation for the killing of some sheep. The case was brought before the courts but dropped for lack of evidence, on which Smith (1880) commented, 'Doubtless had the natives been the murderers instead of the murdered sufficient evidence would have been found or perhaps less conclusive proof deemed sufficient to justify a sentence of death'.

By 1861 when the first report on the mortality of the aborigines was written, most deaths were listed as being due to 'natural rather than violent causes' (Campbell 1939). By this time, the decline in the population could have been due to other factors such as disease, unfamiliar diet, alcoholism, and the disintegration of traditional patterns of marriage leading to infanticide. Smith's (1880) account is a tragic chronicle of the effects of settlement on the demise of Aboriginal people in the Lower South East.

HISTORICAL TOPOGRAPHY

Many visible traces and monuments of aboriginal settlement, however, remain

CAMPSITES

The determinants of aboriginal campsites in the Lower South East, follows the pattern observed throughout aboriginal Australia generally. Preference was given to areas with well-drained sand, if possible higher than the surrounding terrain and close to water. The proximity of food supplies was an essential determinant to a camp's location. If the food supply was static, for example in the case of shell fish, camps would be occupied for longer periods than if the supply had to come from mammals suqh as kangaroos or emus who would quickly be frightened away. Consequently, campsites can be found in abundance on coastal dunes, the inland ridges, and on the sand hills which used to border the now-drained swamps.

The winter climate of the South East was wet and cold, and use was made of cliff overhangs and caves. Evidence of occupation going back as far as 8600±300 B. P. has been found in archaeological excavations in a rock shelter at Mt Burr (Campbell, Edwards & Hossfeld 1963).

If rock shelters were not available, the Aborigines constructed substantial shelters to protect themselves from cold, wet winters. Angas (1847) described them as resembling beehives to protect them in these exposed situations from the cold south and west winds that prevailed during that season. These huts are composed of turf and mud over a framework of sticks and have a small entrance on the leeward side. Along the shores of the Coorong they cover these huts with sand and shells so as to form hollow mounds impervious to the wind beneath which they creep in stormy weather'

HUNTING AND GATHERING LOCALITIES

Seasonal oscillations of food supplies meant that occupation of campsites was also seasonal. In the summer, open campsites were occupied on the seashore and upon neighbouring dunes and lakes. These gave Aborigines access to both littoral and hinddune. The evidence of numerous large middens still preserved at regular intervals along the coastal dunes, discloses shellfish as the main exploited resource (Luebbers 1978). In the winter, when the cold winds and high seas made the shore inhospitable, aborigines would move inland, either to rock shelters or to their hut camps. From these, they sought food from the densely vegetated ranges and swamps Presumably the areas which they exploited would have been no more than half a day's travel from their camps. When these supplies were depleted or dispersed, the camps would shift to a fresh locality.

QUARRIES

The South East is almost devoid of hard rock outcrops. In the upper part of the area near Keith, isolated outcrops of granite, porphyry and similar rocks provided materials for larger forms of implements such as pounders and hammerstones (Campbell & Edwards 1966). Judging from some of the aboriginal songs that have survived, this material's obtaining by southern hordes was frequently a bloody affair, involving raiding parties and a great deal of fighting. Imported basaltic rock was sometimes used as a substitute.

Ground edge axeheads were usually made from diabase or similar igneous rocks obtained from Victoria where both completed implements and 'blanks' (stone roughly shaped but not ground) were traded out.

The one useful rock type that abounds in the South East is flint, and this was the principal stone for tools. Flint pebbles and boulders were freed from the coastal cliffs and offshore reefs by the pounding of the seas and cast as deposits of flint pebbles upon beaches. Other deposits are found inland, being relic beaches of former high sea levels (Campbell & Edwards 1966).

TRAFFICWAYS

Tracks existed to and from major food sites, and between the summer areas of habitation on the coast and the winter areas in the hinterland. Angas (1847) reported well worn tracks extending for many miles along the tops of the sand ridges.

The axehead trade route from Victoria is well authenticated (Campbell & Edwards 1966), and there were probably several other trade routes leading from the South East to the North and West where sites commonly yield tools and fragments of flint.

CEREMONIAL AND ART

There were undoubtedly many assembly grounds, probably maintained in areas of bushland now destroyed. We know that the people of the South East held 'corroborees', for which the local word was *maparena* (Smith 1880). Mr D. Schulz of Rendlesham recalls that his grandfather spoke of a big corroboree ground at the eastern corner of Lake George. Wallis (Campbell 1934) also mentions a corroboree ground at Mt Burr where the people from different areas would come together to sing, dance and fight.

We can only speculate about the purpose of these gatherings. Sacred rites are often associated with aboriginal corroborees, but the link is not universal. Such gatherings may be almost purely social and secular.

Our information suggests that the aborigines of the South East had a recognisably aboriginal religious system. They had stories which explained the formation of landscape features through actions of legendary being (Smith 1880). We know that there were powerful men called *pangal* who healed through access to special powers (Smith 1880). Smith's vocabulary of the language lists *nuyip-nuyip* as meaning 'ordinary song', implying the existence of a class of special or maybe sacred songs. However we have no information about this religious system's expression in the form of ceremonies.

The most interesting recent art discoveries are in two caves whose walls appear to have been engraved. The Tantanoola Cave has scratch marks on the wall covering approximately 20 sq. m. They consist principally of regular and curvilinear incisions, sometimes in parallel sequences and sometimes latticed. They were first reported (1980) by members of the Australian Speleological Federation who suggested that they might be of aboriginal origin (Hamilton-Smith et al. 1980). This is still under investigation.

Rock markings have been found at the Bat Cave near Kongorong. Its walls are covered with incised lattice work, track and vulva motifs. It remains the only confirmed rock art site in the South East and one of the few examples from the southern part of the State (McCourt 1975; G Aslin pers. comm)

INHUMATION

While many individual graves have been recorded in the area, there has been no general study of inhumation. Smith (1880) gives an account of a burial near Robe: 'The grave is dug about three feet deep, and made quite round. A fire is made in it to warm the earth, but not hot enough to heat the body. The corpse is bent together rolled in an opossum skin, and laid in the grave with the head towards the west. It is then covered with bark, and the grave is filled up with earth.'

There have been reports of petrified bodies.P S Sturt discovered a 'petrified' body in a cave near Mt Gambier, 'bent as in the attitude of thought, his elbows resting on his knees' (Campbell 1939) Campbell suggests this might have been a desiccated body. A curiosity of the 1860s was the body of an aboriginal man in a cave at Naracoorte (Woods 1862). Mineralisation had covered the body with a hard translucent film. Its subsequent theft by a travelling showman removed the opportunity of determining how it came to be there.

Exposure of the dead on wooden platforms, common on the Coorong, may also have occurred. The South East people would have been familiar with this mode, which was practised by the Tanganekald, neighbours of the Meintangk. An instance of this was observed by Wallis just inside the Tanganekald territory near the main Meintangk boundary (Campbell 1934) Two bodies were observed on a platform surrounded by seven or eight other bodies placed in sitting positions on the ground.

The dead, it appears, were not buried in defined cemeteries but individually within their home territories. As known grave sites were generally avoided, they would probably have been located away from frequented sites such as cam psites or trackways.

Different modes of burial existed in the region but the causes for differentiation are not known. It may be that, as elsewhere, differing modes of burial depended upon factors such as the sex, age and prestige of the deceased. For the present, the question must remain an open one.

ARCHAEOLOGY

Archaeological remains abound particularly in the deflating dune systems bordering the coast, and the decaying inland dune systems since deforestation.

Private collectors were active from the early days on The Kurtze family from Portland collected widely in the area, as did the McCourts of Beachport (McCourt 1975). The area was surveyed for sites by Tindale in 1932 who submitted that the inland spread of roughly parallel dune systems furnished evidence for Pleistocene changes in sea level (Tindale 1933). McCarthy (1938) reported upon the similarities of flaked bifaces from Mt Gambier to the *coup de poing* implement of the European Palaeolithic. The character and distribution of these flaked bifaces was discussed by Stapleton (1945). Campbell led a series of collecting expeditions to the parallel dune range area from as far north as Cape Jaffa to as far south as Cape Northumberland. A series of papers on the sites, implements and likely food resources emerged (Campbell & Noone 1943a, b; Campbell, Cleland & Hossfeld 1946). After the war, Campbell guided Mitchell to the Kongorong area. The results of this have been reported in Mitchell (1949). Campbell continued his interests in the area, and in collaboration with Hossfeld and Edwards initiated excavations at Bevilaqua Cliffs and Mt Burr (Campbell, Edwards & Hossfeld 1963). In part emergent from this were the excavations of Edwards at Lake George (R. Edwards pers. comm) The most recent work has been Luebbers' who has excavated in coastal dunes and in peat bogs at Wyrie Swamp near Millicent (Luebbers 1975, 1978).

The results of these excavations remain unpublished except for that of Luebbers which is in thesis form and whose chronology is reported here.

The archaeological sequence of the South East spans 10000 years. Luebbers (1978) divides this period into two cultural horizons. The first of 10000-6000 years ago is mainly associated with the exploitation of swamplands as source of food supplies The second began 6000 years ago and can be subdivided into two phases. The first of these, the 'Early' phase, extends from 6000-1300 years ago. The sites from this phase are mostly located on hinddune surfaces and are represented by monospecific middens of either the cockle *Plebidonax* or the mussel *Brachidontes,* both of which are locally extinct Sites of the second, or 'Late' phase, are scattered at a variety of localities throughout the coastal margins, and are characterised by several living species of reef gastropods.

Luebbers postulates that this sequence mirrors a developing economy which began at least 10000 years ago, was at first swamp oriented, and then progressively more coast oriented. He sees the shift in emphasis to coastal exploitation as initially resulting from a greater food resource being available at the coast as animal populations became established on the newly formed Holocene coastline. The even greater emphasis on coastal exploitation in the Late Phase is seen by Luebbers as being due to a decline in swamp resources as the water table shifted, and an improvement in the aquatic biota inhabiting the coast following even further consolidation of the coastline. He states 'the coastal adaptation is therefore seen as an attempt to maximise resources in the face of shrinking supplies in the swamps' (Lubbers 1978).

The technology associated with this sequence became progressively more sophisticated. In the first cultural horizon (10000-6000 B.P.) the stone technology is characterized by large extensively trimmed flake tools, and perhaps included the large flaked bifaces, which have been noted in some instances to be as heavily patinated as the large flakes (Mitchell 1949) (pati nation can serve as a rough guide to age). Associated with these stone tools at Wyrie Swamp was a find of unique archaeological significance, a cache of wooden implements preserved in the peat. The rich array of artefacts included spears, boomerangs and pointed sticks (Fig. 5). These mirror to some extent those used by the Bunganditj, with the notable exception of the spearthrower and shield, which are absent at Wyrie Swamp

The Early Phase of the second cu Itu ral horizon has a technology distinguished by smaller tools produced by pressure as well as flaking techniques, and by new forms such as microliths, awls, backed blades and small scrapers. Luebbers suggests that the microliths were hafted to wooden implements, particularly the spear. He postulates that the spearthrower was introduced at this time and prompted a transition from the one piece wooden spears found at Wyrie Swamp to finely balanced composite spears made of stone tips or barbs glued or lashed to wooden shafts. Further, small tools such as awls and scrapers would have been useful in the manufacture of such spears. This type of spear was a universal adaptation to a coastal environment in late prehistoric Australia, allowing an intense exploitation of marine resources.

Fig. 5. Wooden spear tip from Wyrie Swamp dated to [illegible] BP. (Photo: R. Luebbers).

Fig. 6. Ground stone axeheads.

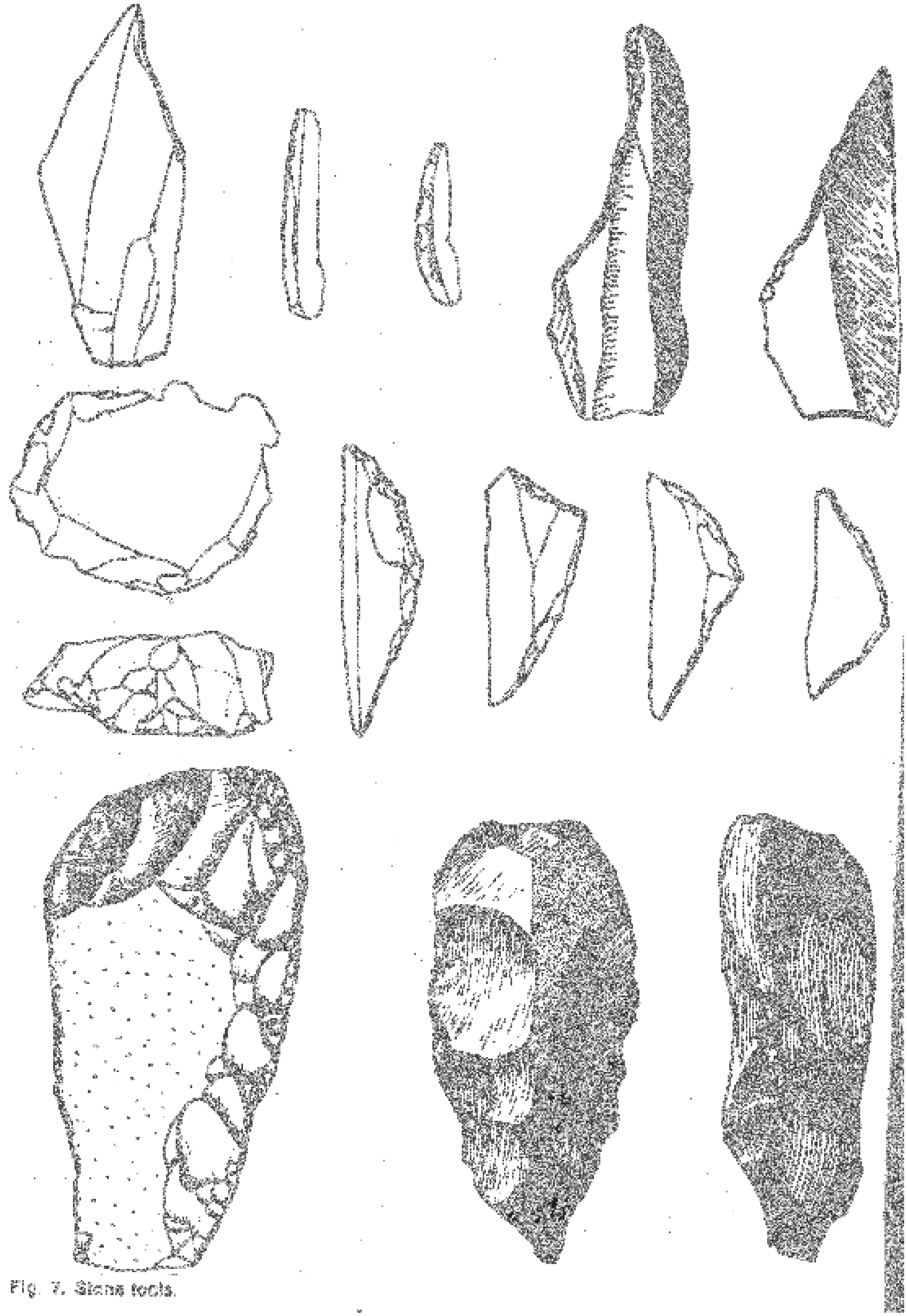

Fig. 7. Stone tools.

The Late Phase had a material culture analagous to the ethnographic Bunganditj. It consisted of a few larger stone tools including flaked bifaces and ground edged axes (Fig 6) alongside a small tool tradition and a developed organic component supplemented by fish weirs and traps. Furthermore, the microlithic component which flourished during the early phase is absent. Rather than viewing this as a loss in material culture, Luebbers regards its discarding as part of a consolidation of technology which brought increased hunting efficiency following the period of adjustment to the reduction of swamp resources.

Seen as a whole, the South Eastern stone tools stand out as one of the most characteristic regional assemblages on the continent. The flaked bifaces and flint scrapers have been noted by McCarthy (1967) as being distinct from the wider stone tool traditions recognized by Tindale (1957). He states 'This flint industry was included by Tindale in his Tartangan culture, but it differs markedly from the implements of the Tartangan type site and appears to be a distinct prehistoric phase in this area.' The assemblage is also distinguishable by the presence of Woakwine point variants of the back blade tradition and ground edge axes. While these tool types are not unique, their presence together with the large flaked bifaces and scrapers constitutes a distinctive regional array (Fig. 7).

CONCLUSION

Ethnically and archaeologically the South East emerges as a distinct region. Why it should have developed as such is still largely unknown, as the extent of ethnographic source analysis and archaeological investigation has been limited. The development of its unique regional culture was undoubtedly due in part to the richness of the biota and the abundance of locally available stone. But to understand the processes which produced this distinctive culture, would require us to know more of the cultural responses of the aborigines to their environment. For example, if high populations did develop there, they may have stimulated territoriality and influenced the South East people to become culturally insular from their neighbours.

We stress the region's potential for important discoveries. Considerable rewards await anyone choosing to sift through the early historic records to reconstruct precontact patterns and the responses of aborigines to settlement. There is vital work to be done in expanding the archaeological record, particularly by focussing on the neglected woodland and highland districts. A high priority is the conservation of the peat swamps, which are in danger of being recklessly obliterated for garden soil, because they hold our sole clue to the ancestry of Australian wooden implements.

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REFERENCES

Angas, G. F. (1846) 'South Australia Illustrated' (T. McLean, London).

Angas, G. F. (1847). 'Savage Life and Scenes in Australia and New Zealand: Being an artists impressions of Countries and People at the Antipodes' (Smith, Elder & Co, London).

Bull, J W. (1885) 'Early Experiences of life in South Australia and an Extended Colonial History' (Facsimile reprint: State Library of South Australia, Adelaide).

Campbell, T. D. (1934). Notes on the Aborigines of the South East of South Australia. *Trans. R. Soc.* S. *Aust.* **58**, 22-32.

Campbell, T. D. (1939). Notes on the Aborigines of the South East of South Australia. *Trans. R. Soc.* S. *Aust.* **63**, 27-35.

Campbell T. D, Cleland, J. B. & Hossfeld, P S (1946). Aborigines of the Lower South East of South Australia. *Rec.* S. *Aust. Mus.* **8**, 445-502.

Campbell, T. D. & Edwards, R. (1966). Stone Implements. Chap 6, *In* B. C Cotton (Ed), 'Aboriginal Man in South and Central Australia' (Govt Printer, Adelaide)

Campbell, T. D., Edwards, R. & Hossfeld, P S (1963). Archaeological Investigation in the South East of South Australia (M.S. in SA Museum).

Campbell, T. D. & Noone, H. V. V (1943a) South Australian Microlithic Stone Implements. *Rec.* S. *Aust. Mus.* **7**, 281-307.

Campbell, T. D. & Noone. H. V V (1943b). Some Aboriginal Campsites in the Woakwine Range Region of South East of South Australia. *Rec.* S *Aust Mus.* **7**,371-395

Dixon, R. M. W (1980). 'The Languages of Australia' (Cambridge University Press, Melbourne)

Donovan, P F., & Rowney, B. G. (1977). Woakwine Folk Province; Outline sketch of cultural sites situated within the province. National Folk Province Feasibility Study, Paper No. 15, *In* G. L Pretty (Ed.) (Govt Printer. Adelaide)

Hamilton-Smith, E, Mathews, P B. & Spate, A. P (1980). Scratched Markings in Tantanoola Cave (L 12) South Australia Paper to The Australian Speleological Federation Conference Melbourne 1980

Howitt, A. W (1904) 'The Native Tribes of South East Australia' (Macmillan, London).

Laut, P *et al* (1977). 'Environments of South Australia Province 1 South East' (CS.I.R.O., Canberra).

Leubbers, R. (1975) Ancient boomerangs discovered in South Australia. *Nature* **253**, 39.

Leubbers, R. (1978) Meals and menus A study of change in prehistoric coastal settlements in South Australia Ph.D. Thesis, (Aust. Natl Univ, Canberra).

McCarthy, F. D. (1938) A Comparison of the prehistory of Australia with that of Indo China, the Malay Peninsula, and the Netherlands East Indies. Proceedings 3rd Congress of Prehistorians of the Far East, Singapore 30-50.

McCourt, T (1975) 'Aboriginal Artefacts' (Rigby, Adelaide).

McCourt, T. & Mincham, H. (1977). Two Notable South Australians (Beach port Branch of The National Trust)

Mitchell, S R. (1949). 'Stone Age Craftsmen' (Tact, Melbourne).

Smith, C (1880) The Booandik Tribe of South Australian Aborigines (Facsimile reprint: State Library of South Australia, Adelaide).

Stapleton, P. de S. (1945) Bifaced Stone Implements from South Eastern South Australia. *Rec.* S. *Aust. Mus.* **8** (2), 281-287.

Tindale, N. B. (1933). Tantanoola Caves, South East of South Australia; Geological and Physiographical Notes. *Trans. R. Soc. S. Aust.* **57**,130-142.

Tindale, N B. (1940) Results of the Harvard-Adelaide Universities Anthropological Expedition, 1938-1939 Distribution of Australian Aboriginal Tribes A Field Survey *Trans R. Soc.* S. *Aust* **64**, 140-231

Tindale, N. B. (1957). Cultural 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 Their Terrain, Environment Controls. Distribution, Limits, and Proper Names' (Australian National University Press. Canberra)

Tolmer, A. (1882) 'Reminiscences of an Adventurous and Chequered Career at Home and at The Antipodes.' 2 vols (Sampson Low. London)

Williams, M. (1974). 'The makmg of the South Australian Landscape. A study in the historical geography of Australia' (Academic Press, London)

Woods, J. E. (1862). 'Geological Observations in South Australia: Principally in the District southeast of Adelaide' (Longman & Green, London)

12: Mammals

by P. F. AITKEN. (Deceased 11 December 1982)

INTRODUCTION

Australian mammals belong to three basic geographical assemblages: a tropical group confined to the humid coastal regions of the north; a temperate group inhabiting Tasmania and the coastal forests of southeastern Australia and a desert group centred on the arid interior. Most of South Australia has a dry climate with sparse vegetation and so the majority of its mam mals are derived from the desert group. But in the South East and, to a lesser extent, on Fleurieu Peninsula and Kangaroo Island where the climate is wetter and the vegetation more luxuriant, there IS an entirely different mammal fauna derived from and representing the most westerly extension of the temperate group.

MAMMALS AT SETTLEMENT

It is evident from modern bone deposits in caves, dated by the presence of introduced mammal remains, plus the few museum specimens available and the records of early colonists that, at the time of Caucasian settlement, native mammals were not only much more abundant in the South East than they are today, but that many more species were present. This is hardly surprising in view of the extent to which natural conditions have been upset over the ensuing 140 years. During this period much of the original topography and vegetation of the South East has been drastically altered by artificially imposed drainage schemes and pastoral development; still more of the vegetation has been totally cleared for agricultural, viticultural, forestry and urban development; and every corner of the region has been invaded by highly efficient competitive and predatory aliens like rabbits, foxes and cats. As a resu lt of these and other less obvious environmental changes such as chemical pollution by insecticides and industrial wastes, many once common native mammals have vanished because they could no longer find adequate food, nest-sites or cover from their enemies. Most of those species that have survived are restricted to an unduly hazardous existence on isolated remnants of their former territories, often in perilously low numbers.

The mammals which are presumed to have become extinct in the South East since the advent of Caucasian settlement, *i. e.* those for which there have been no reliable records for at least 40 years, are: Eastern Quoll *(Dasyurus viverrinus),* reported to have survived until just after 1900 but last recorded near Mt Gambier in 1890; Tiger Quoll *(D. maculatus),* last recorded near Mt Gambier in 1897; Greater Barred Bandicoot *(Perameles gunnii),* last recorded near Mt Gambier in 1893; Koala *(Phascolarctos cinereus),* reported to have survived until the early 1900's and recently reintroduced; Eastern Hare Wallaby *(Lagorehestes leporides),* last recorded near Naracoorte in 1870; Toolache Wallaby *(Maerapus greyii),* last recorded from Robe in 1924 but bel ieved to have survived in that district until 1927 (Finlayson 1927); White-footed Rabbit Rat *(Conilurus albipes)* reported from 'south-eastern S.A.' only before 1843; and Dingo *(Canis familiaris dingo),* not known in its pure form since the 1930's. It is probable that three other mammals, for which there are no records, also lived in the South East during early Caucasian times since their remains are abundant in Recent cave deposits in the region and they were known to occur in adjacent and simi lar districts of south-western Victoria at the same time. These were:

Long-nosed Potoroo *(Potoraus tridaetylus),* Tasmanian Bettong *(Bettongia gaimardl)* (Wakefield 1967) and Burrowing Bettong *(B. lesueur).*

These mammals that have vanished from the South East lived mainly in woodlands or grasslands which, because they required little or no clearing, were not only the first habitats to be exploited by Caucasian settlers, they were also the ones exploited to the greatest extent. Those mammals which have survived in the region are mainly forest, scrub or swamp dwellers whose habitats have still not been exploited so completely .

MAMMALS TODAY

All mammals recently recorded from the South East are listed below with outlines of their known distributions, estimates of their current status and a guide to the habitats in which they are most likely to be found.

NATIVE SPECIES

Short-beaked Echidna *(Tachyglossus aculeatus):* Common in scrub, heath, woodland and eucalypt forest throughout the South East, but seldom seen because of its solitary, secretive habits and because it is largely nocturnal and often inactive in cold, wet weather. Its presence is best detected by signs of smashed logs plus diggings in termite mounds and ant-nests where it has been searching for food; also by its characteristic d roppi ngs com posed of cylinders of earth and sand mixed with indigestible insect remains, 1-2 cm diameter with abruptly broken, not rounded, ends.

Yellow-footed Antechinus *(Antechinus flavipes):* Common in eucalypt forest east of a line joining Kybybolite, Naracoorte, Penola, Wandilo and Donovan's Landing, but possibly also distributed in both eucalypt forest and woodland to the west. An insectivore with excellent climbing ability, basically nocturnal but often seen running up and down tree trunks at dusk or dawn.

Swamp Antechinus *(Antechinus minimus).* An uncommon and critically endangered species once widespread in the coastal swamps of the South East but now known from only three small areas of dense sedgeland; one between Lake Frome and the northern end of Canunda National Park, one near Lake Robe and one at the southern end of Bucks Lake. The decline of Swamp Antechinus has been due to almost total alteration of its restricted swam p habitat to short grass pastures for cattle grazing, a process which is still continuing. Probably it can only be saved from extinction in the region by incorporating its one still extensive and relatively pristine locality at Lake Frome into the adjacent Canunda National Park.

Fat-tailed Dunnart *(Sminthopsis crassicaudata):* Common in open-scrub, woodland and grassland, including pasture, throughout the South East. An alert, nocturnal insectivore of open country that may be found by day sheltering beneath old stumps, fallen timber or large stones.

Common Dunnart *(Sminthopsis murina):* Apparently rare in the South East where it has been recorded on only two occasions from heath at Big Heath Conservation Park and woodland with a heath understorey in the Hundred of Caroline. It is, however, probably more common than these records indicate, since both were made with in the last 10 years and it is a cryptic mammal that *leaves* little trace of its presence.

Brush-tailed Phascogale *(Phascogale tapoatafa)* Rare in the South East with only one record this century from woodland near Joanna in 1967. An agile climber that favours open, park-like country comprising old trees surrounded by deep litter and a short grass understorey, where it nests in tree-hollows and hunts at night for birds, insects and other small animals both up trees and on the ground. It was extremely unpopular with early settlers for its constant raids on their chickens.

Lesser Brown Bandicoot *(Isoodon obesulus):* Uncommon and endangered in the South East where it is now confined ,to scattered colonies in eucalypt forest with a dense and diverse understorey within the area enclosed by Nangwarry, Millicent and Mt Gambier. The few specimens found in the last 15 years *have* all been from either Mt Gambier or Mt Burr Forest Reserves and no colonies are known to exist on any Conservation Park in the region. The Lesser Brown Bandicoot has declined because most of its former habitat has been replaced by exotic pine plantations with practically no understorey: and understorey on much of the remainder has been thinnned and degraded by too frequent burning. This has led to enormously increased predation by foxes and its su*rvival* in the region will probably depend on management policies designed to maintain suitably dense and diverse understoreys on the two Forest Reserves in which it still occurs.

Western Pigmy Possum *(Cercartetus conncinnus):* Common in open scrub north of a line joining Robe, Millicent and Nangwarry A solitary nocturnal acrobat that feeds on the nectar, fruit and leaves of shrubs but also forages amongst litter for insects and spiders, spending the day curled up asleep in a hollow branch or dead stump.

Eastern Pigmy Possum *(Cercartetus nanus):* Rare in the South East where it has been recorded on only two occasions from open eucalypt forest; once at Millicent in 1925 and once near Naracoorte in 1965. It is much more plentiful in the still extensive native forests of Victoria, Tasmania and New South Wales.

Little Pigmy Possum *(Cercartetus lepidus):* Not discovered in the South East until 1976 when one was captured in open scrub with a heath understorey at Fairview Conservation Park. It is, however, probably quite common in heath vegetation throughout the northern half of the region.

Feathertailed Glider *(Acrobates pygmaeus):* Now rare in the South East where it has not been recorded since 1956 at Lucindale. It was previously common in both woodland and eucalypt forest east of a line from Avenue through Millicent and Mt Gambier to the border. Marauding cats have undoubtedly contributed to its decline.

Sugar Glider *(Petaurus breviceps):* Uncommon but locally plentiful in patches of relatively undisturbed woodland, eucalypt forest and, occasionally, scrub th roughout the inland region of the South East north of Princes Highway, especially where tree-form banksias are abundant. A communal species in which family groups sleep in large leaf nests up hollow trees and emerge at night to feed on blossoms and insects.

Yellow-bellied Glider *(Petaurus australis):* A very recent discovery in the South East as yet known from only one colony found in manna gum forest near Caroline in 1981. A sap feeder which leaves characteristic, long bleeding wounds in the bark of its food trees.

Common Ringtail Possum *(Pseudocheirus peregrinus):* Common, especially near lakes and swamps, in coastal ti-tree scrub, woodland, eucalypt forest and, occasionally, the edges of pine forest, south of a line from Kingston through Furner and Penola to the border. A semi-communal climber that sleeps by day in either tree-hollows or twig and leaf dreys built in the densest canopy available. It is seldom seen on the ground.

Common Brushtail Possum *(Trichosurus vulpecula):* Common in woodland, eucalypt forest, roadside trees and many human settlements throughout the South East. A solitary, nocturnal opportunist found mainly in trees but also at home in buildings or feeding on the ground.

Koala *(Phascolarctos cinereus):* Currently represented by only one colony in the South East that was introduced to woodland east of Avenue in 1969 The original Koala population became extinct in the region soon after 1900.

Common Wombat *(Vombatus ursinus):* Once common and widespread over much of the South East but now reduced to remnant and potentially endangered populations in eucalypt forest adjacent to the border around Comaum; in coastal grassland and sedgeland from Cape Banks to Lake Hawdon North and in open scrub on limestone ridges north of Avenue. Clearing and alteration of its habitat for soft-wood forests, cereal crops and improved pastures, plus human persecution and competition from rabbits and stock have all contributed to its decline. If it is to survive in the region, Canunda National Park, Beachport Conservation Park and Comaum Forest Reserve must all be managed to retain enough of its preferred habitats.

Swamp Wallaby *(Wallabia bicolor):* Although there is no specimen evidence to prove its modern occurrence in the South East, recent observations by local naturalists suggest that colonies of Swamp Wallaby still inhabit patches of woodland with dense undershrub near the border around Dismal Swamp. Further investigation is needed to clarify this matter.

Red-necked Wallaby *(Macropus rufogriseus):* Once abundant throughout the South East but now reduced to a discontinuous population of mostly small colonies in the few remaining undisturbed areas of heath, scrub, woodland or forest with relatively dense undershrub. Any further decline in numbers may well place this species at risk.

Eastern Grey Kangaroo *(Macropus giganteus):* Uncommon in the South East where it now survives in only four colonies: two of probably viable size in eucalypt forest and on fire-breaks in pine forest at Myora and Caroline Forest Reserves, and two of much smaller size, one in woodland with associated grassland near Mt Benson and one in dense sedgeland surrounded by cleared pasture at Meringa Swamp, Cape Jaffa. Both the latter are definitely at risk from illegal shooters, the Cape Jaffa colony, for example, has been reduced to about 15 individuals in recent years (Poole 1977).

Western Grey Kangaroo *(Macropus fuliginosus):* Common although sporadic in distribution throughout the South East in open scrub, woodland, eucalypt forest, young pine forest, fire-breaks in mature pine forest and grassland, incuding pasture and crops.

Australian Water Rat *(Hydromys chrysogaster):* Apparently decreasing in numbers and becoming uncommon in the South East where it is now known to occur only in fresh water creeks and drains near the coast south of a line from Conmurra through

Furner and Tarpena to the border. It may still live in suitable watercourses further inland but, if so, its colonies must be quite rare. A major factor in the decline of this species has been a reduction in its usable habitat resulting from artificial alteration of the regional drainage.

Ash-grey Mouse *(Pseudomys apodemoides):* Locally common in heath, or open scrub with a heath understorey, on sandy terrain in the north east corner of the region south to a line joining Avenue, Big Heath, and MacKinnon Swamp. More ubiquitous in the still extensive heaths of the upper South East north of Dukes Highway. A social mouse, cryptic and nocturnal in habits, that lives in a large, complex burrow system and feeds mainly on seeds and fruits.

Swamp Rat *(Rattus lutreolus):* Locally common in the South East especially in sedge land and wet grassland, but also found where there is dense groundcover around swamps in scrub, woodland or forest south of a line from Penola through Glencoe and Reedy Creek to the coast. It lives in extensive warren systems with conspicuous spoil heaps and is most active at dusk and dawn when it travels down well-marked runways to feed on sedge stems and grasses in the cooler seasons, and seeds and insects in the summer.

Bush Rat *(Rattus fuscipes):* Common but with a low population density throughout eucalypt forest and coastal scrub in the South East south of a line from Comaum to Robe. A shy, nocturnal omni.vore that lives in simple, inconspicuous shallow burrows and seldom constructs runways by which its presence may be detected.

White-striped Mastiff Bat *(Tadarida australis):* Apparently rare in the South East where it is known from only one record near Naracoorte, but future collecting may well prove it to be more plentiful in the region. A fast-flying bat that usually hawks for insects above tree-canopy height and roosts in groups of less than 10 in hollow trees.

Flat-headed Mastiff Bat *(Tadarida planiceps):* Apparently rare in the South East where it has been recorded only once from Bool Lagoon. Elsewhere, it is usually found in dry woodland or open scrub roosting in colonies of up to 100 under loose bark, in hollow trees or, occasionally, old buildings.

Large-footed Myotis *(Myotis adversus):* Rare in the South East where there is a single colony at Dry Creek Cave on the Glenelg River. A cave dwelling bat nearly always found near water, which it 'rakes' for aquatic insects at night.

Gould's Wattled Bat *(Chalinolobus gouldii):* Common over scrub, woodland and eucalypt forest in the South East where it roosts in colonies of up to 30 in hollow trees or, occasionally, wells, mines, culverts, drainpipes, etc.

Chocolate Wattled Bat *(Chalinolobus moria):* Apparently uncommon in the South East where occasional individuals have been found flying over open scrub and woodland north of a line from Kingston to Penola. It may, however, be more common and widespread than these few records indicate. I n temperate zones it usually roosts in small colonies of less than 20 in hollow trees.

Lesser Long-eared Bat *(Nyctophilus geoffroyi):* Common throughout all habitats in the South East including semi-cleared pasture. A slow-flying bat with a 'flutter' flight that hawks low to the ground and roosts'in colonies of up to 30 under bark, in hollow trees and in buildings of all types.

Little Brown Bats *(Eptesicus* spp.). Three species of *Eptesicus* live in the South East King River Eptesicus *(E. regulus),* Large Forest Eptesicus *(E. sagittula)* and Little Forest Eptesicus *(E. vulturnus).* Together, they are common over scrub, woodland and eucalypt forest throughout the region but their individual abundances and distributions have yet to be determined. All of them roost in hollow trees.

Common Bent-wing Bat *(Miniopterus schreibersii)* (Fig. 1). Common over eucalypt forest in the South East, east of a line from Kybybolite through Naracoorte and Millicent to Port MacDonnell. A cave-dwelling bat which is found between March and early September spread throughout this range in separate colonies of up to 10 000, but which congregates during summer in a single breeding colony of about 200 000 at the Naracoorte Bat Cave (Dwyer & HamiltonSmith, 1965).

INTRODUCED SPECIES

House Mouse *(Mus musculus):* Abundant in all rural and urban habitats of the South East. Originally from the steppes of central Asia, this tough and adaptable rodent has now been transported to all parts of the world by man, it reached Australia as a stowaway with the earliest Caucasian immigrants.

Fig. 1. Common Bent-wing Bat *(Miniopterus schreibersii)* emerging from Naracoorte Bat Cave. Photo: Graham Anderson.

Black Rat *(Rattus rattus):* Common in coastal scrub and around human settlements throughout the South East. A daring, agile climber and fair swimmer that will eat almost anything, this highly successful rodent probably evolved in southern Asia but is now worldwide and reached Australia in the late nineteenth century. It supplanted the Brown Rat *(R. norvegicus)* to become the common ship-rat of the World when steam supplanted sail on ships in the mid-nineteenth century, but was rare on the Australia run until the opening of the Suez Canal in 1869.

Brown Hare *(Lepus capensis):* Common in cereal-growing areas of the South East where it was introduced in the late 1860's and first run for coursing in 1873. Previously, the Eastern Hare Wallaby had been used in the region as game for this sport.

Rabbit *(Oryctolagus cuniculus):* Abundant throughout the South East where it was first released in the 1870's near Naracoorte, but by 1886 had overrun the surround ing district and amalgamated with Victorian rabbits spreading westward from an earlier established colony on the Glenelg River (Rolls 1969). It has remained a serious pest ever since.

Fox *(Vulpes vulpes):* Abundant throughout the South East where it was probably entrenched by the late 1880's, since it was reported in numbers along the Coorong in 1888 and had almost certainly arrived there by crossing the region from western Victoria. A cunning and resourceful predator of native wildlife, the fox was brought to Australia for hunting and first released successfully near Ballarat and Point Cook about 1871 (Rolls 1969).

Cat *(Felis catus):* Abundant in all rural and urban habitats of the South East, it has proved a devastatingly efficient killer of small native animals, in both its domestic and feral forms, since being brought to the region by the first Caucasian settlers.

Red Deer *(Cervus elaphus):* Formerly quite plentiful in scrub on the central flats of the South East, but not recorded since 1956 when a small herd was sighted between Killanoola and Old Callandale. It was first established in the region at Yallum Park near Penola prior to 1895 (Bentley 1967).

Fallow Deer *(Dama dama):* Now uncommon in the South East where it is presently restricted to small herds in the forests around Nangwarry and in woodland adjacent to Bakers Range drain. It, too, was first established at Yallum Park before 1895 (Bentley 1967).

MARINE SPECIES

There are no resident colonies of seals around the South East coast but stragglers, especially adult males, from various species frequently 'haul out' for short periods on protected beaches in the region, usually during rough weather in mid summer. Those most commonly recorded have been Australian Fur Seal *(Arctocephalus pusillus doriferus)*, normally found in Bass Strait to the east, and Australian Sea Lion *(Neophoca cinerea),* which normally ranges from the Pages east of Kangaroo Island to Houtman's Abrolhos in Western Australia. Much rarer visitors have been Southern Elephant Seal *(Mirounga leonina),* which used to live on King Island in Bass Strait but now breeds only on Macquarie and other subantarctic islands; and Leopard Seal *(Hydrurga leptonyx)*, Crabeater Seal *(Lobodon carcinophagus)* and Ross Seal *(Ommatophoca rossi),* all of which are based on Antarctica.

A variety of whales also occur in waters off the South East coast. The most common and ubiquitous are Bottle-nosed Dolphin *(Tursiops truncatus)* and Common Dolphin *(Delphinus delphis),* both of which are frequently seen close inshore. Less common ocean going species whose identities have been confirmed by stranded specimens are:

Southern Right Whale *(Eubalaena australis),* Pigmy Right Whale *(Caperea marginata),* Sperm Whale *(Physeter catodon),* Pilot Whale *(Globicephala melaena)* and Shepherd's Beaked Whale *(Tasmacetus shepherdi).*

MAMMALS IN THE FUTURE

It might be assumed that those native mammals adaptable enough to have survived the past 140 years of increasing Caucasian disruption in the South East could continue to survive, although not necessarily thrive, in the region if current environmental conditions remained fairly static. Quite obviously, however, they will not do so and, equally obviously, the trend cannot now be reversed. Sheep, cattle, rabbits, foxes and cats are there to stay; and constantly improving pastures, cereal crops, pine forests, vineyards etc., are needed to sustain rural 'industry in this important region, without which the economy of South Australia would be critically impaired. Therefore, methods must be found to control the progress of future environmental change so that as many native mammals as possible are conserved without unduly retarding development.

The foundation of any program to protect mammals and, indeed, most other wildlife from adverse environmental change is the creation of a system of State owned reserves, which conserve viable examples of all essential habitats. Such a system is being set up in the South East and, although it is far from ideal because not all habitats are adequately represented, it is probably the best that could be achieved given the limited amounts of still uncleared land and public money available. Another possible weakness of the system is that not all its reserves are controlled by the National Parks and Wildlife Service; most of the eucalypt forest component is owned by the Woods and Forests Department whose commitment to wildlife conservation, although stated policy, has yet to be secured by Act of Parliament.

Nevertheless, the mere creation of a reserve system is not enough to effectively conserve native mammals. Each reserve in the system must be carefully managed, firstly to maintain opti mum vegetation conditions for its resident mammals and secondly to provide adequate, but separate, recreational facilities for human visitors where they will not significantly disturb the resident mammals. So far, practically no management of this type has been earnestly attempted in the South East but, even if it had, the conservation of native mammals in the region could not be assured because the reserves in the system would still represent only small, scattered and mostly single habitat island sanctuaries in a sea of hostile territory and, as such, would not cater for the seasonally varying habitat requirements of some mammals, the vast spatial requirements of other sparsely distributed mammals, or the corridor requirements of migratory and nomadic mammals. These species, at least, will need additional sanctuaries on private land if they are to survive in the South East; and this leans that some responsibility for their conservation will have to be accepted by the rural community, subsidised where necessary lrough grants or taxational concessions.

It follows, therefore, that to ensure the survival of those native mammals still living in the South East, many of which are already either rare, seriously endangered or potentially at risk:

1. an appropriate regional program of reserve management must be implemented with its emphasis and priorities based not on individual reserves treated in isolation but on the combined attributes and resources of all State-owned reserves; and
2. a concurrent program must be initiated to purchase new reserves or, if this is not feasible, to negotiate properly managed sanctuaries on private land for those native mammals which are either not represented or are only marginally represented on existing State reserves.

Unfortunately, these programs would be impossible to design at present because not enough is known about the true status and distributions of native mammals in the South East and even less is known about their biology. It is thus imperative that intensive surveys are conducted to discover exactly how many mammals remain and where they are to be found; also that these surveys are complemented by detai led research studies to define their precise ecological needs.

Without such surveys and research studies, plus a resulting overall management program, the future for many native mammals in the South East could be extremely bleak. At least eight and probably 11 species of native mammals have already become extinct in the region during Caucasian times; another nine have apparently become very rare and a further five now seem to be endangered. Even some of the supposedly more common species may, in fact, be declining unmonitored at alarming rates This is not a record of which we should be particularly proud.

REFERENCES

Aitken, P. (1977) Rediscovery of Swam p Antechinus in South Australia after 37 years. *S. Aust. Nat.* **52**(2), 28-30

Bentley, A. (1967). 'An introduction to the deer of Australia'. (Hawthorn Press, Melbourne).

Dwyer, P D. & Hamilton-Smith, E. (1965). Breeding caves and maternity colonies of the Bent-winged Bat in south-eastern Australia. *Helectite* **4**(1),321.

Finlayson, H. H. (1927). Observations on the South Australian members of the subgenus *Wallabia. Trans. R. Soc.* S. *Aust.* **51**, 363-377.

Poole, W. E. (1977). The Eastern Grey Kangaroo, *Maeropus giganteus.* in South-east South Australia: its limited distribution and need of conservation. *CSIRO Aust. Divn Wildl. Res. Tech. Pap.* (**31**): 1-15.

Rolls, E. C (1969). 'They all ran wild' (Angus & Robertson, Sydney).

Wakefield, N. A. (1967). Some taxonomic revision in the Austral ian marsupial genus *Bettongia* (Macropodidae) with description of a new species. *Vict. Nat.* **84**(1), 8-22.

13: Birds

by SHANE A. PARKER and NICHOLAS C. H. REID

INTRODUCTION

Materials for an account of the avifauna of the South East are few. Moreover, they consist largely of sight records, with a strong observational bias towards spring and summer. How well they reflect the true picture lor any species involved is thus an open question.

The present account is in the form of an annotated list. The annotations deal with new inlormation, obscure or critical sources, contentious matters and other points of special interest, such as recent taxonomic developments *(e.g.* Golden Whistler, pardalotes), new records *(e.g.* Red-chested Button-quail, Painted Honeyeater), probable and virtual local extinctions *(e.g.* Ground Parrot, Barking Owl, Spotted Quail-thrush, Grey-crowned Babbler) and reports that have recently been shown to be incorrect or questionable *(e.g.* Glossy Black Cockatoo, Speckled Warbler, Little Crow).

We do not intend presenting here an ecological and biogeographical analysis. However, a few simple preliminary comparisons and comments will be useful in demonstrating just how rich and interesting this avifauna is. From the South East, with only 1.6% of the State's area, has been acceptably reported 73.7% (319) of the State's bird species, 79.2% (61) of its non-breeding migrants (mainly seabirds and waders) and 63.9% (198) of its native breeding birds. Of the species in the last category, (7%) 14 isvirtually or apparently extinct in the South East:

Magpie Goose (now being re-established), Little Bittern, White-breasted Sea-Eagle, Australian Bustard, Peaceful Dove, Little Lorikeet, Ground Parrot, Barking Owl, Red-capped Robin, Spotted Quail-thrush, Grey-crowned Babbler, Southern Whiteface, Diamond Firetail and Apostlebird. Two other species in this category are well down the road to local extinction: Southern Stone-curlew and Red-tai led Black Cockatoo. The case of the cockatoo is singularly worrying, for the local population belongs to a distinctive subspecies only recently recognized, and confined to a small and dwindling area of woodland straddling the South Australian/Victorian border. In addition, three species of unknown breeding status in the region have not been recorded for some years: King Quail, Azure Kingfisher and Olive-backed Oriole.

Ten species and three subspecies have, within South Australia, been reported breeding only in the South East: Little Bittern, Magpie Goose, Bridled Tern, Long-billed Corella, Blue-winged Parrot, White-bellied Cuckoo-shrike, Olive Whistler, Satin Flycatcher, Eastern Fieldwren and Forest Raven; and Red-tailed Black Cockatoo *Calyptorphynchus magnificus* subsp nov., Singing Bushlark *Mirafra javanica keasti* and Golden Whistler *Pachycephala pectoralis youngi.*

That the three local subspecies have only recently been discerned reflects the great increase in ornithological studies in the South East in recent years, an increase that has resulted also in the discovery there of the Satin Flycatcher, Eastern Striated Pardalote and Forest Raven, and of hybridization between the Spotted and Yellow-rumped Pardalotes. Yet sadly, by 1976, when systematic investigations began in earnest, over 90% of the original vegetation of the region had been cleared (Harris *et al.,* 1976*),* and almost 90% of its extensive wetlands drained (Jones 1978). With clearing of the remaining scrub continuing unabated, further attempts to add to our ornithological knowledge of the South East are becoming in many cases a race against the clock.

We remarked above that materials for the present account consisted largely of sight records. That the greater part of ornithological records (in Australia at least) consist of such records may help explain the disesteem enjoyed by ornithology among other branches of natural history wherein, for studies in distribution and classification, specimens are regarded as essential. The relative dearth of specimens available for ornithological studies, which has severely retarded local systematic ornithology, is partly attributable to the widespread opposition to the collecting of birds (Parker 1977b).

BIRDS RECORDED IN THE SOUTH EAST

(SOURCES *Residents*-*Hood* 1932, 1934a & b, 1935a & b, 1936; Ey 1940, 1944, 1946; Attiwill 1946, 1954, 1963, 1972a & band *ms;* Austin 1951; Pawsey 1966 and in SEDB 1980; Bakker in SEDB 1980; Bourne *ms.;* Rowley *ms.;* May *ms.;* Gepp & Fife 1975. *Visitors*-Morgan 1919, 1922; Sutton 1923, 1927, 1929, 1931; Ashby 1927; Parsons 1927, 1928; Brummitt 1933, 1934a & b, 1935, 1937; Condon 1942; Francis 1946; Storr 1951; Storr *et al.* 1952; Glover 1954; Bonnin 1968a & b; Parker *et al.* 1979 and in prep.; Reid & Vincent 1979; Jaensch *ms.;* and numerous brief reports by Cox, Jaensch, Joseph, Close, N. & J. Reid and others in Bird Reports and Bird Notes in recent issues of the *South Australian Ornithologist* (SAO), *South Australian Ornithological Association Newsletter* (SAON) and *Bird Talk* (BT).

KEY

1. *Incidence*
   - A At least several records for each season; includes the concept 'resident' where strict resident status (as opposed to turnover by replacement) has in the absence of banding studies not been demonstrated.
   - S Spring-summer; S* mainly spring summer.
   - W Autumn-winter; W* mainly autumn-winter (where the period substantially straddles these main periods, it is denoted by the months in Roman numerals).
   - Ir Irruptive/nomadic.
   - O Occasional, vagrant, accidental.
   - ^Beach-washed only.
2. *Abundance (density within specified* habitats and periods).
   - H High; M Moderate; L Low; F One or a few only.
3. *Breeding status*
   - B Breeding; N Non-breeding; N(B) Mainly non-breeding.
4. *Historical status*
   - D Decreased (although presumably applying to most species inhabiting native vegetation, it is applied here only where specifically mentioned by resident observers).
   - Inc Increased
   - Int Introduced
   - R Re-established
   - E Apparently or virtually extinct
5. *Habitats* (Parentheses in the list denote less favoured habitats)
   1. Marine and coastal; 1 * additionally, one or a few blown inland; 1 ** oceanic only (over, or beyond, edge of continental shelf).
   2. Subcoastal lakes (including samphire fringes but excluding *Melaleuca* thickets).
   3. Inland waters (including swamps and drains).
   4. Coastal and subcoastal scrub (including *Melaleuca* thickets of subcoastal lakes, and heath on offshore islands).
   5. Wet tussock grassland (mainy cutting-grass, *Gahnia* spp.).
   6. Inland heath.
   7. Forest (*Eucalyptus baxteri, E huberana, E. fasciculosa, E. leucoxylon* and associated communities).
   8. *Eucalyptus camaldulensis* woodland (often swampy).
   9. Cleared or largely cleared areas (including crops, pasture, roadside verges and forest-edge).
   10. Ornamental shrubs and trees in gardens and towns.
   11. *Pinus* plantations, and smaller stands around homesteads.

LIST OF SPECIES

DROMAIIDAE

Emu *Oromaius novaehollandiae'*
A, M, B, 3-7, 9,11.

PODICIPITIDAE

Great Crested Grebe *Podiceps cristatus*
Ir, S, L, B, (2),3.
Hoary-headed Grebe *Poliocephalus poliocephalus*
Ir, S*, M, B, (1), 2, 3.
Australasian Grebe *Tachybaptus novaehollandiae*
Ir, S*, L, B, D, 2,3,8

'For emus to spoonbills, see Parker *et al.* 1979; for additional notes on seabirds see Parker & May 1982.

SPHENISCIDAE

Rockhopper Penguin *Eudyptes chrysocome* at,
O^, F, N, 1.
Fiordland Penguin *E. pachyrhynchus* at,
O^, F, N, 1.
Snares Penguin *E. robustus* at,
O^, F, N, 1.
Little Penguin *Eudyptula minor*
A, M, B, 1.

DIOMEDEIDAE

Wandering Albatross *Oiomedea exulans*
V-II, L, N, 1.
Royal Albatross *O. epomophora*
0, F, N, 1 **.
Black-browed Albatross *O. melanophrys*
A, M, N, 1.
Buller's Albatross *O. bulleri*
0, F, N, 1 **.
Grey-headed Albatross *O. chrysostoma*
IV-Xllt, F, N, 1.
Yellow-nosed Albatross *O. chlororhynchos*
A, L, N, 1.
Shy Albatross *O. cauta*
S*, M, N, 1.
Light-mantled Sooty Albatross *Phoebetria palpebrata*
0, F, N, (one only, inland).

