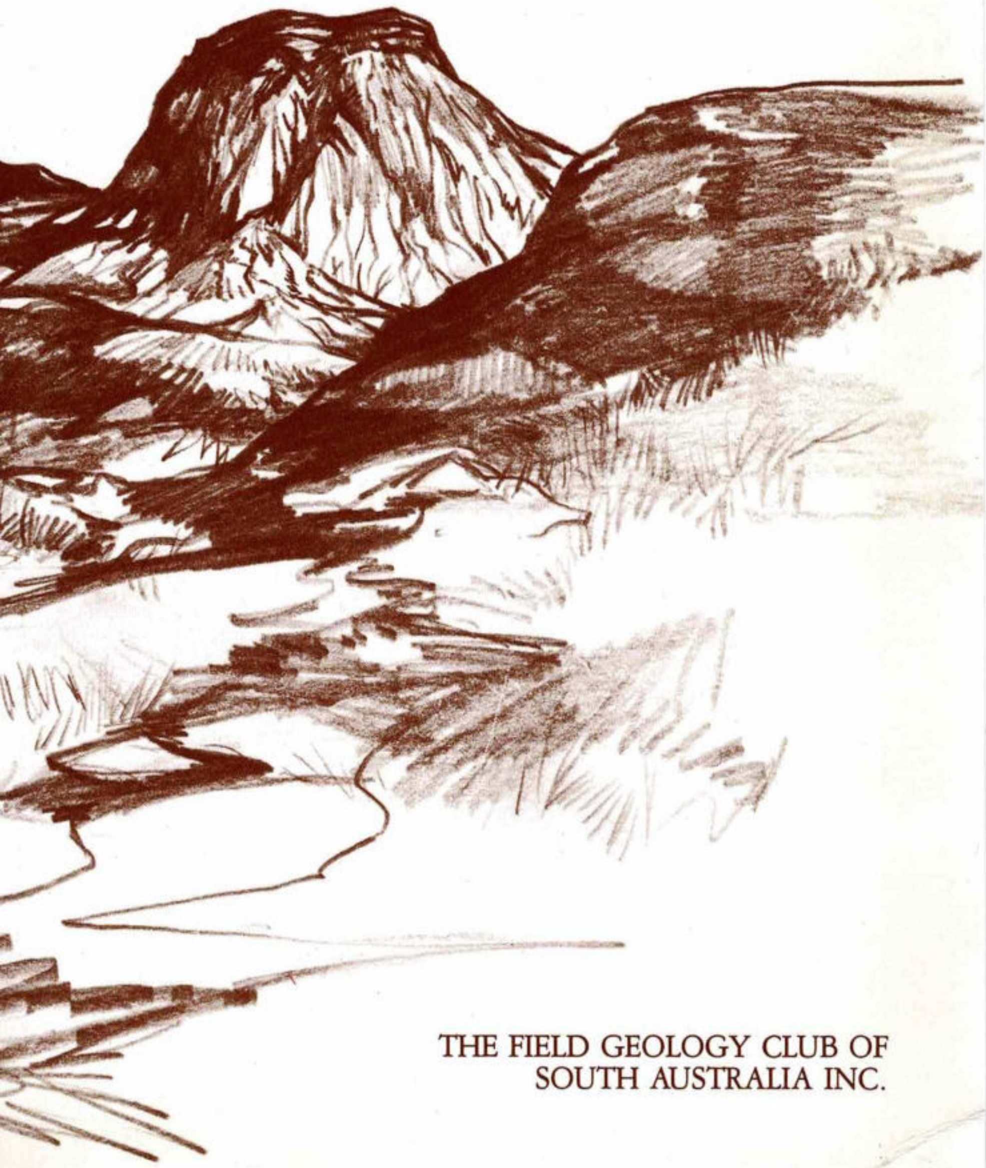
A Field Guide to the

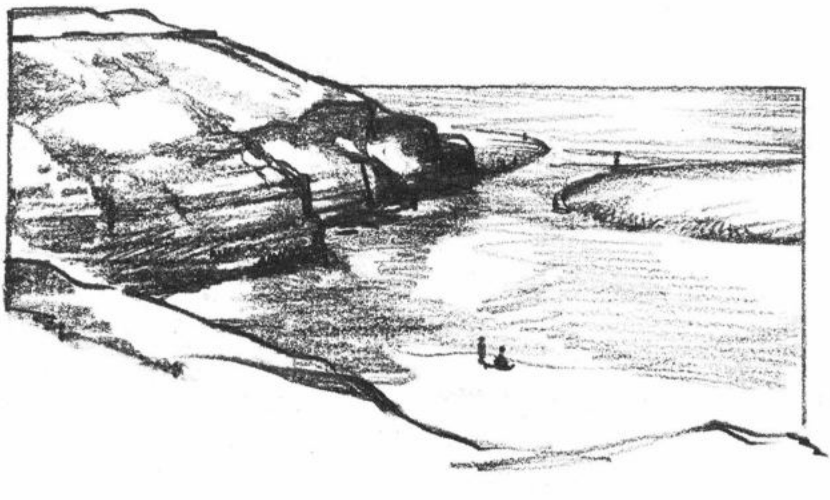
Coastal Geology of Fleurieu Peninsula



THE FIELD GEOLOGY CLUB OF SOUTH AUSTRALIA INC.

A FIELD GUIDE TO THE COASTAL GEOLOGY OF FLEURIEU PENINSULA

PORT GAWLER TO VICTOR HARBOR



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PREFACE

This is the second booklet on geology produced by the Field Geology Club of South Australia since its formation in 1971. It sets out to interpret the geology of the Adelaide region for a reading public of interested amateurs and students, using the outcrops along the coastline from Port Gawler to the mouth of the River Murray.

The authors of the various chapters, all amateurs themselves, have visited the places described during the Club's regular monthly excursions led by professional geologists. They have supplemented their field observations with information from the scientific literature available. Important amongst these sources of information have been the reports and maps issued by the Geological Survey of South Australia and unpublished research theses in the University of Adelaide. It is a mark of respect for the integrity and standing of the Club that many geologists have willingly read selected passages and offered advice upon these. Mrs Pamela Hasenohr, in particular, has worked hard to establish the accuracy of statements made in the booklet and to get the publication into its final state. In this she has worked under the experienced direction of Dr David Corbett as co-editor.

The members of the Field Geology Club believe that a deeper understanding of the geology will assist in the protection of geological features in the natural environment and add to the interest of those who enjoy outdoor recreation. A code of conduct is included to emphasise the need for responsibility by all who engage in field studies.

It was the successful reception of their earlier booklet, 'A Field Guide to the Geology of Yorke Peninsula' (1976), that encouraged the Club to describe the local Adelaide area. Any comments from users of this booklet will be received with interest and will assist the Club in knowing whether it has achieved the aims outlined above.

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University of Adelaide

ACKNOWLEDGEMENTS

Many people, professional geologists and amateurs, have helped in the production of this book. Special thanks are due to Miss Maud McBriar MSc for her continued interest in the project, her constructive suggestions and for generously making available her wide-ranging expertise concerning geological monuments of the coast, notably the Hallett Cove area. The late Dr Brian Daily, one of the Club's staunchest supporters, gave considerable assistance in checking localities in the field and in critically reading much of the early draft of the manuscript. His boundless enthusiasm for geology and his strong commitment to field studies will remain an inspiration to the Club. He is remembered with respect and affection. Other members of the Department of Geology and Geophysics at the University of Adelaide who gave generously of their time and knowledge in reading sections of the text and/or in field inspections were Dr Pat James, Dr Richard Jenkins, Dr Robin Oliver and Dr Brian McGowran. From the Department of Mines and Energy, Mr Bob Major, President of the Club 1985-86, has provided advice and helped to maintain the momentum of the project during its latter stages, and Dr Neville Alley has reviewed the contributions on Permian glaciation. Miss Millie Swann, formerly draughtswoman in the Department of Geology and Geophysics advised on the drawing of maps. Mrs Frances Taylor was responsible for the line drawings and Mrs Jacqueline Galazowski for the sketches used for the chapter headings and the front cover. Mrs Margaret Sando and Mrs Gill Briggs assisted in the proof-reading. Permission to reproduce illustrations has been generously provided by: The SA Department of Environment and Planning (Fig.11), The Department of Geology and Geophysics, The University of Adelaide (Figs.6,7,13,24,25,26,27,28) and The National Trust of SA (Pl.8). Finally, thanks are due to Mr Peter Cotton of Gillingham Printers for his helpful advice during the printing stage of production.

While the assistance and support of the above are acknowledged gratefully, the text and photographs are the work of the members of the Field Geology Club of SA Inc. and they and the Club accept the responsibility for the information contained in this guide.

INTRODUCTION

The sea coast provides a fascinating natural environment which appeals to people for a wide variety of reasons. Australians in particular have a reputation for appreciating the recreational attractions of their magnificent beaches and with seven out of ten of the population living within an hour's drive from the sea such an affinity is easily enjoyed.

To the naturalist the narrow zone where land and ocean meet is full of interest. It is a hard, uncompromising environment where conditions are in a continual state of flux. Yet it is here, at the edge of the sea, that nature displays a marvellous profusion of organisms, all beautifully adapted to life in an ever-changing world.