PROCELLARIIDAE

Southern Giant Petrel *Macronectes giganteus*
0, F, N, 1.
Northern Giant Petrel M. *halli*
0, F, N, 1.
Southern Fulmar *Fulmarus glacialoides*
VII-X, L, N, 1.
Cape Petrel *Oaption capense*
IV-XI, L, N, 1.
Great-winged Petrel *Pterodroma macroptera*
O^, F, N, 1.
White-headed Petrel *P. lessonii*
O^, VIII-XI, F, N, 1*.
Kerguelen Petrel *P. brevirostris*,
O^, F, N, 1.
Mottled Petrel *P. inexpectata*,
O^, F, N, 1.
Gould's Petrel *P. leucoptera* at,
O^, F, N, 1.
Blue Petrel *Halobaena caerulea* at,
O^, F, N, 1.
Fairy Prion *Pachyptila turtur*
A, M, N, 1.
Grey Petrel *Procellaria cinerea*
O^, F, N, 1.
Sooty Shearwater *P. griseus*
0^, F, N, 1.
Short-tai led Shearwater *P. tenuirostris*
S*, L, B, 1*.
Fluttering Shearwater *P. puffinus gavia*
W*, H, N, 1*.
Little Shearwater *P. assimilis*
O^. F, N, 1.

HYDROBATIDAE

Wilson's Storm-Petrel *Oceanites oceanicus*
W, M, N, 1**.
Grey-backed Storm-Petrel *O. nereis*
W*, M, N, 1**.
White-faced Storm-Petrel *Pelagodroma marina*
O^, F, N, 1.

PELECANOIDIDAE

Common Diving-Petrel *Pelecanoides urinatrix*
O^, F, N, 1.

PELECANIDAE

Australian Pelican *Pelecanus conspicillatus*
A, M, N, 1-3.

Contra SEDB, not claimed by Ey (1944) or Pawsey (pers. comm.) as a breeding bird; nearest breeding colonies in Coorong.

SULIDAE

Australasian Gannet *Sula serrator*
W*,M,N,1.

ANHINGIDAE

Darter *Anhinga melanogaster*
0, F, N, 3.

Bool Lagoon only: two, 27 Sept. 1953 (Attiwill *ms.),* three, 31 Jan. 1980 (Reid SAON 93).

ANHINGIDAE Darter *Anhinga melanogaster* 0, F, N, 3.

PHALACROCORACIDAE

Black-faced Shag *Leucocarbo fuscescens*
A. M, B, 1.
Great Cormorant *Phalocrocorax carbo*
S*, L, B, 2,3.
Pied Cormorant *P. varus*
A, L, B, 1, (2, 3).
Little Black Cormorant *P. sulcris*
A, M. B, 1-3.
Little Pied Cormorant *P. melanoleucos*
A, H, B, 1-3, 8

Much early confusion between Black-faced Shag and Pied Cormorant (Parker & May in prep.). Former strictly marine, breeding both main islands of Baudin Rocks, islet in Nora Creina Bay, Penguin I., and possibly Goat I., islet off Little Dip, Mounce and Battye Rock, No. 1 Rock and Whale Rock. Latter breeds south island Baudin Rocks, largely marine, vagrant inland.

PHAETHONTIDAE

Red-tailed Tropicbird *Phaethon rubricauda*
0, F, N, 1.

ARDEIDAE

Pacific Heron *Ardea pacifica*
S*, L, B, 3, 8, 9.
White-faced Heron A. *novaehollandiae*
A, M, B, 1-4,8,9.
Great (White) Egret A. *alba*
Ir, S*, M, B, Inc, 2, 3, 8.
Little Egret *A. garzetta*
S, F, N, Inc, 2.
Intermediate (Plumed) Egret *A. intermedia*
S, L, N, 3.
Eastern Reef Egret *A. sacra*
S, L, B, 1.
Cattle Egret *Bubulcus ibis*
IV-XI, M, N, Inc, 3, 9.

Only two of the numerous reports of egrets are based on specimens; for problems associated with the acceptance of sight records of egrets, see Parker *et al.* 1979.

Great Egret: bred on island in L. Bonney 1943 (Ey 1944); now breeds regularly Bool Lagoon (single pairs bred 1942, 1960, *fide* Attiwill ms., first large colony, 100+, noted Nov. 1964, Attiwill SAO 24: 58).

Little Egret: acceptable sight-records from L George only, Oct.-Jan. 1977-78 (J. B. Cox pers. comm.); reports from Robe and Bool Lagoon require substantiation.

Intermediate Egret: seven unsubstantiated reports Bool Lagoon, Killanoola and Robe 1954-1976; first detailed reports: Bool Lagoon one 6 Mar. 1980 (Jaensch & Close SAON 94: 13), one 6 Dec. 1980, 22+ on 25-26 Feb. 1981 (Jaensch SAON 97: 7), 15-23 in March, April, Aug. 1981 (Jaensch SAON 100: 7).

Cattle Egret: first SE report 21 Jun. 1970,3 at Bool Lagoon (Attiwill SAO 26: 15), now regular and increasing; some flocks of over 100.

Rufous (Nankeen) Night Heron *Nycticorax caledonicus*
S*, L, B, D, 1-4.
Little Bittern *Ixobrychus minutus*
S, B, D, 3.

Apparently not infrequent Bool Lagoon 1930s *(e.g.* Hood *in* Sutton 1934 and eggs in SAM), last records for early period 10 Dee 1942, nest with 2 eggs, and 28 Dec. 1946, nest with five eggs (Attiwill ms.). Sole recent record: single bird in drain at south-western corner of Bool Lagoon Nov. 1979 (Bourne & Bakker SAON 94: 13, Bourne pers.comm.).

Australasian (Brown) Bittern *Botaurus poiciloptilus*
VIII-V, M, B, D, 3

THRESKIORNITHIDAE

Glossy Ibis *Plegadis falcinellus*
Jr, S*, M, B, 3.
Sacred (White) Ibis *Threskiornis aethiopicus*
S*, M, B, 2-4, 8, 9.
Straw-necked Ibis *T. spinicollis*
S*, H, B, 2-4, 8, 9.
Royal Spoonbill *Platalea regia*
S*, M, B, 2, 3.
Yellow-billed Spoonbill *P. flavipes*
S*, M, B, 2, 3, 8 (9).

ANATIDAE[2]

Magpie Goose *Anseranas semipalmata*
A, F, B, E:R, 3
Currently being re-established by NPWS at Bool Lagoon, having become extinct there ca 1911.
Plumed Whistling-Duck D*endrocygna eytoni*
0, L, N, 3.

Eight reports Aug.-Nov., Feb., March, May.

Sole SE report of similar Wandering Whistling-Duck D. *arcuata* (Maaoope July 1951, SAO 20: 90) may be of D. *eytoni*

Black Swan *Cygnus atratus*
Ir, S*, H, B, 1-3.
Freckled Duck *Stictonetta naevosa*
Ir, S*, H, N(B), 3

Erupts periodically from interior, *e.g. 1956*7, 1964-5, 1979-80. Bool Lagoon now a very important refuge: one of the few large undrained swamps.

Cape Barren Goose *Cereopsis novaehollandiae.*
0, F, N, 3

Contra SEDB, captive stocks at Baal Lagoon do not constitute reintroduction, for apparently never more than occ. nonbreeding visitor.

'For waterfowl to gulls and terns (Anatidae-Laridae) see Parker *et al.* in prep.

Mountain Duck *Tadorna tadornoides*
A+S, H, B, 2, 3, 8, 9.
Pacific Black Duck *Anas superciliosa*
A+S, H, B, 2, 3, 8.
Mallard *A. platyrhynchos*
0, F, N, Int, 3.
Contra SEDB, there are no breeding records for SE (C. Pawsey pers. comm.).
Grey Teal *A. gibberifrons*
Ir, S', H, B, D, 2, 3, 8.
Chestnut Teal *A. castanea*
S', L, B, 2, 3.
Blue-winged Shoveler *A. rhynchotis*
S', H, B, 3.
Pink-eared Duck *Malacorhynchus membranaceus*
Ir, S', H, B, 3.
Hardhead *Aythya australis*
Ir, S', M, B, 3.
Wood-Duck *Chenonetta jubata*
A, L, B, Inc, 3, 8, 9.
Blue-billed Duck *Oxyura australis*
A, L, B, 2, 3.
Musk Duck *Biziura lobata*
A, M, B, 2, 3, 8.

PANDIONIDAE

Osprey *Pandion haliaetus*
0, F, N, 1.
Once reported on Baudin Rocks (Brummitt 1934b), no details.

ACCIPITRIDAE

Black-shouldered Kite *Elanus caeruleus*
?Ir, A, W', M, B, Inc, 9,11.
Letter-winged Kite *E. scriptus*
Ir, 0, L, N, 9,11.
Erupts periodically from interior into southern dists. Reported SE March-Dec. 1977, but *contra* SEDB no breeding observed (Attiwill SAON 82: 15, Pawsey SAON 86: 10 and pers. comm., Bourne SAON 86: 10; Lovell BT 2: 1-2; one found dead, B30800).
Black Kite *Milvus migrans*
0, F, N, 3, 9.
Whistling Kite *Haliastur sphenurus*
A, M, B, D, 3, 8, 9,11.
Brown Goshawk *Accipiter fasciatus*
A, S', M, B, D, 3, 4, 7-9,11.
Collared Sparrowhawk *A. cirrhocephalus*
A, L, B, 3, 4, 7, 11.
Grey (White) Goshawk *A. novaehollandiae* W, F, N, 9.
Three records, all of white-phase birds: one shot attacking aviary, Carcoola 19 Mar. 1965 (Attiwill SAO 24: 96, B30516); dead bird found near Robe 23 May 1971 (B. R. Hutchins pers. comm.); one seen Mingbool 6 May 1976 (Pawsey SAON 79: 12).
Brummitt recorded a pair of grey-phase birds breeding at Fairfield near Robe on 13 Nov. 1933 (Brummitt 1934a and pers. comm.). The eggs, however (B19755), resemble those of the Brown Goshawk A. *fasciatus.*
White-bellied Sea-Eagle *Haliaeetus leucogaster*
0, F, B, E, 1.
Three reports: nest on Penguin I., May, ?1840 (Cleland 1946); Baudin Rocks, no details (Brummitt 1934b); Canunda, 1963 (Pawsey pers. comm.).
Wedge-tailed Eagle *Aquila audax*
A, M, B, D, 3, 4, 7-9,11.
Little Eagle *Hieraaetus morphnoides*
0, F, B, 3, (7), 9.
Spotted Harrier *Circus assimilis*
0, F, N, 4, 9.
Swamp Harrier C. *approximans*
A, S', M, B, 2-5,8, 9.

FALCONIDAE

Black Falcon *Falco subniger*
A, L, N(B), 3, 9.
Peregrine Falcon *F. peregrinus*
A, L, B, D, 4, 7, 9.
Little Falcon *F. longipennis*
A, L, B, 3, 7, 8.
Brown Hawk *F. berigora*
A, H, B, (1), 3, 6, 7, (8), 9, 11.
Nankeen Kestrel *F. cenchroides*
A, H, B, 3, 4, 7-9, 11.
(Report of Grey Falcon *F. hypoleucos,* two at Hell's Hole near Caroline 19 July 1964, SAO 24: 60, requires substantiation).

MEGAPODIIDAE

Malleefowl *Leipoa ocellata*
A, M, B, D, 6, 7.

PHASIANIDAE

Stubble Quail *Coturnix novaezelandiae*
Ir, A, H, B, 9.
Brown Quail *C. ypsilophora*
S', L, B, D, 3.
King Quail *C. chinensis*
E?,6.
One report: 'Occurs in some heathy places in the Dismal Swamp area' (Austin 1951).

TURNICIDAE

Painted Button-quail *Turnix varia*
A, L, B, 6, 7.
Little Button-quail *T. velox*
S, L, N, 9.
Red-chested Button-quail *T. pyrrhopygia*
S, L, N, 9
For notes on status of *Turnix* spp. in SE, see Bourne 1982.

RALLIDAE

Buff-banded Rail *Gallirallus philippensis* S*, L, B, 3-5.
Lewin's Rail *Rallus pectoralis*
S*, L, B, 2-4.
Baillon's Crake *Porzana pus illa*
S*, M, B, 3, 4.
Australian Crake *P. fluminea*
S*, M, B, 2-4.
Spotless Crake *P. tabuensis*
S*, L, 3, 4.
Black-tailed Native-hen *Gallinula ventralis*
Ir, H, B, 3, 5, 8.
Dusky Moorhen *G. tenebrosa*
A, H, B, 2, 3, 8.
Purple Swamphen *Porphyrio porphyrio*
A, H, B, Inc, 2, 3, 8, 9
Coot *Fulica atra*
A, H, B, Inc, 2, 3, 8.

GRUIDAE

Brolga Grus rubicundus
S/W, F/M, B, D, 3, 9
The small summer population is markedly augmented in winter, apparently by birds from breeding grounds in western Victoria.

OTIDIDAE

Australian Bustard *Ardeotis australis.*
Five reports traced: one shot near Millicent 5 May ?1840 (Cleland 1946); nest with three chicks Maaoope ca 1866 (Campbell 1900: 765); once very common Bool Lagoon dist., last recorded 1931 (Hood 1934b); nest with one egg Callendale 1932, and bird seen Reedy Ck, 13 Feb. 1949 (Bourne pers. comm.).
For use of the specific name *grallarius* instead of *magnirostris* see Schodde & Mason 1980 11-12.

BURHINIDAE

Southern Stone Curlew *Burhinus gallarius*
A, F, B, D, 7.
Now extinct as a breeding bird over much of its former range in S.A: still occurs in very small numbers in SE north to Kybybolite, west to Joanna and south at least to Wrattonbully

For use of the specific name *grallarius instead of magnirostrus* see Schodde & Mason 1980: 11-12

ROSTRATULIDAE

Painted Snipe *Rostratula benghalensis*
S*, L, B, 3, 5.

HAEMATOPODIDAE

Pied Oystercatcher *Haematopus ostralegus*
S, L, B, D, 1, (2).
Sooty Oystercatcher *H. fuliginosus*
S, M, B, 1.

CHARADRIIDAE

Masked (Spur-winged) Plover *Vanellus miles*
A, H, B, Inc, 1-3,5,8,9.
Banded Plover *V. tricolor*
Ir, S*, M, B, 9
Grey Plover *Pluvialis squatarola*
S, L, N, 1, 3.
Lesser Golden Plover *P. dominicana*
S, M, N, 1-3
Red-kneed Dotterel *Erythrogonys cinctus* Ir, S*, M, B, (2),3.
Hooded Dotterel *Charadrius rubricollis* A, M, B, D, 1, (2).
Little Ringed Plover C. *dubius*
0, F, N, 3, see Jaensch (1982).
Mongolian Plover C. *mongolus*
S, L, N, 2.
Double-banded Dotterel C *bicinctus*
W*, M, N, 1-3.
Large Sand Plover C. *leschenaultii*
S, L, N, 2
Red-capped Dotterel C. *ruficapillus*
A, H, B, 1-3
Black-fronted Dotterel *Elseyornis melanops*
A, M, B, 2, 3, 8

RECURVIROSTRIDAE

White-headed Stilt *Himantopus leucocepha·lus*
Ir, S*, H, B, 3
Banded Stilt *Cladorhynchus leucocephalus*
Ir, S*, H, N, 2, 3.
Red-necked Avocet *Recurvirostra novaehollandiae*
Ir, S*, L, B,3

Eastern Curlew *Numenius madagascariensis*
S, L, N, 1.
Whim brei *N. phaeopus*
0, F, N, 1.
Wood Sandpiper *Tringa glareola*
S* L, N, 3, (5).
Grey-tailed Tattler *T. brevipes*
A,M,N,1,2.
Greenshank *T. nebularia*
S, M, N, 1-3.
Marsh Sandpiper *T. stagnatilis*
S, F, N, 3.
Common Sandpiper *Actitis hypoleucos*
0, F, N, 1.
Terek Sandpiper *Xenus cinereus*
0, F, N, 2.
Latham's Snipe *Gallinago hardwickii*
S, M, N, D, 2-5, 7, 8.
Black-tailed Godwit *Limosa limosa*
S*, F, N, 3.
Bar-tailed Godwit *L. lapponica*
S, L, N, 1, 2.
Red Knot *Calidris canutus*
S*, M, N, 1, 2.
Great Knot *C. tenuirostris*
S*, M, N, 1, 2.
Sharp-tailed Sandpiper *C. acuminata*
S* H, N, (1),2,3,5.
Pectoral Sandpiper **C**. *melanotos*
S*, F, N, 3.
Red-necked Stint *C. ruficollis*
S*, H, N, 1-3.
Long-toed Stint *C. subminuta*
0, F, N, 2, 3.
Curlew Sandpiper *C. ferruginea*
S* H, N, 1-3.
Sanderling *C. alba*
S', H, N, 1, 2.
Ruff *Philomachus pugnax*
S*, F, N, 3.

STERCORARIIDAE

Brown Skua *Catharacta antarctica*
W, L, N, 1.
Arctic Jaeger *Stercorarius parasiticus*
S*, M, N, 1.
Pomarine Jaeger *S. pomarinus*
0, F, N, 1.
Long-tailed Jaeger *S. longicauda*
0, F, N, 1.

LARIDAE

Silver Gull *Larus novaehollandiae*
A, H, B, 1-3,9.
Pacific Gull *L. pacificus*
0, F, N, 1.
Kelp Gull *L. dominicanus*
0, F, N, 1.
Whiskered Black Tern *Chlidonias hyridus*
Ir, S*, H, B, 2, 3, 9.
White-winged Tern *C. leucopterus*
0, F, N, 3.
Gull-billed Tern *Sterna nilotica*
S*, M, B, 2, 3, 9.
Caspian Tern *S. caspia*
S, L, B, 1-3.
Common Tern S. *hirundo*
0, F, N, 1.
White-fronted Tern *S. striata*
W*, L, N, 1.
Bridled Tern *S. anaethetus*
S, F, B, 1.

Pairs bred on Baudin Rocks Jan. 1968 (Bonnin 1968a). An early report (Campbell 1907) from that locality of the very similar Sooty Tern S. *fuscata* may be of this species.

Fairy Tern S. *nereis*
S, M, B, D, 1,2.
Crested Tern S. *bergii*
S, H, B, 1 *, 2.

COLUMBIDAE \

Feral Pigeon (Rock Dove) *Columba livia*
A, M, B, Int, 1,4,9.
Common Bronzewing *Phaps chalcoptera*
A, M, B, 7-9, 11.
Brush Bronzewing *P. elegans*
A, M, B, 4, 7, 9.
Peaceful Dove *Geopelia placida*
A, F, B, D, 7.
Crested Pigeon *Ocyphaps lophotes*
A, L, B, Inc, 9.

PSITTACIDAE

Red-tailed Black Cockatoo *Calyptorhynchus magnificus*
A, L, B, D, 7, 9.

A small, isolated population, inhabiting *Eucalyptus baxteri* and *Casuarina luehmannii* woodland in SE and adjacent W Vie; a distinctive subspecies (R. Schodde pers. comm.), imperilled by clearing (L. Joseph 1982). Reports of the very similar Glossy Black Cockatoo C. *lathami* have been referred to C. *magnificus* by Parker 1982.

Funereal (Yellow-tailed Black) Cockatoo *C. funereus*
A, M, B, Inc?, 6-11.
See Saunders (1979) for the reason why Gould's name Funereal Cockatoo ought to be used for this bird.
Gang-gang Cockatoo *Callocephalon fimbriatum*
0, F, N, 7.
Galah *Cacatua roseicapilla*
A, M, B, Inc, 8, 9,11.
Long-billed Corella *C. tenuirostris*
A, M, B, Inc?, 8, 9.
Whether the apparent increase of this sp is real, or the effect of displacement resulting from clearing of breeding habitat, requires further study. For an historical review of Vie. and N.S.W. pops, see Jarman 1979.
Sulphur-crested Cockatoo *C. galerita*
A, M, B, D, 8, 9,11.
Rainbow Lorikeet *Trichoglossus haematodus*
Ir, S*, M, B, D, 7.
Musk Lorikeet *Glossopsitta concinna*
Ir, S*, M, B, D, 7, 9
Purple-crowned Lorikeet *G. porphyrocephala*
Ir, S*, M, B, D, 4,7,9
Little Lorikeet *Glossopsitta pusilla*
S, B, D,8
Apparently not uncommon Naracoorte-Joanna dist. 1920s, mainly in *Euc. camaldulensis;* since then has declined drastically through clearing, and now extremely rarely seen (Attiwill 1972a and *in litt.* 10.6.1977), though 50+ reported at The Gap, 35 km N of Naracoorte, 7 Jan. 1983 (Mcintyre & Lees SAON 105 9)
Cockatiel *Nymphicus hollandicus*
Ir, S*, L, B, 7, 9.
Ground Parrot *Pezoporus wallicus*
E?
Last reported Jan. 1945 (McGilp SAO 17: 55), possibly extinct through habitat loss. Formerly in Port MacDonnell dist., mainly in *Cladium junceum* swamps (Condon 1942), also *Gahnia.* Report in 1840s of 'swamp parrots' near L. Hawdon (Cleland 1946) equivocal.
Budgerigar *Melopsittacus undulatus*
Ir, S*, H, B.
Swift Parrot *Lathamus discolor*
0, F, N.
Three reports: one, 28 May 1944, Naracoorte (Attiwill 1946); SA/Vic. border near Nelson, no details (Austin 1951); one near Bangham CP, 1 Sept. 1979 (Houston SAON 92: 16, SAO 28: 207-208).
Crimson Rosella *Platycercus elegans*
A,M,B,7-11.
Eastern Rosella *P. eximius*
A, M, B, Inc, (7), 8, 9
Red-rumped Parrot *Psephotus haematonotus*
A, M, B, (7), 8, 9.
Blue-winged Parrot *Neophema chrysostoma*
S/W, L/M, B, D, 4, 7, 9
Elegant Parrot *N. elegans*
0, F, N, 4.
Rock Parrot *N. petrophila*
0, F, N, 1.
Orange-bellied Parrot *N. chrysostoma*
V-XI, L, N, D, 4
Neophema spp. A dearth of specimens renders tentative any account of these very similar species. In the South East, the Blue-winged is probably the most frequent, small numbers breeding north to Naracoorte dist. and west to Compton and Kongorong; marked increase from March-July possibly resulting from post-breeding migrants from Tasmania and/or Victoria. The Elegant is possibly merely a rare post-breeding straggler: one spm, Robe dist., 22 Jan 1969, coil. H. Eckert (B28068) and two unsubstantiated sight-records (possibly of Blue-winged) from Pt MacDonnell dist.: flocks Feb. 1927 (Ashby 1927) and July 1973 (SAG 27: 108). The Rock is apparently an occasional post-breeding visitor *(contra* Condon 1969), with at least five reports from Robe-Baudin Rocks. The Orange-bellied is apparently a very rare post-breeding migrant, declining, small numbers recorded occasionally May-Nov., Robe, Beachport and Pt MacDonnell dists.

CUCULIDAE

Pallid Cuckoo *Cuculus pallidus*
S*, L, B, 9.
Fan-tailed Cuckoo *Cacomantis flabelliformis*
A, S*, L, B, 4, 7, 9, 11
Black-eared Cuckoo *Chrysococcyx osculans*
S*, F, B, 7.
Horsfield's Bronze Cuckoo *C. basalis*
A, S*, M, B, 4, 7, 9,11.
Shining Bronze Cuckoo *C. lucidus plagosus*
S, L, B, (3),4,7,8,11.

STRIGIDAE

Powerful Owl *Ninox strenua*
0, F, N, 7.

One report: bird roosting in *Euc. huberana* near pine plantation, Mt Burr, July-Aug. 1968 (Attiwill SAON 49: 15, SAO 25: 229).

Boobook Owl *Ninox novaeseelandiae*
A, M, B, D, 4, 7,10.

Barking Owl *N. connivens*
?E,8.

Reported from Naracoorte-Bool Lagoon dist. only; formerly not infreq., last report Pearson's Swamp 17 Aug. 1952, nest with three eggs in *Euc. camaldulensis* (Parker 1977a). No further observations, despite regular searches (J. M. Bourne pers. comm.).

TYTONIDAE

Barn Owl *Tyto alba*
Ir, M, B, 9,10.

PODARGIDAE

Tawny Frogmouth *Podargus strigoides*
A, M, B, D, 7.

AEGOTHELIDAE

Australian Owlet-night jar *Aegotheles cristatus*
S, M, B, 7.

CAPRIMULGIDAE

Spotted Night jar *Eurostopodus argus*
0, F, N.

Five records: dead bird 14.4 km NE of Penola 17 Dec. 1967 (SAO 25: 82); one seen Mary Seymour CP Sept. 1970 (Attiwill ms); one seen near Big Heath CP 23 Apr. 1972 (Attiwill SAON 62: 15); wingfeather found at Killanoola 2 Oct. 1977 (B34017); one seen Baal Lagoon 31 Jan. 1980 (Bourne SAON 94: 15).

For the use of *argus* rather than *guttatus,* see Schodde & Mason 1980: 123.

APODIDAE

White-throated Needletail *Hirundapus caudacutus*
S, M, N, aerial.

Fork-tailed Swift *Apus pacificus*
S, M, N, aerial.

ALCEDINIDAE

Azure Kingfisher *Alcyone azurea*

Reported from Glenelg R. by Morgan (1919) and Ashby (1927) (though not Austin 1951), whether S.A. or Vic. not stated. Recent report from Penola State Forest (Gepp & Fife 1975) unsubstantiated.

Laughing Kookaburra *Oacelo novaeguineae*
A, M, B, D, 7-9,11.

Sacred Kingfisher *Halcyon sancta*
S, L, B, (3), 7-9.

Red-backed Kingfisher *Halcyon pyrrhopygia*
0, F, N, 9.

One record: B31176, coll. 1 km E of Beachport, 26 Oct. 1977.

MEROPIDAE

Rainbow Bird *Merops ornatus*
S, L, B, 9.

CORACIIDAE

Dollarbird *Eurystomus orientalis*
0, F, N.

Two published reports, poss. of same bird: one, Naracoorte dist. 11 Mar. 1963 (Brummitt BT 1: 5); one near Moyhall May 1963 (Attiwill 1963).

ALAUDIDAE

Singing Bushlark *Mirafra javanica*
A, M, B, Inc, 5, 9.

Subsp. M. *j. keasti,* apparently confined to SE, definitely recorded (spms) only from Bool Lagoon dist.; observations (? subsp.) from Kalangadoo, Millicent and Konetta (Mayr & McEvey 1960).

Skylark *Alauda arvensis*
A, H, B, Int, Inc, 2, 3, 9.

HIRUNDINIDAE

Welcome Swallow *Hirundo neoxena*
A, H, B, 1-6,8-10.

Tree Martin *H. (Cecropis) nigricans*
S*, H, B, 3, 4, 7-9.

Fairy Martin *H. (C.) ariel*
S*, M, B, 3, 8, 9.

MOTACILLIDAE

Richard's Pipit *Anthus novaeseelandiae*
A, M, B, 2, 3, 9.

CAMPEPHAGIDAE

Black-faced Cuckoo-shrike *Coracina novaehollandiae*
A, M, B, 4, 7-9, 11.

White-bellied Cuckoo-shrike *C. papuensis*
S*, L, B, 7, 8.

Ground Cuckoo-shrike *Pteropodocys maxima*
0, F, N, 8.

One record: one seen Kybybolite dist. 12 June 1938 (Johnstone SAO 14: 199).

White-winged Triller *Lalage sueurii*
Ir, S, M, B, 7-9.

TURDIDAE

White's Thrush *Zoothera dauma*
A, L, B, 4, 7, 11.
Blackbird *Turdus merula*
A, M, B, Int, 4, 7, 9-11
Southern Scrub-robin *Orymodes brunneopygia*
S, L, 3, 6, 7.

PACHYCEPHALIDAE

Pink Robin *Petroica rodinogaster*
W, F, N, 4, 7.

See Rowley & Paton (1978) for records. The similar Rose Robin *P. rosea* has been reported from Darwent's WH 40 km S of Keith, 24 Aug. 1967 (SAO 25: 20, 22), so mayalsooccurin SE in winter.

Flame Robin *P. phoenicea*
W, L, N, 9.
Scarlet Robin *P. multicolor*
A, M, B, (3),7,11.
Red-capped Robin *P. goodenovii*
S, F, B, D, E?, 9, 10.
See Attiwill 1954.
Hooded Robin *Melanodryas cucullata*
A, L, B, 7-9.
Eastern Yellow Robin *Eopsaltria australis*
A, M, B, 4, 7,11.

Apparently very rare in early days (cf Morgan 1906, 1919, Ashby 1927), since increased (Storr *et al.* 1952, Brummitt SAO 22: 19), and now advancing N along Coorong (R. Hawkes pers. comm.).

Jacky Winter *Microeca leucophaea*
A, M, B, 7-9.
Crested Shrike-tit *Falcunculus frontatus*
A, L, B, 7, 8, (11).
Olive Whistler *Pachycephala olivacea*
A, L, B, D, 4, (7), (10).

First reported 1940 (Ey 1940); mainly coastal and subcoastal: L. Robe, Nora Creina Bay, Woolley's L., L. Bonney, Ewen's Ponds, Dingley Dell; recent inland report from Mt Burr, 4.12.1980, two in *E. baxteri* forest (Carpenter SAON 97: 11).

Gilbert's Whistler *P. inornata*
0, F, B, 7.

One record: pair breeding Bangham CP early Nov. 1980 (Ragless & Joseph BT 2: 25, Joseph & Kernot 1982).

Golden Whistler *P. pectoralis*
S/W, F/L, ?B, (3),7,10,11.

Mainly a non-breeding* winter visitor April-Sept. The form involved is *P.p. youngi* also known from S. Vie. and S.E. N.S.W. It differs from *P. p. fuliginosa* (collected S to Salt Ck and Padthaway dists) in that ad. females and subads have undersurface not cinnamon but g reyish-wh ite.

*Attiwill's (1972a) inclusion of this species in his list of birds breeding in the Naracoorte dist. was based solely on a clutch of eggs taken north of Padthaway, and therefore of *P. p. fuliginosa* (J. M. Bourne pers. comm.). The very few remaining breeding reports are under investigation.

Rufous Whistler *P. rufiventris*
A, M, B, D, 3, 7, (8), 11.
Grey Shrike-thrush *Collurincincla harmonica*
A, M, B, 4, 7-9, 11.
Crested Bellbird *Oreoica gutturalis*
A, L, B, 7.
Satin Flycatcher *Myiagra cyanoleuca*
S, L, B, 7.

Recent observations (see Reid & Cox 1978, also Close & Cox SAON 89: 14, and Kernot SAON 97: 12) suggest that this sp. is a regular spring-summer breeding visitor, in small numbers, to stringy-bark forests in Millicent, Mt Burr, and Glenelg R. dists. Reid & Cox *(op.cit.)* did not accept the sole SE report of the very similar Leaden Flycatcher M. *rubecula,* from Killanoola.

Restless Flycatcher *M. inquieta*
A, M, B, 7-9.
Grey Fantail *Rhipidura fuliginosa*
A, M, B, 4, 7-11.

The Rufous Fantail *R rufifrons* has been reported from Glenelg R. (SA/Vic. border, Austin 1951), and collected at Coombe, Upper SE, 10 Dec. 1933 (B17110). It may well therefore occur in the Lower SE as a nonbreeding straggler, or even as a breeding bird in the Glenelg R. dist.

Willie Wagtail *R. leucophrys*
A, M, B, 3, 7-11.

ORTHONYCHIDAE

Spotted Quail thrush *Cinclosoma punctatum*
B, ?E.

One definite record traced: clutch of two eggs (B29904) from near Mt Gambier, 8 Nov. 1898. Possibly now extinct in SE, though Austin (1951) reported it as occurring 'sparingly but widely throughout all the forest country on the lower reaches of the Glenelg River.'

Grey-crowned Babbler *Pomatostomus temporalis*
0, F, B, D, 4, 7-9.

Apparently once common and widespread breeding bird in SE, but in decline in 1930s and last definite sighting for this period 1941, in Pt MacDonnell dist. (Condon 1942). Subsequently reported from Mt HopeRendelsham dist., one 1972-73, and near southern boundary of Bangham CP, 1-2, 1979-80 (Houston 1981).

White-browed Babbler P. *superciliosus*
A, L, B, 4, 7, 8.

SYLVIIDAE

Clamorous Reed-Warbler *Acrocephalus stentoreus*
S*, M, B, 3.

Little Grassbird *Megalurus gramineus*
S*, M, B, 1-4.

Golden-headed Fantail Warbler *Cisticola exilis*
A, M, B, Inc, 3, 5, 8, 9.

Rufous Song lark *Cincloramphus mathewsi*
Ir, S, L, B, (7), 8, 9.

Brown Song lark *C. cruralis*
S*, M, B, 2, 9.

MALURIDAE

Superb Wren *Malurus cyaneus*
A, H, B, 3, 4, 6-9, 11.

Variegated Wren *M. lamberti*
0, F, 7.

The basis for Attiwill's (1972a) inclusion of this species in his list of birds breeding in the Naracoorte district was a nest found north of Padthaway (J. M. Bourne pers. comm.). However the species may be retained on the list for the South East on the strength of two parties seen in Bangham CP on 7.1.1977 (NCHR pers. obs.).

Southern Emu-wren *Stipiturus malachurus*
A, M, B, 4-6, (7).

ACANTHIZIDAE

Rufous Bristlebird *Dasyornis broadbenti*
A, H, B, 4.

White-browed Scrubwren *Sericornis frontalis*
A, H, B, 3, 4, 7, 9,11.

Chestnut-rumped Heathwren *Hylacola pyrrhopygia*
A, L, B, 3, 6, 7.

Eastern Fieldwren *Calamanthus fuliginosus* A, M, B, 2, 4-6, 9.

For a revision of the taxonomy and nomenclature of the fieldwrens, see Parker & Eckert (1983). Between C. *fuliginosus* of the Lower SE and C. *campestris winiam* of the Ninety-Mile Desert (a long-billed subspecies of the Western Fieldwren), contact has not yet been reported, but has been postulated by Parker & Eckert on the grounds of apparent character displacement in C. c. *winiam.* C. *fuliginosus* has been recorded north to Kingston and Bool Lagoon, and C. c. *winiam* south to the Keith district; specimens and observations are needed from the ornithologically very poorly known intervening area to determine whether there is contact.

The 1868 record of the Speckled Warbler *Chthonicola sagittata* from Tarpeena north of Mt Gambier was referred by Parker (1980) to the Eastern Fieldwren.

Weebill *Smicrornis brevirostris*
0, F, B, 7.

Status in SE very poorly known. Reports from 4.8 km N of Naracoorte (Attiwill *ms),* Baker's Range (breeding, G. B. Ragless pers. comm.), Mary Seymour CP (J. M. Bourne pers. comm.) and Fairview CP (NCHR pers.obs.).

White-throated Warbler *Gerygone olivacea*
S, L, B, 4, 7, 10.

Brown Thornbill *Acanthiza pusilla*
A, H, B, 3, 4, 6-9, 11.

Buff-rumped Thornbill *A. reguloides*
A, M, B, 6, 7, 9,11.

Yellow-rumped Thornbill *A. chrysorrhoa*
A, H, B, 2-4, 6-9, 11.

Striated Thornbill *A. lineata*
A, M, B, 4, 7,10,11.

The single SE report of the similar Yellow Thornbill A. *nana* (County Grey, breeding, SED B) requires substantiation.

Southern Whiteface *Aphelocephala leucopsis*
B, D, ?E, 3, 8, 9.

As in other southern districts of S.A., seems to have declined since the 1930s to or nearly to local extinction (Bourne pers. comm.).

NEOSITTIDAE

Varied Sittella *Daphoenositta chrysoptera*
A, M, B, D, 7, 9, 11.

CLIMACTERIDAE

White-throated Treecreeper *Cormobates leucophaea*
A, M, B, D, 7.

Brown Treecreeper *Climacteris picumnus*
A, M, B, D, 7-9.

MELIPHAGIDAE

Red Wattlebird *Anthochaera carunculata*
A, M, B, 4, 7, 9.
Little Wattlebird *A. chrysoptera*
A, M, B, 4, 7, 9.
Spiny-cheeked Honeyeater *Acanthogenys rufogularis*
S*, M, B, 4, (7), (9).
Little Friarbird *Philemon citreogularis*
0, F, N, 10.
One caught in shade-house, Naracoorte, 14 Oct. 1973 (SAO 27: 109; see also SAON 68: 12, where record listed under Noisy Friarbird P. *corniculatus) .*
Regent Honeyeater *Xanthomyza Phrygia*
0, F, N.
One published report: one seen at Naracoorte Jan. 1954 (Glover 1954). See also Austin 1951 for records from Apsley, Vic., near S.A. border.
Blue-faced Honeyeater *Entomyzon cyanotis*
A, L, B, 8, 9.
Noisy Miner *Manorina melanocephala*
A, L, B, D, 8, 9.
Yellow-faced Honeyeater *Meliphaga chrysops*
S*, M, B, 4, 7, 8.
Singing Honeyeater *M. virescens*
A, M, B, (3), 4.
White-eared Honeyeater *M. leucotis*
A,M,B,7,11.
Yellow-tufted Honeyeater *M. melanops*
0, W*, L, N, 7.
See Hood & Attiwi1l1958, Bourne SAON 86: 14 and Moorhouse SAON 96: 12.
Purple-gaped Honeyeater *M. cratitia*
0, F, N, 9.
One report: Bangham dist., one seen 11 Apr. 1977 (N. C. H. Reid pers. obs.).
Yellow-plumed Honeyeater *M. ornata*
0, F, N, 7.
One report: Fairview CP, one seen, 9 Apr. 1977 (N. C. H. Reid pers. obs.).
Fuscous Honeyeater *M. fusca*
0, W*, L, N.
See Hood 1939 and Moorhouse SAON 96: 12.
White-plumed Honeyeater M. *penicillata*
A, H, B, D, 7-9.
Black-chinned Honeyeater *Melithreptus gularis*
S*, L, B, 7, 8.
Brown-headed Honeyeater *M. brevirostris*
S*, M, B, 7, (8,9).
White-naped Honeyeater *M. lunatus*
S*, M, B, D, 7-9,11.
Painted Honeyeater *Grantiella picta*
0, F, N, 10.
One report: one seen for two days in April 1978, in homestead garden 8 km SW of Bool Lagoon (Moorhouse SAON 92: 17, detailed description).
New Holland Honeyeater *Phylidonyris novaehollandiae*
A, H, B, 3, 4, 7-11.
White-fronted Honeyeater P. *albifrons*
0, F, N, 6, 7, 9, 10.
Reported April-Nov. 1977 only, when small numbers were seen 2.5 km N of Frances, in Big Heath, Fairview and Mary Seymour CPs, and in a homestead garden near the SW corner of Bool Lagoon (N. Reid, A. R. Attiwill and J. M. Bourne pers. obs.).
Tawny-crowned Honeyeater *P. melanops*
S*, M, B, 6-8.
The two reports, unsubstantiated, of the Crescent Honeyeater P. *pyrrhoptera* we consider.more likely referable to one or two of the other species of the genus: five noted between Mt Mcintyre and Mt Burr Forest Dec. 1922 (Sutton 1923); 'occurs sparingly in heath lands near the coast from Port MacDonnell to Portland' (Austin 1951).
Eastern Spinebill *Acanthorhynchus tenuirostris*
S*, L, B, 7,11.

EPHTHIANURIDAE

White-fronted Chat *Ephthianura albifrons*
A, H, B, Inc, 2, 3, 6, 9.

DICAEIDAE

Mistletoebird *Dicaeum hirundinaceum*
S*, M, B, 7.

PARDALOTIDAE

Spotted Pardalote *Pardalotus punctatus*
7.
Yellow-rumped Pardalote P. *xanthopygus*
4,7.
Recent evidence of hybridization between these two largely allopatric taxa in the Mt Lofty Ranges and the South East is presented by Parker & Reid (in prep.). Material collected in the South East in 1976-78 by Reid & J. B. Cox confirmed earlier reports of the presence of both forms there, but also revealed hybridization: *punctatus:* 2 km N of Donovan's Landing and Mary Seymour CP; *xanthopygus:*
Woolley's L. and 12 km Waf Penola; hybrids:

Mary Seymour CP and 12 km W of Penola. Because of the presence of hybrids, sight-records are of no value to the resolution of the situation; further specimens must be secured.

Striated Pardalote *P. striatus* subspp.
S', H, B, D, 7, 8, 9.

Until recently, it was assumed that *P. striatus substriatus* ('Red-tipped Pardalote') was the sole form of this species occurring in the South East, though the possibility of the occurrence of the nominate subspecies ('Yellow-tipped Pardalote') in winter was recognized (a specimen having been collected north of the South East, *vide* Condon & Waterman, 1965). Reid & Cox (1981) pointed out that although *'substriatus'* had been reported throughout the South East, only five specimens had been collected, and that one of these was in fact a specimen of *P.* s. *ornatus* ('Eastern Striated Pardalote'): *substriatus* (s.s.): B2409, ad. *cf,* Kingston, 28 Oct. 1918; B30576, ad. *Q,* Big Heath CP, 5 Jan. 1977; B30839, imm. if, Naracoorte, 25 Mar. 1977; B32082, subad., Mary Seymour CP, 16 Feb. 1979; *ornatus:* B30430, ad. 6', Big Heath CP, 5 Oct. 1976. Of eleven further specimens collected in the district in Nov. 1981 by SAP, J. M. Bourne and P. Cockerham, two are referable to *ornatus* (B34254-55) and nine to *substriatus* (B34256-64).

The suggestion of Reid & Cox (1981) that *ornatus* and *substriatus* are morphs of a single form may well be correct. It is difficult to impossible to distinguish the two in the field; further analysis of the situation should involve further collecting. These pardalotes are currently common in the region, particularly in the many old lerp-infested gums scattered through the largely cleared pasturelands.

ZOSTEROPIDAE

Silvereye *Zosterops lateralis*
A, H, B, 2-4, 6-8, 10, 11.

SEDB lists two silvereyes for the SE: Silvereye Z. *lateralis* and Grey-backed Silvereye Z. *halmaturina.* The situation is that the common resident form Z. *I. halmaturina* is sometimes joined by migrants of Z. *I. lateralis,* the Tasmanian breeding form (voucher specimens of latter B27233-4, Millicent, Feb. 1966, coil. C. Pawsey).

FRINGILLIDAE

Goldfinch *Carduelis carduelis*
A, H, B, Int, 3, 4, 7, 9-11.

Greenfinch C. *chloris*
A, M, B, Int, 4, 9, 10.

PASSERIDAE

House Sparrow *Passer domesticus*
A, H, B, Int, 3, (8),9, 10.

ESTRILDIDAE

Red-browed Finch *Emblema temporalis*
A, M, B, 4, 7, 9, 11.

Beautiful Firetail *E. bellum*
A, M, B, 2, 4, 6, 7.

Diamond Firetail *E. guttatum*
B, E?

Formerly not uncommon in Bool LagoonNaracoorte dist., last (breeding) record 6 Nov. 1943, nest with *cl5* (Attiwill ms.).

STURNIDAE

Starling *Sturnus vulgaris*
A, H, B, 3, 4, 7, 9.

ORIOLIDAE

Olive-backed Oriole *Oriolus sagittatus*
E.

According to a former Curator (J. Sutton: ms. 30 Nov. 1936), F. W. Andrews collected two specimens from Mingbool in Dec. 1867 and one from Tarpeena in Oct. 1868. Sutton was quoting from a list written by Andrews (now lost), the specimens being not extant. (These records understandably were not mentioned in Crouch's, 1970, review of the species' status in South Australia).

CORCORACIDAE

White-winged Chough *Corcorax melanorhamphos*
A, L, B, D, 3, 7, 9-11.

Apostlebird *Struthidea cinerea*
B, E.

Two reports: 'Skin in S.A. Museum taken *5/7/1868* by F. W. Andrews at Tarpeena .. .' *(fide* McGilp, 1943, skin no longer in collection); noted by Hood (1935b), who reported a single breeding flock near Naracoorte.

GRALLINIDAE

Magpie-lark *Grallina cyanoleuca*
A, M, B, 3, 8, 9.

ARTAMIDAE

White-breasted Woodswallow *Artamus leucorhyncus*
O, F, N.

Two records traced: B26202, subadult cJ, Rivoli Bay, 3 Mar. 1960, coil. R. Braham; B31532, adult c!, Bool Lagoon, 17 May 1978, coil. J. Bourne (SAON 87: 12).

Masked Woodswallow *A. personatus*

Ir, S, L, B, 7, 9.

White-browed Woodswallow *A. superciliosus*

Ir, S, H, B, 7-9.

Dusky Woodswallow *A. cyanopterus*

A, H, B, 4, 7-9.

Attiwill (1972a) also recorded Black-faced Woodswallow *A. cinereus* as very rare in the Naracoorte district. J. Bourne (pers. comm.), present when these observations were made, now considers the birds to have been Dusky Woodswallows.

CRACTICIDAE

Grey Butcherbird *Cracticus torquatus*

A, L, B, D, 4, 7, 8.

White-backed Magpie *Gymnorhina tibicen leuconota*

A, H, B, Inc, 4, 6-11.

Grey Currawong *Strepera versicolor*

A, M, B, 4, 7, 9,11.

South East breeding populations are referable to S. v. *melanoptera.* An early report of a specimen (now lost) of S. v. *versicolor* from the South East requires confirmation (Anon. 1923, Condon 1951).

Australian Raven *Corvus coronoides*

A, F, N, 7, 9.

Recorded specifically from between Naracoorte and Bool Lagoon, and generally from throughout the South East, in Aug. 1970 by Moore (1977). Other records from and just beyond northern boundary of South East are: 1.6 km N of Padthaway, 26 Oct. 1958, B26215, coil. V. J. Wood; 10 km N of Frances, 27 Dec. 1976, B30582, coil. A. Lees; Bangham dist., heard 4 Oct. 1976,7.1. and 11 Apr. 1977 (N. Reid pers. obs.); southern end of Coorong N of Kingston, heard Feb. 1978 (N. Reid pers. obs.).

Rowley (1970) demonstrated that the 'Australian Raven' of earlier literature consisted in fact of three very similar species (this and the next two). The account of distribution of the ravens presented here is based chiefly on records of calls and must therefore be regarded as provisional until substantiated by specimens.

Forest Raven C. *tasmanicus*

A, M, B, 3, 4, 7-11.

Recorded north to the Bangham dist., west to Fairview CP, Big Heath CP and Rendelsham, thence NW in coastal and subcoastal districts to Robe and L. Hawdon (Reid *ms.,* and specimens in S.A. Museum); mainly in vicinity of forest, introduced *Pinus* plantations and dense tall coastal scrub. First formally reported from SE by Moore (1977), though B23518 collected in Millicent dist. in 1938 by A. Ey as an example of the birds he distinguished as the Australian Raven (Ey 1944) is in fact an example of C. *tasmanicus.* (And antedating even Ey's perception that two species of *Corvus* were resident in the SE is that of inhabitants of the Naracoorte district, as reported by Ashby 1927).

Little Raven C. *mellori*

A, M, B, 3, 4, 7, 9, 10.

Recorded from north-eastern section W to 5 km W of northern end of Big Heath CP, S to Wattle Range and 16 km ESE of Penola, also Millicent and surrounding dists. N to Mullins' Swamp and 9 km ENE of Hatherleigh, S to German Flat and coastal strip W of L. Bonney', and E to Mt Burr, and further northwest in coastal dists. between Robe and Nora Creina.

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*The Little Crow C. *bennetti* also has been reported breeding in coastal *Casuarina stricta* west of L. Bonney in the 1930s and 1940s but not found there since (Ey 1944, *in litt.* 28 July 1977, and pers. comm. 22 Oct. 1981, Rowley 1970). The voucher specimen collected to Identify thiS population, a breeding female B23519 taken in Septem ber 1944 and identified the same month at the SAM as C *bennetti,* has recently been redetermined by us as an aberrant Little Raven with whitish, not grey, featherbases.

REFERENCES

Anon. (1923). Monthly proceedings of the South Australian Ornithological Association. Jan. 1923. S. *Aust. Orn*. 7, 38-39

Ashby, E. (1927). Notes on birds observed during a motor trip to the South-East of South Australia and coastal western Victoria. S. *Aust. Orn* **9***,* 131-141.

Attiwill, A. R. (1946). Bird notes from Naracoorte. S.*Aust. Orn.* **18**, 21,30.

Attiwill, A. R. (1954). Field notes on Red-capped Robin. S. *Aust. Orn*. 21,35-36.

Attiwill, A. R. (1963). Southern record of Dollar-bird.S. *Aust. Orn.* 24, 15.

Attiwill, A. R. (1972a). Birds breeding in the Naracoorte district, 1941-1971. *S. Aust. Orn. **26**,* 59-64.

Attiwill, A. R. (1972b). A list of the birds of Big Heath.S. *Aust. Nat.* **47**, 38-40.

Austin, C. (1951). Birds of the southern end of Victoria-South Australian border. S. *Aust. Orn.* **20**, 14-15.

Bonnin, J. M. *(1968a).* The Bridled Tern breeding in South Australia. S. *Aust. Orn.* **25**, 18, 22.

Bonnin, J. M. (1968b). The Baudin Rocks-a further report. S. *Aust. Orn.* **25**, 49-50.

Bourne, J. M. (1982). Remarks on the status of the Painted, Little and Red-chested Button-quails in the South-East of South Australia. S. *Aust. Orn.* **29**, 5-6.

Brummitt, D. W. (1933). Birds noticed around Robe in the summer, 1932-33. S. *Aust. Orn.* **12**, 57-60.

Brummitt, D. W. (1934a). A trip to the South-east of this State. S. *Aust. Orn.* **12**,172-176.

Brummitt, D. W. (1934b). The Baudin Rocks S. *Aust. Orn.* **12**, 202-203.

Brummitt, D. W. (1935). Some nesting observations in the South-East in the summer of 1934-35. S. *Aust. Orn.* 13,49-51.

Brummitt, D. W. (1937). A few notes from the SouthEast forthesummer 1936-1937. S. *Aust. Orn*. **14**, 45-46.

Campbell, A. J. (1900). Nests and Eggs of Australian Birds. (Published by the author, Sheffield).

Campbell, A. J. (1907). Annotations. *Emu* **6**, 136-138.

Cleland, J. B. (1946). References to South Australian birds by George French Angas in 1847. *S. Aust. Orn*. **17**, 84-86.

Condon, H. T. (1942). Birds seen near Pt MacDonnell, S.E. of South Australia. *S. Aust. Orn*. **16**, 14, 23.

Condon, H. T. (1951). Notes on the birds of South Australia: occurrence, distribution and taxonomy. S. *Aust. Orn.* **20**, 26-68.

Condon, H. T. (1969). A Handlist of the Birds of South Australia. 3rd ed. *(S. Aust. Orn. Assoc.,* Adelaide).

Condon, H. T. & Waterman M. H. (1965). Banding of Yellow-tipped Pardalote in South Australia. *Emu* **64**, 298.

Crouch, H. W. (1970). The Olive-backed Oriole in South Australia. S. *Aust. Orn*. **25**, 195-200.

Ey, A. E. (1940). The Olive Whistler. A new record for South Australia. S. *Aust. Orn.* **15**, 67.

Ey, A. E. (1944). Birds breeding in the Millicent district. S. *Aust. Orn.* **17**, 32-37.

Ey, A. E. (1946). Birds breeding in the Millicent district. Additions. S. *Aust. Orn.* **17**, 92.

Francis, L. S. (1946). Birds seen during a trip to the South-East of South Australia. S. *Aust. Orn. **17**,* 86-87.

Gepp, B. C. & Fife, A. J. (1975). Birds seen in forest reserves in South Australia. S. *Aust. Orn.* **27**,1217.

Glover, B. (1954). Bird observations in the SouthEast and elsewhere. S. *Aust. Orn.* **21**, 31-32.

Harris, C. R., Beare, J. A., Lewis, N. B. & Rowe, G. P. (1976). Vegetation clearance in South Australia. Report of the Interdepartmental Committee on Vegetation Clearance. (S. Aust. Govt, Adelaide).

Hood, J. B. (1932). Bool Lagoon notes. S. *Aust. Orn* **11**, 140-141.

Hood, J. B. (1934a). Bird notes. Bool Lagoon, S.E. SA *S. Aust. Orn.* **12**, 177-178.

Hood, J B. (1934b). The birds in the Bool Lagoon district. S. *Aust. Orn.* 12,207-211.

Hood, J. B. (1935a). Notes from Bool Lagoon, S.E. SA S. *Aust. Orn. 13*, 18-19.

Hood, J. B. (1935b). Nesting, etc., in the Bool Lagoon district, S.E. SA, during the 1934 season. *S. Aust. Orn.* **13**, 107-119.

Hood, J. B. (1936). Bird notes. S. *Aust.* Orn. 13,175. Hood, J. B. (1939). The Fuscous Honeyeater *(Meliphaga fusca). S. Aust. Orn.* **15**, 47-48.

Hood, J. B. & Attiwill, A. R. (1958). The Yellow-tufted Honeyeater-a new record for South Australia. *S. Aust. Orn*. **22**, 58.

Houston, C. (1981). Recent records of the Greycrowned Babbler. *S. Aust. Orn.* **28**, 159-160.

Jaensch, R. (1982). Little Ringed Plover at Little Bool Lagoon. S. *Aust. Orn.* **28**, 201-204.

Jarman, H. (1979). The corellas in Victoria and the Riverina, N.S.W. *Aust. Bird Watcher* **8**, 103-117.

Jones, W. (1978). The wetlands of the South-East of South Australia. (Nature Conserv. Soc. S. Aust, Adelaide).

Joseph, L. (1982). The Red-tailed Black Cockatoo in south-eastern Australia. *Emu* **82**, 42-45.

Joseph, L. & Kernot, R. (1982). Range extensions of Gilbert's Whistler. *S. Aust.*

Orn. **28**, 217-218.

Mayr, E. & McEvey, A. R. (1960). The distribution and variation of *Mirafra javanica* in Australia. *Emu* **60**,155-192.

McGilp, J. N. (1943). List of the birds of South Australia. *S. Aust. Orn.* **16**, 78-79.

Moore, L. A. (1977). The Forest Raven *Corvus tasmanicus-a* new record for South Australia. *S. Aust. Orn.* **27**, 251-253.

Morgan, A. M. (1906). The birds of Kangaroo Island. *Emu* **5**, 224-225.

Morgan, A. M. (1919). The birds of the South Eastern part of South Australia. *S. Aust. Orn.* **4**, 7-20.

Morgan, A. M. (1922). A trip to the Baudin Rocks. S.*Aust. Orn*. **6**, 133-134.

Parker, S. A. (1977a). Records of the Barking Owl from South Australia. *S. Aust. Orn.* **27**, 204-206.

Parker, S. A (1977b). Further comments on collecting. S. *Aust. Orn. Assoc. News.* **84**, 4-8.

Parker, S. A (1980). The records of the Speckled Warbler from South Australia. *S. Aust. Orn.* **28**, 102-103.

Parker, S. A. (1982). The records of the Glossy Black Cockatoo from the South-East of South Australia. *S. Aust. Orn*. **28**, 209-210.

Parker, S. A. & Eckert, H. J. (1983). Remarks on the taxonomy of the genus *Calamanthus* (fieldwrens). *S. Aust. Orn.* **29**, in press.

Parker, S. A, Eckert, H. J., Ragless, G. B., Cox, J. B. & Reid N. C. H. (1979). An Annotated Checklist of the Birds of South Australia. Pt 1, Emus to spoonbills. (S. Aust. Orn. Assoc., Adelaide).

Parker, S. A, Eckert H. J. & Ragless G. B. (in prep.).An Annotated Checklist of the Birds of South Australia, Pt 2, waterfowl to gulls and terns.

Parker, S. A. & May, I. A. (1982). Additional notes on seabirds recorded in South Australia. *S. Aust. Orn.* **28**, 213-216.

Parker, S. A & May, I. A. (in prep.). Remarks on the status of the Black-faced Shag and Pied Cormorant in the South-East of South Australia.

Parker, S. A. & Reid, N. C. H. (in prep.). Hybridization between the Spotted Pardalote *Pardalotus punctatus* and the Yellow-rumped Pardalote *P. xanthopygus* in South Australia.

Parsons, F. E. (1927). Further notes on birds of South-East of South Australia. *S. Aust. Orn.* ***9***, 67-68.

Parsons, F. E. (1928). A trip to the South-East of South Australia. S. *Aust. Orn.* **9**, 191-206.

Pawsey, C. K. (1966). Birds in relation to the pine forests of the South-east of South Australia. S. *Aust. Orn.* **24**, 93-95.

Reid, N. C. H. & Cox, J. B. (1978). The status of Satin and Leaden Flycatchers in South Australia with a note on female plumages. S. *Aust. Orn.* **27**, 277279.

Reid, N. C. H. & Cox, J. B. (1981). The Eastern Striated Pardalote *Pardalotus striatus ornatus* in the South-east of South Australia. S. *Aust. Orn.* **28**, 154-155.

Reid, N. C. H. & Vincent, D. J. (1979). Report on an ornithological survey of South Australian national, conservation and recreation parks and game reserves, with comments on the adequacy of bird conservation in South Australia, pp. 1111. (S. Aust. am. Assoc., Adelaide, Mimeo).

Rowley, D. & Paton, J. B. (1978). The Pink Robin in South Australia. S. *Aust. Orn.* **28**, 21-22.

Rowley, I. (1970). The genus *Corvus* (Aves: Corvidae) in Australia. *CSIRO Wildl. Res.* **15**, 27-71.

Saunders, D. A. (1979). Distribution and taxonomy of the white-tailed and yellow-tailed black cockatoos *Calyptorhynchus* spp. *Emu* **79**, 215?27.

Schodde, R. & Mason, I. J. (1980). 'Nocturnal Birds of Australia.' (Lansdowne, Melbourne).

South Eastern Drainage Board (1980). Environmental impact study on the effect of drainage in the South-East of South Australia, Appendix IX, Bird List 98-104.

Storr, G. M. (1951). Notes on some species breeding at Bool Lagoon. *S. Aust. Orn.* **20**, 6-8.

Storr, G. M., Lendon, A. H. & McKechnie, R. W. (1952). Some observations in south-eastern South Australia and adjacent parts of Victoria. *S. Aust. Orn.* **20**, 70-71.

Sutton, J. (1923). A trip to the South-east of South Australia. S. *Aust. Orn.* **7**, 51-61.

Sutton, J. (1927). A week in the Robe district. S.*Aust. Orn.* **9**, 5-29.

Sutton, J. (1929). A trip to the South-East of South Australia. *S. Aust. Orn.* **10**, 56-71.

Sutton, J. (1931). A trip to Bool Lagoon, South-East, SA *S. Aust. Orn.* **11**, 74-92.

Sutton, J. L. (1934). Additional records for South Australia. *S. Aust. Orn.* **12**, 184-188.

14: Reptiles and Amphibians

by MICHAEL B. THOMPSON and MICHAEL J. TYLER

INTRODUCTION

The South East is exceptional amongst cool areas in that it includes 36 species of reptiles (excluding the vagrant marine turtles). There are also a few species which cannot be readily assigned to Central Eyrean or eastern Bassian influence.

The reptiles of the South East have been collected inadequately. This is reflected by the deficiency of knowledge of distribution and, to some extent, in the taxonomy of many species. It is possible to draw up a species list for any region in Australia and include most of

Table 1. REPTILES AND AMPHIBIANS OF THE SOUTH EAST. SPECIES MARKED WITH AN ASTERISK HAVE NOT BEEN COLLECTED, BUT ARE LIKELY TO OCCUR THERE.

TURTLES: CHELIDAE
- *Chelodina longicollis*

SNAKES: TYPHLOPIDAE
- *Typhlina australis**
- *T. bituberculata**

ELAPIDAE
- *Unechis brevicaudis*
- *U. flagellum*
- *Drysdalia coronoides*
- *D. mastersi*
- *Echiopsis curta*
- *Austrelaps superba*
- *Notechis scutatus*
- *Pseudonaja textilis*
- *Simoselaps semifaciata*
- *Pseudechis porphyriacus**

LIZARDS: PYGOPODIDAE
- *Aprasia striolata*
- *Delma impar*
- *Pygopus lepidopodus*

VARANIDAE
- *Varanus gouldii*

GEKKONIDAE
- *Phyllodactylus marmoratus*
- *Underwoodisaurus milii**

AGAMIDAE
- *Amphibolurus barbatus*
- *A. muricatus*
- *A. pictus**
- *Tympanocryptis lineata*

SCINCIDAE
- *Ctenotus brooksi*
- *C. robustus*
- *Egernia whitii*
- *Hemiergis decresiensis*
- *H. peronii*
- *Leiolopisma delicata*
- *L. entrecasteauxii*
- *L. guichenoti*
- *L. trilineata*
- *Lerista bougainvillii*
- *L. distinquenda*
- *Moretha obscura*
- *Sphenomorphus tympanum*
- *Tiliqua nigrolutea*
- *T. scincoides*
- *Trachydosaurus rugosus*

FROGS: HYLIDAE
- *Litoria ewingi*
- *L. raniformis*

LEPTODACTYLIDAE
- *Geocrinia laevis*
- *Limnodynastes dumerili*
- *L. peroni*
- *L. tasmaniensis*
- *Neobatrachus pictus*
- *N. sudelli*
- *Pseudophryne bibroni*
- P. *semimarmorata*
- *Ranidella signifera*

the presently described species, i.e. regional species distributions are known, but they are patchy in some areas. The South East is one such uncertain area. Consequently it is also possible to add to the known species, others which (on the basis of collections in nearby areas and in similar habitats elsewhere) are likely to occur in the area (Table 1).

In the first handbook of the reptiles and amphibians of South Australia, Waite (1929) did not mention a single south-eastern locality for a frog. In reality it was not until the early 1960's that any attention was devoted to the frog fauna there. Unfortunately the intervening period was a crucial one, because deforestation, drainage and the planting of pines unquestionably affected the wet habitats formerly so important for frogs (see Chapter 10, and the paper by Beck (1975)).

Despite the drainage, and in particular the reduction of marshy areas, there remains a substantial number of species in the area. Allowing for the generally depauperate nature of the South Australian frog fauna within a predominantly arid State (only 24 of the 178 Australian species currently recognised inhabit South Australia), the total of 11 in the South East is a significant component This is emphasised when it is appreciated that the South East occupies only 1.25% of the surface area of S.A.

REPTILES

TURTLES AND TORTOISES

Species of both families of marine turtles, the Cheloniidae and Dermochelyidae, have been sighted in South Australian waters (Houston 1979) but, because such sightings represent vagrant individuals and not breeding populations, they do not warrant a detailed account

The side-necked tortoises (Pleurodira) are an excellent illustration of the lack of knowledge of reptiles of the South East Many Australians have encountered the common long-necked tortoise, *Chelodina longicollis,* which is probably the most widespread species in Australia, occurring in all suitable habitats in south-eastern and eastern Australia. It is the only species known from the South East Nevertheless very few specimens are included in the South Australian Museum collection. Before 1979 there was only one specimen from the South East (near Canunda National Park). Now three more localities have been added. Tortoises are known to occur in every dam, swamp and creek south of Bordertown but there are few voucher specimens to confirm this knowledge.

SNAKES

Only one family of snakes (the Elapidae) has been recorded, although it is likely that the Typhlopidae, the blind snakes, ultimately will be shown to occur as well. Pythons (Boidae) occur in South Australia, but are unlikely to extend so far south.

Although there are no blind snakes from the South East in the collection of the South Australian Museum, two species, *Typhlina australis* and *T. bituberculata,* are known from the ninety-mile desert region. *T. australis* is a widespread species and we consider it likely to occur in the South East In the experience of the first author, this is a group of animals that is encountered more by chance than as a result of specific collecting activity. They are cryptic, burrowing snakes which feed largely on termites and come to the surface only at night (Cogger 1975). All species are cylindrical, lack eyes (although they have pigmented eye spots), are completely smooth and have a spine on the tip of the tail. They are non-venomous.

The Elapidae, or front-fanged snakes, which include the tigers, browns and copperhead are the only snakes collected in the South East. Nine species have been recorded, with a possible addition known. The major groups of the Elapidae have been described, but many species-groups remain to be defined, and the phylogenetic relationships of the species have yet to be established. For example in the last decade, the little whip snake, *Unechis flagellum,* has been placed in the genus *Cryptophis* by Worrel (1970), *Denisonia* by Rawlinson (1971) and *Unechis* by Cogger (1975). Together with many other small species it is presently being investigated.

Even the taxonomy of the tigers, browns and copperheads is confusing. However only one species of each of these genera occurs in the South East, and on the whole the large elapid snakes from the South East are well represented in the S.A. Museum collection Surprisingly, there are no specimens of the red-bellied black snake, *Pseudechis porphyriacus.* M.B.T. has received reports of their occurrence in the region on a numberof occasions. The smaller, more cryptic species are not so well represented in collections.

The copperheads *(Austrelaps superbus)* of the South East are the largest in the State, occasionally exceeding 1 m in length. It is a very robust snake which enhances its apparent size. Individuals generally occur near swamps and feed predominantly on frogs. Copperhead venom is extremely toxic (Fairley 1929; White 1981). Copperheads vary from light brown to almost black with differing amounts of copper and/or maroon laterally, extending posteriorly from the mouth. Some individuals are very dark, with maroon extending two-thirds of the length of the body. On occasions this colouration has led to the erroneous reporting of red-bellied black snakes in the South East.

Tiger snakes *(Notechis scutatus)* are common. Although they too feed predominantly on frogs, they seem less closely associated with the water than are copperheads, and are found in rubbish dumps, pine forests and buildings. This species is extremely dangerous. Not only is its venom very toxic (Sutherland & Coulter 1977), but it is the most aggressive snake in the area and is often encountered. It deserves the utmost respect and should be given a wide berth. Although actual attacks are uncommon, a tiger snake often will stand up to a person with its head raised like a cobra, and will not retreat in the manner of most other snakes.

Brown snakes *(Pseudonaja textilis)* occur in many habitats. They are opportunistic feeders, eating frogs, mice and lizards. Because of their liking of mice they are frequently found in rubbish dumps and farm buildings where mice abound. This species is large, on occasions exceeding 2 m. This snake should also be treated with care (see Coulter *et al.* 1979).

The white-lipped snake *(Drysdalia coronoides)* is the only other common snake. It is a small (up to 40 cm), cryptic snake that is seldom seen on the surface by day. It is venomous but not harmful to humans.

The five other small snake species that have been collected in the South East are not known by more than a few individuals.

LIZARDS

Three lizard families, the Pygopodidae or legless lizards, the Agamidae or dragons, and the Varanidae or goannas have been included in recent taxonomic revisions which relate to South Australia and are therefore reasonably well known (Kluge, 1974; Houston, 1978). The Scincidae (skinks) are also well known but diverse and no modern comprehensive taxonomic work has been published, whilst the Gekkonidae (geckos) is still in a state of taxonomic turmoil which may only be resolved by use of modern genetic and biochemical techniques.

The legless lizards are represented by three species. The best known is the striped, worm lizard, *Aprasia striolata,* which is a secretive burrowing species. The representation of this species in the Museum collection is better from the South East than for most of the rest of its range. This is not true for the other species: the common scaly-foot, *Pygopus lepidopodus,* which is diurnal and hunts on the surface, and *Delma impar,* known in S.A. only from two localities. One specimen came from near Naracoorte and 16 from Bool Lagoon. Clearly specimens from other localities would be very useful in determining the range of this species in S.A.

Only one specimen of goanna, *Varanus gouldii rosenbergi,* is represented in the Museum from the South East. More specimens are needed to establish the distributions of *V.* g. *gouldii* and *V.* g. *rosenbergi.*

Like the goannas, the geckos are represented by one species: *Phyllodactylus marmoratus.* However, this situation may be more apparent than real, and attributable to lack of collecting. The thick-tailed gecko, *Underwoodisaurus milii,* which occurs extensively on Kangaroo Island and the Mt Lofty Ranges, ultimately should be shown to occur in the South East also.

The familiar bearded dragon, *Amphibolurus barbatus,* and the tree dragon, *A. muricatus* are both known from the South East. Information on the habitat preferences of the latter would be valuable, because it occurs sympatrically with the very similar species, *A. nobbi coggeri,* in some areas of the State. The morphological differences between these species are small and it is unknown whether they are separate in the field or in direct competition with each other. One specimen of *Tympanocryptis lineata* has been collected in the South East. This was about 300 km from the nearest other specimen and, as such, may represent an isolated population. It would be interesting to establish the distribution of this species in the South East. The painted dragon, *A. pictus,* is widespread in the State and usually occupies sandy habitats. No specimens have been collected in the South

East but there is one specimen from near Bordertown. It occurs in coastal habitats in the South East.

The Scincidae is the best represented family of lizards and illustrates the origins of the reptile fauna there. Sixteen species have been collected, and there is a preponderance of Bassian species. Nine species, *Leiolopisma guichenoti, L. trilineata, L. entrecasteauxii, L. delicata, Sphenomorphus tympanum, Tiliqua nigrolutea, Egernia whitii, Hemiergis decresiensis* and *H. peronii,* are of Bassian origin, whereas only three species, *Ctenotus brooksi, Morethia obscura* and *Lerista distinquenda,* are of Eyrean origin. The remaining four species, *Lerista bougainvillii, Trachydosaurus rugosus, Tiliqua scincoides* and *Ctenotus robustus,* occur commonly in both regions and cannot be assigned to either one of them (Rawlinson 1971). Skinks have occupied all habitats favourable to lizards in the South East. Some species are confined to highly specific habitats, others are slightly less so, and a few more are ubiquitous.

Most of the skinks are sma!l and some are secretive. For example the four-toed skink, *Hemiergis peronii,* lives under logs and rocks and is rarely encountered in the open. In contrast other small species such as the grass skink, *Leiolopisma guichenoti,* and the threelined skink, *L. trilineata,* bask in the sun and actively hunt insects on the forest floor and so are seen often. Many of the medium sized skinks, such as the water skink, *Sphenomorphus tympanum,* and White's skink, *Egernia whitii,* are often seen during the day. These lizards are extremely fast and take shelter rapidly at any sign of danger. The larger skinks such as the common blue tongue, *Tiliqua scincoides,* and the stumpy tailed lizard, *Trachydosaurus rugosus,* are relatively slow moving, and most obvious because they often occur on roads and in open areas. Rather than retreat when threatened they hiss loudly and expose their blue tongues in an effort to deter the attacker. Another large species, the blotched blue tongue, *Tiliqua nigrolutea,* occu rs in the area but is far less obvious, because it is usually associated with dense vegetation near swamps where it is difficult to detect.

AMPHIBIANS

FROGS

The overall knowledge of the frog fauna of the South East probably is better than anywhere else within South Australia and equal to any comparable area in Australia; a situation attributable from the mid-1960's to the field surveys initiated by F. W. Aslin, R. G. Beck, P. Roach and D. Von Behrens. With the exception of the work on *Geocrinia laevis,* outlined below, distributional data were obtained and assembled by Aslin and recently these were incorporated in the S.A. distribution maps of Brook (1981). An introductory key to identification was produced by Tyler (1966, 1977), and colour illustrations of all species and more detailed data are included in the State handbook of Tyler (1978).

The frogs represent two families: the Hylidae which is a group of species commonly known as tree frogs, but which beyond the South East includes a few burrowing species, and the Leptodactylidae which range from terrestrial to swamp dwelling and burrowing habits.

Within the South East are four species and one subspecies not found elsewhere in South Australia, and two of the additional species there exhibit local colour patterns.

The scarcest of the South East species is the small, squat *Geocrinia laevis* which is confined to a few tiny relict populations (Beck 1975) but is more abundant in western Victoria. The marsh dweller *Limnodynastes peroni* and the toad let *Pseudophryne semimarmorata* are each widespread and reasonably abundant, but the burrowing frog *Neobatrachus sudelli* is known from only a few scattered localities. The specific identity of *N. sudelli* was resolved only recently, although the existence of an unnamed species in the South East has been known for 15 years Its identity was resolved by M. Mahoney and J. D. Roberts (pers comm.) and added to the State faunal distribution maps by Brook (1981). The specimens of *N. sudelli* in the South East are particularly small-adult at a body length of as little as 35 mm, compared with 55-60 mm for sympatric *N. pictus.*

The bullfrog *Limnodynastes dumerili* is represented by the subspecies *L. d. variegatus* which is distinguished from the race on the River Murray and further north and west by the extensive black reticulations on the undersurface and areas of pale blue in the groin.

Although not considered to merit formal taxonomic status the populations of two other species in the South East differ from those elsewhere in the State. Thus the South East *L.*

tasmaniensis commonly exhibit brilliant, narrow red lines bounding the cream midvertebral stripes exhibited by many specimens. Similarly many of the southeastern *Litoria ewingi* exhibit extensive patches of green on their backs or are entirely green, whereas elsewhere in the State none is green.

DISTRIBUTION

As indicated in the Introduction to this book, the South East is a highly significant zone in terms of being the western limit of distribution of species whose centre of distribution is further east in Victoria or New South Wales. Understandably, this faunal unit (the Bassian) tends to be dominated by species adapted to life in a cool temperate zone.

Our data indicate that species diversity in frogs is associated with latitude over a north-south transect (Fig. 1). As indicated there is a progressive reduction of frog species from 37°45' to 36°30', and in fact the trend is even more emphasised if the transect is continued into the markedly arid conditions further north. The Bassian reptile species differ from this trend in peaking in diversity at 36°45' where conditions evidently are optimal.

We believe that the changes in available habitats have harmed some species and benefited others. Those species relying upon

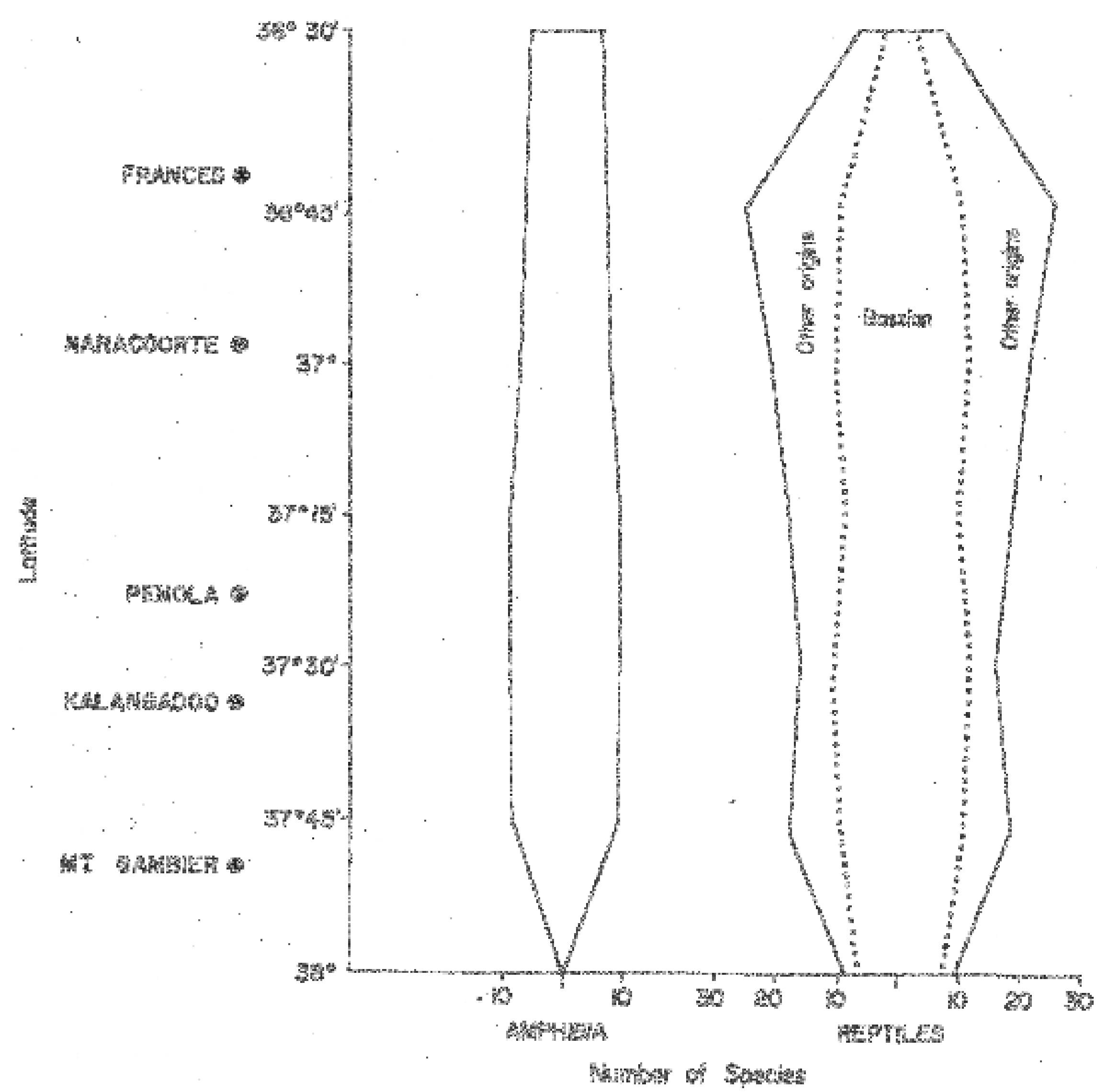

Fig. 1. Diversity of amphibians and reptiles throughout the South East.

water, such as the long-necked tortoise and the copperhead snake, will have experienced a reduction in suitable habitat and therefore distribution. Similarly, land clearance no doubt reduced the distribution and abundance of *Geocrinia laevis* (Beck 1975).In contrast, the brown snake and the stumpy tailed lizard *(Trachydosaurus rugosus)* will have benefited by these same activities. However, within South Australia, the species that can benefit from such activities of man are already ubiquitous, whereas those species variously threatened by habitat disturbance are not found elsewhere within the State.

REFERENCES

Beck, R. G. (1975). Factors affecting the distribution of the leptodactylid frog *Geocrinia laevis* in the South-East of South Australia. *Trans. R. Soc.* S. *Aust.* **99**,143-7.

Brook, A. J. (1981). 'Atlas of frogs of South Australia.' Pub!. (4). Dept Zoology, Univ. Melbourne.

Cogger, H. G. (1975). 'Reptiles and Amphibians of Australia.' (Reed, Sydney).

Coulter, A. R., Broad, A. J. & Sutherland, S. K. (1979). Isolation and properties of a high molecular weight neurotoxin from the eastern brown snake *(Pseudonaja textilis). In:* Chubb, I. W. & Geffen, L. B. (Eds) Neurotoxins fundamental and clinical advances'. (Adelaide Univ. Union Press, Adelaide).

Fairley, N. H. (1929). The present position of snake bite and the snake bitten in Australia. *Med. J. Aust.* **1**, 296-313.

Houston, T. F. (1978). Dragon Lizards and Goannas of South Australia, *Spec. Educ. Bull. Ser.* S. *Aust Mus., Adelaide.*

Houston, T. F. (1979). Sea turtles in South Australia. S. *Aust. Nat.* **53**, 42-6.

Houston, T. F. & Tyler, M. J. (1979). Reptiles and Amphibians. *In:* Tyler, M. J., Twidale, C. R. & Ling, J. K. (Eds) 'Natural History of Kangaroo Island.' (Royal Soc. S. Aust., Adelaide).

Kluge, A. G. (1974). A taxonomic revision of the lizard family Pygopodidae. *Misc. Publ. Mus. Zool., Univ. Michigan (147).*

Rawlinson, P. A. (1971). Amphibiansand Reptilesof Victoria. Reptiles. *In:* 'Victorian Year Book' (85).

Sutherland, S. K. & Coulter, A. R. (1977). Three instructive cases of tiger snake *(Notechis scutatus)* envenomation-and how a radioimmunoassay proved the diagnosis. *Med. J. Aust.* **2**, 117-80.

Tyler, M. J. (1966). 'Frogs of South Australia.' (South Australian Museum, Adelaide).

Tyler, M. J. (1977). 'Frogs of South Australia', 2nd Edtn. (South Australian Museum, Adelaide).

Tyler, M. J. (1978). 'Amphibians of South Australia' (Govt Printer, Adelaide), 84 pp.

Waite, E. R. (1929). 'The Reptiles and Amphibians of South Australia' (Govt Printer, Adelaide).

White, J (1981). Ophidian envenomation: a South Australian perspective. *Rec. Adelaide Children's Hosp.* **2**, 311-421.

Worrell, E. (1970). 'Reptiles of Australia', 2nd Edtn. (Angus & Robertson, Sydney).

15: Freshwater and Marine Fishes

by C. J. M. GLOVER

INTRODUCTION

The South East inland fish fauna is significant because it occupies the most westerly part of Australia's South East Coast Drainage Division, and for three freshwater species (the Dwarf Galaxias, *Galaxiella pusilia,* the Australian Grayling, *Prototroctes maraena,* and the Yarra Pigmy Perch, *Nannoperca obscura)* it also represents the most westerly range extension on the Australian mainland. The coastal and adjacent offshore fauna is significant because of its commercial importance.

FRESHWATER FISHES AND OTHERS OF INLAND WATERS

The inland waters in the South East range in salinity from fresh through brackish to very saline: thus they can be selectively occupied by exclusively freshwater or exclusively marine fishes, as well as species which tolerate intermediate ranges of salinity. Table 1 indicates which species fall into these categories.

Twenty-four marine and freshwater species have been recorded from ·the inland waters of the South East.

Several marine fishes-including shark and ray (Elasmobranchii), flounder (Pleuronectiformes), Sea Bream *Seriolella brama,* Trevelly *Caranx georgianus,* King George Whiting *Sillaginodes punctatus* and Australian Salmon/Salmon Trout *Arripis trutta-have* been reported to occur in coastal inland waters. It is quite probable that some of these, and other marine fishes, regularly and commonly enter larger waterways connecting with the sea, especially the Glenelg River.

Most of the species listed in Table 1 are restricted to the temperate waters of southern Australia. None are endemic to south east South Australia; most range widely across the southern part of Australia (including Tasmania), and a few extend north into tropical or sub-tropical waters (Sea Mullet *Mugil cephalus,* Marine Hardyhead *Pranesus ogilbyi,* Mulloway *Argyrosomus hololepidotus,* Goldfish *Carassius auratus,* Mosquito Fish *Gambusia affinis).*

Twelve of the 24 species listed in Table 1 are exclusively freshwater forms, their entire life cycles being restricted to fresh (low salinity) water. Six are not indigenous and at least two have been deliberately introduced into the South East from elsewhere in Australia. Five other species are known to regularly move between the sea and fresh or brackish estuarine waters to breed: another species may live part of it's life in the sea. A further four species are essentially marine forms which nevertheless regularly enter brackish estuarine and fresh inland waters, as well as inland saline waters. The two remaining marine species are exclusively saltwater forms whose occurrences inland evidently are restricted to saline waters connecting with the sea.

Not unexpectedly, the exclusively freshwater species are usually found further inland, away from saline waters, while exclusively marine species are found in saline waters close to the sea, i.e. in saline estuaries or saline coastal lakes opening to the sea. Species able to tolerate a wide range of salinity, or must necessarily move between fresh and saltwater to breed, are often found over a greater geographical range between the coast and inland.

The Common Galaxias *Galaxias maculatus,* frequently found in surface waters, is occasionally found in cave waters.

The general biology of most of the listed species has been studied to some extent and is outlined in one or other of the cited general texts. The interested reader is also referred to the following more specialised publications and theses: Ainslie (1970), Backhouse & Vanner (1978), Bayly & Williams (1966), Harbison (1974), Jackson (1978), Lee (1969), Lee & Williams (1970), Llewellyn (1971, 1974), McDowall (1978), Pollard (1971a, 1971b, 1972a, 1972b, 1973, 1974), Potter (1970),

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Table 1. A PROVISIONAL CHECKLIST OF THE INLAND FISHES OF THE LOWER SOUTH EAST OF SOUTH AUSTRALIA

Family and Species	*Common Name*	*Comments on Status in South East (indigenous unless otherwise stated)*
Mordaciidae [3]*Mordacia mordax* (Richardson, 1846)	Short-headed Lamprey	Lives in both the sea and freshwater: adults ascend into freshwater streams to breed. Does not appear common.
Geotriidae [3]*Geotria australis* Gray, 1851	Wide-Mouthed Lamprey	Lives in both the sea and freshwater: adults ascend into freshwater streams to breed. Does not appear common.
Anguillidae [3]*Anguilla australis* Richardson, 1841	Short-finned Eel	Lives in both freshwater and the sea: adults migrate to sea to breed. Inhabits some of the larger coastal waterways
Galaxiidae [3]*Galaxias maculatus* (Jenyns, 1842)	Common Galaxias (Common Minnow)	Lives in both freshwater and the sea. Normally, adults in streams descend to tidal reaches to spawn; larvae drift out to sea and juveniles later return to freshwater. Some land locked breeding populations also known. Very common, especially near coast. Found in creeks, drains, ponds. Occasionally found in cave waters.
[1]*Galaxias olidus* Gunther, 1866	Mountain Galaxias (Mountain Minnow)	Lives only in freshwater. Uncommon. Restricted occurrences inland, away from the coast.
[1]*Galaxietla pusilla* (Mack, 1936)	Dwarf Galaxias (Dwarf Minnow)	Lives only in freshwater. Common, but more inland; in streams, drains and swamps.
Prototroctidae [4]*Prototroctes maraena* Gunther, 1864	Australian Grayling	Certainly a freshwater species for at least part of its life: probably also spends part of its life in the sea. One of Australia's rarest and most extinction-threatened fishes. In the lower S.E. it has only been recorded in Ewens Ponds.
Mugilidae [3]*Mugil cephalus* Linnaeus, 1758	Sea Mullet	Lives in both freshwater and the sea: adults migrate to sea to breed. Reported in some of the larger coastal streams and drains, also in Lake George.
[5]*Aldrichetta forsteri* (Cuvier & Valenciennes, 1836)	Yellow-eyed Mullet	A marine species: commonly enters brackish estuarine and fresh waters near the coast (especially juveniles) Very common in coastal streams near the sea.
Atherinidae [2]*Atherinosoma microstoma* (Gunther, 1861)	Small-Mouthed Hardyhead	A marine species: restricted inland to coastal saline waters connecting with the sea. Uncommon.
[1]*Craterocephalus stereusmuscarum* (Gunther, 1867)	Mitchellian Hardyhead	A freshwater species: a few occurrences but uncommon.
[2]*Pranesus ogilbyi* Whitley, 1930	Marine Hardyhead	A marine species: restricted inland to coastal saline waters connecting with the sea. Uncommon.
Percidae [1]*Perca fluviatilis* Linnaeus, 1758	Redfin (European) Perch	A freshwater species: common away from the coast in numerous creeks, swamps. lakes and lagoons Introduced.
Sciaenidae [5]*Argyrosomus hololepidotus* (Lacepede. 1802)	Mulloway (Butterfish)	A marine species: enters estuaries. Reported in some of the larger coastal waterways; also in Lake George.
Sparidae [5]*Aeanthopagrus butcheri* (Munro, 1949)	Black Bream	A marine species: also inhabits estuaries and other coastal waterways, where it breeds. Reported in some of the larger coastal waterways.
Kuhliidae [5]*Nannoperca australis australis* Gunther, 1861	Southern Pigmy Perch	A freshwater species: common in both coastal streams and other inland waters-creeks, drains, lakes, lagoons, ponds.
[5]*Nannoperca obscura* (Klunzinger, 1872)	Yarra Pigmy Perch	A freshwater species: recorded in only a few waters. Uncommon.
Bovichthyidae [1]*Pseudaphritis urvitlii* (Cuvier & Valenciennes, 1830)	Congolli	A marine species: enters estuaries and freshwater Commonly found in the lower reaches of coastal streams and drains

Gadopsidae [1]*Gadopsis marmoratus* Richardson, 1848	Blackfish (Slippery)	A freshwater species. Widely distributed; especially common in coastal waters
Salmonidae [1]*Salmo trutta* Linnaeus, 1758	Brown Trout	A freshwater species. Stock are liberated from time to time in various streams and lakes. Introduced.
[1]*Salmo gairdnerii* Richardson, 1836	Rainbow Trout	A freshwater species. Stock are liberated from time to time in various streams and lakes. Introduced.
Cyprinidae [1]*Carassius auratus* (linnaeus, 1758)	Goldfish (Golden Carp)	A freshwater species known only in Lake Bonney. Introduced.
[1](?) *Tinea tinea* (Linnaeus, 1758)	Tench	A freshwater species: a few reports of specimens. Evidently rare. Introduced
Poeciliidae [1]*Gambusia alfinis* (Baird & Girard. 1853)	Mosquito Fish	A freshwater species: recorded in only a few inland waters. Introduced

1 = exclusively freshwater species.
2 = exclusively marine species whose occurences inland are restricted to saline waters connecting with the sea.
3 = species which migrate between the sea and freshwater in order to breed.
4 = species *suspected* to migrate between the sea and freshwater in order to breed.
5 = marine species which commonly and regularly enter estuarine or freshwater but not necessarily to breed.

Potter & Strahan (1968), Thomson (1957a, 1957b), Weng (1971).

Many of the species listed in Table 1 are illustrated in Figs 1 & 2. To further confirm identifications or to identify any unfigured, unlisted or unrecognised fish, or for additional information pertaining to any species, the reader is referred to the general texts by Scott, Glover & Southcott (1974), Lake (1967, 1971, 1978), McDowall (1980), and Thomson (1977).

COMMERCIAL FISHES OF INLAND WATERS

The inland fishery of the South East is a very small industry conducted by a few part-time fishermen. Operations centre mainly upon Lake George in which the following marine species are reportedly taken: Sea Mullet, Yellow-Eye Mullet, Mulloway, Australian Salmon/Salmon Trout, King George Whiting, Sea Bream and Flounder. No exclusively freshwater species is taken commercially, although a trout farm (Rainbow Trout *Salmo gairdnerii)* is being established adjacent to Ewens Ponds.

SPORT FISHES OF INLAND WATERS

Fishermen generally seek the freshwater Rainbow Trout, Brown Trout *Salmo trutta* and Redfin Perch *Perca fluviatilis* in inland waters; and the marine species Mulloway, King George Whiting, Sea Mullet, Yellow-Eye Mullet and Black (Silver) Bream *Acanthopagrus butcheri* in waters nearer the coast. Some other marine species which enter inland waters are also taken.

Organizations and individuals have periodically liberated Rainbow and Brown Trout, obtained from hatcheries outside the region, in various inland streams, lakes and other waters over the years. The Mt Gambier City Council stocks the Valley Lake, a popular fishing venue, with these species. Local angling clubs reportedly stock other waters with Redfin Perch from time to time.

ECOLOGICAL CONSIDERATIONS OF INLAND WATERS

The land surface of the South East is, for the most part, a plain traversed by some small natural waterways and numerous artificial drains, some of which enter the sea, together with scattered lakes, swamps, "lagoons" and spring-fed "ponds". Much of the region's freshwater is ephemeral. With periodic summer droughts, many waters, particularly shallow swamps and smaller lakes, dry up completely.

Prior to the construction of the region's extensive network of drains the swamps were much more extensive: just what effect their reduction has had on the indigenous inland fish is uncertain. Certainly there is less swamp habitat for indigenous species which live in swamps (Dwarf Galaxias, Southern Pigmy Perch *Nannoperca australis,* Yarra Pigmy Perch), but they also inhabit other types of water bodies and undoubtedly some of the larger drains do provide more permanent and stable habitats than existed formerly. Also, the drains presumably facilitate dispersion of these fishes throughout the region, thereby enhancing their survival prospects: conversely, the drains undoubtedly have facilitated the dispersal of introduced

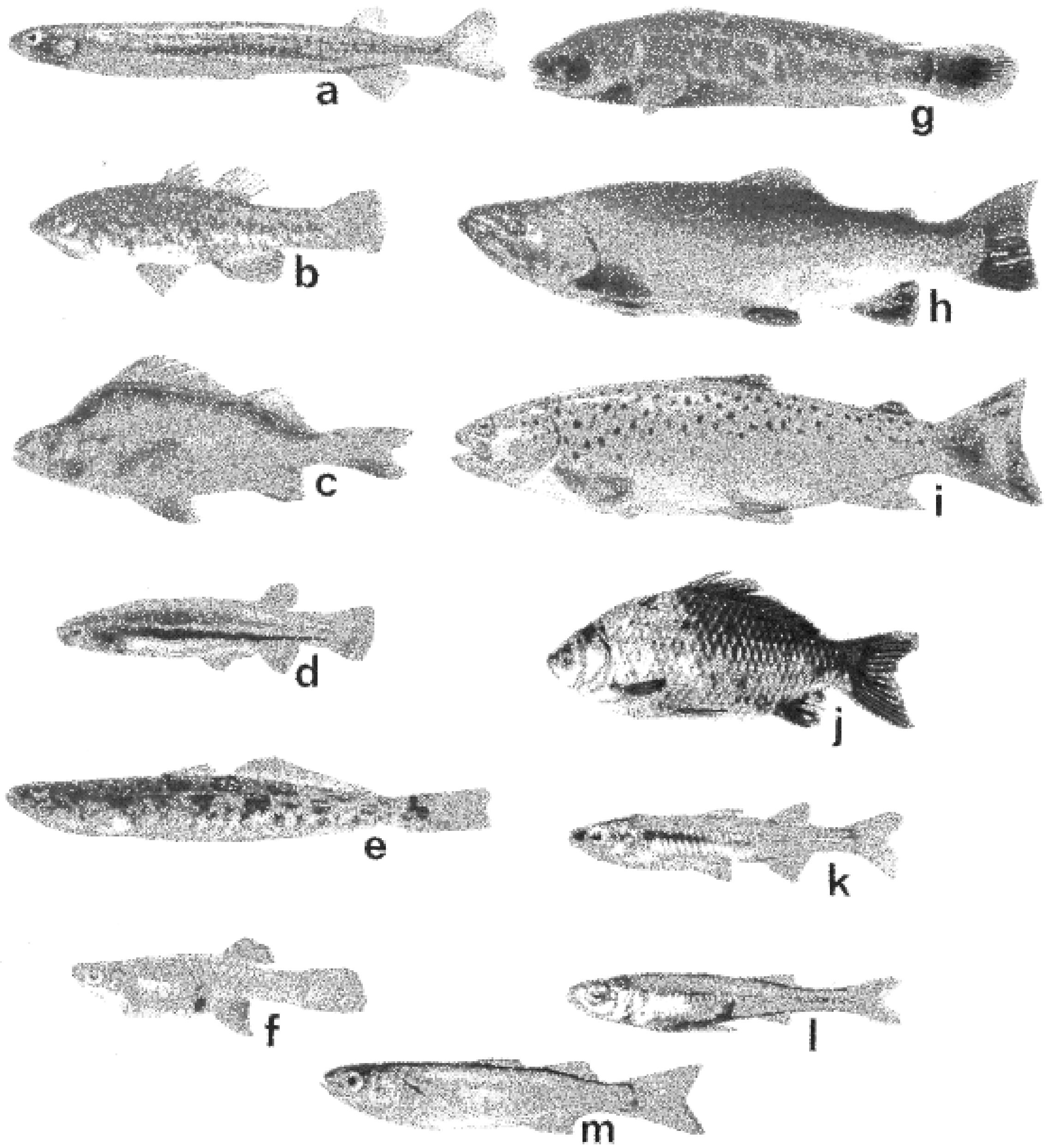

Fig. 1. Inland Fishes of the South East (with maximum lengths): (a) Common Galaxias *Galaxias maculatus*—19 cm; (b) Southern Pigmy Perch *Nannoperca australis*—8.2 cm; (c) Redfin Perch *Perca fluviatilis*—50 cm; (d) Dwarf Galaxias *Galaxiella pusilla*—3.9 cm; (e) Congolli *Pseudaphritis urvillii* 36 cm; (f) Mosquito Fish *Gambusia affinis*—6 cm; (g) Blackfish *Gadopsis marmoratus*—61 cm; (h) Rainbow Trout *Salmo gairdnerii*—77.5 cm; (i) Brown Trout *Salmo trutta*—90 cm; (j) Goldfish *Carassius auratus*—40 cm; (k) Mitchellian Hardyhead *Craterocephalus stercusmuscarum*—10 cm; (l) Small-Mouthed Hardyhead *Atherinasoma microstoma*—7 cm; (m) Yellow-Eye Mullet *Aldrichetta forsteri*—40 cm (juvenile figured).

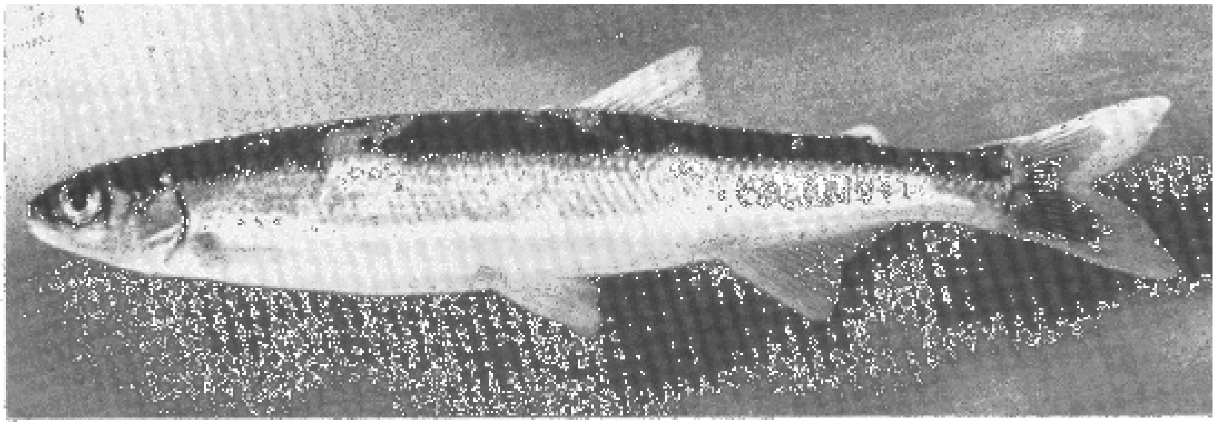

Fig. 2. Australian Grayling *Prototroctes maraena*—maximum length 30 cm.

non-native fishes. Furthermore, those artificial drains which enter the sea have provided supplementary habitats and access routes for fishes which must move between marine and freshwater in order to breed, and marine fishes which commonly enter estuari ne and fresh waters.

Almost certainly the introduced non-native fishes have had some deleterious effect on the indigenous species through predation and/or competition for space and food. A. F. Flint (pers. comm.) reported that since the introduction of Redfin Perch and Brown Trout the indigenous Common Galaxias and Blackfish *Gadopsis marmoratus* in Mosquito Creek have been restricted to the lower reaches near Bool Lagoon. Such displacement of indigenous fishes by introduced species has almost certainly occurred elsewhere in the South East. Rainbow and Brown Trout are recognised as predatory and competitive upon galaxiids, with which they share similar niches, according to Tilzey (1976). The establishment of a trout farm, mentioned earlier, alongside galaxiid-inhabited Ewens Ponds, must therefore be viewed with concern-especially since these ponds are inhabited by what is regarded as one of Australia's most extinction-threatened fishes (the Australian Grayling Fig. 2) as well as galaxiids. The Redfin Perch is notoriously carnivorous upon smaller fishes and has the capacity to rapidly establish abundant populations which compete vigorously with other species for food and space.

It is thus reasonable to assume that the introduction of fishes not native to the region has resulted in at least some reduction in the distribution and abundance of the indigenous fishes, the displacement of which can only be accelerated by the continued introduction of Trout and Redfin Perch.

R. Beck (pers. comm.) suggests that the widespread use some years ago of a pesticide eradicated aquatic faunas, including fish, in some swamps. The use of agricultural chemicals at such concentrations is to be deplored in view of their known toxic effects on fish and other aquatic faunas, so upsetting the whole ecological balance.

A striking example of industrial pollution is Lake Bonney which has been continuously and heavily polluted with chemical effluent from a paper processing mill at Millicentsince the late 1950's. Although several species of fish have been recorded in this water body over the past decade-Common Galaxias, Mitchellian Hardyhead *Craterocephalus stercusmuscarum,* Southern Pigmy Perch, Goldfish and Yellow-Eye Mullet-this fauna has probably been affected in some way by the clearly visible pollution of the lake's waters.

Without doubt the indigenous fish fauna of the South East of South Australia is under threat on several fronts. Measures must be taken soon if the processes described above are not to proceed to the ultimate widespread elimination of this interesting native fauna.