The coastal zone is also one of great physical diversity where bays, beaches and dunes, spits, headlands and cliffs have been created by the relentless cycle of erosion and deposition which operates here. The coastline is being constantly moulded by the dynamic action of the sea and it is the interplay of tide and current, storm waves and longshore drift that has formed the coastal scenery with which we are so familiar. Material is broken from the land to form cliffs and pounded into sand which is then moved from one place to another. Geology in large measure determines coastal landforms and the greater the variation in rock type and structure the more contrasts there will be in coastal scenery. Hard rocks, resistant to erosion, form headlands, while softer sediments are worn away to leave bays and dune-backed sandy beaches. A variable sedimentary sequence flanks the Gulf St Vincent shore while more uniformly resistant metamorphic and igneous rocks are dominant around much of the Fleurieu Peninsula and in the Victor Harbor area where the resistance of granite to erosion is reflected in the conspicuous headlands and off-shore islands.

The cliff sections around our coasts provide some of our best and freshest rock outcrops, often displaying evidence that is not found further inland. This is well demonstrated in the Adelaide region where the generally soft Tertiary strata crop out poorly away from the coast but are well-known from the classic sections in the cliffs along the southern metropolitan beaches.

Some of the earliest geological observations in South Australia were made along the local coastline. In 1877, Professor Ralph Tate discovered the glacial features at Hallett Cove and later he carried out pioneer studies on the Tertiary rocks in the Aldinga Bay-Port Willunga area. Another early South Australian geologist, Walter Howchin, together with Professor Edgeworth David from Sydney University found Cambrian fossils in the limestones close to the coast in the Normanville-Sellick Hill region, a discovery which was to prove crucial in helping to determine the age of the old rocks of the Mount Lofty Ranges. In 1923, Howchin published a geological description of the sea-cliffs from Brighton to Sellick Hill together with panoramic sketch sections and this was extended in 1925 from Sellick Hill to Victor Harbor by Cecil Madigan, another Adelaide University geologist. More modern studies have been concerned with fossil faunas and detailed stratigraphy, particularly of the Tertiary rocks and of these the papers by Reynolds (1953), Lindsay (1967) and Cooper (1979) are notable. Cambrian stratigraphy has been described by Abele and McGowran (1959) and Daily (1963), and the metamorphosed Kanmantoo Group rocks by Daily and Milnes (1971, 1973). It is only in recent years that the complexities of the Fleurieu Peninsula coast have begun to be unravelled, not least because of the difficulty of access to much of this area.

In the chapters which follow, the coastal geology from Port Gawler to Port Elliot is described in seven sections. There are gaps in the story as at Moana and Aldinga where there are no rock outcrops and on the southern coast of the peninsula because of the problems of access. While it might have been convenient to end descriptions at Cape Jervis, the Victor Harbor area has been included for here a vital episode in the geological history of the region, namely the intrusion of granite, is graphically recorded.

Clearly in describing what is in effect a continuous traverse along a narrow line of section, our coastal descriptions do not give a complete picture of the geology of the Adelaide region. To fill in the gaps, outcrops occurring inland would need to be studied. With this minor qualification however, the excellent exposures at the localities described and their ease of access make it possible to obtain a very clear understanding of the geological evolution of the Adelaide region over the past one thousand million years.

To help place the gradually unfolding story in context, the first chapter outlines the main events and changing geographies during this long and eventful history. The geologist as historian uses the rocks as 'documents' which provide the evidence needed to reconstruct the distant past. This book is designed to help you to interpret the evidence displayed in the cliffs, bays and beaches all within a day's drive from Adelaide, and we hope that in doing so it will enhance your appreciation and enjoyment of our magnificent coastline.

A Code for Geological Field Work

Introduction

The Geologists' Association in Britain, a large group comprising both amateur and professional geologists, has published a code of conduct which has been supported by many other geologists and conservation bodies in Britain. The principles it embodies are equally relevant here in Australia and an amended version of the code is given below:

A geological 'Code of Conduct' has become essential if opportunities for field work in the future are to be preserved. The rapid increase in field studies in recent years has tended to concentrate attention upon a limited number of localities, so that sheer collecting pressure is destroying the scientific value of irreplaceable sites. At the same time the volume of field work is causing concern to many site owners. Geologists must be seen to use the countryside with responsibility; *to achieve this, the following general points should be observed.*

1. Remember to shut gates and leave no litter.
2. Always seek prior permission before entering private land.
3. Don't interfere with machinery.
4. Don't litter fields or roads with rock fragments which might cause injury to livestock, or be a hazard to pedestrians or vehicles.
5. Avoid undue disturbance to wildlife. Plants and animals may inadvertently be displaced or destroyed by careless actions.
6. On coastal sections, be sure you know the local tide conditions.
7. Don't take risks on insecure cliffs or rock faces. Take care not to dislodge rock, since other people may be below.
8. Be considerate. By your actions in collecting, do not render an exposure untidy or dangerous for those who follow you.