MARINE FISHES OF COASTAL AND OFFSHORE WATERS

Unlike the inland fishes the exclusively marine species of coastal and offshore waters are relatively poorly documented, but the marine fishes can be expected to comprise many forms typical of south-eastern Australian waters. Furthermore, this fauna probably comprises many of those marine species recorded in South Australia by Scott,

Table 2. A PARTIAL AND PROVISIONAL CHECKLIST OF THE COASTAL AND OFFSHORE MARINE FISHES (SHORE-CONTINENTAL SLOPE INCLUSIVE) OF SOUTH EAST SOUTH AUSTRALIA .
* = addition to South Australia's recorded fish fauna

CLASS: PETROMYZONES
FAMILY MORDACIIDAE (Short-Headed Lampreys)
Mordacia mordax (Richardson, 1846)
FAMILY GEOTRIIDAE (Pouched Lamprey)
Geotria australis Gray, 1851

CLASS: MYXINI
FAMILY EPTATRETIDAE (Hagfishes)
Eptatretus longipinnis Strahan, 1975

CLASS: ELASMOBRANCHII
FAMILY HETERODONTIDAE (Port Jackson Sharks)
Heterodontus portusjacksoni (Meyer, 1793)
FAMILY HEXANCHIDAE (One-Finned Shark, Six and Seven Gilled Sharks)
Hexanchus griseus (Bonnaterre, 1788)
**Notorhynchus cepedianus* (Peron, 1807)
FAMILY ORECTOLOBIDAE (Wobbegong or Carpet Sharks, & Catsharks)
Parascyllium variolatum (Dumeril, 1853)
FAMILY ALOPIIDAE (Thresher Sharks)
Alopias vulpinus (Bonnaterre, 1788)
FAMILY LAMNIDAE (White Pointer & Blue Pointer Sharks)
Isurus oxyrinchus Rafinesque, 1810
Carcharodon carcharias (Linnaeus, 1758)
FAMILY SCYLIORHINIDAE (Swell Sharks & Catsharks)
Cephaloscyllium isabella (Bonnaterre, 1788)
FAMILY TRIAKIDAE (Gummy Shark, Whiskery Shark)
Mustelus antarcticus Gunther, 1870
Galeus boardmani (Whitley, 1928)
FAMILY CARCHARHINIDAE (School Shark, Whaler Sharks)
Galeorhinus australis (Macleay, 1881)
FAMILY SQUALIDAE (Dogshark, Dogfishes, Black Shark)
Dalatias licha (Bonnaterre, 1788)
Squalus acanthias Linnaeus 1758
Squalus megalops (Macleay, 1881)
Centrophorus scalpratus McCulloch, 1915
Deania quadrispinosa (McCulloch, 1915)
**Deania calcea* (Lowe, 1839)
FAMILY SQUATINIDAE (Angel Sharks)
Squatina australis Regan, 1906
FAMILY PRISTIOPHORIDAE (Saw Sharks)
Pristiophorus cirratus (Latham, 1794)
FAMILY RAJIDAE (Skates)
**Raja whitleyi* Iredale, 1938
**Raja* sp.
FAMILY UROLOPHIDAE (Stingarees)
Urolophus viridis McCulloch, 1916
FAMILY TORPEDINIDAE (Electric Rays)
Hypnos monopterygium (Shaw & Nodder, 1795)
FAMILY RHINOBATIDAE (Shovel nose Rays, Guitar Fishes, Fiddlers)
Trygonorhina fasciata Muller & Henle, 1841

CLASS: HOLOCEPHALI
FAMILY CALLORHYNCHIDAE (Elephant Shark/Fish)
Callorhynchus milii Bory de St Vincent, 1823

CLASS: TELEOSTOMI
FAMILY IDIACANTHIDAE (Blackdragons)
**Idiacanthus niger* Regan, 1914
FAMILY GALAXIIDAE (Galaxiids)
Galaxias maculatus (Jenyns, 1842)
FAMILY CHLOROPHTHALMIDAE (Cucumber Fish)
Chlorophthalmus nigripinnis Gunther, 1878
FAMILY MYCTOPHIDAE (Lanternfishes)
*Myctophidae sp.
FAMILY ANGUILLIDAE (Eels)
Anguilla australis Richardson, 1841
FAMILY CONGRIDAE (Conger & Ladder Eels)
Conger wilsoni (Bloch & Schneider, 1801)
FAMILY HEMIRAMPHIDAE (Garfishes)
Hyporhamphus melanochir (Valenciennes, 1846)
FAMILY MORIDAE (Codfishes)
Physiculus barbatus (Gunther, 1863)
Lotella callarias Gunther, 1863
Mora dannevigi Whitley, 1948
Tripterophycis intermedius Whitley, 1948
FAMILY MACROURIDAE (Whiptails)
Lepidorhynchus denticulatus Richardson, 1846

'Macruronus novaezelandiae (Hector, 1871)
Coelorhynchus fasciatus (Gunther, 1878)
'Coelorhynchus innotabilis McCulloch, 1907
'Lionurus nigromaculatus (McCulloch, 1907)
FAMILY MACRORHAMPHOSIDAE (Bellows Fishes)
Centriscops humerosus (Richardson, 1846)
FAMILY SYNGNATHIDAE (Pipefishes, Pipehorse, Seahorses, Seadragons)
Vanacampus poecilolaemus (Peters, 1869)
Pugnaso curtirostris (Castelnau, 1872)
Nannocampus ruber Ramsay & Ogilby, 1886
Histiogamphelus cristatus (Macley, 1882)
FAMILY LAMPRIDAE (Moonfish)
Lampris regius (Bonnaterre, 1788)
FAMILY TRACHIPTERIDAE (Ribbon Fishes)
Trachipterus arawatae Clark, 1881
FAMILY TRACHICHTHYIDAE (Roughies, Sawbellies)
Paratrachichthys sp.
FAMILY BERYCIDAE (Swallowtail, Nanygai)
**Beryx splendens* Lowe, 1833
Trachichthodes gerrardi (Gunther, 1887)
FAMILY ZEIDAE (Dories)
Cyttus australis (Richardson, 1843)
**Cyttus novaezelandiae* (Arthur, 1885)
**Cyttus traversi* Hutton, 1872
FAMILY MUGILIDAE (Mullets)
Mugil cephalus Linnaeus, 1758
Aldrichetta forsteri (Cuvier & Valenciennes, 1836)
Myxus elongatus Gunther, 1861
FAMILY ATHERINIDAE (Hardyheads, Silversides)
Atherinasoma microstoma (Gunther, 1861)
Pranesus ogilbyi Whitley, 1930
FAMILY SERRANIDAE (Sea Perches)
Promicrops lanceolatus (Bloch, 1790)
Polyprion oxygeneios (Bloch & Schneider, 1801)
Caesioperca rasor (Richardson, 1839)
Othos dentex (Cuvier & Valenciennes, 1828)
FAMILY APOGONIDAE (Cardinal Fishes, Gobbleguts)
Siphaemia cephalotes (Castelnau, 1875)
Vincentia conspersa (Klunzinger, 1872)
Apogonops anomalus Ogilby, 1896
FAMILY SILLAGINIDAE (Whitings)
Sillaginodes punctatus (Cuvier & Valenciennes, 1829)
Sillago schomburgkii Peters, 1865
FAMILY CARANGIDAE (Trevally, Yellow tail, Samson Fish, Scad, Horse Mackerel, Pilot Fish)
**Decapterus russellii* (Ruppell, 1831)
Caranx georgianus Cuvier & Valenciennes, 1833
Seriola hippos Gunther, 1876
FAMILY BRAMIDAE (Ray's Bream)
Brama brama (Bonnaterre, 1788)
FAMILY ARRIPIDAE (Australian Salmon, Tommy Ruff)
Arripis trutta Whitley, 1951
Arripis georgianus (Cuvier & Valenciennes, 1831)
FAMILY SCIAENIDAE (Mulloway)
Argyrosomus hololepidotus (Lacepede, 1802)
FAMILY SPARIDAE (Snapper, Black/Silver Bream)
Chrysophrys unicolor Quoy & Gaimard, 1824
Acanthopagrus butchei (Munro, 1949)
FAMILY MULLIDAE (Red Mullet)
Upeneichthys vlamingii (Cuvier & Valenciennes, 1829)
FAMILY PEMPHERIDAE (Bullseyes)
Pempheris multiradiata (Klunzinger, 1879)
FAMILY SCORPIDIDAE (Sweeps, Moonlighter)
Scorpis aequipinnis Richardson, 1848
FAMILY KYPHOSIDAE (Zebra Fish, Drummer)
Girella zebra (Richardson, 1846)
FAMILY ENOPLOSIDAE (Old Wife)
Enoplosus armatus (White, 1790)
FAMILY OPLEGNATHIDAE (Knife Jaw)
Oplegnathus woodwardi (Waite, 1900)
FAMILY POMACENTRIDAE (Scaly Fins)
Parma victoriae (GUnther, 1863)
FAMILY LABRIDAE (Wrasses, Parrot Fishes, Blue Groper)
Pictilabrus laticlavius (Richardson, 1839)
Pseudolabrus tetricus (Richardson, 1840)
Pseudolabrus fucicola (Richardson, 1840)
Achoerodus gouldii (Richardson, 1843)
Pseudolabrus parilus (Richardson, 1850)
FAMILY ODACIDAE (Weedy Whitings, Rock Whitings, Herring Cale)
Neoodax radiatus (Quoy & Gaimard, 1835)
Neoodax balteatus (Valenciennes, 1839)
Neoodax semifasciatus (Valenciennes, 1839)
Neoodax beddomei (Johnston, 1885)
FAMILY URANOSCOPIDAE (Stargazers)
Pleuroscopus sp.
FAMILY CHIRONEMIDAE (Kelpfishes, Silver Spot)
Threpterius maculosus Richardson, 1850
FAMILY APLODACTYLIDAE (Sea Carp)
Oactylosargus arctidens (Richardson, 1839)
FAMILY CHEILODACTYLIDAE (Morwongs, Strongfish, Magpie Perch)

Nemadactylus macropterus (Schneider, (1801)
Oactylophora nigricans (Richardson, 1850)
Cheilodactylus nigripes Richardson, 1850
**Cheilodactylus spectabilis* Hutton, 1872
FAMILY LATRIDAE (Trumpeters, Trevalla)
Latris lineata (Bloch & Schneider, 1801)
FAMILY BOVICHTHYIDAE (Congolli)
Pseudaphritis urvillii (Cuvier & Valenciennes, 1831)
FAMILY GOBIIDAE (Gobies)
Callagobius mucosus (Gunther, 1872)
**Istigobius* sp. (Gunther, 1872)
**Istigobius* sp
FAMILY BLENNIDAE (Blennies)
Pictiblennius tasmanianus (Richardson, 1849)
FAMILY CLiNIDAE (Weedfishes)
Heteroclinus perspicillatus Cuvier & Valenciennes, 1836
Heteroclinus johnstoni (Saville-Kent, 1886)
Heteroclinus sp.
FAMILY OPHIDIIDAE (Lings, Blindfish)
Genypterus blacodes (Bloch & Schneider, 1801)
FAMILY GEMPYLIDAE (Barracoutas, Gemfish)
Rexea solandri (Cuvier & Valenciennes, 1832)
FAMILY SCOMBRIDAE (Tunas, Mackerels)
Scomber australasicus Cuvier, 1831
**Gasterochisma melampus* Richardson, 1845
FAMILY XIPHIIDAE (Swordfish)
Xiphias gladius Linnaeus, 1758
FAMILY CENTROLOPHIDAE (Deep Sea Trevalla, Sea Bream)
Hyperogylphe antarctica (Carmichael, 1818)
Seriolella brama (Gunther, 1860)
FAMILY SCORPAENIDAE (Rock Cads, Gurnard Perches)
Helicolenus papillosus (Bloch & Schneider, 1801)
Scorpaena ergastulorum Richardson, 1842
FAMILY TRIGLIDAE (Gurnards)
Chelidonichthys kumu (Lesson & Garnot, 1826)
**Trigla* sp.
**Peristedion picturatum* McCulloch, 1926
FAMILY PATAECIDAE (Prow Fishes)
Aetapcus maculatus (Gunther, 1861)
Neopataceus waterhousii Castelnau, 1872
FAMILY GNATHANACANTHIDAE (Red Velvet Fish)
Gnathanacanthus goetzeei Bleeker, 1855
FAMILY PLATYCEPHALIDAE (Flatheads)
Neoplatycephalus speculator (Klunzinger, 1872)
Platycephalus sp.
FAMILY HOPLICHTHYIDAE (Deep Sea Flathead)
Rhinhoplichthys haswelli (McCulloch, 1907)
FAMILY PSYCHROLUTIDAE (Blobfish)
**Neophrynichthys marcidus* McCulloch, 1926
FAMILY PLEURONECTIDAE (Right-hand Flounders)
Azygopus pinnifasciatus Norman, 1926
FAMILY MONACANTHI DAE (Leatherjackets)
Brachaluteres jacksonianus (Quoy & Gaimard, 1824)
Eubalichthys mosaicus (Ramsay & Ogilby, 1886)
Meuschenia australis (Donovan, 1824)
Meuschenia flavolineata H utchi ns, 1977
Meuschenia hippocrepis (Quoy & Gaimard, 1824)
Nelusetta ayraudi (Qoy & Gaimard, 1824)
Penicipelta vittiger (Castelnau 1873)
Scobinichthys granulatus (Shaw, 1790)
FAMILY OSTRACIONTIDAE (Boxfishes, Cowfishes)
Aracana aurita (Shaw, 1798)
Aracana ornata (Gray, 11338)
FAMILY TETRAODONTIDAE (Toadfishes, Puffers)
Tetractenos glaber (Freminville, 1813)
FAMILY DIODONTIDAE (Porcupine Fishes, Globe Fishes)
Oiodon nichthemerus (Cuvier, 1818)
FAMILY GOBIESOCIDAE (Clingfishes, Shore Eels)
Alabes dorsalis (Richardson, 1845)
Cochleoceps spatula (GLi nther, 1861)
FAMILY MOLIDAE (Sunfishes)
Masturus lanceolatus (Lienard, 1840)
Mola ramsayi (Giglioli, 1883)

Glover & Southcott (1974), Glover & Branden (1978) and Glover (1974, 1975a, 1975b, 1979, 1982), particularly those species known to extend eastwards to Victoria or beyond (especially to Tasmania). Conversely, it is probable that some southern Australian (especially south-eastern Australian) fishes, hitherto unrecorded from South Australia, will be found to inhabit this region; several species listed in the Table 2 checklist are in this category.

For identifications the reader is referred to the above texts, Coleman (1980), FAO species identification sheets for fishing areas 57 & 71 (1974-), Maxwell (1980) and Munro (19561961).

The checklist (Table 2) has been compiled from museum collections, reliably reported sightings and documented commercial and sport fishes. Although undoubtedly far from complete, the list indicates a diverse fauna including 148 species of 81 families. With the possible exception of the hagfish *Eptatretus longipinnis,* none of the species listed is believed to be endemic to the South East and the majority extend well beyond South Australian waters.

In view of the exposed natu re of the reg ion's coast in relation to the Southern Ocean and westerly water currents, and the close proximity to shore of the continental slope, it also is to be expected that oceanic or deepwater fishes such as the Moonfish *Lampris regius* or the Point Tailed Sunfish *Masturus lanceolatus,* though not resident species, will occasionally be found inshore. However, the single report by Kailola & Jones (1981) of the normally tropical Queensland Grouper *Promicrops lanceolatus* was evidently a rare event.

When the regional fish fauna is known better it is probable that the South East will be found to represent the most easterly or westerly extension of certain species found in southern Australian coastal waters.

COMMERCIAL FISHES OF COASTAL AND OFFSHORE WATERS

Apart from a substantial crustacean (crayfish/rock lobster) fishery the region's principal commercial marine fisheries are a developing deepwater (beyond 183 m) trawl fishery taking principally Gemfish *Rexea solandri* and Blue Grenadier *Macruronus novaezelandiae,* and a long line fishery for School and Gummy Sharks *Galeorhinus australis* and *Mustelus antarcticus.* The remaining commercial fishing activity is generally very small. Fishermen handline inshore for Red Snapper *Trachichthodes gerrardi,* Sweep *Scorpis* sp., Leatherjackets (Monacanthidae spp.) and Ling *Genypterus blacodes.* Lake George is netted for Sea and Yellow Eye Mullets *Mugil cephalus* and *Aldrichetta foresteri,* Mulloway and Australian Salmon. Other commercial species include Hapuku *Polyprion oxygeneios,* Deep Sea *TrevallaHyperoglyphe porosa,* Tasmanian Trumpeter *Latris lineata,* Tommy Ruff *Arripis georgianus,* King George Whiting and Garfish *Hyporhamphus melanochir.*

SPORT FISHES OF COASTAL AND OFFSHORE WATERS

Sport fishing for coastal and offshore fishes is a thriving recreational pastime in the area, with a large following and a diverse range of target species, e.g. Mulloway, Flathead *Platycephalus* sp., Snapper *Chrysophrys unicolor,* Mackerel *Scomber australasicus,* Australian Salmon, King George Whiting, Garfish, Yellow Eye Mullet, Black Bream and, more recently, Blue Pointer (Mako) Shark *Isurus oxyrinchus.*

ECOLOGICAL CONSIDERATIONS OF COASTAL AND OFFSHORE WATERS

Unlike some more heavily populated and industrialised coastal areas such as the Adelaide region (see Glover & Ling, 1976), the marine environment of the South East does not appear to be subject to any significant threat or disturbance. Barring any major marine pollution accident, such as a massive oil spi II, the future of the existing marine fauna seems assured.

It should be noted that the Australian Marine Sciences and Technologies Advisory Committee (AMSTAC) designated, in 1980, the marine zone off the South East, a high priority area for increased research effort.

A recently conducted South Australian Museum marine fish survey (supported by an AMSTAC-Funding Advisory Panel grant), and Commonwealth-States fisheries surveys off the region's coast, are adding substantially to our knowledge of this fauna.

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REFERENCES

Ainslie, R. (1970). Some aspects of the chloride regulation in the euryhaline teleost *Pseudaphritis bursinus* (Cuv. & Val). B.Sc. (Hans) Thesis, Department of Zoology, University of Adelaide (unpublished).

Backhouse, G. N. & Vanner R. W. (1978). Observations on the biology of the dwarf galaxiid *Galaxiella pusilla* (Mack) (Pisces: Galaxiidae) *Viet. Nat.,* **95**, 128-132.

Bayly, I A. E. & Williams W. D. (1966). Chemical and biological studies on some saline lakes of Southeast Australia. *Aust. J. Mar. Fresh. Res.* ***17****(2),* 177-228.

Coleman, N. (1980). 'Australian Sea Fishes South of 30^{0}S'. (Doubleday Australia, Sydney).

FAO species identification sheets for fishery purposes: eastern Indian ocean fishing area 57 and western central Pacific fishing area 74. Volumes I-IV (1974-). Food and Agriculture Organisation of the United Nations, Rome.

Glover, C. J. M. (1974). The whitetip oceanic shark *Pterolamiops longimanus* (Poey) 1861-A first record from off the southern Australian coast. S. *Aust. Nat.* **49**(1), 12-13 & pit.

Glover, C. J. M. (1976a). The starry toadfish *Boesemanichthys firmamentum* (Temminck & Schlegel, 1850). An addition to the fish fauna of South Australia. S. *Aust. Nat.* **50**(3), 54-56.

Glover, C. J. M. (1976b). The goblin shark *Scapanorhynchus owstoni* (Jordan, 1898): Confirmation of the first Australian record. S. *Aust. Nat.* **50**(4),69-72

Glover, C. J M. (1979). Fishes. *In* M. J Tyler, C R. Twidale & J K. Ling (eds), 'Natural History of Kangaroo Island', pp. 139-153. (Royal Society of South Australia, Adelaide).

Glover, C. J. M. (1982). A provisional checklist of marine fishes (Amphioxi, Petromyzones, Myxini, Elasmobranchii, Holocephali, Teleostomi) recorded in South Australian coastal waters. S. *Aust. Mus. Information Leaflet* (**70**), 1-25.

Glover, C. J. M. & Branden, K. L. (1978). New fish records from South Australia. S. *Aust. Nat.* **52***(4),* 55-60.

Glover, C. J. M. & Ling, J. K. (1976). Marine fishes and mammals. *In* C. R. Twidale, M. J. Tyler & B. P. Webb (eds) 'Natural History of the Adelaide Region', pp. 187-189. (Royal Society of South Australia, Adelaide)

Harbison, P. (1974). The black bream in the Onkaparinga Estuary. Ad. Dip. Biol Sc. Thesis, Salisbury College of Advanced Education, S. Aust. (unpublished).

Jackson, P. D. (1978). Spawning and early development of the river blackfish *Gadopsis marmoratus* Richardson (Gadopsiformes: Gadopsidae), in MacKenzie River, Victoria. *Aust. J. Mar. Freshw. Res*. **29**(3), 293-298.

Kailola, P. J. & Jones, G. K. (1981). First record of *Promicrops lanceolatus* (Bloch, 1790) (Pisces: Serranidae) in South Australian waters. *Trans. R. Soc.* S. *Aust.* **105**(4), 211-212.

Lake, J S. (1967). Freshwater Fish of the Murray-Darling River system. *Res. Bull. N.S.* W. *Fisheries* (7).

Lake, J. S., (1971). 'Freshwater Fishes & Rivers of Australia.' (Nelson, Melbourne).

Lake, J S. (1978). 'Australian Freshwater Fishes' (Nelson, Melbourne).

Lee, C L. (1969). Salinity tolerance and osmoregulation of *Taeniomembras* microstomus (Gunther, 1861) (Pisces Mulgiliformes: Atherindae) from Australian salt lakes. *Aust. J. Mar. Freshw. Res.* **20**(2), 157-162.

Lee, C. L. & Williams W. D. (1970). Meristic differences between two conspecific fish populations in Australian salt lakes. *J. Fish. Biol*. **2**, 55-56

Llewellyn, L. C. (1971). Breeding studies on the freshwater forage fish of the Murray-Darling river system *N.S.* W. *Fisherman* (N.S.W State Fisheries) **3**(13), 1-12.

Llewellyn, L. C. (1974). Spawning, development and distribution of the southern pigmy perch *Nannoperca australis australis* Gunther from inland waters in Eastern Australia. *Aust. J. Mar, Freshw. Res.* **25**(1), 121-149.

Maxwell, J. G. H. (1980). A field guide to trawl fish from the temperate waters of Australia. C.S.I.R.O. Division of Fisheries and Oceanography. Circular (8).

McDowall, R. M. (1978). Sexual dimorphism in an Australian galaxiid (Pisces: Galaxiidae). Aust. Zool. **19**(3), 309-314.

McDowall, R. M. (Ed.) (1980). 'Freshwater Fishes of South-Eastern Australia', (Reed, Sydney).

Munro, I.S.R. (1956-1961). Handbook of Australian fishes. Series published in *Fisheries Newsletter* between July 1956 and December 1961. Fisheries Branch, Department of Primary Industry, Canberra.

Pollard, D. A. (1971a). The biology of a landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). I. Life cycle and origin. *Aust. J. Mar. Freshw. Res.* **22**, 91-123.

Pollard, D. A. (1971b). The biology of a landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). II: Morphology and systematic relationships *Aust. J. Mar. Freshw. Res*. **22**, 125-137.

Pollard, D. A. (1972a). The biology of a landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). III. Structure of the gonads. *Aust. J. Mar. Freshw. Res.* **23**,17-38.

Pollard, D. A. (1972b). The biology of a landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). IV. Nutritional cycle. *Aust. J. Mar. Freshw. Res*. **23**(1), 39-48.

Pollard, D. A. (1973). The biology of the landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). V. Composition of the diet. *Aust. J. Mar. Freshw. Res.* **24**(3), 281-296.

Pollard, D. A. (1974). The biology of a landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). VI. Effects of cestodes and nematode parasites. *Aust. J. Mar. Freshw. Res*. **25**(1). 105-120.

Potter, I. C. (1970). The life cycles and ecology of Australian lampreys of the genus Mordacia. *J. Zool.* (London). **161**, 487-511.

Potter I. C. & Strahan R. (1968). The taxonomy of the lampreys Geotria and Mordacia and their distribution in Australia. *Proc. Linn. Soc. Lond*. **179**(2). 229-240

Scott, T. D., Glover, C. J. M. & Southcott, R. V. (1974). 'The Marine and Freshwater Fishes of South Australia' (2nd Edition), (Govt Printer, Adelaide).

Thomson, J. M. (1957a). Biological studies of economic significance of the yellow-eye mullet, *Aldrichetta torsteri* (Cuvier & Valenciennes) (Mugilidae). *Aust. J. Mar. Freshw*. **8**(1), 1-13.

Thomson, J. M. (1957b). I nterpretation of the scales of the yellow-eye mullet, *Aldrichetta torsteri* (Cuvier & Valenciennes) (Mugilidae) *Aust. J. Mar. Freshw. Res*. **8**(1), 14-28.

Thomson, J. M. (1977). 'A Field Guide to the Common Sea & Estuary Fishes of Non-tropical Australia'. (Collins, Sydney).

Tilzey, R. D. J. (1976). Observations on interactions between indigenous Galaxiidae and introduced Salmonidae in the Lake Eucumbene Catchment, New South Wales. *Aust. J. Mar. Freshw. Res*. **27**(4), 551-564.

Weng, H. T. C. (1971). The black bream *Acanthopagrus butcher*; (Munro); its life history and its fishery in South Australia. M.Sc. Thesis, Department of Zoology, University of Adelaide (unpublished).

16: Vertebrate Fossils

by R. T. WELLS and N. S. PLEDGE

INTRODUCTION

Fossilised remains of vertebrates are relatively common in the South East of South Australia. Bones, teeth, spines and scales of marine animals have been recovered from the ancient marine sediments of the Murray Basin while the caves of the Naracoorte and Mt Gambier regions are veritable grave yards of extinct and extant marsupials, rodents, birds, reptiles and amphibians. These specimens span a time range of 56 million years; the oldest from the sands and clays of the Eocene Knight Group, the youngest from the Late Pleistocene cave sediments.

EOCENE FOSSILS

By far the most ancient vertebrate fossils collected from the South East are the teeth of sharks, easily recognised by their shining dark enamel. These teeth are usually slenderly conical and sometimes triangular in form. Evolved from dermal scales, the teeth lack proper roots and in life are anchored to the skin of the jaw by collagenous fibres, and so are continually shed as the shark grows. There are some remarkably rich collections of fossil shark teeth known from the area which have been collected in the course of drilling for water. It is regrettable that so few collections include accurate records of the depth at which they were found, as such information is essential in determining the age of these specimens. Most teeth appear to be derived from the sediments of the Middle Eocene Tartwarp Formation (Knight Group) and Upper Eocene Lacepede Formation (Buccleuch Group).

The fauna includes several species of shark (Pledge 1967): *Heptranchias* cf. *agassizi* (7-gilled shark, Fig. 1), *Scapanorhynchus maslinensis* (goblin shark, Fig. 2), two species of nurse shark *(Odontaspis macrota)* and O. *acutissima), Lamna* sp. the mackerel shark and *Carcharhinus* sp., a relative of the whaler sharks. Skates and sting-rays also are present. Eagle-ray tooth plates of *"Myliobatis"* sp and sting ray spines of *Dasyatis* sp. have been collected. Bony fish (teleosts) are represented by vertebrae, fin spines, occasional teeth and earbones or otoliths.

OLIGOCENE-MIOCENE FOSSILS

Overlying the Buccleuch Group sediments are extensive deposits of Gambier Limestone and its equivalents. They extend from the lower South East, through the Murray Lands, and are evidence of a shallow sea (the Murravian Gulf) that covered this area for 25 million years. This sea harboured the large Oligocene *Procarcharodon angustidens,* the ancestor of the great white shark *P. megalodon* of Miocene times, a truly giant predatory species estimated at some 20 m long. A single tooth 14.9 cm high (Fig. 3) was unearthed at Lake Bonney in the 1940s, and is believed to be one of the three largest shark teeth in the world. In Miocene times the sea was also the habitat of the giant blue pointer *Isurus hastalis,* which was smaller than *P. megalodon.* Whales and penguins also flourished there.

The skeletal remains of extinct whales of the Oligocene and Miocene epochs have been recovered from the limestones of the South East. They include portions of skulls, jaws, teeth, ribs and vertebrae of several unidentified species, and teeth of the shark toothed whales *Metasqualodon harwoodi, Parasqualodon wilkinsoni* and *"Squalodon" gambierense,* Fig. 4 (Glaessner 1955, Pledge & Rothausen 1978).

Penguin bones from the same period were discovered in limestone at the Mt Gambier quarry. One is a rather small femur; the other bone, a humerus, probably representing a different species, bears tooth marks Fig. 5 (Glaessner 1955, Simpson 1957).

With the retreat of the sea in mid Miocene times about 15 million years ago, the limestones were exposed to a period of subaerial weathering leading to the development of a karst topography, a surface dominated by sinkholes, dolines and caves (see Chapter 4). Remnants of these ancient

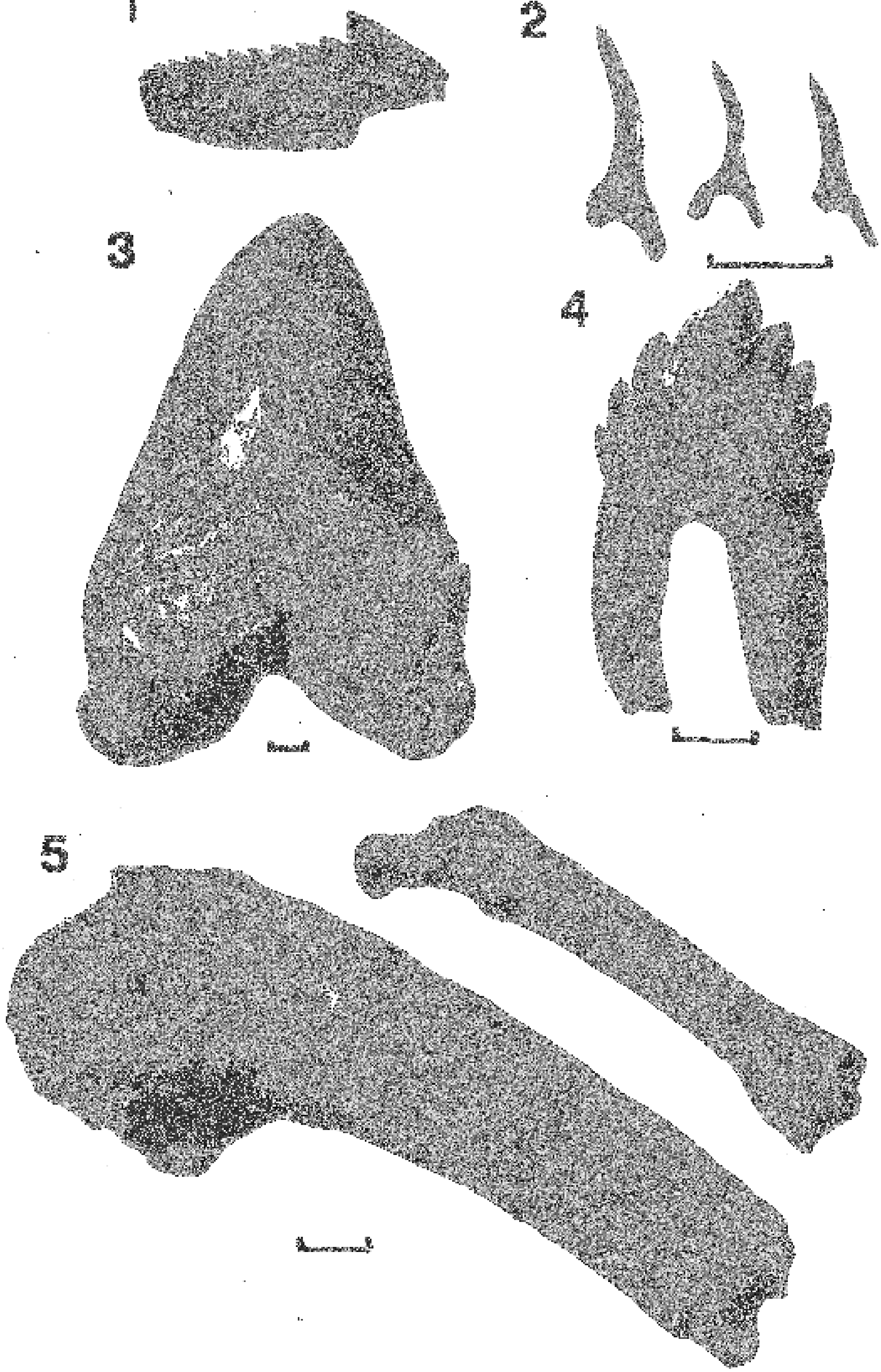
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Fig 1. (Heptranchias cf. *agassizi)* Lateral tooth of a Seven-gilled Shark. Eocene, E. & W.S. Bore No.5, Naracoorte.

Fig 2. (Scapanorhynchus maslinensis) Anterior teeth of a Goblin Shark. Eocene, E. & W. S. Bore No.5, Naracoorte (Scale bar equals 1 cm).

Fig 3. (Procarcharodon megalodon) Tooth of the Giant White Shark. Miocene, Lake Bonney S.E. (Scale bar equals 1 cm).

Fig 4. (Squalodon gambierense) Molar tooth of a shark-toothed whale. Miocene, Pritchard Bros. Quarry, Mt Gambier.

Fig 5. Damaged penguin wingbone (humerus) with tooth marks, and leg bone (femur). Miocene, Pritchard Bros Quarry, Mt Gambier.

caves infilled with the red Parilla sands of the Pliocene period can be readily observed in the quarries of the Naracoorte region. It is surprising that fossil vertebrates have not been discovered in these ancient cave fills: they certainly warrant careful examination.

Another transgression of the sea at the close of the Pliocene arrested cave development. With the coming of the Pleistocene ice age there followed a period of intermittent transgression and regression of the sea, each phase clearly recorded by an abandoned shoreline dune (Cook & Idnurm 1981 and Chapter 3). With each successive fall in sea level there followed an increase in the groundwater gradient leading to a deepening of the labyrinthine cave systems. The present high sea level maintains an elevated groundwater table such that the deeper cave systems of the Mt Gambier region remain permanently flooded. In the north in the region of Naracoorte much of the cave system occu rs on the u pthrown side of the Kanawinka "Fault" leaving many of the chambers well above the phreatic zone of the water table (Fig. 6) (Wells *et al. 1982).*

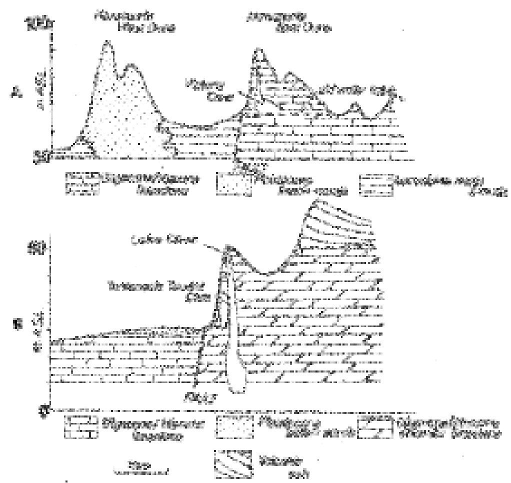


Fig. 6. Transverse sections showing relationship of caves to faults at (a) Naracoorte, (b) Tantanoola.

PLEISTOCENE FOSSILS

Most Pleistocene fossils have been found in caves, but a few are from open sites-former streams or swamps. Fossil vertebrates were first reported from the area by Fr J. E. Tenison Woods (Woods 1860, 1862, 1866). In his search for evidence of the Noachian flood he reported the discovery of leg bones of a giant emu-like bird he called *Dromaius australis* at a site somewhere near Penola. The bones were allegedly deposited in the Penola Institute but have not been seen since. Stirling believed this bird to be *Genyornis newtoni* (Stirling & Zietz 1900), and recorded another leg bone from a cave at Mt Gambier. A neck vertebra was also found recently in Blanche Cave at Naracoorte (Rich 1979).

In 1881 the teeth of the giant marsupial *Diprotodan aptatum* were recovered from a swamp near Millicent during the construction of the railway line. Later, drain diggers working near Hatherleigh unearthed some bones including jaws of *Diprotadon* and a wombat; this was reported in the 'South East Times' of January 28, 1884. Similarly during the construction in 1954 of a road bridge near Kingston, a small assemblage of marsupial fossils was collected from an ancient stream deposit (Williams 1980). It included extinct and extant kangaroos as well as *Zygomaturus trilobus* and *Oiprotadan* sp., both large extinct quadrupedal browsing marsupials.

Fossils are also preserved in the stranded beach dunes and a natural endocranial cast and mould of the skull of a Tasmanian Devil *(Sarcaphilus)* was found in hardened dune rock near Beachport in 1973.

Great accumulations of Pleistocene fossil vertebrates are found in the caves of the South East. Woods was first to report fossil vertebrates from Blanche Cave Naracoorte (Woods 1860, 1862, 1866). Within the Naracoorte Caves fossil bones were in such profusion as to warrant special comment in 1879 by a correspondent to 'The Register'. Any traces of these early discoveries have long vanished beneath the feet of tourists and revellers in the days when the caves were a favoured venue for picnics and gala festivities. Fossil vertebrates were again found at Naracoorte in 1907 when Stirling reported the excavation of the remains of extinct marsupials from Specimen Cave. These included the great blade-like teeth of the marsupial 'lion' (Stirling 1908), the first partial skeleton of which was later recovered in 1959 during blasting operations at James Quarry, Naracoorte (Daily 1960).

By far the largest deposit of fossil vertebrates was discovered at Naracoorte in 1969 during exploration of Victoria Cave (Wells 1975; Wells *et al.* 1982). A single chamber measuring some 60 m x 20 m contains, arguably, the richest deposit of Pleistocene marsupials yet found in Australia. The remains of countless tens of thousands of animals ranging from small frogs, reptiles and rodents to giant extinct marsupials lie buried in the sediments filling this cavern The discovery of the Fossil Chamber was followed in a matter of months by yet another, the Ossuary, several hundred metres beyond (Wells 1975, Wells *et al.* 1982). For millenia these dry caves have acted as pitfall-traps for the unwary, as dens for carnivores and as roosts for owls and bats. Recent studies of the bones and sediments place their ages between 18000 and 150000 years. Another site at Naracoorte, the Henschke Fossil Cave, yielded a large collection of fragmentary bone prior its removal by quarrying operations.

Further south, other important cave sites occur in the Tantanoola area (Tindale 1933, Pledge 1980a). One of these, Tantanoola Tourist Cave, is a dry chamber which occurs on the upthrown side of a fault in a similar manner to those at Naracoorte (Fig. 6). The faulting caused a sea cliff to develop, and the sea breached the original cave. Its deposits may date back to the last interglacial age 100000-170000 years ago, and include beach debris such as fish bones, seal ion bones *(Arctocephalus)* and shells.

Yet another site, Greenwater Hole, is a flooded cave (Pledge 1980) Work on this extremely hazardous deposit is continuing: it has yielded excellently preserved material and some important, and as yet largely undescribed, fossils as well as aboriginal artifacts (R. T. Wells and D. L. G Williams pers. comm.).

A composite list of the vertebrate species represented in these deposits is given in Table 1.

Table 1. PLEISTOCENE FOSSIL VERTEBRATES FROM THE SOUTH EAST

Class and Family		Genus and Species
AMPHIBIA		
HYLIDAE		*Litona ewingi*
LEPTODACTYLIDAE		*Limnodynastes tasmaniensis*
		Limnodynastes ct. dumerili
		Ranidella signifera
		Geocrinia cf. laevis
REPTILIA		
BOIDAE	t	*Wonambi naracoortensis*
ELAPIDAE		*Pseudonaja cf. nuchalis*
		Notechis cf. scutatus
		Pseudechis cf. porphyriacus
VARANIDAE		*Varanus varius*
		V. gouldii
SCINCIDAE		*Trachydosaurus rugosus*
		Tiliqua nigrolutea
		cf. Sphenomorphus tympanum
		Egernia cf. whitei
AGAMIDAE		*Amphibolurus ct. barbatus*
		cf. Emydura macquarii
CHELIDAE		*Chelodina longicollis*
AVES		
CASUARIIDAE		*Dromaius cf. novaehollandiae*
MEGAPODIDAE	t	*Progura naracoortensis*
		Leipoa ocellata

PHASIANIDAE		*Coturnix pectoralis*
		C. *australis*
TURNICIDAE		*Turnix sp.*
		T varia
PEDIONOMIDAE		*Pedionomus torquatus*
RALLIDAE		*Rallus philippensis*
		Tribonyx sp.
CHARADRIIDAE		*Peltohyas australis*
SCOLOPACIDAE		*Tringa glareola*
		Gallinago hardwickii
		Calidris ruficollis
PSITTACIDAE		*indet.*
PLATYCERCIDAE	*	*Pesoporus wallie* us
ACCIPITRIDAE		*indet.*
TYTONIDAE		*Tyto novaehollandiae*
CUCULIDAE		*undetermined*
GRALLINIDAE		*Grallina cyanoleuca*
ANATIDAE		*undescribed species*
CRATICIDAE		*Gymnorhina tibicen*
CORVIDAE		*Corvus sp.*
HIRUNINIDAE tt	t	*Hirundo neoxena*
OROMORNITHIDAE		*Genyornis ct. newtoni*
MONOTREMATA		
TACHYGLOSSIDAE	*	*Zaglossus cf. bruijni*
	t	*Zaglossus ramsayi*
		Tachyglossus aculeatus
MARSUPIALIA		
THYLACINIDAE	*	*Thylacinus cynocephalus*
DASYURIDAE	t	*Sarcophilus cf. laniarius*
	*	*Dasyurus maculatus*
	*	*D. viverinus*
		Antechinus f1avipes
	*	A. *swainsonii*
	*	A. *stuartii*
		Sminthopsis murina
		S. *crassicaudata*
		S.leucopus
PERAMELIDAE		*Isoodon obesulus*
	*	*Perameles gunnii*
	*	P. *bougainville*
PETAURIDAE		*Pseudocheirus peregrinus*
		Petaurus breviceps
BURRAMYIDAE		*Cercartetus nanus*
PHASCOLARCTIDAE		*Phascolarctos cinereus*
VOMBATIDAE		*Vombatus ursinus*
		Lasiorhinus cf. latilrons
MACROPODIDAE		*Macropus giganteus*
	t	M. *titan*
		M. *rulogriseus*
	t	M. *greyi*
		Wallabia bicolor
	*	*Lagorchestes cf. conspicillatus*
	*	*Bettongia penicillata*
	*	B. *gaimardi*
	*	*Potorous apicalis*
	t	P. *plat yaps*
		Aepyprymnus rulescens
	t	*Sthenurus atlas*
	t	S. *andersoni*
	t	S. *gilli*
	t	S. *maddocki*
	t	S. *occidentalis/orienta/is*
	t	S. *brownei*
	t	*Procoptodon rapha*
	t	*Protemnodon roechus*
	t	*Propleopus oscillans*
THYLACOLEONJDAE	t	*Thylacoleo carnifex*
DIPROTODONTIDAE	t	*Zygomaturus trilobus*
		Palorchestes azael
		Diprotodon optatum
CARNIVORA		
OTARIIDAE		*Arctocephalus sp.*

Rodentia		
Muridae		*Pseudomys australis*
	*	*P Albocinereus*
	*	*P. ct. tumeus*
	*	*Mastacomys fuscus*
		Conilurus cf. albipes
		Rattus sp

* Now extinct in the area
t Totally extinct
tt Van Tets & Smith also reported a sheath bill *Chionis minor* but this identification has been challenged by Olsen (1976)

THE ANIMALS

The cave deposits have provided the first partial skeletons of many extinct species Fig. 8, and have given an insight into the life forms of these unusual animals. Extinct species include a giant boid snake *Wonambi naracoortensis* (Smith 1976), giant mallee fowl *Progura naracoortensis* (Van Tets & Smith 1974), large echidna *Zaglossus ramsayi* (Murray 1978, Pledge 1980b), marsupial lion *Thylacoleo earnifex* (Wells & Nichol 1977, Wells *et al.* 1982), eight species of leaf eating kangaroos (Wells & Murray 1979, Wells *et al.* 1982) and a number of large browsing quadrupeds *Zygomaturus trilobus, Diprotodon optatum, Palorehestes azeal.* Murray (in press) has made some reconstructions, his drawings are shown in Fig.7.

Almost half the species of animals represented in the cave faunas no longer occur in the South East, and of these half are extinct. Of those still living elsewhere in Australia most are animals of the dense understory of sclerophyll forests (Wells *et al.* 1982). The absence of these animals from the area today may be due to climatic shifts but may equally be due to the extensive clearing of the understory during the early days of settlement. Of the extinct species kangaroos are by far the most common. They include many sthenurine species showing adaptations to browsing e.g. S. *occidentalis,* S. *brownei, Procoptodon rapha.* These leaf eating kangaroos are found in association with grazer/browsers like the large extinct grey kangaroo *Macropus* titan, or the extinct Toolache wallaby M. *greyi* or the forest dwelling red-neck wallaby M. *rufogriseus.* Even less common species like *Diprotodon, Zygomaturus* and *Palorchestes* have dentitions and skull architecture typical of leaf-eating herbivores. Taken together these faunas represent far greater species diversity than is known for this area in historic time and it is tempting to make inferences on the nature of the climate and vegetation. Wells et al

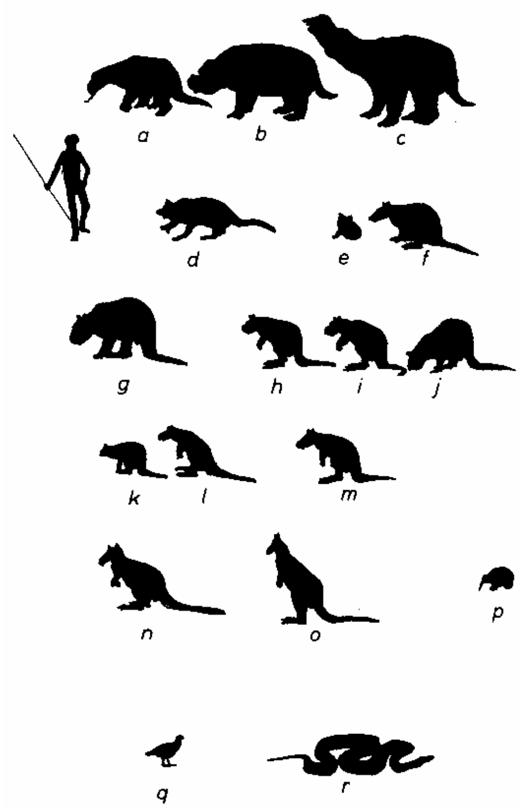


Fig. 7. Silhouettes of extinct late Pleistocene marsupials and reptiles from the southeast of South Australia. Courtesy of Peter Murray. Aboriginal hunter provides the scale.
(a) *Palorchestes azeal,* (b) *Zygomaturus trilobus,* (c) *Diprotodon optatum,* (d) *Thylacoleo carnifex,* (e) *Phascolarctos stirtoni,* (f) *Propleopus oscillans,* (g) *Procoptodon rapha,* (h) *Sthenurus maddocki,* (i) *Sthenurus brownei,* (j) *Sthenurus occidentalis,* (k) *Sthenurus gilli,* (l) *Sthenurus atlas,* (m) *Sthenurus andersoni,* (n) *Protemnodon roechus,* (o) *Macropus titan,* (p) *Zaglossus ramsayi,* (q) *Progura naracoortensis,* (r) *Wonambi naracoortensis.*

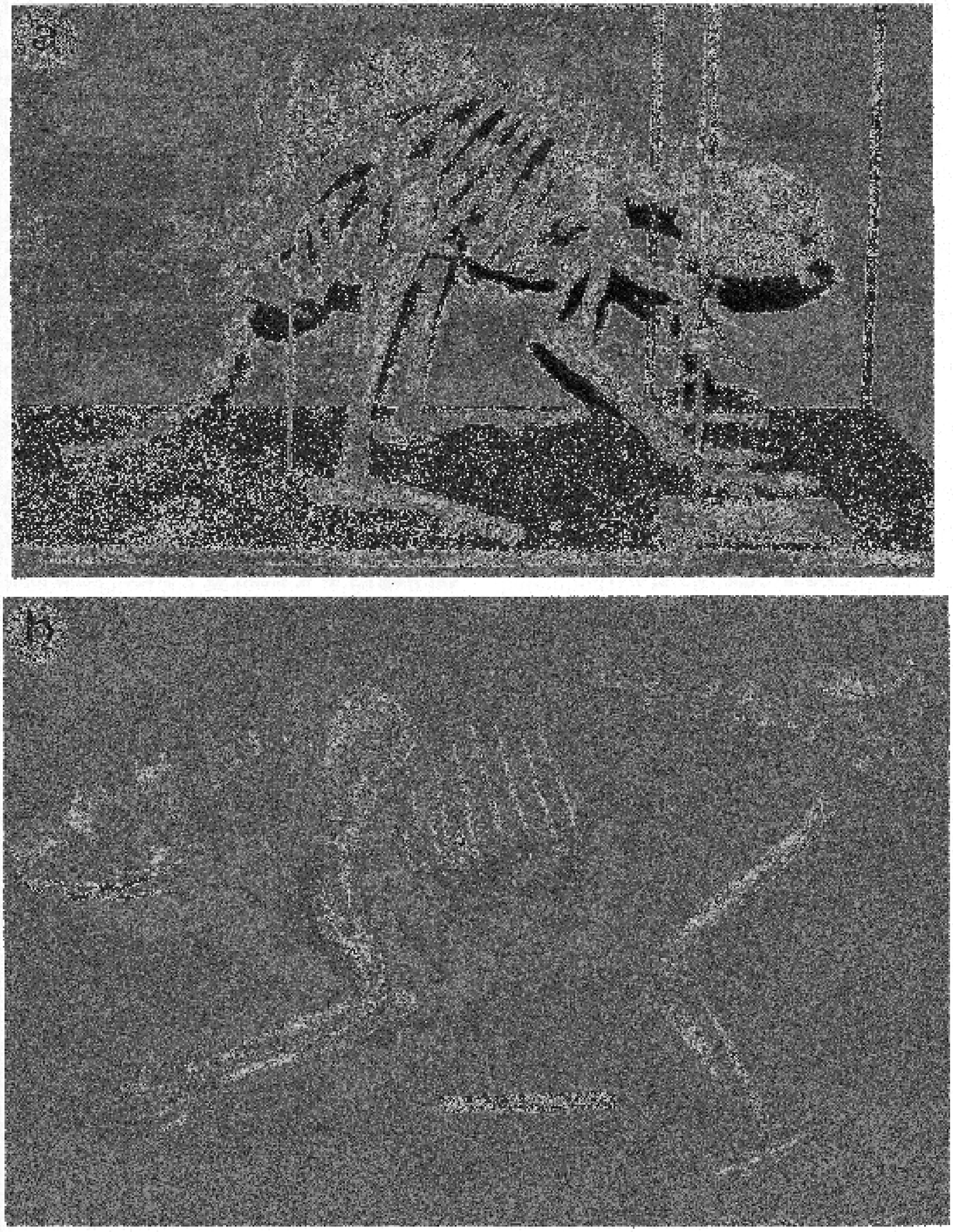


Fig. 6. (a) Skeleton of *Sthenurus occidentalis* an extinct browsing kangaroo. Greenwater Hole, Tantanoola.
(b) Partial skeleton of *Thylacoleo carnifex* the marsupial lion. Victoria Cave, Naracoorte.

(1982) have pointed out the difficulties in unravelling the time sequence in which these cave faunas accumulated and their use in palaeoenvironmental reconstructions is thus limited. However, studies of pollen assemblages in cores from Wyrie Swamp (Dodson 1977) indicate that during the last 40 000 years the vegetation has passed from a eucalypt forest with a scrub understory to an open woodland, a change which is consistent with the disappearance of so many large browsing animals and the large predatory *Thylacoleo* (Wells *et al.* 1982). The reason for these changes remains the subject of research and debate. Some would favour the onset of aridity associated with the last great ice age, aridity which reached its peak approximately 18000 years ago; others would correlate vegetation change and the demise of the megafauna with the activities of aboriginal man, particularly his use of fire. As yet there is no clear evidence of man's involvement, however, stone and bone artifacts have been recovered from sediments containing extinct fauna (R. T. Wells & D. L. G. Williams unpublished). Much work now needs to be done to' clearly establish the time relationships within these deposits.

REFERENCES

Cook, P. J. & Idnurm, M. (1981). Ice and Sea. Ice ages and sea level changes around Australasia. *Hemisphere,* **26**: 116-120.

Daily, B. (1960). *Thylacoleo,* the extinct marsupial lion. *Aust. Mus. Mag.* 1960.163-166.

Dodson, J R. (1977). Late Quaternary palaeoecology of Wyrie Swamp, South Eastern South Australia. *Quat. Res.* **8**: 97-114.

Glaessner, M. F. (1955). Pelagic fossils (Aturia, penguins, whales) from the Tertiary of South Australia. *Rec.* S. *Aust. Mus.* **11**(4), 353-372.

Murray, P. (in press). 'Extinction Downunder: A bestiary of extinct Australian Late Pleistocene monotremes and marsupials.' *In* Martin, P. S. & Klein, (Eds) Quaternary Extinctions.

Pledge, N. S. (1967). Fossil elasmobranch teeth of South Australia and their stratigraphic distribution. *Trans. R. Soc.* S. *Aust.* **91**,135-160.

Pledge, N. S. (1980a). Macropodid skeletons, including *Simosthenurus* Tedford, from an unusual "drowned cave" deposit in the south east of South Australia. *Rec.* S. *Aust. Mus.* **18***(6).* 131-141.

Pledge, N. S. (1980b). Giant echidnas in South Australia. S. *Aust. Nat.* **55**(2), 27-30.

Pledge, N. S. & Rothausen, K. (1978) *Metasqualodon harwoodi* (Sanger, 1881)-a redescription. *Rec.* S. *Aust. Mus.* **17**(17), 285-297.

Rich, P. V. (1979). The Dromornithidae. *Bull. Bur.Min. Res. Geol. Geophys.* **184**, 1-196.

Simpson, G. G. (1957). Australian fossil penguins, with remarks on penguin evolution and distribution. *Rec.* S. *Aust. Mus.* **13**(1),51-70.

Smith, M. J (1976). Small fossil vertebrates from Victoria Cave, Naracoorte. South Australia. IV Reptiles. *Trans. R. Soc.* S. *Aust.* **100**(1), 39-51.

Stirling, E. C. (1908) Report of the Museum Director. *Rept Board of Governors of the Public Library, Museum, and Art Gallery of South Australia for 1907-8.* (Govt Printer, Adelaide): 8-9.

Stirling, E. C. and Zietz, A. H. C. (1900). Fossil remains of Lake Callabonna. Part II 1 *Genyornis newtoni.* A new genus and species of Fossil Struthious bird. *Mem. R.* Soc. S. *Aust*. **1** (2): 41-80.

Tindale, N. B. (1933). Tantanoola Caves, South-East of South Australia: Geological and Physiographical Notes. *Trans. R. Soc.* S. *Aust.* **56**,130-142.

Van Tets, G. F. & Smith, M. J. (1974). Small fossil vertebrates from Victoria Cave, Naracoorte, South Australia. III Birds (Aves). *Trans. R. Soc.* S. *Aust.* **98**(4): 225-228.

Wells, R. T. (1975). Reconstructing the past excavations in fossil caves. *Aust. Nat. Hist.* ***18(6):*** 208-211.

Wells, R. T., Horton, D. R. & Rogers, P. (1982). *Thylacoleo carnifex* Owen (Thylacoleonidae) Marsupial Carnivore? *In* M. Archer (Ed) *Carnivorous Marsupials.*

Wells, R. T., Moriarty, K. & Williams, D. L. G. (1982).The fossil vertebrate deposits of Victoria Cave Naracoorte: An introduction to the geology and fauna. *Proc. Linn. Soc. N.S.* W.

Wells, R. T. & Murray, P (1979). A new sthenurine kangaroo (Marsupialia: Macropodiae) from Southeastern South Australia. *Trans. R. Soc.* S. *Aust.* **103**(8) 213-219.

Wells, R. T. & Nichol, B. (1977). On the manus and pes of *Thylacoleo* carnifex Owen (Marsupialia) *Trans. R. Soc.* S. *Aust.* **101**(6): 139-146.

Williams, D. L. G. (1980). Catalogue of Pleistocene Vertebrate Fossils and Sites in South Australia. *Trans. R. Soc.* S. *Aust.* **104**(5): 101-115.

Woods, J. E. T. (1860). On some Tertiary rocks in the colony of South Australia. *Quart. J. Geol. Soc. Lond.* **16**: 253-260.

Woods, J. E. T. (1862). *Gelogical observations in South Australia: principally in the district south-east of Adelaide.* (Long-Longman Green, London) 404 pp.

Woods, J. E. T. (1866). *On the geology and mineralogy of the South-eastern district of the Colony of South Australia, or that country lying between the River Murray, the 141st meridian of longitude, and the sea.* (Govt Printer, Adelaide

17: The Southern Rock Lobster

by R. K. LEWIS

Amongst the rock lobsters, the family Palinuridae, with 49 species, is a widely distributed and commercially important group. The two largest genera are *Panulirus,* whose 20 species have a pan-tropical distribution, and *Jasus,* represented by seven species with a southern temperate waters disribution centred on approximately 35° S latitude.

Despite its large size, the Southern Rock Lobster *J. novaehollandiae* (Fig. 1) was not recognised as a distinct species until 1963 (Holthuis 1963). Major taxonomic characteristics are the degree of squamiform sculpturing on the abdominal terga and the number and distribution of carapace spines. It inhabits reef areas ranging from southwestern Western Australia across southern Australia to New South Wales. It is the basis of one of Australia's largest fisheries with an annual average production of 4260 tonnes liveweight, 2300 tonnes of which is produced in South Australia. The South East produces 75% of South Australia's catch. The southern rock lobster is the most conspicuous and best known marine species in the South East.

As rock lobsters lack large defensive chela, defence against predators is limited to slashing of antennae ringed with short, stout setae, the deterrent effect of the numerous spines on the carapace and walking legs (pereiopods), avoidance of predators by seeking the shelter of dens during the daylight hours and generally foraging in the open only

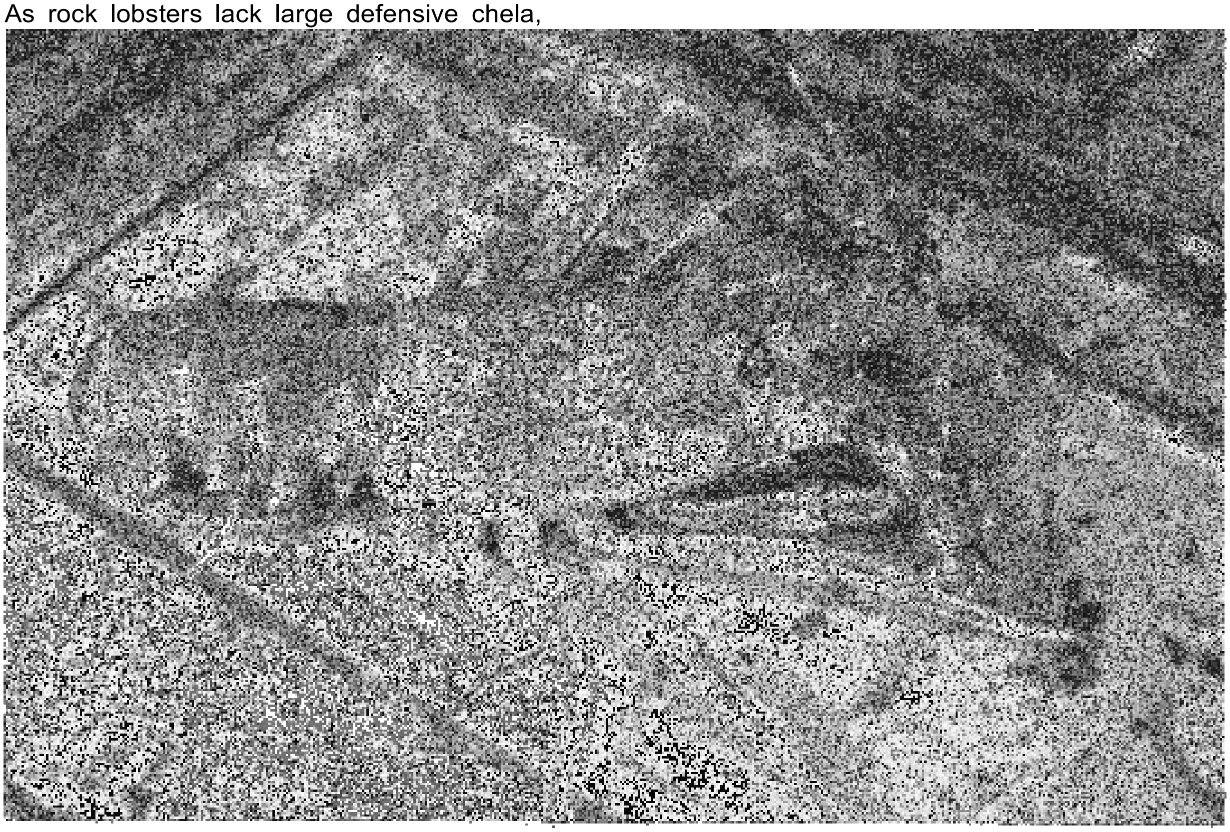


Fig. 1. Southern Rock Lobster *Jasus novaehollandiae.*

during the hours of darkness. Predator avoidance by seeking shelter during the day results in stock densities dependent on the composition and nature of the reef substrate. The majority of the reef substrate in the South East comprises bryozoal limestone which has been eroded to form the extensive den/cave systems in which the lobsters seek protection.

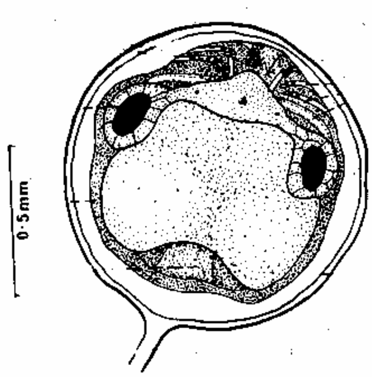
Fertilisation in *J novaehollandiae* is internal and occurs only during June-July following the female moult but before the new exoskeleton has re-hardened. Within days extrusion of ova from the gonopores and deposition onto the pleopods takes place, where the ova develop until hatching in October-November. Ovary development in preparation for the next mating commences December-January, and is believed to be triggered by the intrusion of low temperature, nutrient rich water onto the continental shelf during the summer months (Lewis 1981). The seasonal latitudinal migration of the subtropical high pressure zone results in the prevailing winds shifting from the SW to SE resulting in the offshore movement of surface water which is replaced by cold (11 ° C) nutrient rich (7-8) mmol m^{-3} $N0_3N$) upwelling water. This offshore transportation just after the time of hatching is thought to be the primary dispersal mechanism for this species. Fecundity has been found to vary from 70000 to 800 000 eggs, dependent on the age of the animals

The life cycle of palinurid lobsters consists of approximately 13 transparent, spider-like, planktonic, larval stages (naupliosoma, phyllosoma) lasting up to 15 months, before metamorphosing into a transparent puerulus stage and commencing the bottom dwelling stages of juvenile and adult (Fig. 2). The distribution of naupliosoma and phyllosoma stages in South Australian waters is unknown, but they are thought to travel large distances offshore before returning to the continental shelf to settle. Off Tasmania *J novaehollandiae* naupliosoma and stage I phyllosoma larvae have been captured in the southern Tasman sea, 900-1600 km east of Swan Island, Tasmania, (Winstanley 1970) Peak settlement of pueruli occurs during July-September, although minor settlement does occur at other times of the year. Settlement in the South East occurs when inshore waters have decreased salinities Although magnitude of settlement varies markedly from year to year, growth from mean size at settlement of 10.3 mm total carapace length to a mean size 356 mm total carapace length (T.C.L.) one year later appears constant, and is described adequately by a linear model.

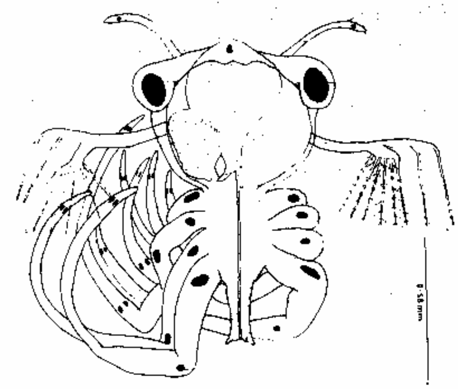
Outward indications of growth in *J novaehollandiae* occur only at the time of ecdysis when the old exoskeleton is shed and replaced with a newly-formed soft exoskeleton: June-July for females and October-November for males. Although the ecdysal period is short, much of the rock lobster's time is spent in preparation for moulting and reproduction. For 10-12 days following ecdysis the lobster is soft shelled (stage A) during which period absorbed water expands the new exoskeleton, which then hardens (stage B) through the deposition of strengthening proteins, other organic material and minerals. There then follows an intermoult period of tissue growth (stage C) and premoult (stage D) in preparation for the next moult, where resorption of material from the old shell takes place. Resorbed material is stored in the blood. The portion of time spent in each stage is variable but may be generally characterised as A and B, 5% or less; C, 40-60%, and 0, 40-60% (Phillips, Cobb & George 1980). This moult cycle is controlled by a little understood interaction of a moult inhibiting hormone (MIH) produced by the X organ of the eyestalk, and the moulting hormone (MH) produced by a yet to be determined moulting gland.

The number of moults per annum varies with age, the larvae having up to 13 stages, whilst Winstanley (1977) found that off southeastern Tasmania the approximate number of moults per annum in the second and subsequent years were 10, 5, 2, 2, 2, 1, 1. .Thus growth of *J novaehollandiae* is determined by both growth frequency as well as growth increments. Factors affecting these are autotomy (the voluntary discarding of appendages when under stress or threat) and subsequent regeneration of appendages, adequate food supply and stock density, optimum water temperatures (14-17°C), eyestalk ablation to remove the X-organ and, particularly in females, the onset of sexual maturity.

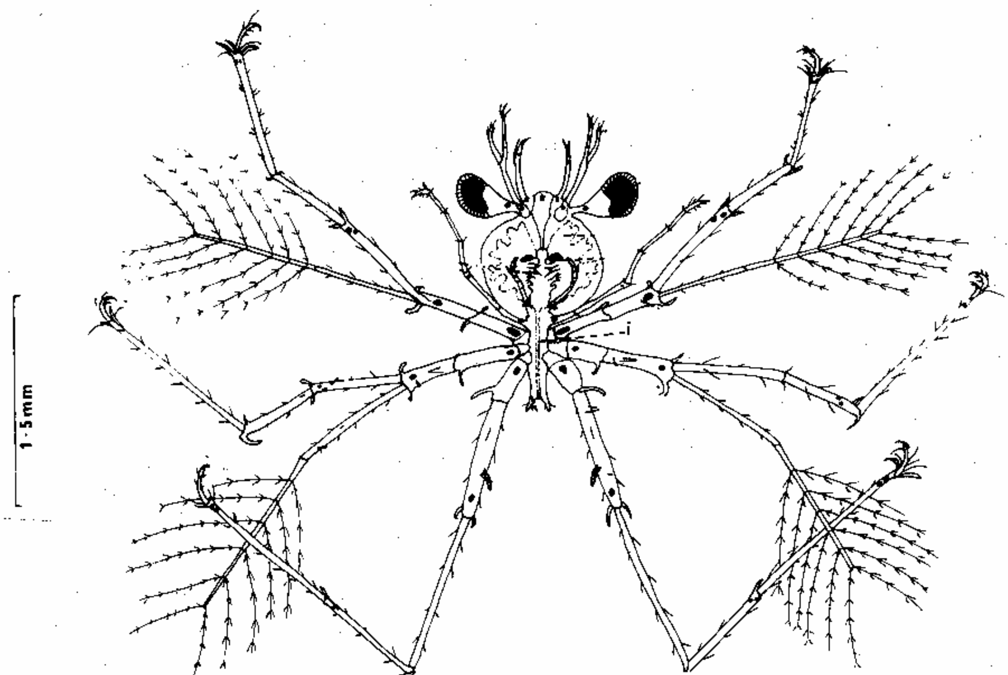
Patterns of movement of *J novaehollandiae* have been described as random in search of food with no long distance movement, the dispersive stage being the larval stages. However recent work has shown that



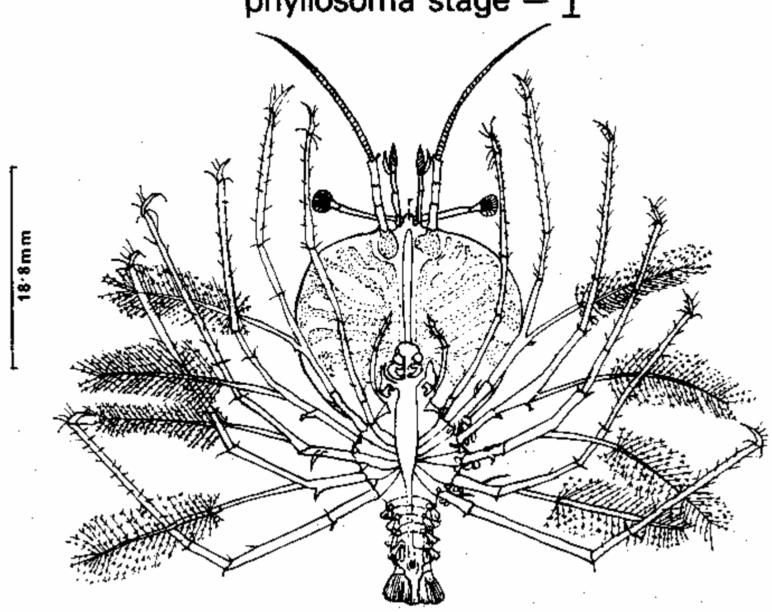
egg



naupliosoma



phyllosoma stage – I



phyllosoma stage – XI

movement patterns in South Austral ian waters fall within two to three distinct behaviour patterns:

1. *Shelter residency and foraging.* Short distance movement while seeking food in the vicinity of shelter. Foraging commences just before dusk, continues throughout the night and ceases at dawn. Peak feeding activity occurs over the two to three hours following dusk. *J. novaehollandiae* is primarily carnivorous feeding on small crustaceans, urchins *(Amblineustes* sp. and *Halopneustes* sp), echinoderms *(Patriella* sp.), and molluscs *(Haliotis ruber, Subninella undulata,* Trochidae spp.).
2. *Dispersive movement.* Long range movement (up to 28km and 120m depth), radiating from any location but frequently from shallow inshore to' offshore areas (Fig. 3). Locomotor stimuli for this activity is believed to be agonistic encounters for available den space with increase in size. Direct observations one year

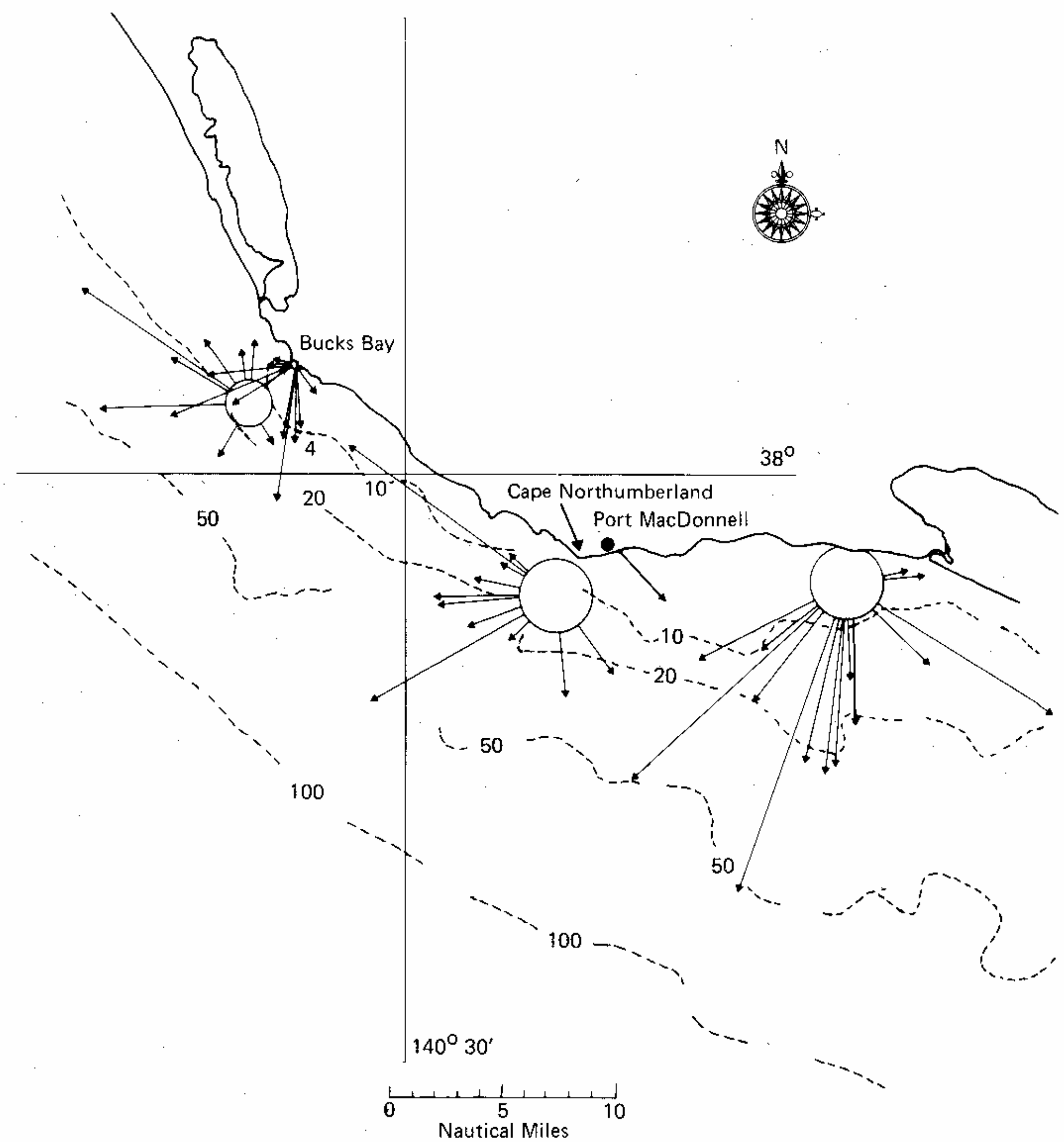


Fig. 3. Movement of Southern Rock Lobster, Port MacDonnell.

after settlement have found that these encounters result in a decrease in density of 1 + age class rock lobsters in the settlement area prior to influx of the new settlement. Reef communities just seaward of the settlement contain large numbers of juvenile rock lobsters whilst further offshore are smaller numbers of larger rock lobsters.

3. *Migration.* Herrnkind (1977) defines migration as direct locomotory movements of a population (or distinct component) within some confined time period over relatively long distances. Although migrations of rock lobster populations have been reported for some Palinurid species (Herrnkind *et al. 1973,* Street 1971), no conclusive evidence for migration within *J. novaehollandiae* populations has been found. However, tagged lobsters have exhibited unified long distance movements in the Cape Jaffa area of the South East from 50 km north of Kingston to 40-50 km west of Cape Jaffa. The hypothesis that these movements are related to a response to reproductive stimuli is being investigated, as the movement is from low reproductive to high reproductive areas. I n the low reproductive areas the effects of the cold water incursion discussed above are not relevant, and the proportion of females in the resident population above the size of sexual maturity during the period July-October in the berried state is less than 5%, whilst in the high reproductive areas where the influence of the cold water incursion has been demonstrated, the proportion of reproducing females averages 75%.

Detailed studies of all stages of the life cycle are continuing to better understand this commercially and recreationally sought after species, which has become the unofficial emblem of the South East of South Australia.

REFERENCES

Herrnkind, W. F. (1977). Movement Patterns in Palinurid lobsters. *In* (Eds) Philips, B. F. &Cobb, S. J. Proceedings of Workshop on lobster and rock lobster ecology and physiology. *Circ. Div. Fish. Oceanogr. CSIRO* **7**.

Herrnkind, W. F., Kanciruk, J, Halusky, J. & McLean, R. (1973). Descriptive characterisation of mass autumnal migrations of spiny lobsters, *Panulirus argus. Proc. Gulf. Carib. Fish. Inst.* 25th Ann. Session: 79-98

Holthuis, L. B. (1963). Preliminary descriptions of some new species of Palinuridae. (Crustacea: Decapoda: Macrura: Reptantia). *Proc. Koninkl. nederl. akad. wetensch.* Ser. C., **66**, 54-60.

Lewis, R. K. (1981). Seasonal upwelling along the southeast coastline of South Australia. *Aust. J. Mar. Freshw. Res.* **32**, 843-54.

Phillips, B. F., Cobb, J. S. & George, R. W (1980). General Biology. *In,* Cobb, J. S. & Phillips, B. F. (Eds). The biology and management of lobsters, Vol. I: Physiology and Behaviour.' Chapt. 1: 1-82. (Academic Press, New York).

Silverbauer, B. I. (1971). The biology of the South African rock lobster *Jasus lalandii* (H. Milne Edwards) 1. Development. *Invest. Rep. Sea Fish. Branch* (S. Afr.) **92**, 1-70.

Street, R. J. (1971). Rock Lobster migration off Otago. *Commer. Fish.* **10** (6), 16-17

Winstanley, R. H. (1970). Rock lobster larvae in the Tasman Sea. *Tasm. Fish. Res.* **4***(1), 11-12.*

Winstanley, R. H. (1977). Biology of the southern rock lobster. Victorian southern rock lobster fishery seminar papers; Portland Arts Centre, 910 June 1977. Paper 1, 1-9.

18: Spiders, Scorpions and other Arachnids

by D. C. LEE

The arachnid fauna of the South East, in latitudes higher than 37°S, is even more poorly known than much of the rest of the State (see Lee & Southcott 1979). This fact is well illustrated by a recent general study of Australian scorpions by Koch (1977), in which 11 species were recorded from South Australia but none from this region. However, a superficial study in the last two years has established the presence there of four species of scorpions. Two species may not occur generally since they were only recorded from just inside the region: the 'marbly slim scorpion' *(Lychas marmoreus)-37*° 14' Sand the 'yellow sand scorpion' *(Urodacus armatus)-37*° 04' S. On the other hand, the 'black rock scorpion' *(U manicatus)* is commonly found under limestone rocks around Millicent and across to Bool Lagoon, and the 'wood scorpion' *(Cercophonius squama)* has been recorded twice from under the bark of gum trees beside Ewens Ponds.

Pseudoscorpions are about 1 or 2 mm long and like small scorpions without tails. They are common under rocks and bark, but only two species *(Austrochthonius cavicola* and *Protochelifer naracoortensis)* are recorded, and these are from the Naracoorte Caves. Harvestmen (Opiliones), like spiders but without any division of the body into two parts, usually survive better in relatively humid envi ron ments and native species of the small short-legged triaenonychids have been found but not identified. A larger (about 4 mm long) 'daddy-long legs harvestman' *(Nelima doriae)* which was accidently introduced from southern Europe and is very common in Adelaide gardens, has been found near Mt Gambier.

Very little is known about mites and ticks (Acari) from the region. The only published record of free-Iiving mites of no economic importance is that of *Austruropoda* (ex *Cilliba) coprophila,* a small brown mite which is sometimes very numerous in bat dung in the Naracoorte Caves. The small (less than 1 mm) white mites, *Tyrophagus putrescentiae* and *Glycyphagus domesticus,* which are found on stored food, sometimes in kitchens, have been collected in Mt Gambier. The parasitic mites and the ticks are better known. The 'tea-tree itch mite' *(Eutrombicula sambani)* is locally common in the coastal strip between Kingston and Port MacDonnell. Whilst the nymphs and adults are red, furry and free-living predators on other small animals, the almost invisible larvae probably parasitise marsupials and rabbits and are notorious for producing a rash of small itchy papules on people. Another itch mite *(Psorergates ovis),* which is not closely related, is found on sheep around Mt Gambier. Two mites which are serious pests of broad leafed annual plants are sometimes too common in the region: the 'red-legged earth mite' *(Halotydeus destructor)* and the 'blue oat mite' *(Penthaleus major).* Both are small (about 1 mm long), blackish mites with red legs and a red anus which on the blue oat mite is unusual in being in the middle of its back rather than at the back end (this can be seen with a low-power hand lens). A 'snout mite' *(Bdellodes lapidaria)* has successfully been introduced into the area in order to feed on and so control the lucerne flea.

Probably the most conspicuous Acari are the ticks, all of which suck blood. The most noticed would probably be *Aponomma hydrosauri,* which can be seen on the Stumpy tail and Common Bluetongue Lizards, the fully engorged females looking like grey beans. If you find a dead echidna on the road it may have.a number of the similar *Aponomma concalor* on it. The 'brown dog-tick' *(Rhiphicephalus sanguineus),* previously restricted to the northern parts of South Australia, is now common in Adelaide and has been found in Mt Gambier. There are no records of ticks in the area being found on man. Also the 'poultry tick' *(Argas* nr. *persicus),* which can spread tick fever amongst young chickens in drier parts of South Australia, is not known from the South East.

The spiders of the region are, as elsewhere, a conspicuous part of the arachnid fauna; especially in the case of species which weave webs to snare their prey. Even so, there are very few published records of spiders occurring in the South East and the following account is based mainly on a single six-day collecting trip in April, 1981. At that time of the year many of the species which weave aerial webs to catch flying insects in the dry summer are still about, and it is moist enough for other species, which feed on crawling animals on the ground also to be active. Some spiders collected were sent to colleagues to be identified (Australian Museum-M. R. Gray; Queensland Museum-V. E. Davies, R. J. McKay: University of Western Australia-B. Y. Main). Their initials are placed in parentheses after the scientific name.

Amongst the large primitive snareless ambushing spiders, members of the two South Australian families that are 'brushfooted mygalomorphs' are not recorded, although *Idiommata blackwalli* is known from just outside the region at Lucindale. The 'trapdoor spiders' (Ctenizidae) are only known by the common *Oyarcyops andrewsi* (B.Y.M.) which, like many other so-called trapdoor spiders, does not build a door to its burrow in the ground, although they may be a low pallisade (less than 1.5 cm high) of twigs or leaves around the entrance. All records are from amongst gum trees near Penola and Naracoorte. A male 'mouse spider' *(Missulena inisgnis* - Actinopodidae) was found west of Bool Lagoon. This male is strikingly coloured, being basically black with a red fang-bases, red around its eyes and a dark blue abdomen. The larger, drabber female lives in a burrow with two doors on its entrance that face in opposite directions. The 'tailed mygalomorphs' (Dipluridae) which have a longer terminal segment on the larger spinnerets are well represented around Mt Gambier and further south by the 'pellet spider' *(Stanwellia nebulosa* - B.Y.M.), so named because it makes a soil and silk pellet which it uses as a door to close off the bottom half of its burrow. On the other hand further north amongst gum trees around Penola and Bool Lagoon, two undescribed species of *Aname* (B.Y.M.) were found.

Amongst the advanced snareless ambushing spiders none of the orb-weavers that have lost the ability to make a web such as the bird-dung spider *(Celaenia kinbergi)* were found, although this may reflect the spider's ability to merge with its surroundings. There were many 'crab spiders' (Thomisidae), both the brightly coloured 'flower spiders' *(Oiaea)* which are camouflaged to be inconspicuous on flowers from which they ambush insects and the drabber *Stephanopis* species and *Sidymella trapezia* which are inconspicuous on bark. The latter species is very common where there are trees and has a triangular shaped abdomen. *Tharpyna* species were also found, which, although dark brown flecked with white, can be hard to spot on bark. A small ground spider (less than 1 cm long) belonging to *Segestria,* has a silk-lined burrow and looks something like a miniature version of the tailed mygalomorphs referred to above.

Many of the spiders which hunt out their prey were found. A number of 'lynx spiders' (Oxyopidae) and 'jumping spiders' (Salticidae), which could not be identified, were collected on vegetation. Other jumping spiders, including *Breda jovialis* and *Holoplatys* species, were found under bark. *Delena cancerides* (M.R.G.), a very flattened member of the large spiders in the 'huntsman' family (Sparassidae), was also widespread under the bark of gum trees. The slightly fatter *Isopoda ?leai* (M.R.G.) was found in the Bool Lagoon-Narac·oorte region, as were at least two species of the much fatter *Olios,* a huntsman that may be green rather than brown when immature, and as an adult can have a conspicuous dark shield-shaped marking under the abdomen. Gnaphosidae, both the pencil-shaped 'white-tailed spiders' *(Lampona)* and *Hemicloea* (which are flattened like small, black huntsman spiders) are commonly found under bark as are pale brown small 'purse spiders' (Clubionidae) belonging to *Clubiona* or the longer legged *Chiracanthium.* Other clubionids are found on the ground like the smart, black and white *Supunna* species.

The commonest hunting spiders on the ground are the 'wolf spiders' (Lycosidae) and similar looking spiders from other families, all of which tend to be dull brown and longlegged, capable runners. *Storena* species (Zodariidae) are exceptions to this, because some are shiny with five pale or white spots on their abdomens. Those collected that are not wolf spiders are *Miturga* (Miturgidae), *Hestimodema* (Zoridae-VE.D.) and, near fresh water, *Dolomedes* (Dolomedidae). Of the wolf spiders, *Trochosa martensii* (R.J.M.) was found amongst vegetation at the waters edge, Bool Lagoon, and a species of *Artoria* (R.J.M.) was found near Port MacDonnell. *Pardosa serrata* (R.J.M.) was found near Penola in burrows with a low pallisade of sticks. A number of species of *Lycosa* were collected, but only three were identified. The smallest, *L. speciosa* (R.J.M.), appeared to be common and widespread; the larger, burrowmaking *L. gilberta* (R.J.M.) and *L. godeffroyi* (R.J.M.) were only collected from localities north of Mt Gambier.

The commonest sheet-web-weaving spider is the 'black house spider' *(Badumna robustus,* previously in *Ixeuticus)* which makes a funnel web, spreading out into a vertical sheet of hackled silk from holes around windows, doors and even on cars, as well as in the bark of large gum trees remote from human habitation. A new species of *Forsterina* (M.R.G.) was found on a small horizontal sheet-web at the edge of a grass tussock west of Bool Lagoon. Juveniles of *Baiami ?glenelgi* (.M.R.G.) were found under chunks of limestone south of Mt Gambier. The 'sombrero spider' *(Stiphidium ?facetum*M.R.G.) occurs in small limestone caverns or under rock ledges at a number of places south of Mt Gambier. The horizontal sheet has a wide funnel in the centre which leads directly upwards to the rock, and the long-legged spider darts up this funnel to hide in a crevice if it is disturbed. Males of the conspicuous 'red-and-black spiders' *(Nicodamus),* possibly belonging to more than one species, were found, as well as immature 'platform spiders' *(Corasoides).*

Amongst the tangle-web weaving spiders, only three species were identified to genus or species. Even though many toilets were visited, no 'daddy-long-legs spiders' *(Pholcus phalangioides)* were seen, although a relative *(Physocyclus* sp.) was found under gum tree bark. The 'grey house spider' *(Achaearanea tepidariorum)* was common around human habitation. 'Red-back spiders' *(Latrodectus hasselti)* were found, but they did not appear to be common.

The orb-weaving spiders include the 'humpback spiders' (Uloboridae) which have hackled, rather than sticky silk. The orbs are small and the supporting strands may be so long and numerous that the webs look more like those of tangle-web weaving spiders. Members of this family were only seen around buildings in the Naracoorte Cave Reserve. One female of *Nephila edulis* (V.E.D.), a large 'golden-orb weaver', was found in the Dingley Dell National Pleasure Resort. Other striking species of Araneidae are only known from a few specimens. A female 'silver-and-gold spider' *(Argiope ?trifasciata-V.E.D.)* was found by a swamp near Wandilo. A few females of the 'night orb-weaver' *(Eriophora biapicata-V.E.D.)* were collected near Naracoorte. This species is so named because it usually eats its web in the morning and spins it again at night. Similarly a few adults of the 'goats-head orb-weaver' *(Eriophora heroine*V.E.D.) were collected from north of Mt Gambier, many young immature stages of the 'lumpy orb-weaver' *(Eriophora pustulosa* V.E.D.) were collected during the April trip. A number of the less striking *Araneus* species have been collected, some of which cannot be identified, probably being new species, but *Araneus arenaceus,* A.. *eburnus* and A. *fulginatus* (V.E.D.) have been identified. Whilst many orb-weavers have a globular or pear-shaped abdomen, some are more sticklike in shape. A species of 'long-jawed spider' *(Tetragnatha),* which looks very stick-like with its long front legs pushed out together in front of it, has been collected beside Ewens Ponds. Also the 'scorpion-tailed spider' *(Arachnura higginsi)* has been found in a Mt Gambier garden. In the more exposed areas, especially the sand-dune heaths in the north, the small and attractive but spiny 'jewel spider' *(Gastera.cantha minax)* is common and may be found in dense aggregates on low shrubs or herbs, with the support strands to the small orb webs attached to the neighbour's web to form an interconnection system of silk. A very common species amongst gum trees is the 'leaf-tolling spider' *(Phonognatha graeffi)* which lives in a rolled-up gum leaf in a space left by a missing sector in the upper part of its orb web.

REFERENCES

Koch, L. E. (1977). The taxonomy, geographic distribution and evolutionary radiation of Australo-papuan scorpions. *Rec.* W. *Aust. Mus.* 5(2): 83-367.

Lee, D. C. & Southcott, R. V. (1979). Spiders and other arachnids of South Australia. *In* 'South Australian Year Book, 1979', pp. 29-43, Bureau of Statistics, Adelaide, *(and* as a separate booklet), (Govt Printer, Adelaide).

19: Terrestrial and Freshwater Invertebrates, excluding Insects and Arachnids

by W. ZEIDLER

INTRODUCTION

The South East has many drains, swamps, sinkholes and creeks which are nearly always full of water and harbour a great variety of animals, some of which are not found elsewhere in the State. Ewens Ponds and Piccaninnie Ponds are especially significant freshwater environments and include invertebrates usually hot found together in any other habitat. The terrestrial invertebrate fauna is also quite plentiful and diverse because the South East is relatively cooler, and has a much higher rainfall than the rest of the State

The faunas of the South East and western Victoria are similar and in the past may have been connected by water, so allowing the aquatic fauna to spread. The remaining waterholes, swamps and drains now form refuges for a once more widespread fauna and are threatened by any further drainage or agricultural development.

Despite the considerable incursion of man, the fauna of the South East is still plentiful and diverse, especially wherever native vegetation still exists. The invertebrate fauna is so diverse that an adequate coverage is beyond the scope of this chapter and only some of the more common groups are noted. Those interested in freshwater life generally should consult Williams (1980) who gives keys, illustrations and a valuable bibliography.

SPONGES

There is a number of freshwater sponges and, although they do not form large structures like their marine counterparts, they can form incrustations several metres wide. The identity of the species in the South East is not known, and there may be several species amongst those commonly occurring on rocks and debris in most drains and sinkholes. They are usually dull grey or brown and form small incrustations usually less than 2 cm deep.

Most sponges are found in the sheltered shallower parts of creeks and waterholes, although some specimens have been collected from a depth of 40 m in some of the sinkholes. Racek (1969) gives keys and descriptions for the Australian species but does not record any from the South East.

ANNELIDS

LEECHES

Leeches are easily distinguished from other worm-like animals as they have a sucker at each end of the body. Very little is known about Australian leeches and indentification often requires expert dissection to determine the arrangement of the reproductive and alimentary systems. There are several species in the South East; they occur in most of the drains and creeks but are particularly abundant in the swamps. The most common and widespread species is *Richardsonianus australis* which is relatively large reaching a length of 10 cm or more and easily recognised by its colour pattern which is yellowish with dark brown longitudinal stripes. This species is also common in the streams and dams of metropolitan Adelaide.

EARTHWORMS

The moist and cooler environment of the South East and the rich volcanic soils there create an ideal habitat for earthworms. The indigenous species belong to the family Megascolecidae and these are usually found in native scrub areas or along the outer edge of pine forests. Jamieson (1974) who reviewed the South Australian species only recorded seven from the South East and it is likely that further species could be found.

The introduced *Lumbricus* sp. and *Allolobophora* sp. family Lumbricidae are common in the paddocks and gardens near settled areas.

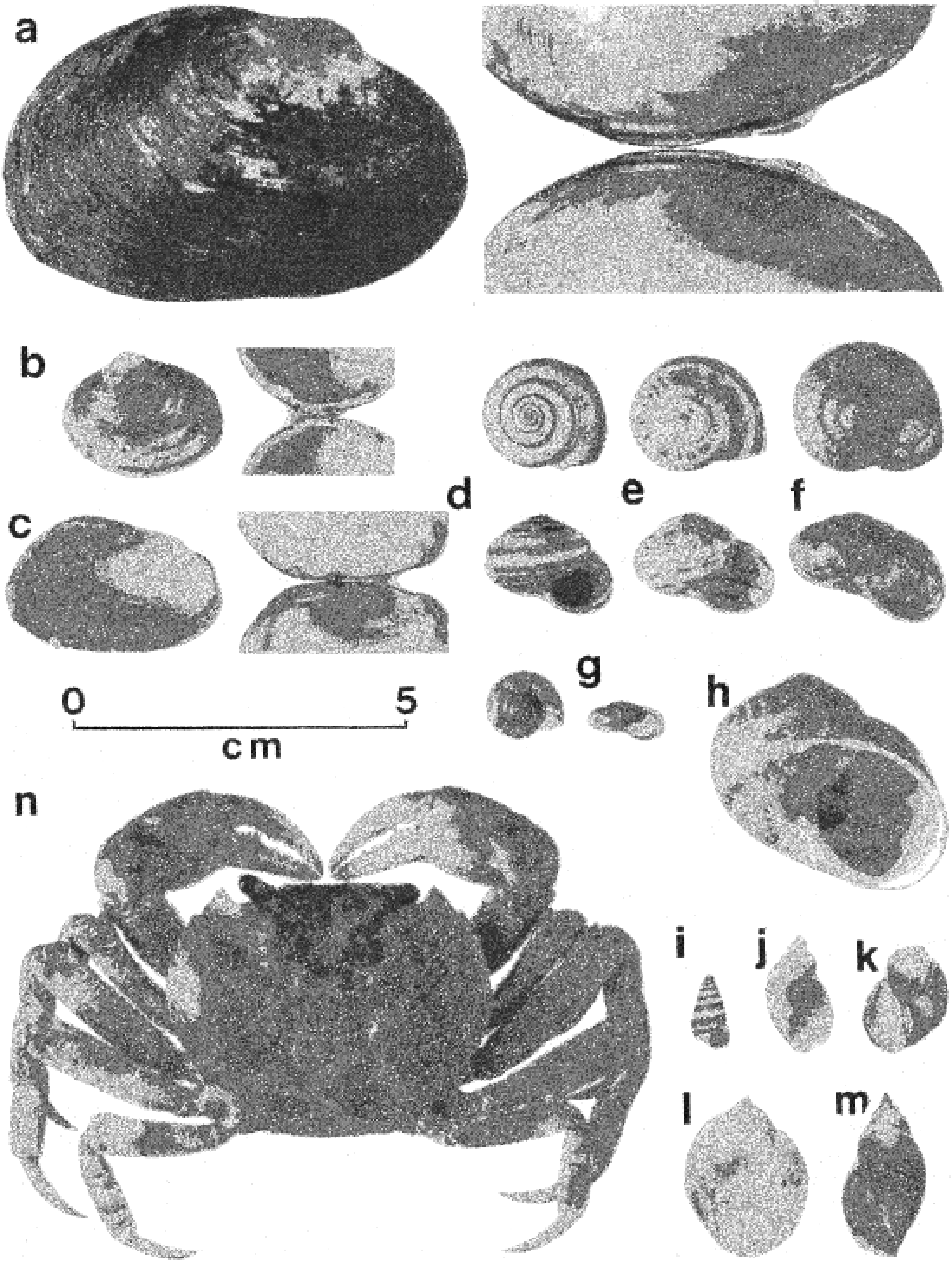


Fig. 1. (a) *Velesunio ambiguus;* (b) *Corbiculina australis;* (c) *Hydridella (Hydridella) narracanensis;* (d) *Cernuella (Cernuella) virgata;* (e) *Theba pisana;* (f) *Strangesta gawleri;* (g) *Oxychilus cellarius;* (h) *Helix (Cryptomphalus) aspersa;* (i) *Cochicella ventrosa;* (j) *Succinea (Austrosuccinea) australis;* (k) *Isidorella newcombi;* (l) *Austropeplea lessoni;* (m) *Physastra gibbosa;* (n) *Leptograpsodes octodentatus.*

MOLLUSCS

The South East is an ideal habitat for molluscs and the fauna is diverse and plentiful. Only the more common species are noted here and further information can be obtained from Smith & Kershaw's (1979) excellent account of the molluscs of southeastern Australia.

BIVALVES

Most bivalves are usually almost buried in mud or sand, although empty shells are readily found on river banks or around the edges of waterholes. The larger live bivalves are easily located by feeling for them with the hand or foot, especially in the quiet shallows of creeks. One of the largest bivalves found in the South East is the freshwater mussel *Velesunio ambiguus* (Fig. 1a) which can grow up to 10 cm in length. It is relatively common and widespread throughout south-eastern Australia and is easily found in larger streams such as Mosquito Creek and Naracoorte Creek. The shell is variable but usually eroded near the hinge. Like most Australian freshwater mussels, it is able to withstand periods of drought by burying in mud.

A species similar to the preceding one, *Hydridella (Hydridella) narracanensis* (Fig. 1c), previously only known from the coastal rivers of central Victoria and the South Esk River system of northern Tasmania, recently has been discovered in Eight Mile Creek: a new record for South Australia. The shell is slightly smaller than *V. ambiguus,* usually only 20-60 mm across, is not as thick and has a strong V-shaped sculpture near the hinge. This species seems to form an isolated population in Eight Mile Creek and its presence in the South East provides more evidence for a past aquatic link with southwestern Victoria.

Another species often found with *V. ambiguus* is *Corbiculina australis* (Fig. 1 b). It is common throughout the south-eastern Australian mainland, and is often abundant in the sand of rivers and creeks. Empty shells are frequently found on river banks, particularly along Mosquito Creek. The species tends to prefer fast flowing water and is often found fouling pipes and drainage systems. The shell is thick and oval with a diameter of 15-25 mm. The exterior of the shell is brownish, shiny but with a sculpture of prominent concentric ridges and is eroded near the hinge. Internally the shell is yellow to pink to purple.

Probably the most common yet inconspicuous bivalve in the South East is the pea-shell *Sphaerium (Musculium) tasmanicum* (Fig. 2a). It is small and fragile and often very abundant in the mud of streams, ponds, sinkholes etc., particularly in still waters with weed. The shell rarely exceeds 10 mm diameter. It is white with a sculpture of fine concentric growth lines and round, with the hinge centrally placed. A slightly smaller (5 mm) similar species *Pisidium casertanum,* has the hinge to one side and lacks sculpture. It may be found in similar habitats although it does not seem to be very common there.

LIMPETS

There are a number of freshwater limpets forming a significant part of the freshwater fauna of Australia. They are usually less than 5 mm across, and well camouflaged. Limpets are usually found attached to dead vegetable matter, reeds and the under-surface of rocks. Only one species *(Ferrissia (Pettancylus) petterdi* Fig. 2b) has been found in the South East, but the similar *F. (P.) tasmanica* which has the apex situated more posteriorly may also be present.

FRESHWATER SNAILS

The snails are probably the most conspicuous part of the freshwater fauna and several species occur in the South East. Most are found clinging to weed, reeds, submerged logs and debris and even rocks. Dead shells are often found in dry creek beds and swamps, where scraping away the dried vegetation will often reveal many shells.

The freshwater snails of the South East occupy three groups: the moderately large, non-operculate snails, the relatively small, operculate, black, river snails and the very small, planispiral snails. Of the large, nonoperculate snails, three species: *Austropeplea lessoni* (Fig. 11), *Physastra gibbosa* (Fig. 1 m) and *Isidorella newcombi* (Fig. 1 k) are relatively common especially in billabongs and slow flowing creeks and pools. These are similar in shape, but *L. lessoni* has a dextral aperture and P. *gibbosa,* while similar to *I. newcombi,* has a much more elongated shell and aperture. *I. newcombi* was originally described from central Australia and appears to be able to survive dry periods buried in mud even though it lacks an operculum.

The most common black river snail is *Potamopyrgus niger* (Fig. 2e). It is usually·

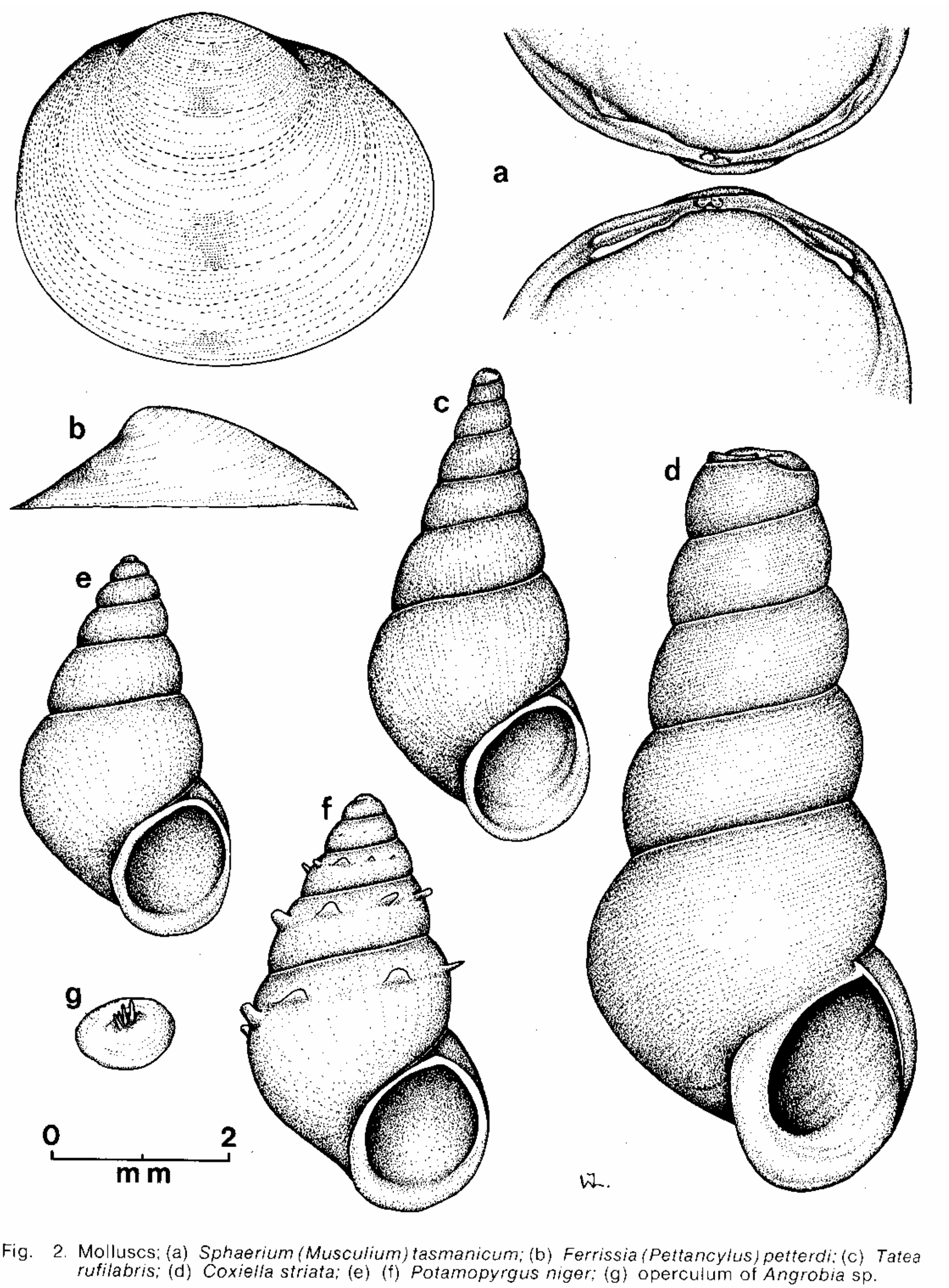


Fig. 2. Molluscs; (a) *Sphaerium (Musculium) tasmanicum;* (b) *Ferrissia (Pettancylus) petterdi;* (c) *Tatea rufilabris;* (d) *Coxiella striata;* (e) (f) *Potamopyrgus niger;* (g) operculum of *Angrobia* sp.

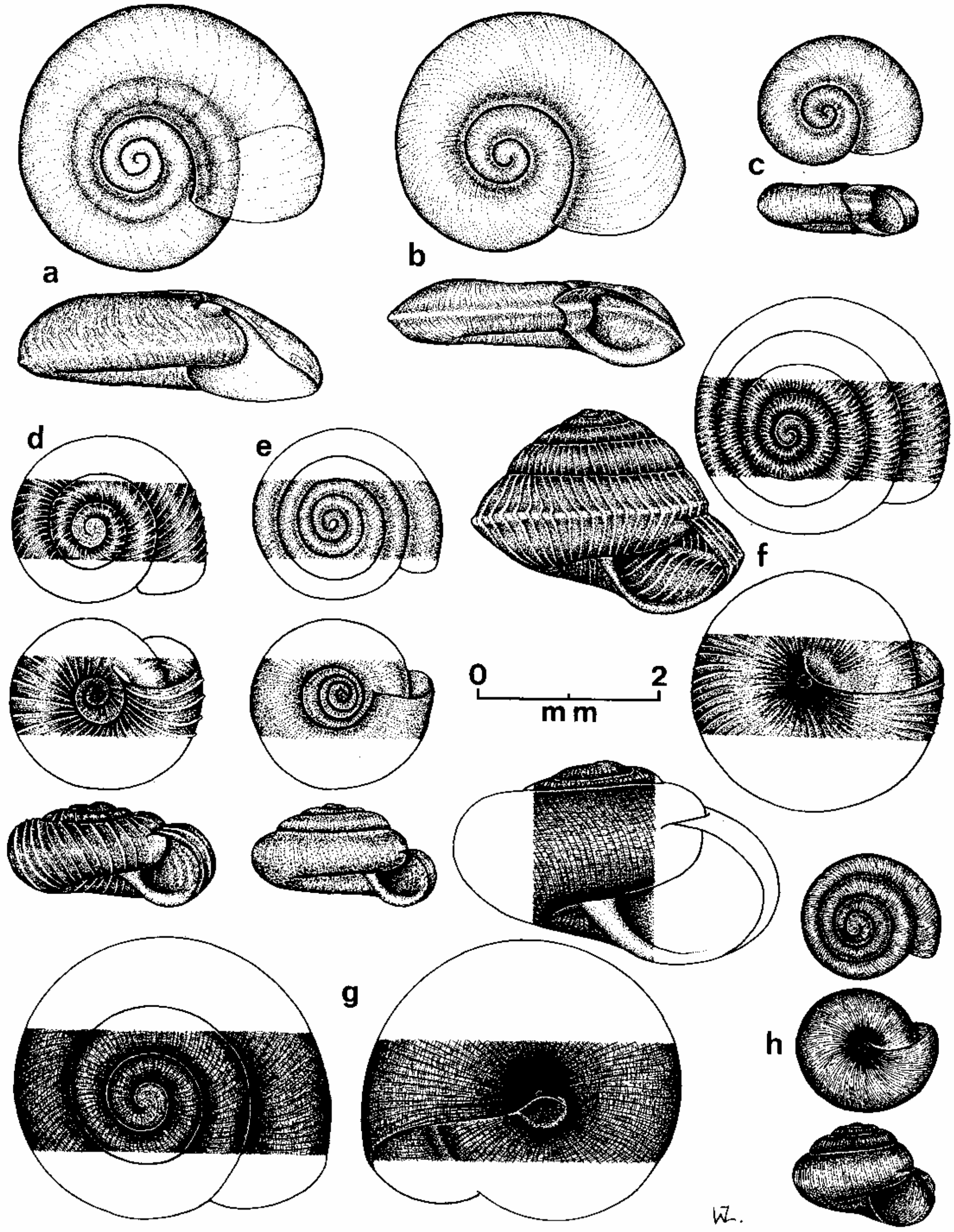


Fig. 3. Molluscs; (a) *Helicorbis victoriae;* (b) *Gyraulus tasmanicus;* (c) *Gyraulus scottianus;* (d) *Paralaoma caputspinulae;* (e) *Laomavix collisi;* (f) *Magilaoma penolensis;* (g) *Excellaoma retipora;* (h) *Miselaoma parvissima.*

attached to weed in small creeks and a variety with a series of large spines on each whorl (Fig. 2f) is relatively common. Another species, *Angrobia* sp., which is almost identical to the smooth form of *P. niger* may be found in similar habitats, but it is easily recognised by the prominent four-pronged peg on the inside of the operculum (Fig. 2g) for muscle insertion. Along the coast in the estuarine sections of creeks is *Tatea rufilabris* (Fig. 2c), which is also similar to *P. niger* but distinguished by having a high, pointed spire and an operculum with a three-pronged peg. It is also appropriate to mention here the pink salt lake snail *Coxiella striata* (Fig. 2d) of inland salt lakes particularly along the coast between Beachport and Robe. *Coxiella* is sometimes so numerous that dead shells mount up around the lake edges giving it a pink appearance.

The planispiral snails are often abundant although usually less than 5 mm in diameter. All of these snai ls have a characteristic sunken spire and are restricted to swamps, ponds and the backwaters of creeks. They are usually found on weed or stones but dead shells can easily be collected in dried swamps or creek beds by carefully searching through the dried vegetation. At least three species are common in the South East: *Helicorbis victoriae* (Fig. 3a) which has a smooth glossy shell with a keel on the ventral margin of the main whorl and prefers duck-weed; *Gyraulus tasmanicus* (Fig. 3b) which has a shell with a fine axial sculpture and rounded keel near the middle of the main whorl, and G. *scottianus* (Fig. 3c) which is similar to G. *tasmanicus* but much smaller, usually less than 2 mm in diameter, and is not keeled.

INTRODUCED LAND SNAILS

Land snails were introduced from Europe during early settlement. Most of these species are considered garden and horticultural pests and are very common in urban areas and along the sides of arterial roads. Only the most common species will be considered here.

The largest and best known species is the common garden snail *Helix (Cryptomphalus) aspersa* (Fig. 1h) which can be a severe pest in any garden or crop. A slightly smaller species *Theba pisana* (Fig. 1e) is also common and can be very numerous, and is as much a pest as *H. aspersa,* particularly on vines. Another similar species *Cernuella (Cernuella) virgata* (Fig. 1d), recognised by the unbroken brown concentric bands on the shell, and is also a crop pest and in dry areas can sometimes be found in great numbers, sealed onto posts, trees and other vegetation. A smaller, conical shaped snail, *Cochlicella ventrosa* (Fig. 1i), is also an agricultural pest but it tends to hide under ground-cover plants, or underneath leaves and stems close to the ground.

The introduced snail *Oxychilus cellarius* (Fig. 19) is regarded a beneficial introduction as it feeds on non-green vegetable matter and on small animals such as pest species of molluscs. It is usually found in the same habitats as C. *ventrosa.* This species and others like it have very thin, glossy and transparent to translucent shells and are sometimes known as 'glass snails'. The similar but slightly smaller *Oxychilus alliarius* may be encountered in similar habitats. It can be distinguished by the black animal and garlic smell when crushed. The animal of O. *cellarius* is pale grey with brown speckles on the mantle edge.

NATIVE LAND SNAILS

The native land snails in the South East are not often collected as they are often small, and usually only found in conjunction with native vegetation. *Strangesta gawleri* (Fig. 11) is probably the largest species and is found under ground cover and logs, particularly in moist situations. Its shell is glossy, particularly on the lower surface and is coloured dark honey to reddish-brown with yellow underneath. It is probably carnivorous, feeding on other animals such as molluscs and insect larvae. In the mal lee scrub or semidesert areas exists the quite small, distinctive *Pupilla australis* (Fig. 4c), under logs or in rock crevices. Several similar species are found in the drier areas of the State but *P. australis* seems to be the only species of Pupillidae found in the South East. *Succinea (Austrosuccinea) australis* (Fig. 1j) is often confused with freshwater species such as *Austropeplea lessoni* because of the similar shell shape and because it is often found in semi-aquatic situations. However, it can also be found underneath logs and in rock crevices in quite dry areas. The shell is rather thin with an elongated spire. It is amber when the animal is alive but bleaches white when dead.