Collecting and Field Parties

1. Students should be encouraged to observe and record but not to hammer indiscriminately.
2. *Keep collecting to a minimum.* Avoid removing in situ fossils, rocks or minerals unless they are genuinely needed for serious study.
3. For teaching, the use of replicas is commended. The collecting of actual specimens should be restricted to those localities where there is a plentiful supply, or to scree, fallen blocks and waste tips.
4. Never collect from walls of buildings. Take care not to undermine fences, walls, bridges or other structures.
5. The leader of a field party is asked to ensure that the spirit of this Code is fulfilled, and to remind his party of the need for care and consideration at all times. He should remember that his supervisory role is of prime importance. He must be supported by adequate assistance in the field. This is particularly important on coastal sections, or over difficult terrain, where there might be a tendency for parties to become dispersed.

Visiting Quarries

1. An individual, or the leader of a party, should have obtained *prior* permission to visit.
2. The leader of a party should have made himself familiar with the *current state* of the quarry. He should have consulted with the Manager as to where visitors may go, and what local hazards should be avoided.
3. On each visit, both arrival and departure must be reported.
4. In the quarry, the wearing of safety hats and stout boots is recommended.
5. Keep clear of vehicles and machinery.
6. Be sure that blast warning procedures are understood.
7. *Beware of rock falls*. Quarry faces may be highly dangerous and liable to collapse without warning.
8. Beware of sludge lagoons.

CHAPTER 1
THE GEOLOGICAL SETTING

The landscapes in the Adelaide region of South Australia are dominated by the massive backdrop of the Mount Lofty Ranges. The geological history of these hills and adjacent coastal plains is one of slow development over many hundreds of millions of years.

We may look at ripple-marked silts and sands forming today on our northern beaches and wonder how sediments like these could have built up, layer by layer, over vast spans of time and then, greatly changed by heat and pressure, rise as a mountain range. Not once, but twice! Rock formations familiar to us as the Aldgate Sandstone, Stonyfell Quartzite, Sturt Tillite, Tapley Hill Formation and Brighton Limestone, which formed part of the first mountains, were deposited as sediments from approximately 800 million years ago. The granites at Victor Harbor intruded this earlier mountain range about 500 million years ago. The glaciated pavements at Hallett Cove and Inman Valley date back to the Permian Ice Age, 270 million years ago. Raised beaches and stranded dunes reveal changes in sea-level and climate in geologically recent times. However, we can see for ourselves the processes which are acting today, and they can help us understand what happened long ago and how past events have determined the present landscape.

Australia as part of Gondwana

In the geological world 'once upon a time . . .' is no mere fantasy. Many millions of years ago, Australia was joined with India, Africa, South America and Antarctica to form one super-continent which has been named 'Gondwana'. The landmass formed by the countries of the northern hemisphere is known as 'Laurasia', and the two great super-continents were separated from each other and surrounded by the Tethys Sea. These great landmasses have since split up and drifted apart (Fig. 1).

Figure 1. Universal landmass Pangaea in Permian times, 250 million years ago

The concept of the mobile continents is not new. In 1915 Alfred Wegener first published a book on the subject entitled 'The Origin of Continents and Oceans'. However, despite the apparent matching fit of adjacent continents and their frequent geological similarity, many geologists were reluctant to go along with a theory that required a mechanism they could not explain. It was not until the mid 1960s, when sea-floor spreading began to be supported by ample evidence from geophysics, palaeomagnetism and deep-sea marine studies, that the theory of continental drift received widespread acceptance. Today, computer studies refine the fit of continental margins. Modern methods of research and exploration, especially in the field of marine geology, have led to exciting new discoveries. Radiometric methods of dating, deep-sea drilling projects and satellite observations, for example, have all made their contribution.

Plate Tectonics

The term used to define the modern explanation of the evolution of the earth's crust is 'plate tectonics'. The seemingly rigid crust in fact, resembles a patch-work quilt of large 'rafts' or 'plates' sliding over the hot semi-plastic layer of the earth's mantle, carrying the continents and oceans with them. The continents are made up of relatively lighter rocks in comparison with the denser crust of the ocean floor. The mantle underlies the crust and comprises the greater part of the volume of the earth, increasing in density

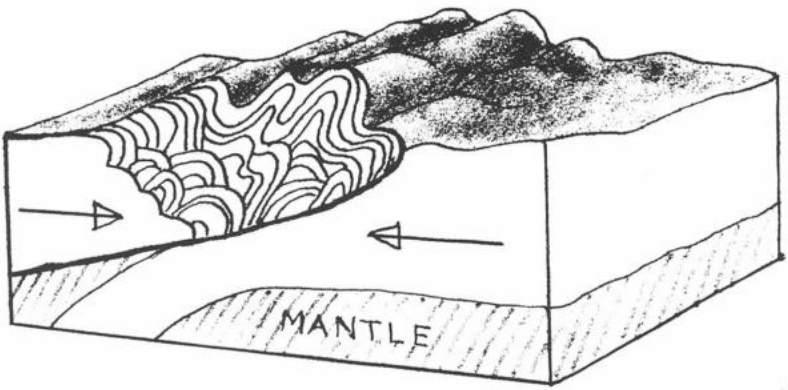


Figure 2. Collision of two continental plates

with depth. Although the plates move slowly, immense forces are at work as they collide and split apart, or as one over-rides another. (Fig. 2).