The remaining land snails dealt with here are the endodonts which belong to the families Punctidae and Charopidae. All small with a complex array of shell sculpture and patterns. The systematics of this group is not

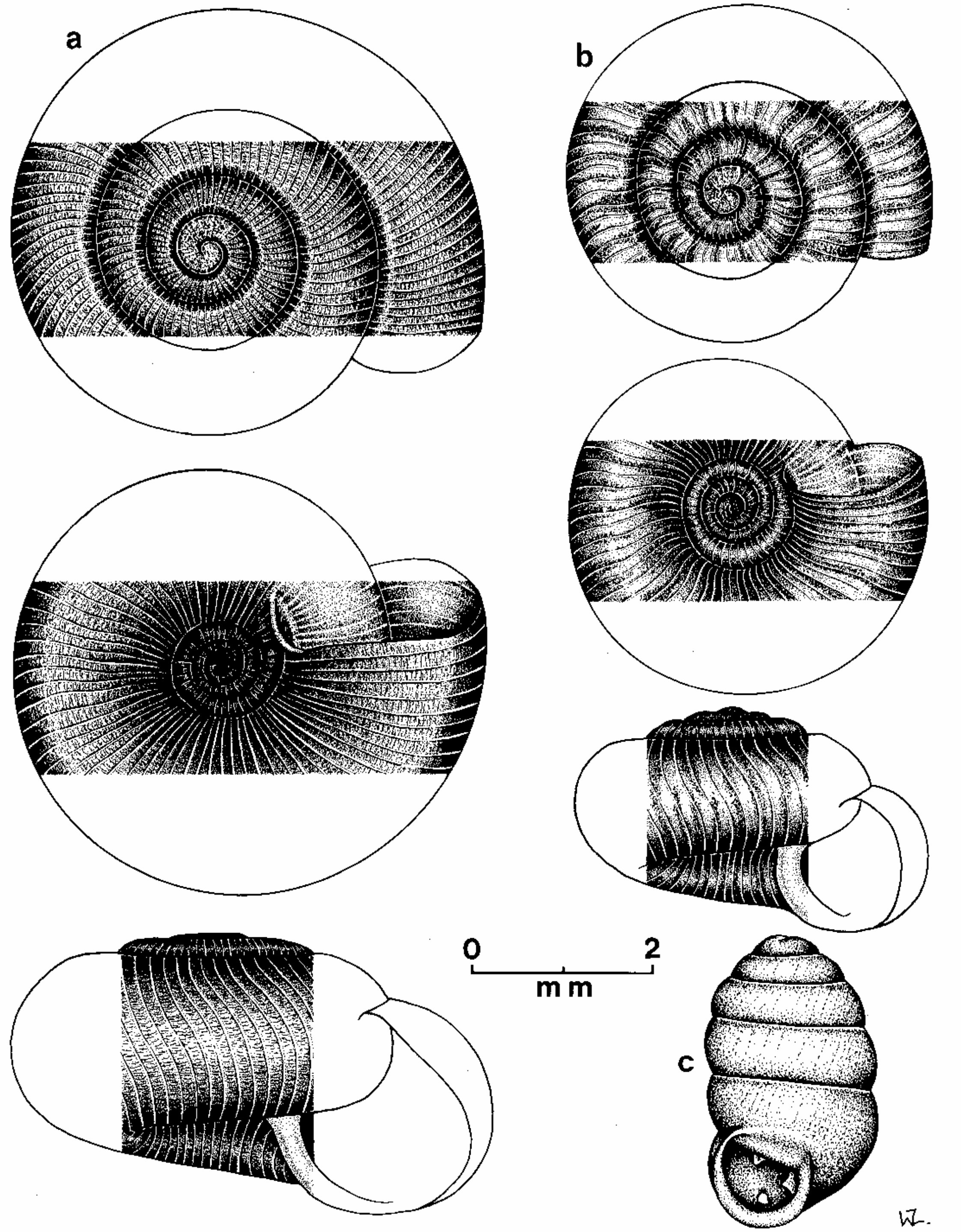


Fig. 4. Molluscs; (a) *Elsothera* sp.; (b) *Pernagera* sp.; (c) *Pupilla australis*.

well understood and their small size makes them difficult to study. The endodonts are *very* common in south-eastern Australia and many new species probably await discovery.

The Punctidae is probably the most interesting group as there are many different forms and most species are extremely small, often less than 2 mm in diameter when mature. One of the most common is *Paralaoma caputspinulae* (Fig. 3d) which is recognised by the bold ribbed sculpture on the shell. It is often abundant under bark and litter at the base of trees. The similar but slightly smaller *Laomavix collisi* (Fig. 3e), has a faintly sculptured shell and is also common and found in similar habitats. Another small species, *Miselaoma parvissima* (Fig. 3h), has been collected also from the South East recently. This is probably the first time that it has been recorded from South Australia. The shell is more turbinate than the preceding two species and the umbilicus (opening at base of shell) is minute. It is found in moss and litter, preferably in moist conditions. Another common and widespread species to be found in litter and moss is *Magilaoma penolensis* (Fig. 3f). It is slightly larger than the preceding three species and is easily recognised by the *convex* spire of the shell, the small umbilicus and the distinct peripheral keel. Probably one of the largest Punctidae in the South East is *Excellaoma retipara* (Fig. 3g) which can reach a diameter of about 6 mm. It is not particularly common but can be found in large numbers at times in litter in dry scrub areas. The shell sculpture consists of *very* close bold radial ribs and faint broken spiral lines, and the umbilicus is almost closed.

The Charopidae is also a *very* diverse group with many species occurring in south-eastern Australia but only a few are found in the South East. Two species, *Eisathera* sp. (Fig. 4a), and *Pernagera* sp. (Fig. 4b), are most likely to be encountered, particularly under rocks and litter in drier woodland areas. Both *have* a shell sculpture of close radial riblets but *Eisothera* sp. is uniformly light brown, whereas *Pernagera* sp. is distinguished by irregular dark brown rays on both sides of the shell.

SLUGS

All of the species of slugs found in the South East have been introduced, mainly from Europe, and probably on machinery, stock plants, etc. during early settlement. Slugs are usually found in *very* damp situations but they are *very* resistant *ta* adverse environmental conditions and, because they are able to seek refuge in *very* small crevices, they are able to withstand the Australian summer. At least six species *have* been found: *Milax gagates, Limax maximus, Deroceras reticulatum, D. panormitanum, Lehmannia (Lehmannia) nyctelia* and *L. (Limacus) flava.* They are not always easy to distinguish and more detail is provided by Altena & Smith (1975) and Smith & Kershaw (1979).

CRUSTACEANS

Of the many crustacean species found in the South East, only the more common or interesting species are mentioned here. Williams (1980) gives keys and references to all of the major groups.

SVNCARIDS

Syncarids are small centipede-like crustaceans that live in still surface and underground waters. They *have* only recently been found in the South East and this constitutes the first record from South Australia. They are regarded by some as the most primitive crustaceans, and fossils very similar to living species are known from the Triassic (about 180 million years ago). They are, therefore, one of the most interesting freshwater invertebrate groups in Australian inland waters. Most species have been discovered in Tasmania but a few *have* also been found in Victoria. The South East species, an undescribed *Koanunga* (Fig. 7a) has been found in sinkholes south of Mt Gambier and near Tantanoola. Apart from being a new record for the State this is a particularly exciting discovery as *Koonunga* species usually inhabit shallow surface waters, and the South East species occurs in sinkholes. Although specimens are usually found near the surface some have been collected from a depth of 40 m. The South East species has a body length of about 2 cm which is at least twice the size of *K. cursor,* which is the only previously known species.

ISOPODS

The isopods are a *very* diverse group of animals occupying marine, freshwater and terrestrial habitats and some forms are *even* parasitic. The most familiar are the slaters found in gardens and under logs and debris in almost any moist situation. The moist environment of the South East is particularly favourable for slaters and many undescribed

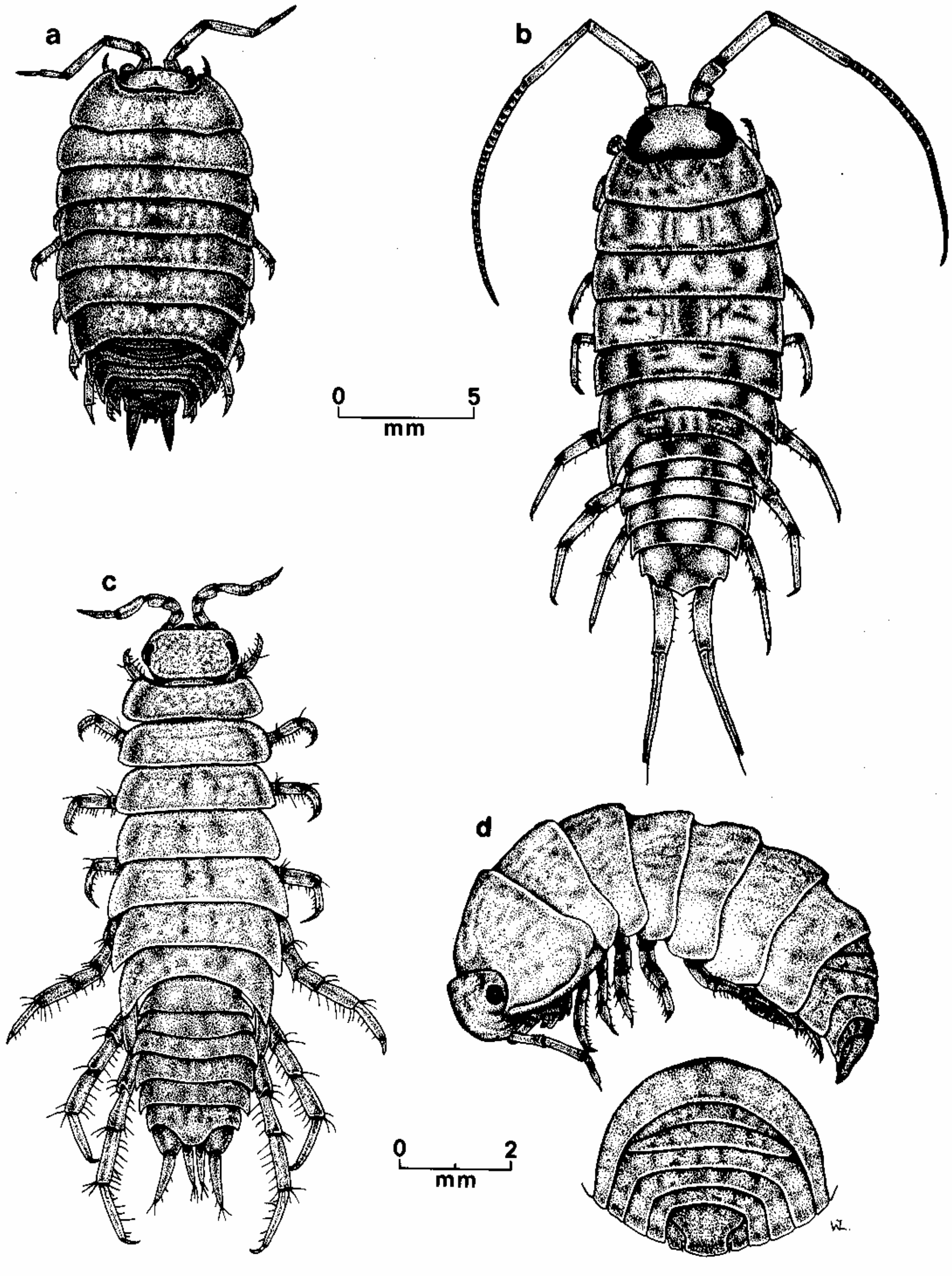


Fig. 5. Isopods; (a) *Porcellio laevis;* (b) *Ligia australiensis;* (c) *Haloniscus searlei;* (d) *Buddelundia albinogrisescens.*

species are known to occur throughout the area, particularly in places with native vegetation. Introduced species are difficult to distinguish from native ones but in general the native species tend to roll into a protective ball when disturbed, whereas the introduced ones run for cover. The most common and widespread introduced species is *Porcellio laevis* (Fig. 5a) which is abundant under debris in gardens and elsewhere. The systematics of the native species is not well known but one of the more common ones found in the South East is *Buddelundia albinogrisescens* (Fig. 5d) which is recognised by the distinct lateral groove on the first thoracic segment and by the short telson. Near the sea-shore, particularly under rocks at the high tide level, is a slightly different isopod, the swift beach louse, *Ligia australiensis* (Fig. 5b). It moves quickly for cover when disturbed and is easily distinguished from other species by its long antennae and uropods and its larger size

Freshwater isopods have not been recorded but it is likely that *Heterias* species, which are very small, are in some ofthecreeks. However, a very interesting aquatic isopod, *Haloniscus searlei* (Fig. 5c), is found in the salt lakes between Beachport and Robe. It looks just like a normal slater but unlike the other members of the family Oniscoidae lives submersed in water. Living in salt lakes subject to periodic inundation with freshwater, *H. searlei* is able to tolerate a wide range of salinities.

AMPHIPODS

These also belong to an extremely diverse group and, although most are marine, there are a great many freshwater and terrestrial species in southern Australia. They are closely related to the isopods, but the body tends to be laterally compressed rather than horizontally flattened. Most species are also sexually dimorphic with the first two pairs of legs being more developed in the male.

The taxonomy of Australian amphipods is confused and in need of revision and many new species await description. There are several freshwater species in the South East but the most common is *Austrochiltonia australis* (Fig. 6b) which is also one of the most widely dispersed species in southern Austral ia. *A. australis* is very abundant in weed in the still waters of creeks or ponds, and is greenish to orange in life. It is only about 5 mm in body length. A similar species, *A. subtenuis,* differs mainly in having a third uropod (Fig. 6c arrowed) with only one segment, and also occurs with *A. australis* but is not as common Another relatively common and slightly larger, freshwater species is *Gammarus haasei* (Fig 6a), but it is not as abundant or as widespread as *A. australis.* This species is easily recognised by the accessory flagellum on the first antenna and by the lack of eyes.

There are many kinds of terrestrial amphipods or land hoppers in the South East and most seem to be undescribed. They are usually found under debris and litter in moist conditions such as on river banks and in dried swamps, and can be very numerous. However, they are quick to seek refuge, and this combined with their smooth, shiny exoskeleton makes them difficult animals to catch. One of the most common species is illustrated in Figure 6c but it is an undescribed species of a new genus awaiting publication.

SHRIMPS

Only one species of freshwater shrimp, *Paratya australiensis* (Fig. 7b), is known from the South East. It is widespread, and abundant in streams and waterholes of southern and south-eastern Australia and Tasmania In the South East it is particularly abundant in Mosquito Creek and the coastal waterways between Port MacDonnell and Victoria. It has a body length rarely exceeding 35 mm; and is therefore of little economic importance.

FRESHWATER CRAYFISH

About 100 different species of yabbies are endemic to Australia (Riek 1969). The yabbie fauna of the South East is surprisingly diverse and resembles closely the fauna of southwestern Victoria. Apart from the *Cherax* species, which was already well known from that area, recent collections have located species of *Euastacus, Geocharax, Engaeus* and *Gramastacus* (Zeidler 1982). Yabbies in the sinkholes often occur at considerable depths: *Cherax* has been collected from a depth of more than 30 m: probably the deepest record for any Australian freshwater crayfish There also have been several sightings of white yabbies but they have not been substantiated with specimens, and it is likely that they were white forms of *Cherax,* as the colour of these species is very variable and very pale forms are known from limestone areas. Because of interest in yabbies the different genera will be treated in more detail and the brief generic diagnoses, discussion and accompanying figures should permit identification. However, as the systematics of

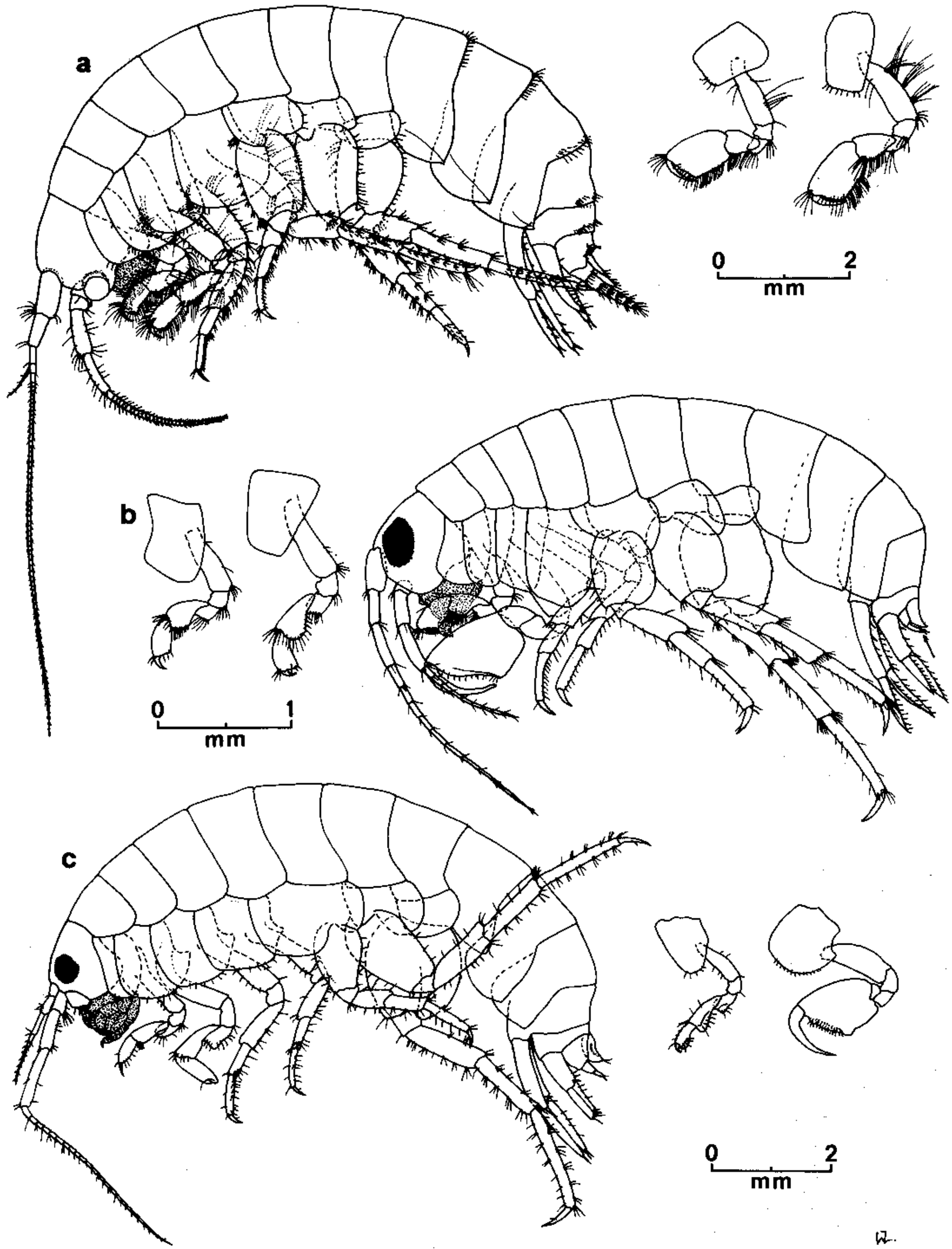


Fig. 6. Amphipods; (a) *Gammarus haasei* ♀, gnathopods 1+2 ♂, (b) *Austrochiltonia australis* ♂, gnathopods 1+2 ♂, (c) undescribed land-hopper ♀, gnathopods 1+2 ♂. (Pleopods not illustrated).

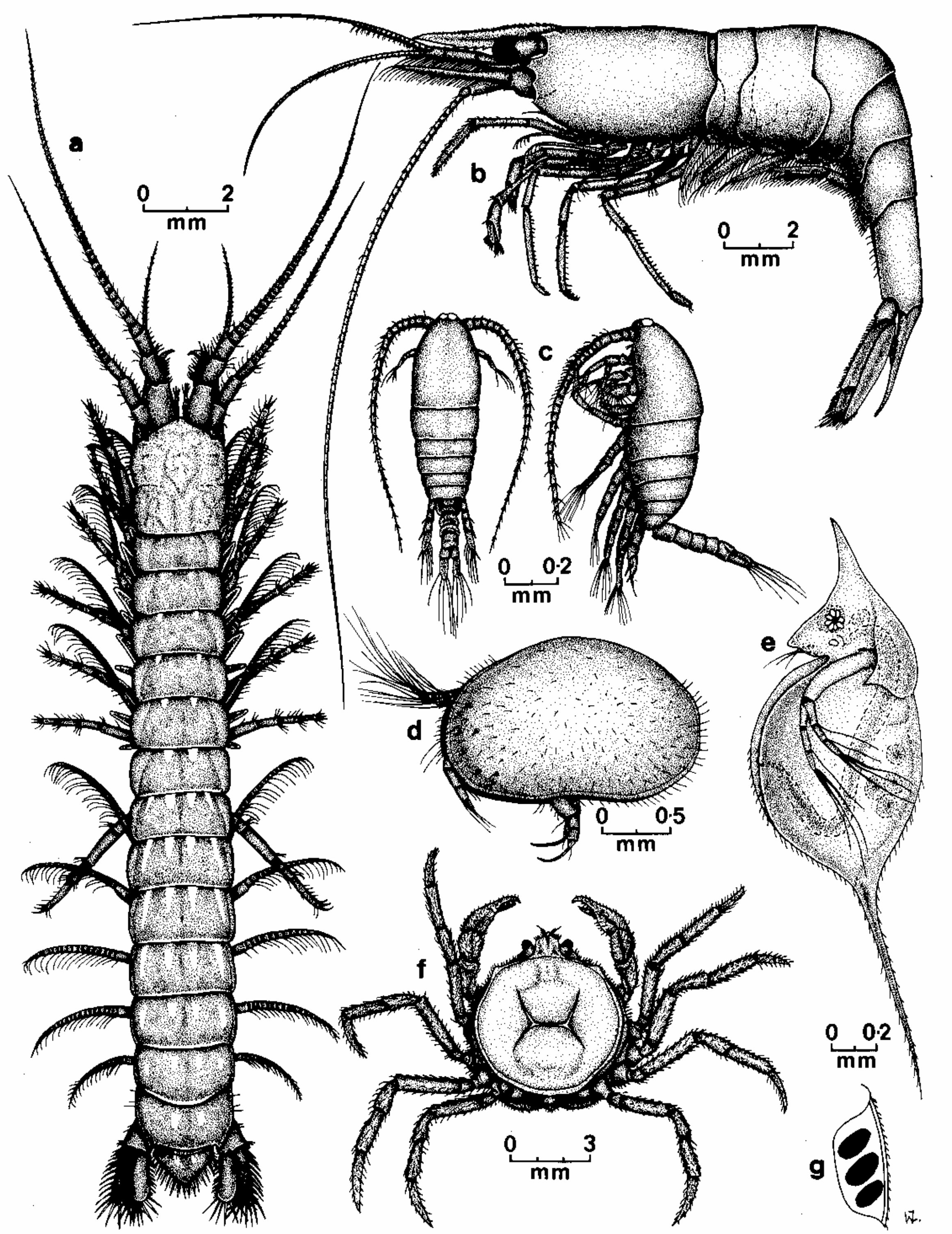


Fig. 7. Various Crustaceans; (a) *Koonunga* sp. (Syncarid); (b) *Paratya australiensis* (shrimp); (c) *Calamoecia salina* (copepod); (d) *Eucypris vireus* (ostracod); (e) *Daphnia lumholtzi* (cladoceran); (f) *Amarinus lacustris* (crab); (g) resting egg of cladoceran, *D. lumholtzi*.

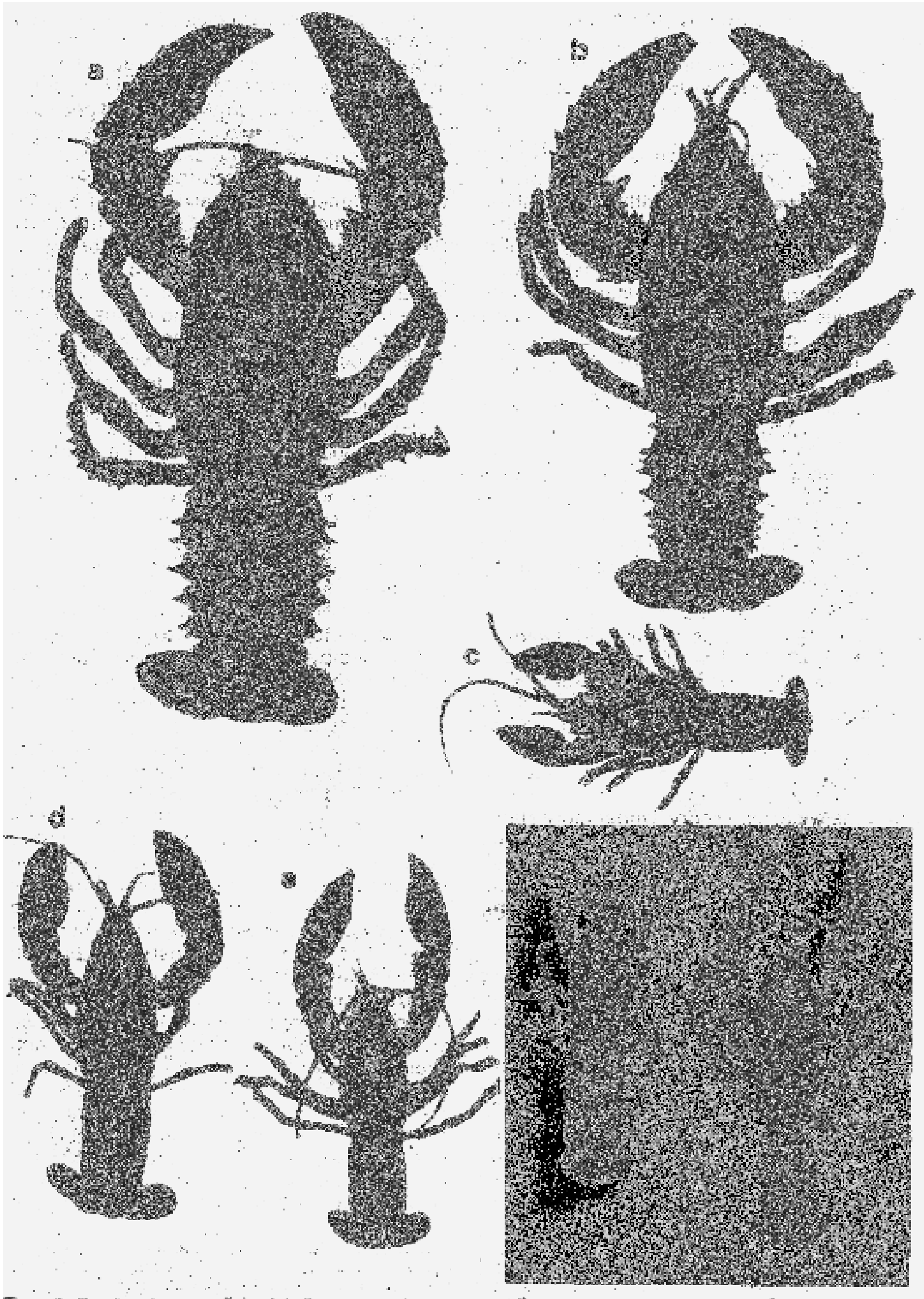


Fig. 8. Freshwater crayfish; (a) *Euastacus bispinosus* (♂, 18 cm); (b) *E. armatus* (♂, 15 cm); (c) *E. bispinosus* (♀, 8 cm); (d) *Cherax* sp. (♂, 12 cm); (e) *Geocherax* sp. (♂, 5.5 cm); (f) *Gramastacus* sp. (♂, 2.5 cm); (g) *Engaeus* sp. (♀, 5.2 cm).

this group is currently being revised, no attempt has been made to assign species names. More information on Austral ian freshwater crayfish may be found in papers by Clark (1936, 1939, 1941a,b) and Riek (1969, 1972).

Cherax:- Brief diagnosis.-Carapace usually smooth, about as high as broad; cervical groove fused with anterolateral extension of branchiocardiac groove rather high on carapace; postorbital ridges variable but usually not well developed. Chela (claws) move in horizontal plane, usually smooth, sometimes with tufts of hairs along the inside edge and between fingers. Telson with posterior portion membranous, easily giving way when pushed gently.

Cherax (Figs 8d, 9f) is easily distinguished from other genera by the smooth carapace, cervical and branchiocardiac grooves (Fig. 9d) and telson. Juveniles could be confused with *Gramastacus* or juvenile *Geocharax* and a qu ick test is to gently push the tel son or try to discern the grooves on the carapace. In the South East only one species of *Cherax* seems to be present; it was previously referred to C. *destructor* or C. *albidus* and is abundant in most of the drains, streams and swamps. Surprisingly it seems to be absent from apparently suitable habitat between Port MacDonnell and Victoria where the other genera mentioned here can be found. *Cherax* species are moderate burrowers and can be found in very deep burrows, often in excess of 1 m, especially when the water level is low or when the waterhole is dry. Under more stable conditions they seek refuge in crevices under submerged logs, rocks or debris. They can attai n a total length of about 16 cm and are considered good eating and suitable for aquaculture.

Engaeus:- Brief diagnosis.-Carapace smooth or minutely tuberculate with short bristles, laterally compressed; cervical groove widely separate from branchiocardiac groove joining it abruptly near middle of lateral side; postorbital ridges obsolete. Eyes relatively small, close together. Rostrum short, distinct constriction between carapace and abdomen. Chela move in vertical plane, often covered with bristles of varying lengths but tufts of hairs usually absent except for region near fingers in some species. Telson entirely calcified.

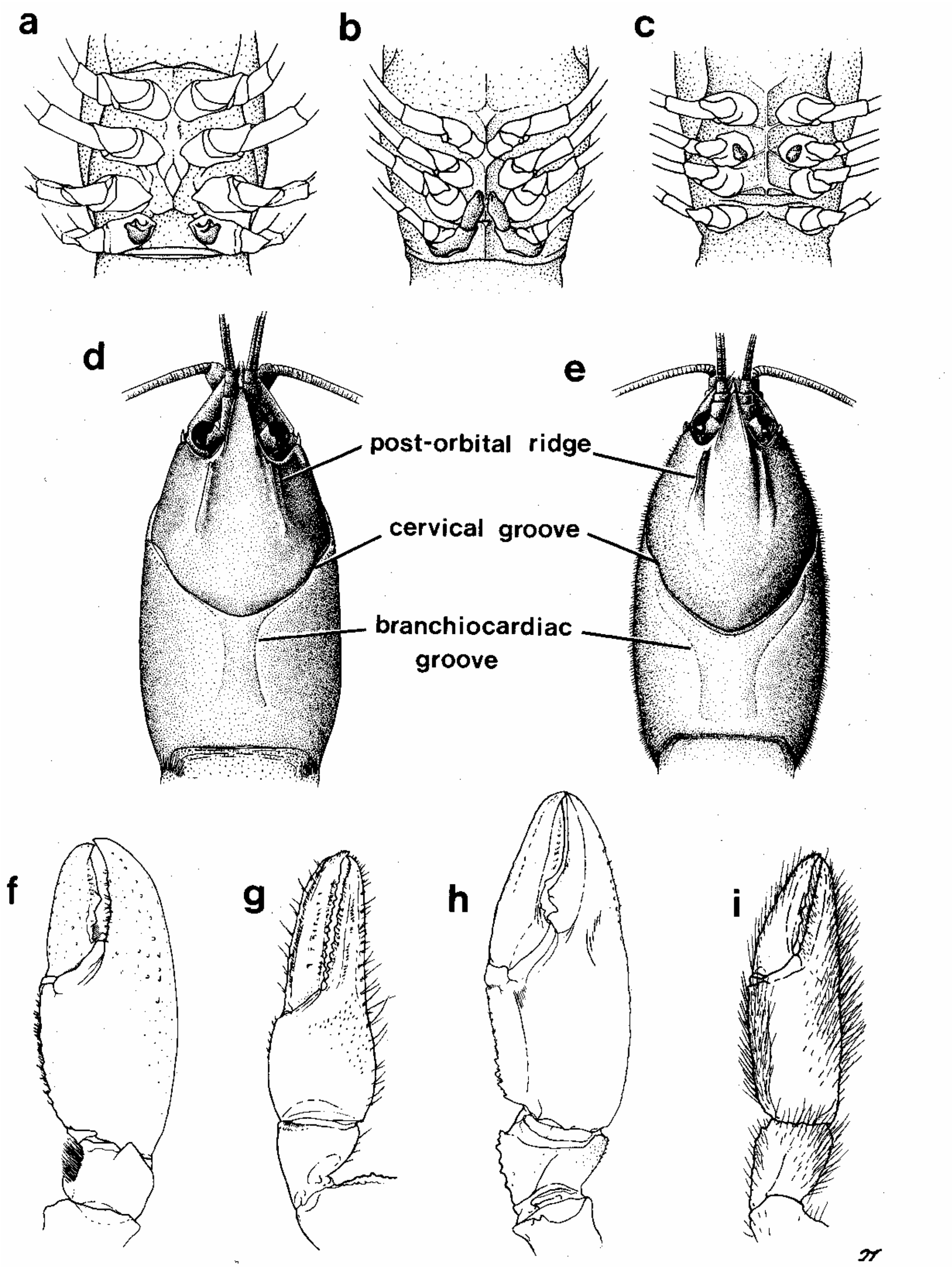
Species of *Engaeus* (Figs 8g, 9g) are usually quite distinctive and only in some cases could they be confused with species of *Geocharax*. The two genera may prove synonymous but for the time being the name *Geocharax* is applied to those species with well developed postorbital ridges (Fig. 9e) and this distinction works very well for the South East species. *Engaeus* is widespread in Victoria, northern Tasmania and King Island in Bass Strait, but in South Australia has only been found in the creeks and drains near the coast between Port MacDonnell and Victoria, where it occurs in deep burrows in dry creek beds, in shallow burrows in the soft mud of drain sides, or crawling freely amongst weed in the shallows of Eight Mile Creek As many as three species may be present. Engaeids are sometimes known as land crayfish as they frequently construct burrows in river banks and paddocks a considerable distance from permanent water. They are very strong burrowers, often constructing an extensive system of tunnels and chambers down to a depth of 1-2 m to reach the water table. The entrances to these burrows are easily recognised by the high chimneys of mud that surround them. Most species of *Engaeus* are relatively small with adults rarely exceeding 6 cm total length.

Euastacus:- Brief diagnosis.-Carapace and abdomen with prominent spines or tubercles. Carapace broader than high; cervical groove fused with anterolateral extension of branchiocardiac groove rather high on carapace; postorbital ridges reduced to spinous process. Chela move in horizontal plane, usually with spines, tubercles and bristles, sometimes with tufts of hairs between fingers. Telson with posterior portion membranous.

Euastacus (Figs 8a-c) is easily distinguished from other genera by its large size, heavy chela and spiny appearance, and even the juveniles (Fig. 8c) are distinctive Most species are moderate burrowers, but they tend to refuge under ledges, submerged tree roots, rocks or debris, and can often be found just wandering along the bottom of the stream, even during the day. *Euastacus* is widespread in south-eastern Australia but in

Next page

Fig 9 Freshwater crayfish; (a-c) sternum illustrating genital openings of *Cherax* rJ (a) *Gramastacus* rJ (b) and *Gramastacus* r3' (c); (d) (e) carapace of *Cherax* (d) and *Geocharax* (e) to illustrate postorbital ridges and cephalothoracic grooves; (f-i) chela, ventral view of *Cherax* (f) *Engaeus* (g) *Geocharax* (h) and *Gramastacus* (i). (Not drawn to scale)


a
b
c
d
e
post-orbital ridge
cervical groove
branchiocardiac groove
f
g
h
i

the South East is known only from the coastal drains, creeks and sinkholes between Port MacDonnell and Victoria. A *Euastacus* species was known to occur in the South East for many years. It was thought to be the Murray Lobster, *E. armatus* (Fig. 8b), and only recent collections have shown it to be *E. bispinosus* (Fig. 8a, 8c) previously only known from the Glenelg River system in Victoria. *Euastacus* species are some of our largest crayfish and although *E. bispinosus* is only a moderately sized species it can reach a total length of about 30 em.

Geocharax:- Brief diagnosis.-Carapace minutely tuberculate with short bristles, higher than broad; cervical groove widely separate from branch iocardiac groove joi n i ng it abruptly near middle of lateral side; postorbital ridges well developed forming distinct groove dorsally. Chela held obliquely, usually bare, rarely with bristles or tufts of hairs, even in juveniles. Telson entirely calcified

Geocharax (Fig. 8e) looks similar to *Cherax* which explains why it had not been recorded from the South East until recently. It is distinguished from *Cherax* by the calcified telson, the well developed postorbital ridges and the widely separate cervical and branchiocardiac grooves (Fig. 9e), and the general shape of the chela (Fig. 9h). Juveniles could be confused with *Gramastacus,* especially as they are sometimes caught together, but the chela of *Gramastacus* (Fig. 9i) is covered with long hairs, especially on the ventral surface, whereas those of *Geocharax* are bare. The Australian distribution of *Geocharax* resembles that of *Engaeus,* but in the South East it is more widespread, occurring in drains, creeks, swamps and sinkholes ranging from Naracoorte to Reedy Creek in the north down to the southern coast. *Geocharax* species are moderate burrowers and construct holes similar to those of *Engaeus* in similar habitats, but usually they are closer to the waterways. Sometimes burrows of *Cherax* and *Geocharax* are adjacent. The juveniles do not seem to burrow and are abundant in surface waters in spring and are then easily caught with a hand net However, adults are rarely caught this way and are usually found in burrows. Current collections from the South East indicate the presence of only one species. Adult specimens rarely exceed 8 cm in total length.

Gramastacus:- Brief diagnosis.Carapace covered with short bristles, slightly higher than broad; cervical groove widely separate from branchiocardiac groove joining it abruptly near middle of lateral side; postorbital ridge defined but does not form deep groove dorsally as in *Geocharax.* Chela held obliquely, covered with tufts of long hairs, especially on ventral side. Telson entirely calcified Male genital papilla very long.

Gramastacus (Fig. 8f) could be confused with juvenile *Cherax* or *Geocharax.* Males are distinguished by the large genital papilla at the base of the last walking leg (Fig. 9b), as are any females in berry, as no species of *Cherax* or *Geocharax* is mature at less than 4 em total length. However, females (genital opening at base of second walking leg-Fig. 9c) are usually distinguished from *Geocharax* by the hairs on the ventral surface of the chela (Fig. 9i), and from *Cherax* by the arrangement of the cervical and branchiocardiac grooves and the calcified telson. Species of *Gramastacus* are not known to burrow but are found swimming freely in the surface waters of shallow swamps and in the marginal zone of small streams. Only two species are known: G *insolitus* from swamps near Moyston and G. *gracilis* from Dwyer's Creek, western Victoria (Riek 1972). In South Australia *Gramastacus* has only been found in the South East, in Puddar Swamp, 16 km south-east of Penola and in a large swamp near 'Lynwood Park', 25 km north-east of Mt Gambier where it occurs in abundance. In Puddar Swamp *Gramastacus* is the only crayfish. Towards the end of summer this swamp tends to dry up and *Gramastacus* then takes refuge under plant debris, presumably being able to withstand some desiccation, but there are no signs of burrows. In the swamp near 'Lynwood Park' *Gramastacus* occurs with *Geocharax* and both are easily caught with a hand net. This swamp has some rather deep holes which provide a permanent refuge during summer The South Australian species is similar to G. *insolitus,* but as the genus is currently under review any specific determination must be in doubt. *Gramastacus* species are extremely small crayfish with mature specimens rarely exceeding 4 cm and females often in berry at 2-3 cm in total length. Because of their small size and close resemblance to juvenile *Cherax* they have been overlooked in the past and may have a much wider distribution than has been recorded.

Local knowledge suggests that yabbies were more widespread in the past before the

South East was extensively drained. Many habitats have been destroyed and those waterholes and drains which have not been fenced have been severely damaged by stock. Fortunately most of the habitats suitable for *Euastacus* and *Geocharax* are also a danger to stock and thus are fenced, but *Engaeus* occurs in open paddocks and in very small, often temporary, streams, and its existence is threatened. *Gramastacus* is only found in swamps amongst pine trees and is absent from apparently suitable habitats on adjacent grazing properties. Ironically the planting of pine forests seems to have ensured the maintenance of the natural flora and fauna associated with swamps and waterways because pine trees are not planted close to them and stock are excluded. *Geocharax* sometimes co-exists with *Cherax,* but *Cherax* is always more abundant while *Geocharax* is relatively rare. When on its own or with genera other than *Cherax, Geocharax* is very abundant suggesting that *Cherax* successfully competes with it when they occupy the same habitat. Because *Cherax* is so successful when introduced to a new environment it spreads quickly and is ideally suited for aquaculture, but it should not be introduced indiscriminantly to the detriment of the existing native fauna.

CRABS

A rather large species which is not regarded as a freshwater crab but which is sometimes found in freshwater situations is *Leptograpsodes octodentatus* (Fig. 1n). It is common in some of the drains and creeks near the coast, especially the brackish ones such as Blackford Drain near Kingston. These crabs can be found under rocks or debris and they also burrow into the soft soil on the drain sides and near the beach. They prefer brackish waters but can tolerate a wide range of salinities and are sometimes found in fresh water.

The only true freshwater crab in the South East is *Amarinus lacustris* (Fig. 7f) which occurs sporadically throughout southeastern Australia, including Tasmania, and has also been recorded from New Zealand, Norfolk Island and Lord Howe Island. It is particularly common in the South East and is often abundant occurring along the edges of drains and sinkholes, especially amongst weed. It is a relatively small crab with a carapace width of 6-10 mm and belongs to a family of spider crabs with mainly marine or estuarine species.

OTHER CRUSTACEANS

Probably the most important animals from an ecological point of view are the small creatures that make up the plankton. In Australian freshwaters Ostracoda, Cladocera and Copepoda, make up the bulk of the plankton and are very important in the food web of many other animals such as fish. Each of these groups consists of a wide range of species and requires specialist expertise for a proper understanding. Most of them are very small animals that can barely be seen with the naked eye but they are often very abundant, especially in still waters, and are easily collected with a fine net or from amongst weed. Only one example of each is given here, and Williams (1980) provides more details for further guidance.

The Cladocera or water-fleas are predominantly a freshwater group, widely dispersed throughout Australia. They are usually rather transparent so that parts of the internal structure are visible. Most specimens are females which produce viable eggs throughout their life and these can usually be seen in the dorsal brood chamber. In unfavourable conditions, such as the waterhole drying up, males become more abundant and, following fertilization, a resting egg is produced by the females. These special eggs, which look like a seed pod (Fig. 7g), are able to resist desiccation and remain dormant until favourable conditions occur. The example illustrated is *Daphnia lumholtzi* (Fig. 7e), a widely distributed species that also occurs in the South East but is not necessarily the most common species.

The Ostracoda is also a widely dispersed group reaching its greatest diversity in the marine environment, but there are also many forms in the inland waters of Australia, and some species are considered terrestrial, living in moss and other moist situations. They have a distinct bivalved carapace enclosing the whole animal and are sometimes mistaken for very small bivalved molluscs. Unlike cladocerans and cope pods they are rarely found swimming freely and usually occur on the bottom or amongst vegetation. Some species can also produce drought-resistant eggs and this ability explains their 'sudden' appearance after rain. The species illustrated is *Eucypris vireus* (Fig. 7d) which is cosmopolitan, commonly found in roadside ditches and temporary pools.

The Copepoda is one of the most diverse groups of crustaceans occupying marine, freshwater and semi-terrestrial habitats, and there are also many forms parasitic on a variety of marine and freshwater animals. The free-living forms are relatively similar in gross structure and are often very abundant, usually forming the bulk of any plankton present Females can often be found with eggs attached to the tail end, and some species are also capable of laying drought resistant eggs. Almost any standing water can contain copepods. The species illustrated is *Calamoecia salina* (Fig. 7c), a common species found in the salt lakes near Beachport However, numerous species occur in the creeks, drains, ponds, dams or sinkholes of the South East.

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REFERENCES

Altena, C. O. van R. & Smith, B. J (1975) Notes on introduced slugs of the families Limacidae and Milacidae in Australia, with two new records. J. *malaC. Soc. Aust.,* **3** (2), 63-80.

Clark, E. (1936) The freshwater and land crayfishes of Australia. *Mem. nat. Mus. Viet.,* 10, 5-58.

Clark, E. (1939) Tasmanian Parastacidae. *Pap. Proe. R. Soc. Tasmania,* 1938, 117-28.

Clark, E. (1941a). Revision of the genus *Euastaeus* (crayfishes, family Parastacidae) with notes on the distribution of certain species. *Mem. nat Mus. Viet.,* **12**, 7-30.

Clark, E. (1941b). New species of Australian freshwater and land crayfishes (family Parastacidae). *Mem. nat. Mus. Viet,* **12**, 31-40.

Jamieson, B. G. M. (1974) Earthworms (Oligochaeta: Megascolecidae) from South Australia. *Trans. R. Soc.* S. *Aust,* 98 (2), 79-112

Racek, A. A. (1969) The freshwater sponges of Australia (Porifera Spongillidae). *Aust.* J. *Mar. Freshw. Res.,* **20**, 267-310

Riek, E. F. (1969) The Australian freshwater crayfish (Crustacea: Decapoda: Parastacidae), with descriptions of new species. *Aust.* J. *Zool.,* **17**, 855-918.

Riek, E. F. (1972). The phylogeny of the Parastacidae (Crustacea: Astacoidea), and description of a new genus of Australian freshwater crayfishes *Aust. J. Zool.,* **20**, 369-89.

Smith, B. J & Kershaw, R. C (1979). *'Field guide to the non-marine molluscs of south-eastern Australia'* (Australian National University Press, Canberra).

Williams, W. D. (1980). *'Australian freshwater life The invertebrates of Australian inland waters.'* (2nd edition), (Macmillan, Aust Pty. Ltd.).

Zeidler, W. (1982). South Australian freshwater crayfish. S. *Aust. Nat.* **56** (3), 36-43.

20: Myriapods, Insects and Allied Forms

by G.F. GROSS

As to be anticipated in a well vegetated, moist and not too cold region, the fauna of the South East is rich, probably including several thousand species. In this short account emphasis is placed on those species which appear to play important roles in the functioning of the ecosystem, or on those which the layman is most likely to see.

Not all of the species discussed occur over the whole area as a number of species in any particular region are restricted to only one or several types of major (vegetation and climatic) habitat. The chief types of these habitats in the region, classified according to the way the fauna is likely to be distributed, are the remaining areas of native forest, the pine forests which have supplanted so much of them, pastures and open woodland, swamps and freshwater lakes, saline lagoons and coastal dune and cliff formations. In each major habitat the arthropod species may occupy only certain layers, or particular parts of plants and in this region these vertical and minor microhabitats would include the soil itself, litter, soil surface, low vegetation, vegetation of the upper storey, fresh and salt water, their surfaces, and the emergent and fringing vegetation associated with these waters.

Other small local environments to which no more than passing mention can be made are the various cultivated crops, dwellings and outbuildings, and caves.

In general the myriapod, insect and closely allied forms of the South East form part of a fauna which tends to be found also in the same types of habitat (wherever developed) in the Mt Lofty Ranges and south-western Victoria which have a similar temperature and rainfall. Moreover, the distribution of this fauna suggests that in a period before the Mt Lofty Ranges were separated from the South East and south-western Victoria by, first incursions of the sea, and subsequently the drier heathlands of the Tintinara-Coonalpyn area, the two areas were connected by a similar kind of vegetation complex and that this was not so much before a very few distinct species had evolved in the now separated areas. For a brief comparative account of the fauna of the Adelaide region see Tyler, Gross, Rix & Inns (1976) and Walker, Bishop, Shiel & Williams (1976).

The many-legged Myriapoda are grouped into two major orders: the Diplopoda or millipedes which are detritus feeders and have a cylindrical body form with many segments, most of which bear two pairs of legsmoreover millipedes do not possess poison glands and fangs-whereas the Chilopoda or centipedes are carnivorous, have a flattened body form of a few to many' segments, most of which bear only one pair of legs, and centipedes do have a pair of poison glands and paired fangs on the head end. There are also several minor orders of very small myriapods, mostly living in soil and litter, which are being passed over here.

The millipedes are of considerable interest as the introduced *Ommatoiulus moreletii* has now reached the region. This species is native to Portugal and Spain and first appeared in Australia in 1953 at Port Lincoln. It has since spread over much of lower Eyre Peninsula, the Mt Lofty Ranges, the South East, and several parts of Victoria. This millipede is smooth and worm-like, usually slatey-grey in colour and averages about 5 cm in length. It occurs both in forests and pastures where it feeds on decomposing plant material. The most abundant native species of millipede is likely to be *Australiosoma castaneum* which is also smooth but chestnut to dark brown in colour and mostly restricted to forests and plantations. There are also some other native species which have a knobbly appearance, some of them dappled with white.

A number of species of small, slender centipedes with a many-segmented body occur under logs in the region, whereas large green or reddish-brown centipedes with fewer segments will be either the widespread *Scolopendra morsitans* or one of the two local species of the genus *Cormocephalus,* the latter in damper situations only.The Collembola or springtails, the Protura and Diplura are three orders of soft-bodied, six-legged wingless arthropods closely allied to the insects but no longer considered to be true insects. The Protura and Diplura are represented in the area by a few species yet to be identified and are not considered further but the Collembola are much more numerous and diverse.

Collembolans are elongate or globular, small (1-3 mm in length) creatures which are white, grey, green, reddish-brown or purple in colour. Their common name, springtails, refers to a hinged fork-like structure inserted ventrally on the end of the abdomen by wh ich they can propel themselves forward.

Except for one introduced pest species, the Lucerne Flea *(Sminthurus viridis),* which is of importance to growers of legumes in the area and *Hypogastrura vernalis* which is often seen forming a purple scum on the surface of water after it has been washed out of gardens and pastures by rain, most collembolans pass unnoticed by the layman due to their small size and where they occur. In fact springtails are numerically a large component of most faunas, especially in the soil and litter layers, where they can occur in densities of up to 300 000/m^2 and together with mites (see Chapter 18) make up an important component of the complex of plants and animals which decompose and return leaf litter and fallen timber to the soil as humus.

Collembola are also to be found under rocks and logs, on the ground surface including the shores of lakes and the sea, on the su rface of freshwater and on the lower parts of vegetation.

I am indebted to Ms Penelope Greenslade, who has worked extensively on Australian Collembola and their habits, including some investigations in the South East, for the information given here on this order. She has ascertained that there are approximately 7080 species of collembolans in the region, or about one-tenth of the known Austral ian species. About one-half of the species are widely distributed over the southern temperate half of Australia, a further one-q uarter extend west as far as the Mt Lofty Ranges and a further one-sixth (in South Australia) have only been recorded from the South East. The remainder fit no common pattern of distribution or their distribution is too poorly known to indicate any pattern.

In forest areas including the litter in pine plantations (at least in winter) there is a rich fauna of springtails similar to that in the same types of habitat in south-western Victoria and the Mt Lofty Ranges and mostly composed of native species. In pastures, agricultural land and other disturbed areas there are many cosmopolitan and introduced species.

The crests of the most seaward and more poorly vegetated sand dunes have a fauna similar in some respects to the inland sandy deserts, e.g. species of *Foisomides* are present whereas the debris around the shores of saline lagoons carries the same species as are found on the seashore, e.g. *Archistoma* spp. and *Isotoma pritchardi.*

The Thysanura or silverfish are believed to be true primitive insects which have never developed wings, whereas all other wingless insects (e.g. fleas, lice and odd members of many other insect orders) are believed to have gone through a stage of having had wings which were subsequently lost. Silverfish are silvery-grey, very fast moving insects which have three slender, filamentous appendages arising from the tail. Two species may occur in houses in the area, namely *Lepisma saccharina* and *Ctenalepisma langicaudata,* whereas the native species are usually found under peeling *Eucalyptus* bark and most likely belong to the genera *Heterolepisma* and *Acratelsella* as in the Mt Lofty Ranges.

The Archaeognatha are smaller but very similar creatures which are not well known; *Allamachilis (raggatti,* abaut 17 mm long, probably occurs on the coastal cliffs.

The Ephemeroptera or mayflies are an order whose systematics and distribution have received scant attention in South Australia. The nymphs live in fresh water and have fully developed mouthparts and gills. There are two winged stages, firstly a subimago which moults to produce the true adults. Adult mayflies are small and usually found close to or over water, and may be recognised by the front portion of the forewings appearing darker and stronger than the rest, together with two long filaments emerging from the apex of the abdomen. The adults are often taken by trout and other su rface-feeding fishes and lures or 'flies' resembling common species of mayfl ies are usually part of the stock in trade of fly fishermen South Austral ian species probably belong in the main to the genus *Atalaphlebia* with some possibly species of *Atalaphlebiaides.*

The dragon and damsel flies, both sections of the order Odonata, are much larger and more conspicuous members of the fauna associated with freshwater. The nymphs live in the water and are predacious with large heads and eyes. When it is time to turn into the adult they climb up onto a stem of a reed or other emergent vegetation. The adults with their large eyes and wings are swift and efficient predators. The smaller and delicate damselflies are represented in the area by *Lestes annulosus,* though there are probably some rarer species in the South East also, and the robust and larger dragonflies include amongst their number the large *Hemianax papuanus* with a conspicuous chocolatebrown abdomen with pale greenish-cream markings. A somewhat smaller species, *Hemicordulia tau,* with a black and orange abdomen is common in South Australia and may well occur in this region though no specimens are yet to hand.

Cockroaches (Order Blattodea) are common in the region under bark on those eucalypts with peeling bark and amongst the bark around the base of trees. They also occur under the leafy part of fallen branches, under logs and under stones. *Laxta granicollis* is a medium-sized insect whose males may be fully winged, with abbreviated wings or with none at all, whereas the females are always wing less. It may be recognised by its flattened shape, dark brown colour and the dorsal surface being covered with small irregular nodules. *Cololampra irrorata* is another medium-sized cockroach with a smooth greyish or brownish-cream upper surface; the males are usually winged but the females have small lobe-shaped wings though individuals of both sexes can be completely wingless. Much smaller cockroaches with the same general appearance of *Calolampra* species are in the area, some may be early nymphs of C. *irrorata* but others are adult and belong to *Robshelfordia* or an allied genus.

Most collections taken by the South Australian Museum have included examples of *Panesthia australis* which is a large blackish cockroach which has wings in very early adult life, but these wings are very soon broken off near the base. It can be distinguished from the cockroaches of the next two genera by a depression medially on the shield over and behind the head, and by the triangular remnants of the wings.

Smooth brown cockroaches without any trace of wings, some species with creamcoloured edges to at least the thoracic segments, belong to the genus *Melanozosteria* and shining black coackroaches without any trace of wings belong also to *Melanozosteria* or *Platyzosteria. Platyzosteria scabrella* is especially common both under bark and under logs.

The Isoptera or white-ants are social insects closely related to cockroaches and easily recognised by everybody. The colony contains a number of castes devoted to the protection of the colony (soldiers), as workers and to reproduction (kings and queens). Immatures and supplementary reproductives may also be present. The male and female reproductives are both winged before mating, but fall to the ground and lose their wings after this has taken place. The common species in termite mounds in the region is *Nasutitermes exitiosus* in which the soldiers do not have strong jaws but are "nasute", i.e. the head is produced into a snout or tube through which a toxic and repellent fluid is exuded.

The white ants found under logs are most likely to be *Calotermes iridipennis, Coptotermes michaelsoni* and *Microcerotermes newmanni.*

There are three species of Mantodea or praying mantids common in the South East, namely *Paroxypilus laticollis, Orthodera ministralis* and *Tenodera australasiae. Paraoxypilus* species are dark brown small mantids, the males are fully winged with an elongate abdomen whereas the females are wingless with a short expanded abdomen with a rough appearance. *Orthodera ministralis* is a medium sized bright green mantid, often seen on garden shrubs or on eucalypt regrowth. Its horny egg sac is often seen attached to branches, fence posts or walls. *Tenodera australasiae* is a much larger, more elongate brown mantid whose thorax is only a little shorter than the abdomen and with many short brown hairs on the hind wings. All Mantodea are useful insects as they prey on a variety of other insects and tend to concentrate on species in locally high abundance, many of which tend to be pests.

The earwigs (order Dermaptera) are represented in the area by at least two species. The local earwigs are both conspicuous and moderate in size to large insects with short wi ngs and easily disti nguished by the forcepslike processes arising from the end of the abdomen. *Labidura riparia truncata* is the largest of the two species and dull brown with straw-coloured markings and long forceps and more likely to be found in drier parts of the region, especially in sandy habitats *Fuborellia annulipes* is a much smaller black earwig with small curved forceps also found in sandy soil. Earwigs eat a wide range of living and dead plant and animal matter. The forceps are used to capture prey, for offence and defence and occasionally to fold the membranous hind wings beneath the leathery forewings.

The stoneflies (order Plecoptera) are an order of insects with aquatic larvae and flying adults which are poorly represented in South Australia as only five of the 84 described Australian species are known to occur here. Our local species belong to the genera *Trinotoperla* and *Leptoperla* whose adults are brownish in colour and several centimetres only in length.

The order Orthoptera is difficult to characterise in a few words. It includes grasshoppers, both of the short- and longantennaed types, locusts and crickets, and a number of other forms which lack a common group name. For the most part orthopteran insects are large, with a soft abdomen and in a number of cases have the ability to Jump Many species "sing" or trill by rubbing various parts of the body together. The mole crickets are subterranean creatures with a brownish colour and strong burrowing forelegs; both South Australian species belong to the genus *Gryllotalpa.* The ordinary crickets are represented by *Teleogryllus commodus,* the black field cricket, which lives in cracks in the soil but feeds on the surface of the ground and is injurious to pastures and crops in the area

The so called "cave crickets" are not closely related to the two groups of true crickets above but more to the group following in that they are slender, very long-legged insects with long antennae. *Novotettix naracoortensis* is known from several caves in the area and from nowhere else in Australia.

Gryllacrids are large nocturnal carnivorous creatures with strong mouthparts and cream or greyish-cream in colour with brown bands on the abdomen. Though most species in South Australia occur in the arid regions an undescribed species from the Mt Lofty Ranges probably occurs in the South East as well.

Tettigoniid or long horned grasshoppers are represented by several species in the area. These creatures are often laterally com pressed and green and there are several species as yet undetermined of this form in the area. Another species likely to be in the area IS *Acripeza reticulata* which is laterally flattened and black in the male, but the female has shelllike wings covering a brightly-banded globular abdomen.

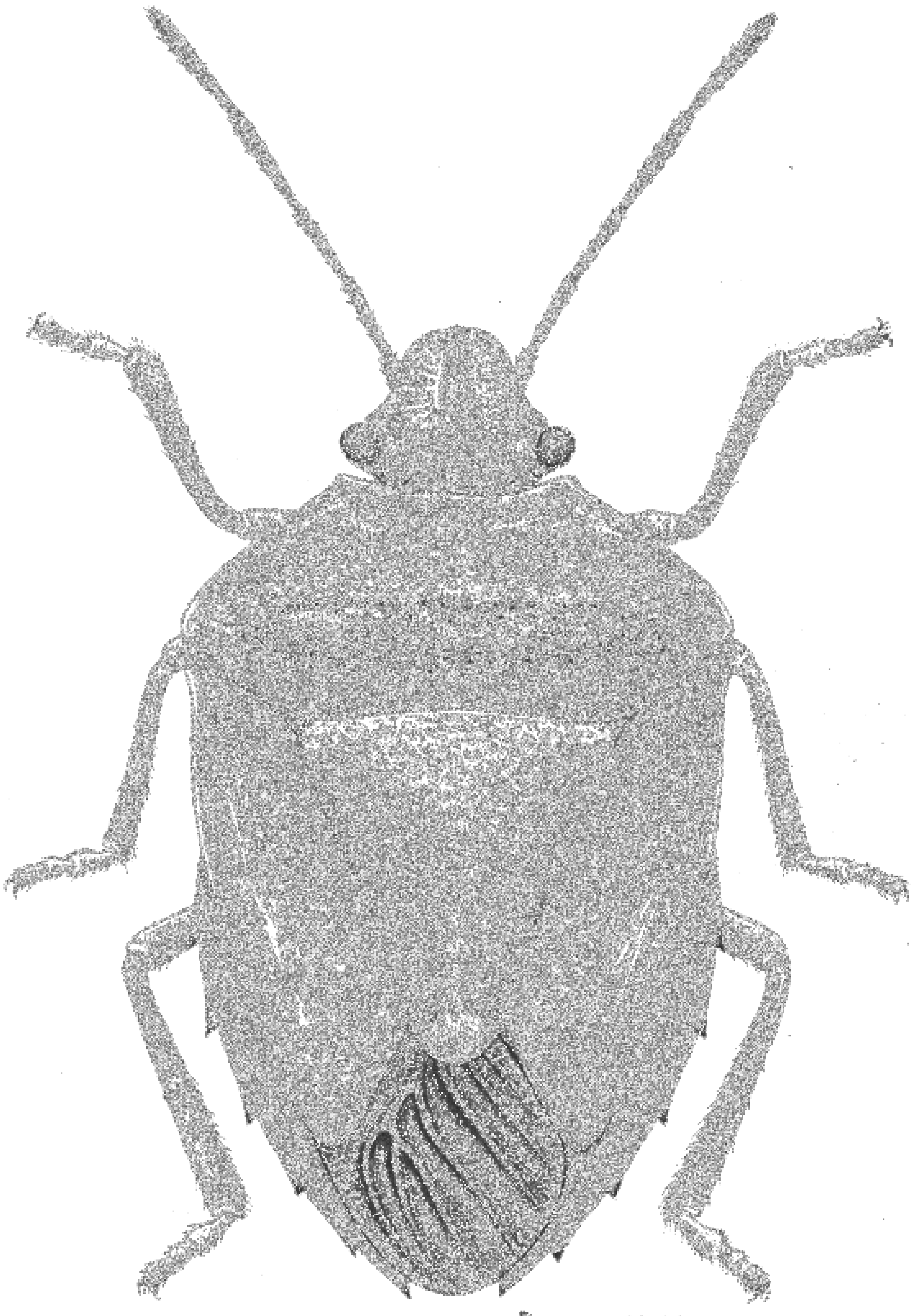
A collection made in late autumn several years ago showed at least five species of grasshopper still active in the area, namely the long-headed grasshopper *Acrida conica,* a wingless grasshopper *Phaulacridium gemlni.* a speckled species *Urnisia guttulosa,* a small plague grasshopper *Austroicetes frater* and the yellow-winged locust *Gastrimargus musicus.*

The taxonomy of the Australian Phasmotodea or stick-insects requires further attention and the one species seen from the Lower South East has not been identified.

The Embioptera (web-spinners), Psocoptera (booklice), and Phthiraptera (lice) are all undoubtably represented in the area but too little is known about these groups there to say anything of value.

The Hemiptera (bugs, leafhoppers, lerp insects, scale insects, etc.) are difficult to characterise from a dorsal view. However on turning one of these creatures over it will be seen that it possesses a sucking beak instead of chewing mouthparts. Many species of the suborder Heteroptera also emit a vile smell when disturbed or th reatened. In the fulgoroid complex of families, a species or two of the cixiid genus *Oliarus* whose nymphs feed underground on grass roots can be expected to be present as can one or more species of the broad squat Eurybrachidae on eucalypt trunks and a species of *Siphanta* which are bright green and resemble little, green, leathery butterflies as do nearly all other flatids

In grassy areas the cercopid *Bathylus albicinctus* which has an appearance vaguely like a ladybird is common in the warmer months but in wooded areas another cercopid, *Anyllis leialia,* which in general appearance resembles more a leafhopper, appears to be very common Cicadas in our South Australian forests have a patchy distribution in time and space usually appearing sporadically and in numbers. The large black red-eyed cicada *Psaltoda moerens,* and a yellowish cicada with strong yellow veins and a zigzag, brown, transverse line on the forewings, *Arenopsaltria nubivena,* and a species of *Melampsalta* with a black abdomen with fine yellow bands should all occur in the area.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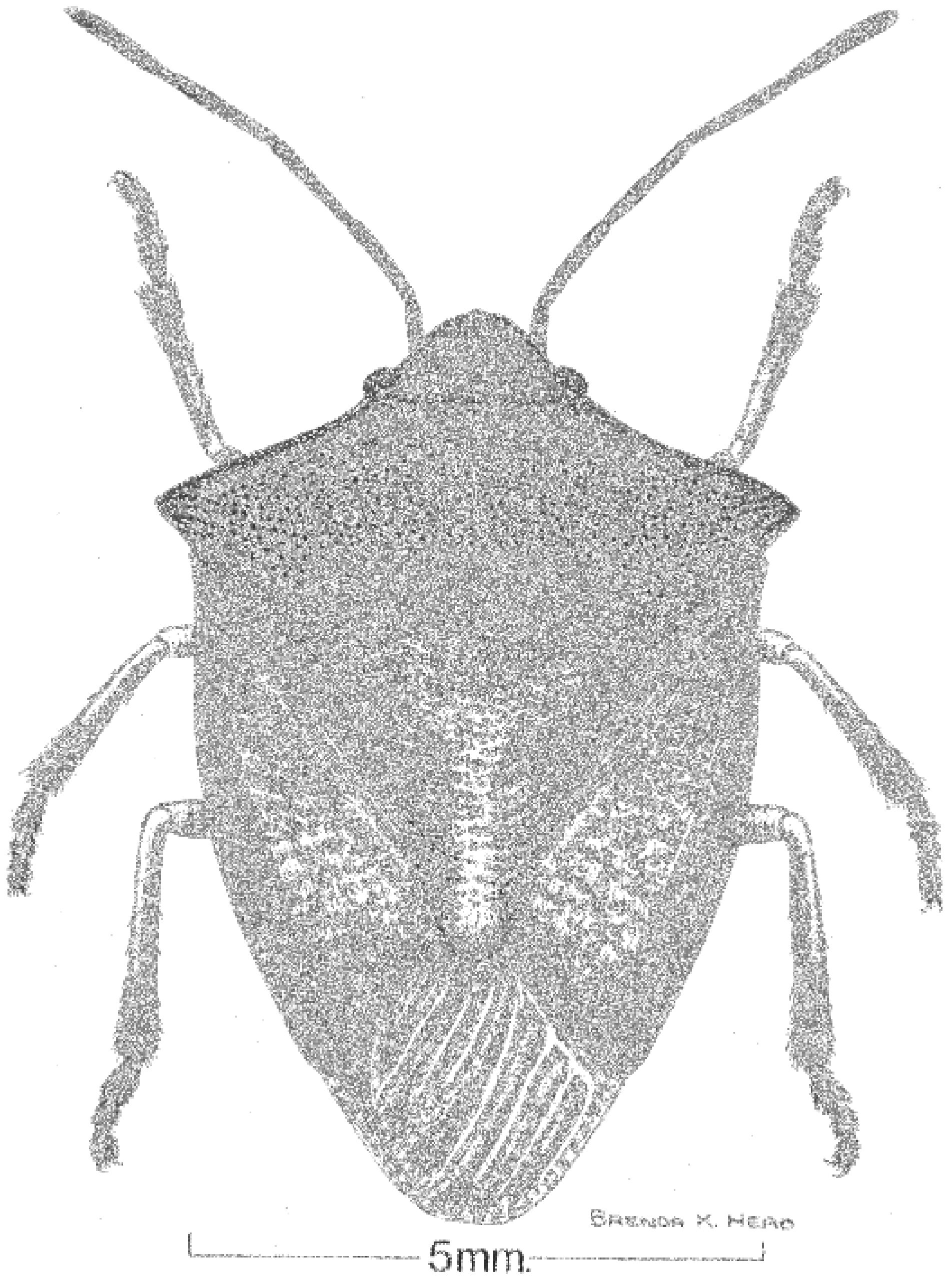


Fig. 1. A species of small, green pentatomid or shield bug, *Oolrrhoa unimaculata* (Westwood), common in the understorey in the South East. Figure reproduced by courtesy of The Flora and Fauna of South Australia Handbooks Committee.

Fig. 2. Another species of small, green pentatomid bug, *Cuspicona obesula* Gross, also found in the understorey in the South East. Figure reproduced by courtesy of the The Flora and Fauna of South Australia Handbooks Committee.

Leafhoppers are strongly wedge-shaped Hemiptera and records from the area include *Ipoella porriginosa,* species of *Eurymeloides* which have black or brown leathery forewings with transverse creamy marki ngs, *Pauripo insularis, Paracephaleus brunneus* and *Stenocotis depressa.* Psyllids or lerp insects occur often on the leaves of eucalypts and include species of *Cardiaspina,* other (usually grey-coloured) species of *Psylla* occur on acacias. The coccids or gall and scale insects will be represented by many forms but conspicuous amongst the woody galls of species of *Apiomorpha,* these galls (depending on the species) ranging from urnshaped to almost spherical.

The number of species of Heteroptera or bugs with a flattened dorsal aspect seen in collections from the area is considerable. Notable amongst them are two bright red and black species of Pentatomidae, *Jalloides rubricosa* and *Agonoscelis rutila,* the latter usually on horsehound and the pretty pyrrhocorid *Dindymus versicolor* which is red and black above but has a bright green abdomen. Many Heteroptera are aquatic and a number of families have species in the area. In the Corixidae or water boatmen samples were recently taken of *Diaprepocoris personatus,* a primitive species whose closest relative lives in New Zealand.

Thysanoptera or thrips will most likely be seen in the gardens in the area where *Thrips imaginis* may appear on a variety of garden plants including roses and gladioli. Other species occur elsewhere in native habitats but are easily overlooked due to their small size.

Lacewings or Neuroptera are represented by species of green Chrysopidae frequently seen on windows at night and shaped rather like moths but with clear wings; a species of Osmylidae probably belonging to the genus *Stenosmylus* and the mantispid *Campion spiniferus* occur also in the region. Mantispids look very like small mantids. Neuroptera are all predacious, and therefore mostly useful insects which include amongst their number the various species of anti ions which are larval members of the family Myrmeleontidae which dig inverted cone-shaped pittraps for ants, the ant lion lies in the soil at the narrow point of the cone with its jaws at the ready.

The Coleoptera or beetles is the largest Order of insects in Australia and is easily characterised by a generally hard body, with hardened forewings under which lie a pair of membranous hind wings. There are a few families whose members live in water, but most beetles are terrestrial. Many groups are predacious but rather more are herbivorous or detritus-feeders. Collections from the South East include a number of species of Carabidae which are small to large predators mostly of the ground surface and amongst the coarser litter, but some species hunt on thetrunks and branches of eucalypts, probably at night as during the day they are usually found concealed under loose but still attached bark. Species of the genera *Scaraphites* (large carabs with the 'waist' between the thorax and abdomen strongly constricted), *Carenum* (smaller carabs with the same general form as *Scaraphites* but very shiny), *Tachys, Notonomus, Sarticus, Amblytelus* (flattened brown species concealed under bark) and *Mecyclothorax* are amongst those present.

The Hygrobiid water beetles are represented by *Hygrobia australasiae,* the dytiscids by *Rhantus suturalis* and the hydrophilids by several large shining black species of *Hydrous.*

In the rove or staphylinid beetles the redheaded but black-bodied devil's coachhorse, *Creophilus erythrocephalus,* occurs under carcasses. There are many smaller species of staphylinids, mostly entirely black, frequenting the leaf litter.

Click, or elaterid, beetles belonging to several genera and a number of species are common under peeling eucalyptus bark. These will jerk off the bark if pulled back from the tree by flexing the body with a sharp click. The related jewel or buprestid beetles are known from some fine species of *Stigmodera* and *Castiarina.* The first are large beetles, the second medium-sized species, but many are beautifully coloured.

There are many other families of beetles which are represented in the area by one, two or a few species, but these will have to be passed over.

Amongst the remaining larger families the Tenebrionidae are represented by species of *Pterohelaeus, Celibe,* and *Adelium* amongst others and the longicorn or cerambycid beetles are similarly represented by a number of genera and species and there are a number of species of leaf-eating or chrysomelid beetles including species of *Paropsis* on eucalypts.

In the Scarabaeidae or chafer-beetles the dung beetle most likely to be seen is *Onthophagus mniszechi* which is a black substantial insect with a single, thin spine on the head and paired thicker spines on the front of the thorax. In the Christmas beetle tribe there is a fine species of *Anoplognathus* which is brown with a greenish sheen and a small, brilliant green chafer of the genus *Diphucephala* is not uncommon on *Leptospermum.* The larvae of *Aphodius tasmaniae* which feed on grass roots area a major problem in pastures throughout the enti re area.

Weevils or Curculionidae are represented by a nu mber of genera and species, the largest being the very strongly armoured species of the genus *Leptopius* with a blunt but projecting head and spines on the forewings.

The Mecoptera or Scorpion-flies have one common species in the area, *Harpobittacus australis,* which is a large, slender insect resembling a crane-fly but with four wings.

The fleas in the area are not well documented but include the dog and cat fleas on household pets and some fleas of rabbits.

The true, two-winged flies (order Diptera), particularly members of those families which frequent swampy vegetation, likewise have not been looked at very closely in the area. The common large mosquito of the forest is *Aedes camptorrhycehus* and large flies which took like king-size blowflies are species of *Rutilia* whose larvae are useful insects feeding on pasture grubs as internal parasites. A little fly with prominent black and yellow bands on the abdomen is one of two very similar looking syrphid or hoverflies, *Syrphus viridieeps* or *Xanthogramma grandicornis.* Tabanids or march-flies are abundant, particularly in late summer and early autumn, the principal species bei ng *Dasybasis eireumdata* and *Dasybasis vetusta.* A pretty species of Stratiomyidae, *Neoexaireta spinigera,* with dusky distal halves to the wings and a distinct pale spot on the margin often visits windows.

Caddis flies (order Trichoptera) are delicate creatures with darker forewings and paler hindwings and in South Australian species with mostly long antennae. The larvae are aquatic and live in tubes. Several unidentified species have been seen in collections from the region.

The butterfly section of the large order Lepidoptera are described in Chapter 21. There are numerous moths in the area, one of the largest being the fawn *Antheraea helena,* one of the emperor gum moths with prominent eye spots on both the fore and hind wings. Another very large moth which flies for only a night or two after hatching is *Trietena argentata,* a member of the ghost moth family (Hepialidae) which is greyish-brown with two long silvery markings on the rather pointed forewings. The Noctuidae have a number of genera and species in the area, the most usually seen being the large brown house moth, *Dasypodia selenophora,* which is usually more grey than brown and has a bluish eye-like marking on the forewing. Other species include the adults of cutworm larvae which feed on grass roots; these are robust brown, orange, grey or blackish moths and include the bogong moth *Agrotis infusa.* The pretty little speckled salt and pepper moths of the genus *Utetheisa* are represented by at least one species.

The most advanced order of insects the Hymenoptera includes the bees, wasps and ants as well as some families mistakenly called "flies" (e.g. sawflies, ichneumon flies); but all winged forms of Hymenoptera have two pairs of wings. The sawflies include *Pterygophorus analis* and *Perga bella;* the adults are not seen frequently but the larvae are often encountered as clustered, repulsive groups on the stems of sapling eucalypts. The Ichneumonidae present include *Lissopimpla semipunetata* with darkened basal halves on the wings, a chestnut body and the front half of the abdomen black with oblique, yellow bars. In this same family are rather laterally compressed yellowish-brown wasps with clear wings belonging to the genera *Enicospilus* and *Netelia.* Scoliid or flower wasps include the large (female), black *Campsomeris anthraeina* and the related tiphiid wasps, the equally large (male) *Guerinius sehuekardi;* male scoliid wasps are much smaller than the females but winged, whereas in *Guerinius* the females are smaller than the male (most other tiphiids have larger females) and all tiphiid females are wingless and look like a fat ant. The so-called blue ant which is a large (1.5-2.0 cm) ant-like creature with a purplish-greenish iridescent body and brown legs is actually the female of another tiphiid, *Diamma bicolor,* of which the males are winged with a black body with a few yellow transverse markings on the abdomen. The Sphecidae are represented by the common *Podalonia suspiciosa,* a small medium sized wasp, black, with the front half of the abdomen orange.

Some small brown or black native bees belonging to several families are present. Amongst the variety of ants present are the smaller jumper ant *Myrmecia pilulosa* and its much larger relative, the inch-ant M. *pyriformis.* Both of these primitive ants can sting like wasps from an apparatus at the end of the abdomen. The meat ant, *Iridomyrmex purpureus,* constructs large nest systems under a low but wide mound of gravel usually on paths in the forest and many of the numerous small black ants are also species of *Iridomyrmex.* The honey- and nectargathering ants seen going up and down the trunks of eucalypts are species of *Camponatus* and allied genera.

REFERENCES

Tyler, M. J., Gross, G. F., Rix, C. E., & Inns, R. W. (1976). Terrestrial fauna and aquatic vertebrates. *In* Twidale, C. R., Tyler, M. J. & Webb, B. P. (Eds) 'Natural History of the Adelaide Region'. (Royal Society of South Australia, Adelaide)

Walker, K. F, Bishop, J. E., Shiel, R. J & Williams, W. D. (1976). Freshwater invertebrates. *In* Twidale, C. R., Tyler, M. J. & Webb, B. P. (Eds) 'Natural History of the Adelaide Region'. (Royal Society of South Australia, Adelaide).

21: Butterflies

by R. H. Fisher

INTRODUCTION

There is a close relationship between the butterfly fauna of an area and the vegetation and as a general rule, any particular species is most likely to be found in the vicinity of its larval food plants. Here the female may be ovipositing and the male may be present by virtue of the biological attraction that occurs between the sexes. There are exceptions, as in the case of a few species that fly considerable distances from their breeding grounds in migratory flights, while there are others whose males are attracted to nearby high ground where their flight characteristics give rise to the term 'hilltopping'.

Extensive destruction of natural vegetation in a particular area must result therefore in a marked reduction of the population density of the butterflies associated with it. Few areas in South Austral ia illustrate this fact more clearly than the South East. I n the course of little more than three generations of European settlement and development, large tracts of native vegetation have been destroyed and replaced by pastures, farmlands and pine forests and, to a lesser extent, by urban development and market gardens. The search for butterflies in this area initially becomes a search for undisturbed native vegetation. As in other parts of the world, there has been a recent awakening to the need for conservation, with the result that a significant number of wildlife reserves has been declared. These areas, where butterflies may be observed but not collected, should ensure the future survival of some species, but their establishment may have come too late for others.

The South East provides interesting examples of the capabilities of species to survive in remnant areas of vegetation, e.g. along roadsides. In particular, those unique and productive areas which occur between railway tracks and the fences which enclose them contribute many examples of the previous nature of the surrounding flora and its associated insects. There are also some areas which have been cleared of forest but not redeveloped. Here rapid regeneration of flowering plants in the understorey provides food in the form of nectar for adult butterflies, and open flight areas for many species. Figs. 1 c and 1 d illustrate such an area near Mt Edward.

Of the 64 species of butterflies listed for South Australia by Fisher (1978), about two-thirds may be found in the South East. As the fauna and flora is closely allied to that of western Victoria it is I ikely that several species extant there may once have occurred in South Australia. But the chance that any of these may survive, unrecorded as yet in the South Australian fauna, seems remote. There are five species whose South Australian distribution is limited to the South East. Two occur in restricted areas, where collecting is prohibited, and two are known only from very early records. Two species are represented by subspecies which do not occur elsewhere in the State.

For the sake of brevity subspecific names have been omitted from the following account unless there is a particular significance in their use. A detailed description of each species and, in particular, what is known of its life history is in Fisher (1978); while some further illustrations of early stages are here in Figs 1 and 2.

HESPERIIDAE (skippers)

This family is represented in the South East by 10 of the 14 species known to occur in South Australia. All have larvae which feed on monocotyledons. *Trapezites eliena* (eliena skipper, Figs. 3a and 4a) has been recorded only rarely and its larval food plant *(Lomandra longifolia)* is now distributed sparsely. *Trapezites phigalia* (phigalia skipper) is also rare; its early stages have been recorded in Victoria on *Lomandra filiform is. Anisynta albovenata* (white veined skipper, Figs. 3c and 4c) occurs near Tintinara in October and its pale green larva (Fig. 2e, f) builds a well-concealed shelter at the base of the tussocky

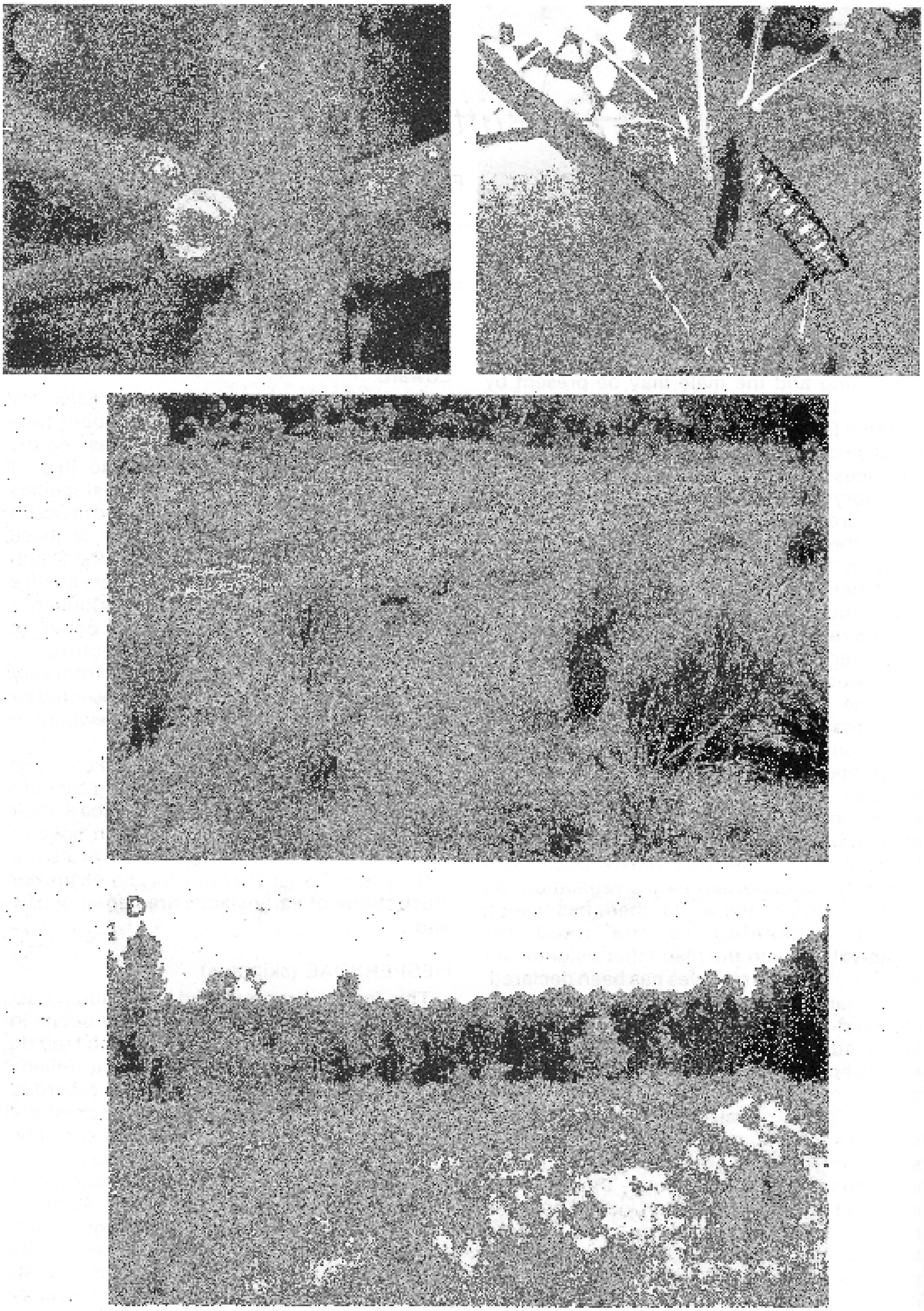


Fig. 1. A. Egg (x15) of *Neolucia agricola*. B. Larva (x1) of *Danaus plexippus* on *Asclepias physocarpa*. C, D. Regrowth of forest understory in cleared area near Mt Edward. Flowering plants in such areas attract a number of butterflies of various families. Regeneration of *Gahnia clarkei* is evident in the foreground of C.

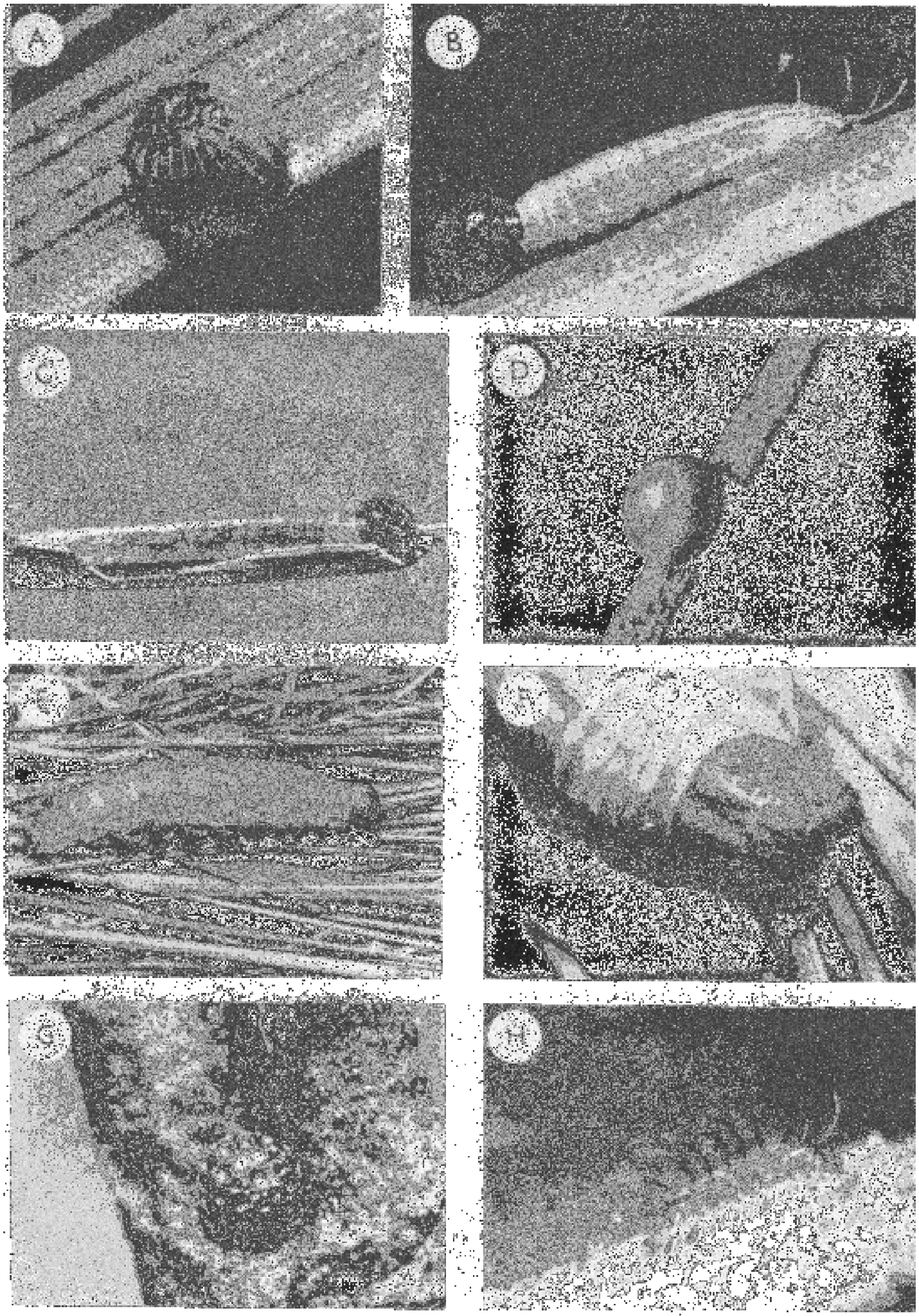
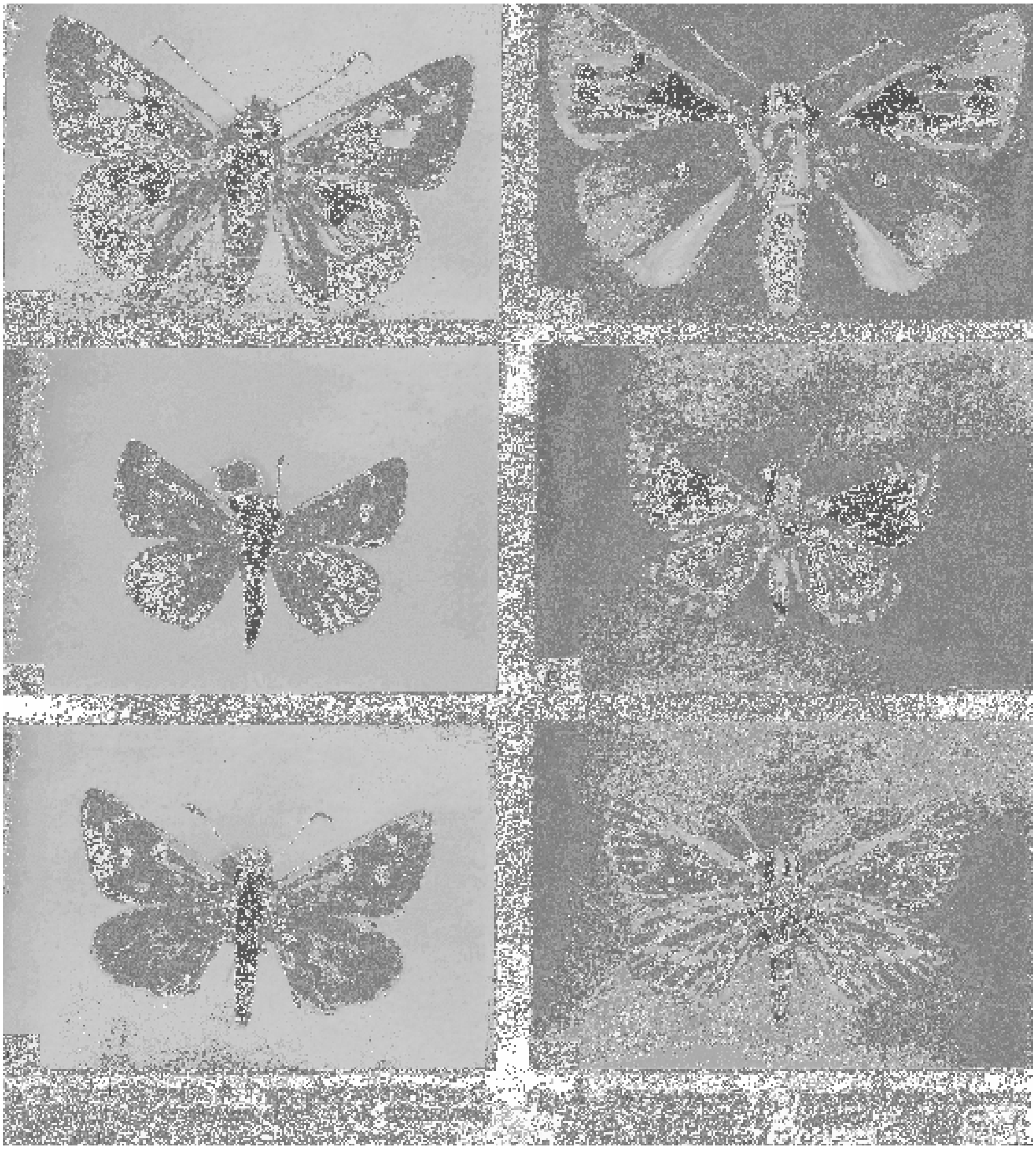


Fig. 2. Early stages. A, B, C. Egg (x25), first instar larva (x25) and second instar larva (x10) of *Trapezites eliena*. D, E, F. Egg (x20), mature larva (x3) and larval head (x10) of *Anisynta albovenata*. G, H. Egg (x20) and first instar larva (x15) of *Ogyris olane*.



spear grass *Stipa semibarbata. Anisynta cynone* (cynone skipper, Figs. 3b and 4b) was first described in 1874from material collected in coastal areas of the South East.

The genus *Hesperilla* is represented by four species, *H. idothea* (flame skipper), *H. chrysotricha* (chrysotricha skipper), *H. f1avescens* (yellowish skipper) and *H. donnysa* (donnysa skipper), in which two subspecies, *delos* and *diluta,* are recognised. The larvae of all of these feed at night on one or more species of *Gahnia* (sword grass,

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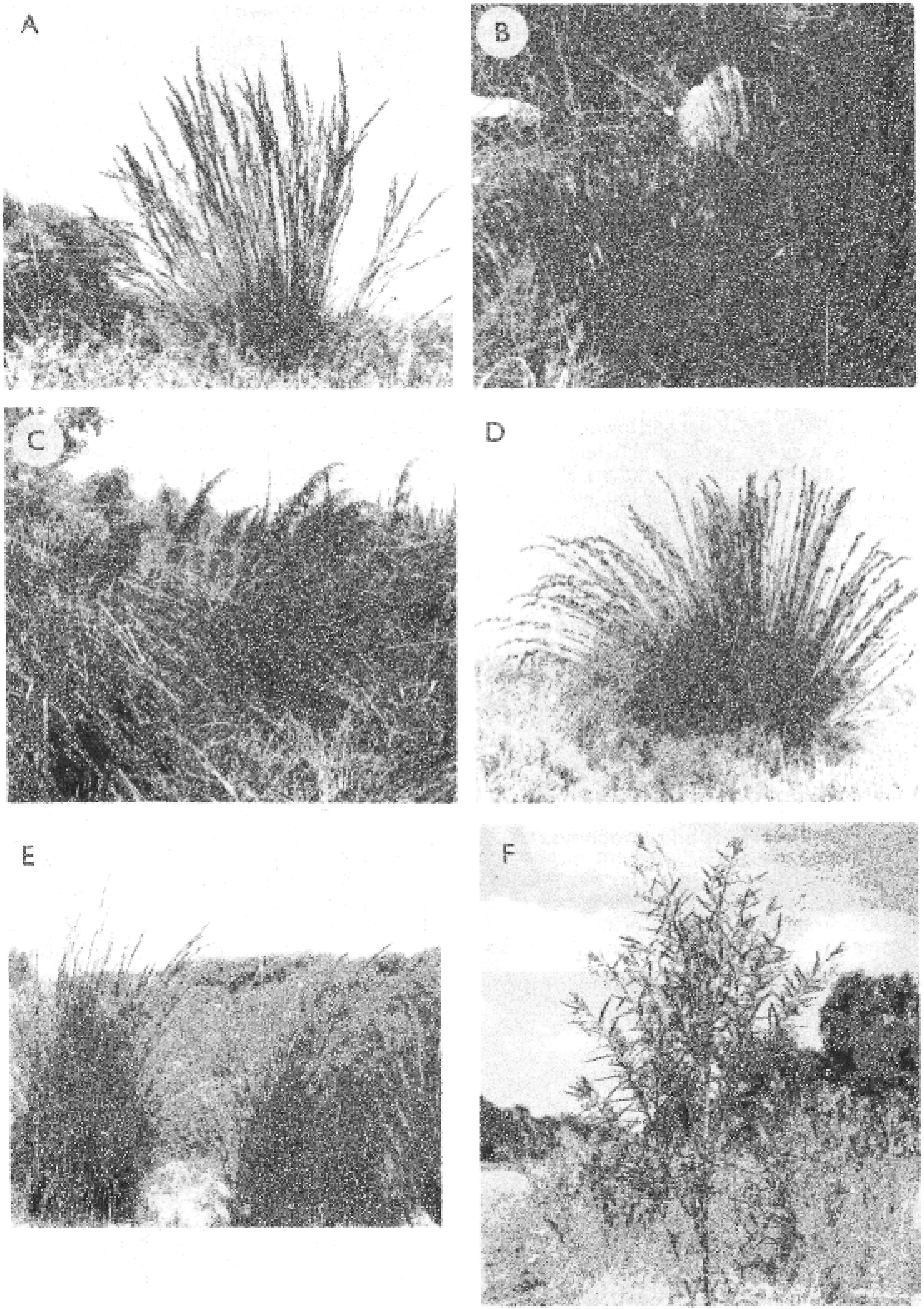
Fig. 5. Larval food plants. A. *Gahnia deusta (Hesperilla donnysa diluta),* Coorong. B. *Gahnia lanigera (Motasingha atralba),* Tintinara. C. *Gahnia clarkei (?Tisiphone abeona* and some *Hesperilla* spp.), Lake Edward. D. *Gahnia triflda (Hesperilla chrysotricha, H. donnysa delos),* Coorong. E. *Gahnia filum (H. chrysotricha, H. donnysa delos),* Coorong. F. *Asclepias physocarpa (Danaus chrysippus, D. pexippus),* Millicent.


A
B
C
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E
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thatching grass), including G *trifida,* G. *filum,* G. *sieberiana,* G. *deusta,* G. *radula* and possibly G. *clarkei.* (See Fig. 5). Several of these sedges are common along roadsides in swampy coastal areas, particularly in the lower South East, and often two or three *Gahnia* species may be found growing together. G. *deusta* occurs mainly in the upper South East and along the Coorong, while G. *radula* seems to have a very limited distribution now, near the Victorian border in the south. The larvae of this genus build tubular shelters by joining leaves of the food plant with silk, and pupation occurs within the shelters. Recognition of features of the shelters may be used to identify the particular species which built them.

Motasingha dirphia (dirphia skipper) occurs in both the upper and lower South East and has a green larva wh ich feeds on the sedge *Lepidosperma carphoides.* The larva builds a shelter open at the top, and situated either at the base of the plant if the plant is small, or towards the extremities of the leaves in the larger plants. M. *atralba* (black and white skipper) is recorded only in the upper South East and its green larva builds a twisted shelter, open at the bottom, on the stunted *Gahnia lanigera* (Fig. 5b). Surprisingly, two small and otherwise widely distributed hesperiine skippers, *Taractrocera papyria* (white grassdart) and *Ocybadistes walkeri* (southern dart) do not appear to have been recorded in the South East

Most of these species have a very limited flying period in either spring or autumn but M. *atralba, H. flavescens* and *H. donnysa diluta* appear in both seasons

PAPILIONIDAE (swallowtails)

Only one species appears naturally in South Australia, although two others have become established in citrus orchards in many parts of the State. The large *Pap ilia demoleus* (chequered swallowtail) has been recorded in the upper South East but this may be its southern limit. Its larvae are found on several *Psoralea* spp. (The *Psoralea patens* complex has been re-examined by Lee, 1980. The name *P. patens* as used in Fisher, 1978 pp. 118-119, should be corrected to read *P. australasica).*

PIERIDAE (whites and yellows)

Probably the most familiar species in this family is the introduced *Pieris rapae* (cabbage white), a well-known garden pest. The colourful *Oelias aganippe* (wood white) is common in some years, but almost completely absent in others. Its larvae feed gregariously when young on several pJants, including *Exocarpus* spp., *Santalum* spp and mistletoes. When older, those larvae which have survived their natural enemies disperse on the food plant but tend to congregate again for pupation. In spring and early summer an occasional individual of *Eurema smilax* (small grass yellow) may appear, its bright yellow colour making it easy to identify. It has been found breeding near Furner on a cultivated *Cassia* sp. Of particular interest is the migratory *Anaphaeis java* (caper white, Fig. 7a and 7b) which may appear in large numbers during November in many parts of the South East, returning north again to its breeding grounds in the Flinders Ranges and northern New South Wales, where its larval food plants, *Capparis* spp and *Apophylum* spp, occur

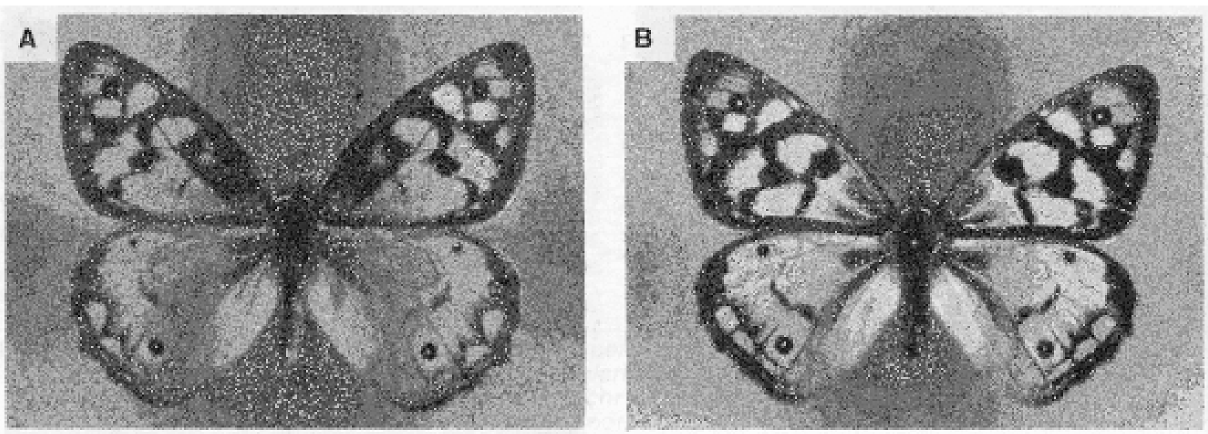

Fig. 6. *Heteronympha penelope* A. male; B. female.

The most recent appearance of such a flight was in 1979, near Furner (J. A. Prance, pers. comm.). Migratory flights such as these are poorly understood and need much more observation and study. There are single records of two other pierids, one of *Catopsilia pyranthe* (common migrant) near Mt Gambier in 1898, and one of *Elodina padusa* (narrow winged pearl white) from the Coorong. Both must be regarded as unusual records due probably to migratory flights from the north.

NYMPHALIDAE (browns, danaids, nymphs)

The 10 species which occur in the South East include three which are not found elsewhere in the State. The subspecies *Oreixenica kershawi kanunda* (Kershaw's brown) was described from specimens collected in what is now Canunda National Park. The type locality of *Tisiphone abeona antoni* (sword grass brown) is a swampy area near Mount Edward, where entry is restricted by the Department of Woods and Forests. Its early stages have not been collected in South Australia although the life histories of related subspecies are quite well known in such areas as the Grampian Mountains, Victoria and on the east coast of Australia. In South Australia its larvae probably feed on *Gahnia clarkei* (Fig. 5c), which grows in dense thickets where the butterfly has been collected. *Heteronympha penelope* (shouldered brown, Fig. 6a and 6b) flies near Millicent in March but does not seem to occur further north. Normally it inhabits open forest formations, but with the disappearance of these it seems to be at home in a much more open environment such as occurs along roadsides between Millicent and the coast. Its larval food plants have not been identified clearly in South Australia, but in Victoria larvae have been found feeding at night on several grasses.

Heteronympha merope (common brown) and *Geitoneura klugii* (Klug's xenica) are usually abundant in much of the South East during summer, and often both species fly together. Their larvae feed on common winter grasses. The sexually dimorphic *H. merope* is of particular interest in that the males appear in flight some weeks before the females. The introduced *Dana us plexippus* (wanderer, monarch, Fig. 8) and the native D. *chrysippus* (lesser wanderer) occur rather spasmodically throughout the area. Both feed on the introduced and now naturalised cotton bushes, *Asclepias rotundifolia,* which occurs in the Coorong, and *A. physocarpa* which grows in coastal areas between Millicent and Beachport (Figs. 5f and 1 b). (The identification of *A. physocarpa* is based on the on ly two previous collections of this species in the Adelaide Herbarium; Andrew for Black 19"19, inland from Beachport, and Cleland 1944, Rendelsham).

Three other nymphalids are seen commonly in gardens as well as in the open countryside. *Vanessa kershawi* (painted lady) has larvae which feed on a variety of common native and introduced plants" A migratory flight of this species was observed near Bordertown in October, 1978. *Vanessa itea* (Australian admiral) often settles with wings outspread on walls and fences. Its larvae eat native and introduced nettles, sheltering during the day in a folded leaf. *Junonia villida* (meadow argus) flies close to the ground and its larvae also feed on a variety of plants.

LYCAENIDAE (blues)

Eleven species of this large family are recorded in the South East but several are comparatively rare. *Ogyris idmo* (large brown azure) is known from two specimens collected near Brimbago, in a locality that has now been cleared of native vegetation. A single

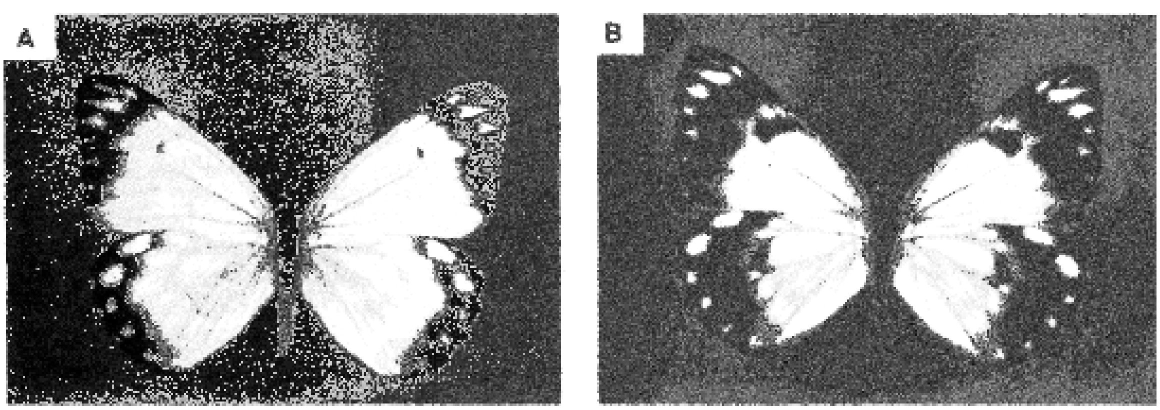

Fig. 7. *Anaphaeis java* A. male; B. female.