Huge undersea mountain ranges have been mapped. These form one type of plate boundary and are known as the 'mid-ocean ridge systems'. Also charted are deep ocean trenches , such as the Marianas Trench in the west Pacific, which is over eleven kilometres deep.

A deep-sea drilling project was carried out in the late 1960s from the research ship *Glomar Challenger.* The aim of this project was to test the theory that a zone of upwelling magma within the mantle may cause the crustal plate above it to break apart and the two halves to move in opposite directions. The upwelling magma would then create new ocean floor along a mid-ocean ridge, causing the two halves of the plate to be carried further and further apart. A series of deep-sea holes was drilled across the Mid-

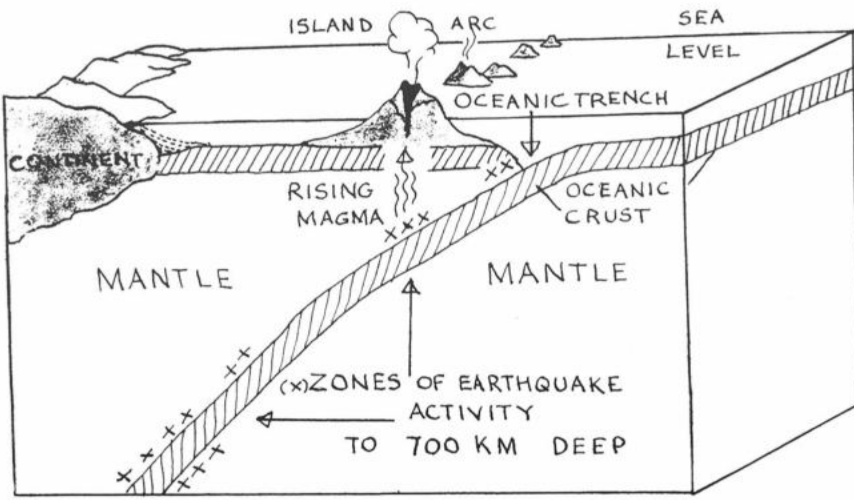


Figure 3. Oceanic trench—collision of two oceanic plates

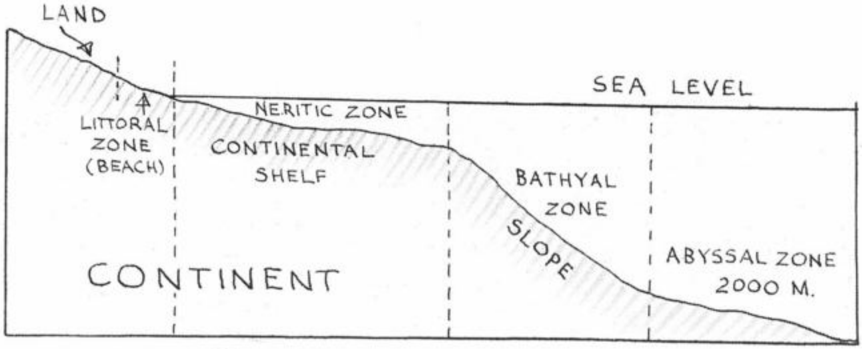


Figure 4. Profile through continental margin

Atlantic Ridge and the cores were dated. Results clearly showed that the crust does get older as the distance from the ridge crest increases and that the age of the ocean floor at the mid-ocean ridge, where the new sea-floor is born, is zero.

At the same time that new ocean floor is forming, older oceanic crust is continually being destroyed and carried down into the mantle at another plate boundary. This gives rise to intense earthquake and volcanic activity which, ultimately, may form island arcs adjacent to continental margins. The Indonesian Archipelago is a good example of this (Fig. 3). When considering continental margins, it is important to remember that the continental shelf may extend far beyond the present coastline. The edge of the continental shelf forms a true geological margin of the continent. (Fig. 4).

Earth Materials

Even with all the aids of modern science, the geologist, using hammer and pocket lens, must painstakingly build up the story of the earth from the rocks observed in the field, noting the order in which they are laid down and the materials from which they are made.

Three major types of rocks are recognised:

IGNEOUS ROCKS which have cooled and crystallised from a molten state, either quickly by eruption at the surface (as fine grained lava, e.g. basalt), or slowly, at considerable depth in the earth's crust (acquiring a coarse-grained texture, e.g. granite).

SEDIMENTARY ROCKS which have been formed from the breakdown of pre-existing rocks by the agents of weathering. The rock fragments are tranported, usually by running water, and eventually deposited as sediments on flood plains, in deltas, lakes or in the sea. In time these sediments are compacted and hardened into sedimentary rock (e.g. sandstone, shale or mudstone). The cycle of uplift, denudation and subsequent depression below sea-level once again may result in other layers of sedimentary rock being deposited on the first sequence. The angular discordance between the two sets of beds is known as an unconformity.

METAMORPHIC ROCKS which have been altered from their original condition as a result of changes in temperature, pressure and chemical activity resulting from permeation or expulsion of fluids and vapours, principally water.

GEOLOGICAL TIME SCALE			AGE IN MY.	MT. LOFTY RANGES SEQUENCE	
CAINOZOIC	QUATERNARY	RECENT			
		PLEISTOCENE	2.5		
	TERTIARY	PLIOCENE	7		Sedimentation in flanking basins. Sandstones, limestones (fossiliferous)
		MIOCENE	26		
		OLIGOCENE	38		
		EOCENE	54		
		PALAEOCENE	65	Unconformity Block Faulting	
MESOZOIC	CRETACEOUS		135		TIME GAP
	JURASSIC		190		
	TRIASSIC		225	Unconformity	
PALAEOZOIC	PERMIAN		280	Unconformity	Glacial sands and clays w. erratics
	CARBONIFEROUS		345		TIME GAP
	DEVONIAN		395	Unconformity	Orogeny/metamorphism Granite intrusion
	SILURIAN		440		
	ORDOVICIAN		500		Kanmantoo Gp. (metamorphic)
	CAMBRIAN		550		Normanville Gp. (fossiliferous sediments)
PRECAMBRIAN	PRECAMBRIAN		↓		Deposition in Adelaide geosyncline
			3800 +	850	Crystalline basement

Figure 5. GEOLOGICAL TIME SCALE
(in millions of years)

Deep-seated earth movements may dislocate the surface layers and huge blocks may be upthrust (as in the case of the Mount Lofty Ranges) or folded against a more resistant block. Existing troughs may fill with sediments and subside further. Climatic conditions, over millions of years, may change from tropical to glacial. Of great assistance in unravelling these past geological events are 'marker beds', rocks which can be identified and recognised in widely separated localities. A marker bed may perhaps show evidence of glacial action during an ice age, or contain fossils which have had a restricted evolutionary time span. These are called 'index fossils' or 'zone fossils'. Gradually as evidence builds up, chronological order can be established, correlations attempted and, with the aid of radiometric dating, more accurate times of deposition determined (Fig. 5).

Geological History of South Australia

The earth is believed to be about 4,600 million years old, and on Eyre Peninsula, the geological history of South Australia has been traced back

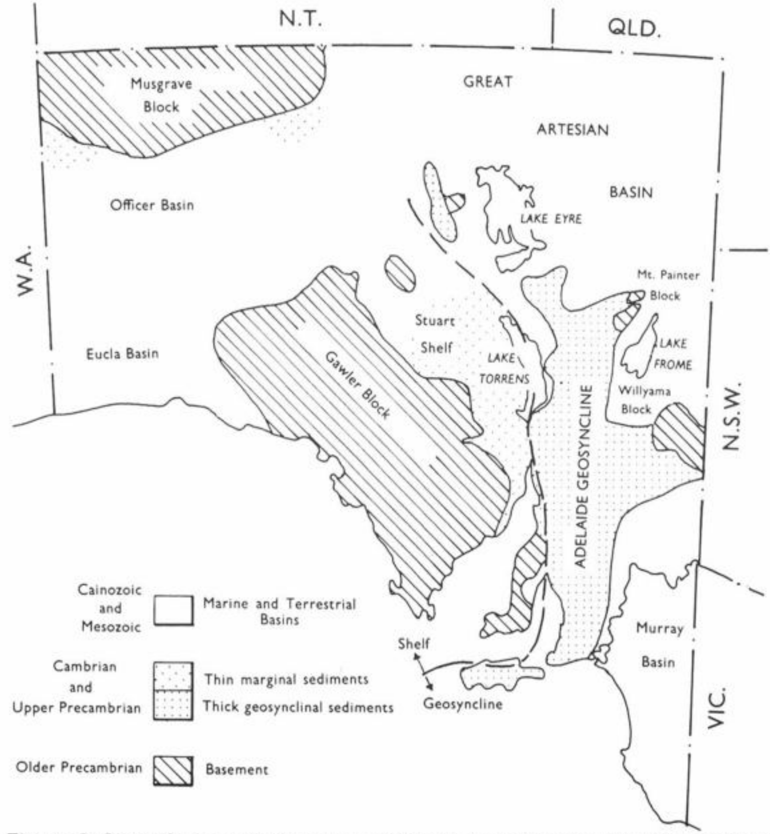


Figure 6. Simplified geological map of South Australia showing the positions of the major blocks and sedimentary basins (From J.L. Talbot and R.W. Nesbitt, Geological Excursions in the Mount Lofty Ranges and the Fleurieu Peninsula).

over 2,000 million years. Not surprisingly, there is no area where a complete chronological sequence appears. Indeed, sometimes only solitary outcrops may be present to provide 'windows' into the past.