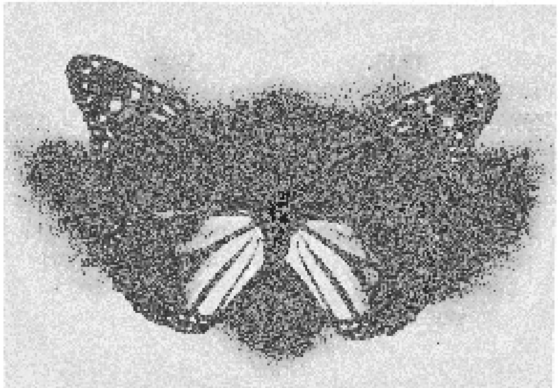

Fig. 8. *Danaus plexippus* female.

specimen of O. *abrota* (dark purple azure) was taken near Mt Gambier in 1896, but none has been recorded since. The larvae of this species feed in Victoria on *Muellerina eucalyptoides,* a mistletoe that occurs in several localities in the South East. A more common species of *Ogyris* is O. *olane* (olane azure, Figs. 2g-h). It is widely distributed throughout the South East though it does not fly far from its larval food plants: two mistletoes of the genus *Amyema* growing usually on eucalypts. Its larvae shelter during the day under bark close to the mistletoe although prior to pupation they attach themselves to the trunk of the host tree nearer to the ground. Adults usually fly in January. *Nacaduba biocellata* (double-spotted line blue) has larvae which feed on the flowers of various Acacia spp., and is often common near these trees in the South East, especially in early summer. *Theclinesthes albocincta* occurs in coastal sandhills where its larval food plant, *Adriana klotzschii,* is abundant. *Theclinesthes serpentata* (chequered blue) is also more common on the coast although it occurs inland. The larvae feed on the flowers of several salt bushes *(Atriplex* and *Rhagodia* spp.).

Neolucia agricola (fringed blue) may be found in many parts of the South East. The brightly coloured larvae bear a marked resemblance to the flowers of the various Papilionaceae which they eat. The egg is small and intricately sculptured (Fig. 1a). The very common *Zizina labradus* (common grass blue) is widespread and has probably suffered little from the clearing of vegetation as its larvae feed on many leguminous plants.

Three of the four South Australian species of *Candalides* occur in the South East. The rare and rather richly coloured C. *cyprotus* (cyprotus blue) is recorded from several localities, usually associated with mal lee heath vegetation. The life history and larval food plant are, as yet, not known. The tiny C. *acastus* (blotched blue) flies over low vegetation near its larval food plants, the twining *Cassytha glabella* and C. *pubescens.* Two subspecies, C. *hyacinthinus hyacinthinus* (common dusky blue) and C. *h. simplex* (western dusky blue) have been collected in different parts of the South East, the former in the south and the latter in the north. The subspecies *simplex* has been reared from larvae feeding on the fruits and buds of *Cassytha melantha.*

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REFERENCES

Fisher, R. H. (1978). 'Butterflies of South Australia'. (Govt Printer, Adelaide).

Lee, A. T. (1980). The *Psoralea patens* complex. *Telopea* **2**(1),129-141.

22: National Parks

by A. C. ROBINSON and G. M. ROWBERRY

INTRODUCTION

There are 24 parks managed by the South Australian National Parks and Wildlife Service in the area south of a line from Kingston to Naracoorte. Collectively they cover an area of 19841 hectares, which is nearly 1.9% of the total area.

These parks are discussed in relation to the environments of the South East Province of South Austral ia accord i ng to Laut *et al.* (1977). Parks occur in four of the five environmental regions described by these authors (Fig. 1). General descriptions of each park are given below, beginning in the South Coast Environmental Region, and moving inland in a north-easterly direction.

The size and complexity of the parks varies considerably as does the amount of resource information available on each. In the following discussion an attempt has been made to summarise this information and to provide the visitor with a brief introduction to the individual parks. Park locations and facilities provided are set out in Table 1.

SOUTH COAST ENVIRONMENTAL REGION

Within the South East region this landform sequence exhibits maximum instability and dynamic change. It includes offshore islands, and the coastline and beaches which are backed by a series of parallel coastal dunes and swales. The dunes frequently enclose extensive lagoons, some of which have filled to form level plains. Locally sea cliffs are present where calcarenite (cemented calcareous sand) outcrops.

1. *Baudin Rocks Conservation Park* (5 ha).

Also known as Godfrey Island, this Park comprises several small, rocky islands which are set aside to protect a breeding colony of Crested Terns *(Sterna bergii)* and Little Penguins *(Eudyptula minor).* Bridled Terns *(Sterna anaethetus)* were observed breeding here on at least three occasions in the late 1960s (Lovell, 1972)

In less exposed areas, the two larger islands have a patchy vegetation cover, primarily of Cushion Bush *(Calocephalus brownii).* The northern island has a sandy beach on its north-eastern corner which provides convenient access, weather permitting, although visitors should make every effort to avoid disturbing breeding birds.

2. *Penguin Island Conservation Park* (8 ha) is also a breeding ground for Little Penguins and Crested Terns, as well as for Silver gulls *(Larus novaehollandiae)* and Black-faced Shags *(Leucocarbo fuscescens)* Single bull Australian Sea Lions *(Neophoca cinerea)* are occasional visitors.

The island is surrounded on all sides by vertical cliffs which rise 10-15 m from the sea. On the southern end there is an extensive rock shelf. The coastal cliff vegetation which covers most of the island includes Grey Saltbush *(Atriplex cinerea),* Coast Twin Leaf *(Zygophyllum billardieri),* Seaberry Saltbush *(Rhagodia baccata),* Bower Spinach *(Tetragonia amplexicoma)* and Sea rocket *(Cakile maritima).*

An historical lighthouse and jetty occur on the island but are no longer used. Both have been placed on the Recorded List of the National Trust of South Australia. The waters surrounding the island and the adjacent Cape Martin are a Rock Lobster Sanctuary managed by the South Australian Fisheries Department.

3. *Guichen Bay Conservation Park* (82 ha) is a secluded area of coastal shrubland along the northern end of the long sandy beach at Guichen Bay. Most of the park consists of low dunes which are stabilised by a dense vegetation cover of Coast Daisy Bush *(Olearia axillaris)* and Currant Bush *(Leucopogon parviflorus),* while typical fore-dune colonising species such as Club Rush *(Scirpus nodosus)* and Cushion Bush *(Calocephalus brownii)* predominate along the coastal margin. Unlike the coastal parks further south, there are virtually no areas of sand drift and, similarly, Coastal Wattle

2. Fig. 1. South East showing Reserves managed by the National Parks and Wildlife Service, areas of natural vegetation managed by the Woods and Forests Department, and 'Environmental Associations' employed by Laut *et al.*, (1977).

Table 1. NATIONAL PARKS & WILDLIFE SERVICE RESERVES IN THE LOWER SOUTH EAST.

Park	Location Map (1:50 000) and approx. Grid Ref.	Area (ha)	Facilities		Access
A. South Coast Environmental Region					
1. Baudin Rocks Conservation Park	Robe 883946	5		C	Island, 8 km N of Robe.
2. Penguin Island Conservation Park	Hatherleigh 127483	8		C	Island, 2 km S of Beachport
3. Guichen Bay Conservation Park	Robe 818945	62		C	3 km SE of C. Thomas. 1.5 km walk along Beach from Boatswain Pt.
4. Little Dip Conservation Park	Robe 920800, Beachport 980750	1988	+ + +	C	3 km S of Robe or from Robe-Nora Creina Road.
5. Beachport Conservation Park	Beachport 085565	710	+ + +	C	4 km along road travelling NW from Beachport on shore of L. George.
6. Canunda National Park	Buffon 300380, Millicent 385285	9096	+ + + +	C	NW boundary 13 km W of Millicent. Access S from Rendelsham or Southend or at Oil Rig Square.
7. Bucks Lake Game Reserve	Benara 470044	137		D	30 km WSW from Mt. Gambier via Benara Rd. 1 km N Carpenter Rocks.
8. Nene Valley Conservation Park	Schank 572862	373	+ +	D	30 km SW of Mt Gambier via Benara Rd and Kongorong.
9. Piccaninnie Ponds Conservation Park	Gambier 885840	397	+ +	D	30 km SE of Mt Gambier. 2 km S along dirt track from Mt Gambier-Nelson Road. Turn off 2 km E of Victorian border.
10. Ewens Ponds Conservation Park	Gambier 818815	24		D	20 km S Mt Gambier via Mt Gambier-Nelson Rd for 17 km then 8 km SE to Eight Mile Creek. Entrance track 800 m W of Memorial Hall at Eight Mile Creek.
11. Dingley Dell Conservation Park	Schank 717894	6	+ + +	D	1.5 km N then 2 km W from Port MacDonnell.
B. Southern Coastal Plains Environmental Region					
12. Bali Hill Conservation Park	Hatherleigh 327529	10		C	NW along Princes H/way for 4 km from Hatherleigh to jn at bend. Park is W of road 1 km S along dirt rd.
C. Mount Gambier Volcanics Environmental Region					
13. Tantanoola Caves Conservation Park	Kalangadoo 560254	14	+ + + +	T D	Borders Princes Highway 22 km SE of Millicent (38 km WNW of Mt Gambier.
14. Gower Conservation Park	Kalangadoo 577255	39	+	D	1.5 km along dirt track leading ESE from Princes Highway 1 km NNW from Tantanoola Caves.
D. Southern Wetlands and Dune Ranges Environmental Region					
15. Reedy Creek Conservation Park	Hatherleigh 384878	82		C	500 m E of Kangaroo Inn Area School, 30 km NW of Millicent.
16. Furner Conservation Park	Kennion 349832	256		C	E along Main South Eastern Road (10 km N of Hatherleigh) from Princes H.way fro 3.5 km. Left (NW) along dirt road for 2 km.
17. Calectasia Conservation Park	Monbulla 801663	14		C	S side of Penola-Robe road 26 km W of Penola.
18. Penola Conservation Park	Monbulla 730655	225	+ +	D	N side of Penola-Robe road 13 km W of Penola.
19. Big Heath Conservation Park	Bool Lagoon 640870	2351		B	2 km N from T-junction at NW corner of Mary Seymour Conservation Park.
20. Mary Seymour Conservation Park	Bool Lagoon 583880	330	+ +	B	18 km WSW from turnoff at Struan on Naracoorte-Penola Road—via Bool Lagoon and Willangee.

Park	Location Map (1:50 000) and approx. Grid Ref.	Area (ha)	Entrance Fees	Walking Trails	Picnic BBQ Areas	Camping	Water	Toilets	Fishing	Swimming	Boating	Resident Ranger	Access Difficult	No Staff Facilities	Location of	Ranger-in-Charge*	FACILITIES	Access
21. Bool Lagoon Game Reserve	Bool Lagoon 740920	2690			+	+	+							+		+	B	7 km W of Naracoorte-Penola Rd. Turnoff at Struan 18 km S of Naracoorte.
22. Hacks Lagoon Conservation Park	Bool Lagoon 754936	193												+			B	N of Ranger's residence at Bool Lagoon Game Reserve.
23. Naracoorte Caves Conservation Park	Struan (Cave) 818011 (C.P.) 830972	272		+	+	+	+	+	+					+			N	4 km E of turnoff from Naracoorte-Penola Road. Turnoff 9 km S Naracoorte.
24. Glen Roy Conservation Park	Struan 878842	541														+	N	1 km E along access track from Naracoorte-Penola Rd. 27 km SSE of Naracoorte.

*B Bool Lagoon Game Reserve
C Canunda National Park
D Dingley Dell Conservation Park
N Naracoorte Caves Conservation Park
T Tantanoola Caves Conservation Park

(Acacia sophorae) is an uncommon component of the vegetation,

4. *Little Dip Conservation Park* (1956 ha) is a large coastal park featuring a complex sand dune system bordered by the sea to the west and large salt lakes to the east. Limestone rises separated by long sandy beaches occur at intervals along the coastal strip between Cape Lannes and Errington Hole. The most exposed of these rises supports Cushion Bush and Spear Grass *(Stipa elegantissima)* whilst more sheltered areas support a heath land of *Beyeria leschenaultii,* Thyme Rice Flower *(Pimelea serpyllifolia)*, and *Goodenia varia.* Extensive areas of unvegetated drifting sand occur throughout the park, while vegetated dunes support a dense shrubland of Coastal Wattle, Golden Wattle *(Acacia pycnantha)* and Currant Bush. Where limestone outcrops further inland, visitors may see Drooping Sheoak *(Casuarina stricta),* Coastal Bitter Bush *(Adriana klotzschii)* and Dryland Teatree *(Melaleuca lanceolata).*

A number of small lakes occur. Most are brackish and are surrounded by dense stands of Salt Water Paper Bark (M. *halmaturorum).* Two contain permanent freshwater, providing important water-bird habitat.

Bush camping and off-road recreational vehicle use are popular activities. A small number of holiday shacks remain near the coast at the end of the Little Dip Road.

5. *Beachport Conservation Park* (710 ha) is situated between the Southern Ocean and Lake George, and is accessible by a track running along the western shore of Lake George. This road follows the route of the old coach road between Beachport and Robe and the site of Smith and Stewart's change stables (which operated between 1879-1907) is found in the park,

Mobile sand dunes occupy nearly 50% of the total area of the park while the remainder contains a variable shrubland formation similar to Little Dip Conservation Park and dominated by Coastal Wattle. A freshwater seepage occurs along the inland margin of the high dunes and forms a fresh water lake known as Two Lakes (sand drift has completely inundated the second of this original two lakes). This is surrounded by tussock sedgeland and low scrub of Silky Teatree *(Leptospermum lanigerum)* and Scented Honey Myrtle *(Melaleuca squarrosa)* Thickets of Salt Water Paper Bark and saltmarsh areas of Beaded Glasswort *(Salicornia quinqueflora)* surround the shores of Lake George.

This diverse range of habitats offered by the park and adjoining coastal and lake environments supports approximately 200 species of birds. The margin of Lake Georgeis a particularly important area for migratory waders such as the Grey Plovers *(Pluvialis squaterola),* Mongolian Sand Dotterels *(Charadrius mongolus),* Greenshanks *(Tringa nebularia)* and Bar Tailed Godwits *(Limosa lapponica).* A common resident breeding species of the vegetated dune areas is the Rufous Bristlebird *(Dasyornis broadbenti).* while the Olive Whistler *(Pachycephala olivacea)* is found in the Salt Water Paper Bark thickets. Woolley Lake is one of the few areas where Leewins Rail *(Rallus pectoralis)* can be regularly seen.

The extensive areas of mobile dune fields in the park are a relic of early grazing, uncontrolled spread of rabbits, past burning and fence construction. They have been calculated to be migrating inland at average rates of 15 m/year downslope and 7.4 m/year into Lake George (Armstrong, 1977) In an effort to control this sand movement and ultimately revegetate the drifting dunes, an extensive and continuing programme of Marram Grass *(Ammophila arenaria)* planting is bei ng carried out on the park. Because offroad vehicle use of the bare sand areas threaten these plantings, stabilised tracks across the dune fields to popular areas of the coast within the park have been marked with orange painted steel posts.

The park also contains extensive areas of aboriginal middens. A particularly notable example at Three Mile Rocks (accessible by four-wheel drive vehicles) has been fenced to ensure its conservation.

6 *Canunda National Park* (9086 ha) is the only National Park to occur in the South East. It extends from the township of Southend on the southern end of Rivoli Bay, southward along the coast for 40 km, varying in width from 0.8 to about 5.5 km. A manned park headquarters is located at Southend.

The coastline in the vicinity was first charted, somewhat inaccurately, by a French expedition under the leadership of Nicolas Baudin during April 1802 The name, Cape Buffon, affixed by the expedition to a now unidentified point of land further south, commemorates George Louis Leclerc, Comte de Buffon (1707-1788), the celebrated naturalist and writer. The present Cape Buffon was originally called Cape Lannes.

Geltwood Beach on the coastline of the park, was so named because of the tragic loss in this area of the 'Geltwood', an iron barque of 1073 tonnes, on her maiden voyage from Liverpool to Melbourne in June, 1876. There were no survivors and at least 27 people perished.

The northern coastline of the park contains spectacular limestone outcrops and offshore reefs. In fact the coast line from Cape Buffon to Cape Banks receives the highest break of wave energy in the South East (Short & Hesp, 1980). Cliff-top vegetation is similar to that described for Little Dip Conservation Park. The remainder of the coastline consists of a long sandy beach whilst the majority of the park is covered by a complex system of dunes, nearly 50 per cent of which are mobile (Cullen & Bird, 1980). These represent the most massive and unstable dune systems in the South East (Short & Hesp, 1980). Like Beachport and Little Dip Conservation Parks, extensive plantings of Marram Gras$, Spiny Rolling Grass *(Spinifex hirsutus)* and Coast Fescue *(Festuca littoratis)* have been carried out to encourage stabilisation of dunes (Zimmerman & Seeliger, 1979). Stable sand dune areas are covered with shrublands dominated by Coastal Wattle and Currant Bush, or occasionally by Dryland Tea-tree. Between the dune system and Lake Bonney are areas of grassland which support a small population of Common Wombats *(Vombatus ursinus)* whilst the shores of Lake Bonney are surrounded by Silky Tea-tree.

As in Beachport and Little Dip Conservation Parks there are a number of freshwater soaks. The Whale Rock soak contains good quality fresh water but additional soaks between Jacky Point and Number One Rock have been polluted by seepage of water from Lake Bonney.

Over the years the Ocean Beach at Canunda National Park has seen many strandings of marine mammals and oceanic birds, many of them rare visitors to Australia's coastline.

Access to the coast by conventional vehicles is provided at Cape Buffon, Boozy Gully and Oil Rig Square. Additional public access tracks which are marked by coloured steel posts occur throughout, but are generally suitable only for 4-wheel drive vehicles and this is the most popular recreational activity in the park. Attractive bush camping areas occur at Abyssinia Bay and Number Two Rocks; McIntyres Beach is an excellent surfing area whilst skindiving and cray-potting are popular between Cape Buffon and Sweep Rock.

8. *Bucks Lake Game Reserve* (137 ha). Before European settlement, overflow water from Lake Bonney flowed south-eastwards to Bucks Lake and ultimately to the sea near Carpenters Rocks. Since the construction of the artificial outlet from Lake Bonney, the amount of water reaching the swamp at Bucks Lake has been considerably reduced. Nonetheless the lake remains a moderate stretch of semi-permanent open water surrounded by a swamp sedgeland of Chaffy Saw-Sedge *(Gahnia filum)* and Sea Rush *(Juncus kraussii)* with patches of Saltwater

Paper Bark. Away from the lake edge, Dryland Tea-tree, Coastal Daisy Bush, Golden Wattle and Coastal Wattle occur. The Southern Bush-rat *(Rattus fuscipes)* is found in both of the latter two habitats whilst the rare Swamp Antechinus *(Antechinus minimus)* inhabits the denser tussock sedgelands.

The reserve provides excellent water-bird habitat and is open for duck shooting by licensed shooters during the South Australian Open Season.

9. *Nene Valley Conservation Park* (373 ha) is a relatively large area of low-lying but undulating coastal dunes dominated by *Acacia sophorae.* Near the coast the Coastal Wattle forms a low shrubland with Currant Bush, Coastal Daisy Bush and Coast Everlasting *(Helichrysum paralium),* whilst further inland it forms a tall shrubland with Golden Wattle, Coastal Daisy Bush, Coast Everlasting and scattered low trees of Drooping Sheoak. Low-lying depressions between the dunes are occupied by sedges and tussock grassland.

At a number of places along the coast there are shingle beaches composed entirely of flint nodules. These were used by Aborigines to fashion implements and remnants of this industry can be seen in middens in the dunes. Former strand lines of past higher sea levels are particularly obvious in this park because they are marked by rows of old shingle beaches which are now covered with sand and partly vegetated.

10. *Piccaninnie Ponds Conservation Park* (397 ha) is bounded by a long sandy beach backed by typical bands of coastal vegetation. However, the major feature of the park is a large reed swamp which is surrounded by a narrow belt of dense Silky Tea-tree and Coast Saw-sedge. The main swamp area is inundated by water for a greater part of the year and is dominated by large, robust aquatic Water Ribbons *(Triglochin procera).* Other plants to occur in the swamp include the Common Reed *(Phragmites vulgaris)* and Bull Rush *(Typha angustifolia).* In addition, a number of rare South Australian plant species occur in the reserve. These include the Maroon Leek Orchid *(Prasophyllum hartii),* Swamp Green-hood *(Pterostylis tenuissima), Gentiana diemensis,* Needlebush *(Hakea nodosa)* and *Leucopogon lanceolatus* (Kraehenbuehl, 1964).

The Piccaninnie Ponds wetlands originally drained east into Victoria but sometime before the Second World War the present channel was cut to the sea, increasing the outflow from the swamps and lowering the water level. The reason for cutting this channel is obscure but it was probably to provide more grazing land or to improve the habitat of the Short-finned Eel *(Anguilla australis).*

The Piccaninnie Ponds area is one of Australia's best and most popular cave diving spots, renowned for its exceptional water quality and depths more than 60 metres. Much of the early exploration of these water-filled sinkholes was done by members of the Mount Gambier Spearfishing and Skindiving Club which was formed in 1961 The Mt Gambier divers kept the discovery quiet for a year or so but gradually word leaked out and 'outsiders' started to trickle in until finally, after several drownings, a permit system for divers was introduced. In 1964 Mick Potter and Brian Rodger dived to a depth of about 70 m: quite a feat in those days of relatively unsophisticated equipment. Several others have since reached the same level. The main shaft has never been bottomed and its depth remains unknown. Further details of cave diving in this park are reported by Lewis & Stace (1980). The popularity of this area with divers can be judged from the fact that in 1980-81,319 scuba diving and 519 snorkel diving permits were issued for the park and it is estimated that the total number of individual dives per year now numbers nearly 2000. Because of the dangers associated with cave diving only persons with current category 2 rating with the Cave Divers Association of Australia can obtain a scuba diving permit. Diving is restricted to a depth of 36.5 metres.

11. *Ewens Ponds Conservation Park* (24 ha) consists of a small but dense remnant patch of Messmate Stringybark *(Eucalyptus obliqua)* forest with a rich diversity of understorey species including Blackwood *(Acacia melanoxylon),* Swamp Gum *(Eucalyptus ovata),* Native Cherry *(Exocarpus cupressiformis)*, Currant Bush and Bracken *(Pteridium aquilinum).*

The park is adjacent to the popular diving spot Ewens Ponds which comprises three small ponds probably formed as a result of collapsed dolines. The ponds are spring-fed and connected to one another by Eight Mile Creek, a natural water course that ultimately empties into the sea east of Port MacDonnell.

Prior to clearing in the 1940s the vegetation of the whole Ewens Ponds area was described in detail by Eardley (1943)

12. *Dingley Dell Conservation Park* (6 ha) Dingley Dell, former home of poet Adam Lindsay Gordon, was built in the early 1860s and purchased by Gordon in 1864. It remained in the Gordon family until the turn of the century and the State Government purchased the cottage and surroundings in 1922. The cottage has intermittently been open as a museum since that time. It was extensively renovated by the National Parks and Wildlife Service in the mid to late 1970s and has been open to the public since November 1978. It now features a display based on three themes: Adam Lindsay Gordon-The Man; Adam Lindsay Gordon-The Poet; and, the History of Dingley Dell. Further details of the life of Adam Lindsay Gordon are outlined in the Visitor Guide to Dingley Dell (NPWS 1978). In its first year after re-opening, it attracted 8000 visitors.

The park surrounding Gordon's former home contains one of South Australia's last remaining stands of the large fruited form of South Australian Blue Gum *(Eucalyptus leucoxylon* var. *macrocarpa),* together with Golden Wattle and Currant Bush. A variety of introduced plants such as Furze *(Ulex europaeus)* and Greater Periwinkle *(Vinca major)* are common in some areas of the park and a weed control programme is underway in an attempt to return the park to a more natural appearance.

SOUTHERN COASTAL PLAINS ENVIRONMENTAL REGION

This region is characterised by more stable conditions than the South Coast Environmental Region The dunes, which tend north-westerly, are mainly consolidated, consisting of cemented calcareous sands (calcarenite) and form low but distinct ridges separated by narrow swales. The former lagoons form swamps or plains which are subject to varying degrees of seasonal flooding. Active dunes are locally present overlying the older dune system.

13. *Belt Hill Conservation Park* (10 ha) is a small remnant of natural vegetation on undulating sand dunes with some limestone outcrops at the western end. The dominant plant species are Silver Banksia *(Banksia marginata)* and Golden Wattle in a dense thicket up to five metres high. Understorey shrub species are generally lacking and the ground is covered with a carpet of moss and patches of Bracken. Large Drooping Sheoaks, Currant Bush, Coastal Wattle and occasional Blackwood trees occur at intervals, particularly around the park margin. Aboriginal implements also occur, indicating their past occupation of the area.

MT GAMBIER VOLCANICS ENVIRONMENTAL REGION

This region has a wide range of attributes and a distinctly higher relief and altitude than surrounding regions. It consists of a limestone plain above which rise several volcanic cones. Airborne volcanic ash is widespread around the cones. Calcarenite dunes also occur here. The combination of permeable limestone rock, deep sands and ash soils in an elevated position have given rise to intensive forms of land use consisting of pine plantations on the sands and agriculture on the ash soils. Little natural vegetation remains.

14. *Tantanoola Caves Conservation Park* (14 halo A former marine cliff, known as Up-and-Down Rocks, runs the length of this park and is in itself an important geological feature. The major reason for dedication of the park, however, was the preservation of two major caves: Tantanoola Tourist Cave and Lake Cave. The Tourist Cave was discovered in 1930 by Boyce Lane who was searching for a lost ferret. The entrance was subsequently enlarged and the Lane family conducted tours of the cave.

These proved so popular that electric lighting was installed and in 1930 the area was proclaimed a National Pleasure Resort with management vested in the Tantanoola District Council. Various improvements were carried out by the Council over the years and in 1972 the National Parks and Wildlife Service took control of the caves as a Conservation Park. Day-to-day management of the park continued to be the responsibility of the District Council of Millicent which now incorporates the old District Council of Tantanoola. The Tourist Cave is an important element of the tourist industry of the lower South East and attracts almost 40 000 visitors annually.

In 1936 an investigation of the geology of the Tourist Cave, and a further small cave 5 m northwest, was undertaken (Tindale, 1933). During this investigation a variety of sub-fossil mammal bones was collected and additional bones have since been collected from another small cave 150 m north of the Tourist Cave (Tidemann,1976).

In 1957 an extension of a cave previously noted by Tindale (called North Cave) was explored. It terminated in a large and beautifully decorated chamber with a large lake and was subsequently named Lake Cave. Entrance to this cave is now barred by a locked grate but experienced speleologists are g ranted access.

15. *Gower Conservation Park* (39 ha) is surrounded on three sides by pine plantations and by pasture on the southern boundary. The park contains a largely undisturbed eucalypt forest which is representative of the type of vegetation which once covered much of the dune ranges of the South East The vegetation is dominated by multi-trunked Brown Stringybark trees which form a closed forest over a medium dense understorey of Bracken and Yaccas. Throughout the park there are a few very large Brown Stringybark trees with trunk diameters of 1-1.5 m. The Yaccas also stand on trunks up to 2 m tall with skirts of leaves reaching to the ground indicating that the park has not been burnt for many years. Little is known of the fauna in the park but the Flame Robin *(Petroica phoenicea)* is known to occur here.

SOUTHERN WETLANDS AND DUNE RANGES ENVIRONMENTAL REGION

The Southern Wetlands and Dune Ranges Environmental Region comprises a series of north-northwesterly trending low ridges and intervening plains, reflecting a system of parallel coastal dunes stranded during successive phases of retreat of the sea. Naracoorte Range, the innermost dune ridge, forms the eastern boundary of the region. Locally, the calcarenite dune ridges are overlain by younger sands. Well-drained, deep and shallow sands are typical of the dune ridges and are characterized by impermeable soils derived from marl, clay and silt Because of this impermeability and the lack of an organized natural drainage network, seasonal flooding occurs and lakes and swamps are common features.

16 *Reedy Creek Conservation Park* (82 ha) preserves remnant River Red Gum *(Eucalyptus camaldulensis)* open forest in the bed of Reedy Creek. The construction of Reedy Creek to Wilmot Drain has substantially reduced the area of wetland habitat along the former course of Reedy Creek but small areas of swampland remain in the Park.

17. *Furner Conservation Park* (286 ha) is a largely undisturbed patch of open forest on the north-western slopes of the Reedy Creek Range. The south-eastern boundary of the park adjoins the pine plantations of Mt Burr State Forest The gently undulating sandy hills of the park support two major plant communities which provide habitat for a small population of Red-necked Wallabies *(Macropus rufogriseus).* An open Pink Gum *(Eucalyptus fasciculosa)* woodland with a grassy understorey and occasional bushes of Kangaroo Thorn *(Acacia paradoxa)* is found on the ridge tops whilst the lower slopes and valleys support an open forest of Messmate *(Eucalyptus obliqua)* with an understorey of Bracken *(Pteridium aquilinum)* and Vacca *(Xanthorrhoea australis).* The Messmate forest contains a number of particularly large trees with multiple trunks of approximately 3 m diameter and canopy diameters of around 20 m.

The park has not been burnt for many years and the bracken understorey, so characteristic of areas which have been frequently burned, is decreasing. To reduce the risk of accidental fire, this park is closed to the public during the summer months.*

18. *Calectasia Conservation Park* (14 ha) was set aside primarily to conserve one of the major South Australian occurrences of the Blue Tinsel Lily *(Calectasia cyanea).* It occurs in a low woodland of Brown Stringybark with large bushes of Desert Banksia *(Banksia ornata)* and a dense heath understorey. There are over fifty individual plants of the Tinsel Lily and they are enclosed by a rabbit-proof fence built in the late 1960s. Public access to this area is gained by a stile adjacent to the Penola-Millicent Road.

The path adjoins the Baker Range Drain and about 70% is low lying and has been cleared in The past The cleared area now supports a dense grassland of mainly introduced species.

19. *Penola Conservation Park* (226 ha) preserves a range of habitat types representative of the stranded dune and swale terrain of the lower South East The park incorporates both dune and swale with an associated seasonal swamp covering nearly 10 ha and known locally as Green Swamp. The majority of the park is covered with an open forest of Brown Stringybark over an understorey of Bracken. Almost all of this habitat was burnt in a recent fire (in 1976) which entered from adjoining land. This has resulted in many areas of regenerating Blackwood trees. Green Swamp is surrounded by a River Red Gum woodland

*. Completely burnt Ash Wednesday 1983. Others burnt were Reedy Creek and Colectasia Conservation Parks

with a very open, seasonally inundated understorey. The western end of the swamp supports an extensive heath land of Prickly Tea-tree *(Leptospermum juniperinum),* Needlebush *(Hakea* rugosa) and Dwarf Oak *(Casuarina paludosa).* On the southern side of the swamp a limited occurrence of mixed Rough-barked Manna Gum *(Eucalyptus huberana)* and Swamp Gum, over Prickly Teatree and Yaccas is found (Mowling & Barrett, 1980). The swampy areas support a population of Swamp Rats *(Rattus lutreolus)* and Tiger Snakes *(Notechis scutatus),* while in the surrounding forest, Western Grey Kangaroos *(Macropus fuliginosus)* and Red-necked Wallabies are common. A winter influx of waterbirds occurs into the swampy areas. Although not extensively used, some bush camping occurs in this park.

20. *Big Heath Conservation Park* (2351 ha) conserves an area of the once extensive wet heath lands of the South East and was the subject of a major biological survey conducted by the Nature Conservation Society of South Australia in 1969 (Smyth, 1972). The park occupies a low lying flat between Stewart and Woolumbool Ranges and, before European settlement, was periodically flooded by water flowing towards the sea from the catchment area of Mosquito and Yelloch Creeks in the east. This water first entered Bool Lagoon and then overflowed into Big Heath. The construction of the Bool Lagoon outlet drain in 1909 actually increased the flow of water into Big Heath but then in 1967 the upper end of Drain M was linked to the Bool Lagoon outlet drain diverting much of the water away from the area. The main sources of water to the Big Heath swamps now consist only of local run-off. The park is a complex of low limestone hills, sand dune remnants, flat plains, shallow depressions and swamps, each with a characteristic vegetation type. The limestone outcrops of the Stewart Range support Dryland Tea-tree as well as some very large specimens of Christmas Bush *(Bursaria spinosa),* Native Hop *(Oodonaea* viscosa) and Drooping Sheoak. Much of the higher areas in the rest of the park support an open woodland of Pink Gum and South Australian Blue Gum with a very open understorey of grasses and small areas of Yaccas. At the western end of the park the deep sand on the rises supports an open forest of Brown Stri ngybark and on the lower slopes this merges into a dense shrubland of Desert Banksia containing many heath species.

The swampy depressions on the flood plain are almost bare or covered with small native annuals. Dense thickets of Cutting Grass are also found in some of these depressions or as a fringing band. As elevation slowly increases away from the depressions the Cutting Grass is replaced by a wet heath of Tea-trees *(Melaleuca neglecta* and M. *gibbosa),* Needlebushes *(Hakea nodosa* and *H. rostrata)* and Prickly Tea-tree *(Leptospermum juniperinum).*

The park has a rich fauna, including 115 species of birds which includes 15 breeding waterbird species. Important breeding records are the Freckled Duck *(Stictonetta naevosa)* and the buff-banded Rail *(Rallus philippensis).*

Seven species of amphibians and 17 species of reptiles are known from the park. The dark form of the Sand Goanna *(Varanus gouldii rosenbergi)* is probably near the southern limit of its distribution in the park. Of the seven native mammals recorded, the Ashy Grey Mouse *(Pseudomys apodemoides),* a species more common in the heathlands of the Ninety Mile Desert further north, is probably also at the southern extent of its range in this park.

21. *Mary Seymour Conservation Park* (379 halo This park, known locally as 'The Lorimer', has two major landforms; a low lying area subject to inundation, and an area of gently undulating calcarenite ranges overlain by sand. The low lying areas support a dense shrubland of Prickly Tea-tree, *Melaleuca neglecta,* Silver Banksia and Needlebush *(Hakea nodosa)* (Mowling & Barrett, 1980). On the edge of the swamp is a small area of River Red Gum, South Australian Blue Gum and Pink Gum woodland with a sparse ground cover. The higher areas support a forest of Brown Stringybark and Pink Gum over a Bracken and Vacca understorey. Twenty-two of the twenty-nine waterbird species recorded in the park have been observed breeding on occasions when the swamp has held water. These include the only South Australian breeding records of the Brolga *(Grus rubicunda),* three species of Rails, the Australasian Bittern *(Botaurus poiciloptilus)* and the Whiskered Tern *(Chilidonias hybrida).* This area is consequently considered to be the third most important wetland area in terms of the number of breeding bird species in the South East of South Australia.

22. *Bool Lagoon* Game *Reserve* (2690 ha) and *Hacks Lagoon Conservation Park* (193 ha) together constitute the largest

swamp in the South East and one of the most important managed wetland areas in south-eastern Australia. They consist of a series of irregular, saucer-shaped, shallow to medium depth lagoons, varying in size from ten to several hundred hectares. They are bounded by high embankments called lunettes and form a near permanent open swamp occupied by Water Ribbons with smaller areas of Reeds and Bullrushes The main lagoon also has an important area of Saltwater Paperbark. In addition to their importance as a natural wetland area the lagoons are managed as an equalising basin to regulate the flow of floodwaters down Mosquito Creek. A series of embankments, inlet and outlet drains and water level regulators, have been constructed. These works now enable a considerable degree of water level control over the lagoons and provide the opportunity to actually increase the importance of Bool Lagoon as a drought refuge for waterbirds in southeastern Australia These lagoons are now the only area in South Australia where large concentrations of Brolgas can be seen. Of the seventy-five species of waterbirds recorded from the area, forty-seven are known to breed there, making this by far the most important area in the South East for waterbirds. In years with good water levels an estimated 10000 Ibis breed in the Paper Bark areas.

In addition to its importance in waterbird conservation, Bool Lagoon Game Reserve has been a popular duck shooting area for many years. In recent years there have been several open days for hunting during the South Australian duck hunting season. Between 500 and 2000 shooters per day have utilized the lagoon on each of these occasions. In 1980 there were unusually large numbers of the uncommon Freckled Duck on Bool Lagoon (as well as on other wetland areas of southern Australia) and at Bool Lagoon about 1000 of these protected birds were shot on the opening day of the duck season. This resulted in the closure of the lagoon to shooting forthe remainder of that season Freckled Ducks were again present in the lagoon in 1981 and although only a very small number were shot on the opening day, it was again decided to close the lagoon to shooting for the rest of the season. The continuing presence of a population of Freckled Duck on the lagoon in the future will be a continuing source of conflict between the hunting and conservation roles of the Game Reserve-a conflict which can only be solved by more intensive management of the area.

23. *Naracoorte Caves Conservation Park* (285 ha) contains seventeen of the approximately sixty known caves which extend for some 25 km along the Cave Range. Blanche Cave was the first to be discovered when, in 1845, a local station manager searching for some sheep stolen by Aborigines found them hidden in the cave This cave became a popular place for social outings from Naracoorte and parties and dances were actually held in the main chamber of Blanche Cave. In 1855 the Forest Board appoi nted a caretaker at the cave and this job was held by William Reddan between 1887 and 1919. Reddan was very active in the development of the caves for visitors and he personally discovered a number of new caves, including the beautifully decorated Alexandra Cave. In 1915 control of the caves passed to the South Australian Tourist Bureau and the Caves Reserve was subsequently established in 1917. A considerable amount of development was carried out both within the caves and on the surface. Lighting systems were established and ornamental trees and gardens were planted. The discovery of caves, even in an area as well known as this, continues. In 1981 Telecom Australia broke into a cave system while digging a trench for a new telephone line. This cave, now known as Cable Cave, contains some good displays of cave formations and some fossil material. Though nearly all of the cave is in the park, the entrance is on private land. A padlocked grille door prevents access to the cave pending further investigation.

The major discovery at Naracoorte Caves Conservation Park, however, was undoubtedly that unearthed by the exploration in 1969 of an extension to the Victoria Cave (which had itself been discovered in 1894). Visitors to Naracoorte Caves Conservation Park are now able to enter the Fossil Cave from the old Victoria Cave through an enlarged entrance with a modern lighting system. During this tour they can see the fossi l excavation from a vantage point above the silt bed while the guide explains details of the fossil fauna and the significance of the deposits. A display outlining details of the fauna of Victoria Fossil Cave, together with some information on formation of caves and cave exploration (Wells *et al.,* 1980) can be viewed in the Park's Visitor Centre.

Before leaving the world of the caves in Naracoorte Caves Conservation Park, mention must be made of Bat Cave which is a major breeding site for the Bent-wing Bat *(Miniopterus schrebersii)* (Dwyer 1963). In spring each year the bats converge on Bat Cave from as far as 400 km away and up to 250000 bats can sometimes be concentrated in the cave. The enormous heap of guano accumulated by the bats over thousands of years was once mined as a source of fertilizer. Today the entrance to Bat Cave is closed to the visiting public so as to protect this important maternity site. Nevertheless groups with a special interest can, by prearrangement with the Park Ranger, visit the cave and see the spectacle of thousands of bats emerging at dusk to hunt for insects in the surrounding area.

Although the caves are generally considered to be the main feature of the park, a large part of its total area is still covered with natural vegetation. The limestone ridges support a relatively open shrubland of Dryland Tea-tree and, where soils are deeper, an open forest of Brown Stringybark over a largely Bracken understorey. Along the course of Mosquito Creek which travels through the park is a River Red Gum woodland and some low lying sedge-covered areas which are subject to inundation during wet winters. This area seems to be close to the north-western limit of the distribution of a number of species such as the Sugar Glider *(Petaurus breviceps)* and the Forest Raven *(Corvus tasmanicus)* which have their centres of distribution in the forests of south-eastern Australia. The Brush-tailed Phascogale *(Phascogale tapoatafa),* now a very rare mammal in South Australia, also occurs in the park. This animal was well known to the Reverend Tenison Woods when he wrote his classic work on the South East of South Australia (Woods 1862). He said of the an imal he knew as the native squirrel: "This little animal is most destructive and pugnacious, lives in dead hollow trees, and I have only seen it near low land."

Naracoorte Caves Conservation Park is visited by 50000-70000 people a year and is one of the major tourist attractions in the South East of the State. It also serves an important educational function for school groups from South Australia and Victoria. In addition to the provision of tours of the caves, picnic and camping areas, a caravan park and a kiosk are provided. In the last ten years a major redevelopment of the caves has been undertaken and this work is still continuing. The next major challenge will be concerned with the development of Blanche Cave and the gradual redevelopment of the surface of the park, particularly in the vicinity of the tourist caves, to integrate the surrounding bushland more closely with the caves area and to provide a more natural and enjoyable visit to the area.

24 Glen Roy Conservation Park (541 ha) is bounded on three sides by the pine plantations of Comaum State Forest. The majority of the park is covered by an open forest of Brown Stringybark with an understorey of Bracken, while the western section supports a River Red Gum woodland with scattered Drooping Sheoaks and a grassy understorey. Along the edge of this woodland is an open forest of Rough-barked Manna Gum and Pink Gum with some very large Silver Banksias up to ten metres tall and scattered Black Wattles *(Acacia mearnsii).* In addition there is a swampy area along the eastern boundary with thickets of Prickly Teatree on its edge, grading into an open heath on the margins of the forest. The park supports small populations of both Rednecked Wallabies and Common Wombats. The southern part of the park has not been burnt for at least 25 years but the stringybark forest areas have been subjected to a much higher fire frequency and this is reflected in the predominance of Bracken in the understorey.

FRANCIS PLATEAU ENVIRONMENTAL REGION

This region consists of two environmental associations, only one (the Kybybolite Environmental Association) of which lies within the area considered in this chapter. It consists of a gently undulating plain of tertiary sands with local ferruginous cappings and scattered low dunes. Lunettes have developed on the fringes of sinkholes and depressions created by solution of the underlying limestone, some of which contain lakes or swamps. There is no integrated surface drainage but much of the water disappears underground. The land has been cleared to open parkland and sown to pasture which is grazed moderately intensively by beef cattle and sheep. Lakes swamps and forest remnants constitute local features but there are no parks to represent the original vegetation cover.

DISCUSSION

The National Parks and Wildlife Service reserve system in the lower South East contains a wide variety of scenically attractive and scientifically important natural areas and provides both tourists and local residents with an opportunity to see the land as it was before the arrival of Europeans nearly 150 years ago. Nevertheless, in view of the substantial amount of cleared land in the area, an assessment should be made of the park system in relation to the total variation of the orig i nal vegetation and associated fauna that previously occupied the region. Laut *et al.'s* Environmental Regions are defined as "aggregations of land systems with some unifying theme". In the area under consideration they are based mainly on geomorphological criteria. Table 2 shows the proportion of each of the five environmental regions in the area set aside for conservation as National Parks and Wildlife Service reserves.

It is clear that the South Coast Environmental Region is the only area that can be considered to be at all well conserved.

An alternative means of examining the adequacy of the conservation reserve network is to make a comparison with the original vegetation of the whole area. The most recently published vegetation map for the lower South East is that of Boomsma & Lewis (1980) which is a slight modification of that published by Specht (1972). This recognises six major structu ral forms of vegetation in the region. Specht *et al.* (1974) have similarly classified the vegetation in the National Parks and Wildlife Service reserve system into these six structural types. With appropriate modifications to allow for the subsequent increase in knowledge of these areas and for new reserves which were not classified by

Table 2. PARKS OF THE SOUTH EAST IN RELATION TO ENVIRONMENTAL REGIONS (after Laut *etal* 1977)

Environmental Region	*Total area (ha) of Environmental region*	*Area (ha) of region in zone considered*	*No. of parks in each zone*	*Total area (ha) of parks in each zone*	*%of area reserved*
1 South Coast	108 000	93 000	11	12784	13.74
2. Southern Coastal Plains	328 000	268 000	1	10	< 0.01
3 Mt Gambier	111000	111000	2	53	<0.01
4. Southern Dune Ranges	857500	549300	10	6994	1.27
5 Francis Plateau	223 000	31000	0	0	0
Total	1 627500	1 052300	24	19841	1.89

Table 3. PARKS OF THE SOUTH EAST IN RELATION TO STRUCTURAL VEGETATION TYPE (after Boomsma & Lewis 1980)

Vegetation Type	*Total area (ha) originally covered by each vegetation type (a)*	*Area (ha) of vegetation type* in *parks (b)*	*Number of parks with vegetation type represented*	*%of reserve system now In each vegetation type (b 19841)x 100*	*% of each original vegetation type* now *reserved* % x *100*
Forest	189414	1888	10	95	10
Woodland	473535	629	7	32	01
Open Scrub	10523	182	5	09	17
Shrubland	94707	1 168	4	59	1.2
Grassland	189414	3828	8	193	2.0
Coastal Succession	52615	12146	9	612	22.9
Total	1052300	19841	24	10000	19

Table 4. AREAS OF UNCLEARED LAND REMAINING IN THE SOUTH EAST (after Harris 1976)

	Total area	*Area uncleared* (1976)	*% of county uncleared*	*Area of parks (1980)*	*% of county dedicated* as *park*	*Park* as *% of uncleared land*
County Grey	529395	23881	4.5	11330	21	47.4
County Robe	508157	49514	9.7	8511	1.7	172
Total	1037552	73395	7.1	19841	19	270

Specht *et al.,* it is possible to determine the area of the six vegetation types conserved. (Table 3).

It is clear that the "coastal succession" type is well represented in the park system. On an area basis it is the structural type which compares best with the original vegetation of the area. Whilst both forest and grassland types occupy a relatively high proportion of the existing park system, they nevertheless represent a very small proportion of the original vegetation cover. Scrubland and woodland are very poorly represented.

These trends are clearly a reflection of past vegetation clearing and drainage activities with the agriculturally less attractive coastal belt retaining the majority of the remaining natural vegetation in the lower South East. The Report of the Interdepartmental Vegetation Clearance Committee (Harris 1976) has examined the extent of natural vegetation remaining in the agricultural areas of South Australia. If we consider only the area covered by Counties Grey and Robe, then Table 4 shows the parks in relation to the uncleared land actually remaining in the lower South East. Uncleared areas are taken from Harris' 1976 figures whilst park areas are calculated for 1980. The proportion of uncleared area is consequently overestimated.

Although the park system occupies only 1.9% of this region, it constitutes 27% of the remaining uncleared land. Given the extent of clearance of the natural vegetation, every remnant patch takes on an added importance. The Woods and Forests Department has also set aside a number of areas of natural vegetation in the lower South East (Fig. 1) and for comparative purposes details of these are shown in Table 5.

It is beyond the scope of this chapter to discuss each of these areas in detail but they must be considered in any assessment of the adequacy of conservation reserves. The inclusion of these areas means that in the

Table 5 AREAS OF NATURAL VEGETATION IN THE SOUTH EAST MANAGED BY THE SOUTH AUSTRALIAN WOODS & FORESTS DEPARTMENT

Forest Reserve	*Native Vegetation*	*Area (ha)*
Noolook		
	Bagdad Scrub	451
Mt Burr		
	Furner	39
	Logging Track	69
	When nan's Scrub	170
Tantanoola		
	Glencoe Hill (a)	66
	Glencoe Hill (b)	44
	Windy Hill South	125
	Long's Scrub	152
	The Bluff Scrub	81
	Wool wash	289
	Burr Slopes South	172
	Frill West	142
	Mt Lookout	341
	Native Wells	204
Mt Gambier		
	Bonney's (a)	60
	Bonney's (b)	67
	Hackett's Hill	599
	Medhurst's	281
	Wandilo Scrub	389
	Grundy's Scrub	306
	Honan's Scrub	925
	The Marshes	459
Comaum		
	Dead Man's	545
	Alcock's	85
	Headquarters	104
	Berkin's Scrub	153
Penola		
	Topperweins	158
	Horseshoe	72
	Headquarters	1700
	McLeans (3	102
	Little Forest	344
Caroline		
	Donovans	125
	E. pauciflora	137
	Gooch's Scrub	51
	Honeysuckle Flat	267
	Wild Dog Flat	407
	Bottlebrush	183
	Total	9862

lower South East 40% of the remaining natural vegetation is contained in areas managed by either the National Parks and Wildlife Service or by the Woods and Forests Department.

CONCLUSIONS

The natural vegetation at present conserved in parks in the lower South East is clearly not an ideal representation of all the variation in the area prior to Eu ropean settlement. Some vegetation types and their associated fauna have gone forever, while others exist in extremely small patches whose long-term viability must be in doubt. Nonetheless, the remaining conservation areas contain some magnificent natural features; the coastal parks in particular provide a significant recreational function and in general thewhole system contributes a diversity to the landscape of the lower South East which helps to make this area one of the major tourist attractions in South Australia.

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REFERENCES

Armstrong, D. (1977). Drift Sand Migration, NW corner of Lake George. Department of Mines, South Australia Rept Bk 77/133

Boomsma, C. D. & Lewis, N. B. (1980) The Native Forest and Woodland Vegetation of South Australia Bulletin 25 Woods & Forests Department, South Australia.

Cullen, P. & Bird, E. (1980). The Management of Coastal Sand Dunes in South Australia. Unpublished Report to Coast Protection Board.

Dwyer, P D. (1963) Reproduction and Distribution of *Miniopterus* (Chiroptera) *Aust. J.* Sci. 25,435.

Eardley, C. M. (1943). An ecological study of the vegetation of Eight Mile Creek Swamp. A natural South Australian coastal fen formation. *Trans. R.* Soc. S. *Aust.* 67, 200-223.

Harris, C. R. (1976). ed. Vegetation Clearance in South Australia: Report of the Interdepartmental Committee on Vegetation Clearance. (Govt Printer, Adelaide)

Kraehenbuehl, D. W. (1964) Report of the Natural History of Piccaninnie Blue Lake, Lower South East, South Australia. Unpublished report, Field Naturalists Society of SA Inc.

Laut, P., Heyligers, P. C, Keig, G, Loffler, E., Margules, C., Scott, R. M. & Sullivan, M. E. (1977). Environments of South Australia, Province 1, South East. Division of Land Use Research, CSIRO, Canberra.

Lewis, I. & Stace, P (1980). 'Cave diving in Australia'. The Author.

Lovell, R. H. (1972) Bridled Tern on Troubrldge Island. S. *Aust. Ornith* 26,36.

Mowling, F. A. & Barrett, M. K. (1980). 'The Natural Vegetation of the South East.' (Harman & Jacka Pty Ltd, Unley, SA).

National Parks & Wildlife Service (1978) 'Dingley Dell, Home of Adam Lindsay Gordon.' (Govt Printer, Adelaide)

Short, A. D. & Hesp, P. A. (1980). Coastal Engineering and morphodynamic assessment of the coast within the South East coast protection district. Coastal Studies Unit, Dept of Geography, University of Sydney.

Smith, M. J (1971) Small Fossil Vertebrates from Victoria Cave, Naracoorte, South Australia. I Potoroinae (Macropodidae), Petauridae & Burramyidae (Marsupialia). *Trans. R.* Soc. S *Aust.* **95**, 185-189.

Smith, M. J (1972). Small Fossil Vertebrates from Victoria Cave, Naracoorte, South Australia II Peramelidae, Thylacinidae & Dasyuridae. *Trans. R.* Soc. S. *Aust.* **96**, 125-137

Smyth, M. (1972). ed. Big Heath Conservation Park, A Guide to its Natural History. S. *Aust. Nat.* **47***,* 21-42.

Specht, R. L. (1972) 'The Vegetation of South Australia.' (Govt Printer, Adelaide).

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. Ser.* **7**, 236-318.

Tidemann, C R. (1976). Some mammal remains from cave deposits in the South-east of South Australia. S. *Aust. Nat.* **42**, 21-27.

Tindale, N. B. (1933). Tantanoola Caves, South East of South Australia. Geological and Physiographical notes. *Trans R.* Soc. S. *Aust.* **57**, 130-142.

Tyler, M. J. (1977) Pleistocene Frogs from Caves at Naracoorte, South Australia. *Trans R.* Soc. S *Aust.* **101,** 85-89.

Van Tets, G. F. & Smith. M. J (1974) Small fossil Vertebrates from Victoria Cave, Naracoorte, South Australia III Birds (Aves). *Trans R.* Soc S *Aust.* **98**, 225-227.

Wells, R. T. (1972). Fossil Research at Naracoorte (Victoria Cave) *Proc. 8th Biennial Coni of the A ust. Speleo. Fed.* pp. 63-65

Wells, R. T. (1975) Reconstructing the Past. Excavations in Fossil Caves. *Aust. Nat. Hist* **18***,* 208-211.

Wells, R. T. (1978). Fossil Mammals in the Reconstruction of Ouaternary

Environments *In* D. Walker (Ed.) Biological problems in the Reconstruction of Ouaternary Terrestrial Environments. *Aust. Acad.* Sci. *Symposium*

Wells, R., Williams, D. & Lawson, P. (1980) Science and Tourism: The Naracoorte Experience. *Proc. Third Aust. Cont. Cave Management* & *Tourism,* **3,** 149-154**.**

Woods, J. T. (1862) Geological Observations in South Australia Principally in the district south- east of Adelaide. (Longman, Green, Longman, Roberts & Green, London).

Zimmerman, D. L. & Seeliger, M. 1. (1979). Land Description of South East coast (Maps only). Soil Conservation Branch Report SB7 SA Dept of Agriculture.