About 1,500 million years ago a number of isolated land masses comprised the nucleus of the continent of Australia. These nuclei formed the stable Australian Precambrian Shield against which younger sediments have been deposited and compressed. The Gawler Block, embracing Eyre Peninsula, marks the eastern margin of the Shield.

The oldest rocks in our region are crystalline gneisses and schists referred to as the 'basement' or 'Barossa Complex'. For the most part, they were originally sediments eroded from the ancient 'shield' blocks and deposited on their margins and in sedimentary basins between them. These sediments were subsequently deformed, strongly metamorphosed and intruded by various igneous rocks, including granites and pegmatites. The most extensive of these basement outcrops occur in the Houghton and Aldgate areas, north and south of Mount Compass and along the coast south of Normanville.

The Adelaide Geosyncline

The next significant geological event was the development of the Adelaide Geosyncline. This commenced in the north of the State over 1,000 million years ago when the area lying east of the Gawler Block began to subside and sediments accumulated in the resulting trough. (Fig. 6). In the late Precambrian, some 800 million years ago, the sea swept in a wide arc across eastern South Australia and into the Northern Territory. Although there was algal life in the sea, as evidenced by stromatolites, the land was still barren as no terrestrial plants or animals had yet made their appearance. Subsequently, the first mountain range was folded from these sediments. An outline of the stages of development which usually occur in the formation of a geosyncline is given below.

SEDIMENTATION — Most of the world's major mountain chains are formed of great thicknesses of sedimentary rocks (e.g. limestone, sandstone, conglomerate and shale). These usually developed in comparatively shallow waters close to a coastline. This suggests that the sea-floor sinks during sedimentation, and that the depressed area forms a long, narrow trough close to a continental coastline. The name 'geosyncline' is given to such a sedimentary trough.

COMPRESSION AND FOLDING — Sedimentation is followed by a period of compression which forces the newly formed sediments against the adjacent stable continental mass. The horizontal layers of sediments are buckled into a series of folds. The upward-arched folds are known as 'anticlines', the down-bent troughs are called 'synclines'.

MOUNTAIN BUILDING (OROGENESIS) — As compressive forces increase, folding becomes more intense and fracturing occurs, followed by movements along faults. The result is the crumpling of the former sediments into a mountain range. This is accompanied by metamorphism and frequently by igneous activity, especially into layers buried deeply in the crust. The total process is known as 'orogenesis', which means 'mountain forming'.

The above sequence of events is well shown in the Adelaide region as the Adelaide Geosyncline developed into a mountain range. The Precambrian sediments were deposited in the geosyncline over a period of more than 300 million years, a long time interval which saw many changes of climate and environment and spanned the later part of this era. Then followed a period when deposition did not take place, as shown by the break in the succession of stratified sedimentary rocks (unconformity), after which sedimentation continued for perhaps 50 million years into the Cambrian period.

Geological Sequence in the Adelaide Syncline

The Precambrian rocks of the Adelaide Geosyncline were laid down between about 850 to 550 million years ago. They represent three intervals of time of roughly equal length known as the Torrensian (oldest), Sturtian and Marinoan (youngest).

The **Torrensian** includes the oldest sediments in the Adelaide Region. The main rock types are slate and phyllite, although dolomite and hard sandstone, known as quartzite, are the most prominent rocks exposed. One important quartzite horizon, the Stonyfell Quartzite, occurs along the western escarpment of the Mount Lofty Ranges, and most of the quarries visible today are developed in this unit.

The **Sturtian** overlies the Torrensian and includes two distinctive rock formations, the Sturt Tillite and Tapley Hill Formation. The tillite constitutes the debris left behind from an early ice-age. Sir Douglas Mawson considered the deposits to be similiar to those forming off the coast of Antarctica today, where icebergs drop large quantities of unsorted pebbles and boulders amongst finer detritus on the continental shelf. The great thickness of the grey-green siltstone which comprises the Tapley Hill Slate was formed from sediments deposited under more moderate climatic conditions as the ice continued to melt and the sea-level rose. The Brighton Limestone, quarried at Brighton, marks the boundary between the Sturtian and the Marinoan.

The **Marinoan** includes the purple and green siltstones and cross-bedded sandstones which are prominent on the shore platform and cliffs at Hallett Cove.

The Precambrian rocks are followed, after a time gap, by the Cambrian. The Normanville Group belongs to the early Cambrian Period which is notable for the first appearance of creatures with hard protective parts. Great numbers of very diverse species appeared in the warm Cambrian seas. Some of these creatures, such as the trilobites and the *Archaeocyathids*, flourished for only a limited time and are used as index or zone fossils. *Archaeocyatha* can be seen in limestones near the old Sellick Hill

Road and, recently, trilobites have been discovered nearby. The rocks of the Normanville Group were deposited in the shallow and relatively undisturbed western part of the geosyncline.

The Kanmantoo Group rocks crop out extensively in the eastern Mount Lofty Ranges. Thick sequences of sandstone and shale were poured into a deep, rapidly sinking sedimentary basin, known as the Kanmantoo Trough, which developed on the eastern side of the Adelaide Geosyncline in early (but post-Normanville Group) Cambrian times. These rocks are characterised by their metamorphic mineralogy and textures. No fossils have been found in them.

The Delamerian Orogeny

Sedimentation was succeeded by compression and folding of the sediments of the Adelaide Geosyncline and its subsidiary Kanmantoo Trough against the more stable Gawler Block. The rocks were metamorphosed, strongly folded and faulted, and some were even overturned as at Normanville. Granites, dated by radiometric methods at about 500 million years, were intruded during and after the climax of metamorphism and can be seen at Victor Harbor and Port Elliot.

The final stage of the Delamerian Orogeny, as this mountain-building episode is called, was the formation of a great chain of mountains referred to as the Delamerides. These mountains are believed to have continued southwards into Antarctica, which was then, like Australia, part of Gondwana. A long period of denudation followed, during which the mountains were strongly eroded, and the next recorded event in our geological development is the Permian glacial episode of about 270 million years ago.

The Permian Glaciation

Evidence of Permian glaciation found in Australia and on all continents which were formerly part of Gondwana, indicates that the old supercontinent was still intact at this time. The Permian glaciation lasted for over 50 million years in some areas and during this time the ice over-rode the land, much as in Antarctica today, deepening the valleys, rounding the hills, and polishing and scouring the rocks over which it moved. Huge boulders were plucked from the land surface and borne along by the irresistible tide of ice, which extended far out to sea as an ice-shelf. Polished surfaces with glacial striations, known as 'glacial pavements', can be seen at Hallett Cove and in the Inman Valley.

The Break-up of Gondwana

Another major time gap in our geological history followed. There was extensive erosion of the still rugged mountains until a subdued landscape with very low relief (a peneplain), was produced. This was covered by a thick layer of iron-rich residual soil (laterite). Meanwhile, about 160 million years ago, in the Jurassic, vast floods of basaltic lava erupted on all of the southern continents forming, in Australia, the Tasmanian Dolerite.

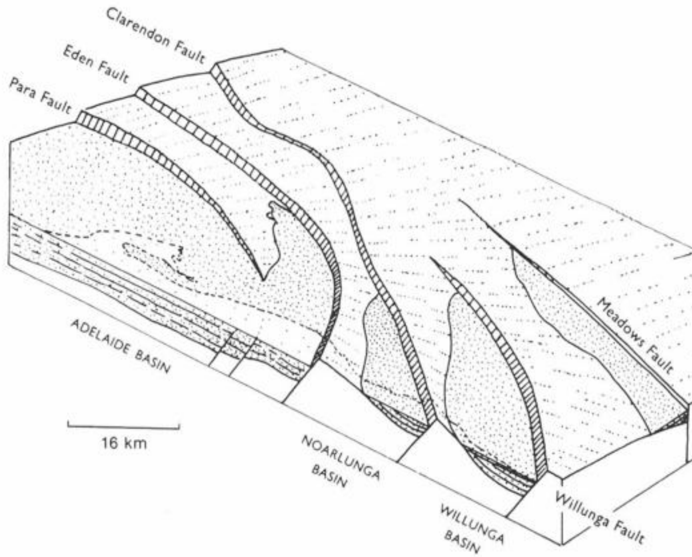


Figure 7. Simplified block diagram of Adelaide region showing the uplifted fault blocks and the Tertiary basins (From J.L. Talbot and R.W Nesbitt, Geological Excursions in the Mount Lofty Ranges and the Fleurieu Peninsula).

Over the next few million years narrow seas, resembling the present Red Sea, gradually formed between the sections of the super-continent of Gondwana. Stresses increased as coastal margins were down-warped and slowly separated from each other. As Australia drew away from Antarctica, a series of basins formed along southern Australia, including the Murray Basin and the St. Vincent Basin on which Adelaide is located.

In the Adelaide region the ancient north-south lines of weakness, dating from the Delamerian Orogeny, again became active. The old plain surface became broken into a series of step-like blocks, the eastern blocks being raised to form the present Mount Lofty Ranges. Rejuvenated streams excavated deep valleys in these blocks, but remnants of the former plain can still be recognised in the uniform height of the hill-tops in many places. Abrupt differences in summit heights indicate the considerable movement along the fault lines which separate the blocks. The most obvious fault lines are those which divide the Adelaide Plains from the ranges (Fig. 7). Movement along these faults allowed the western blocks to sink below sea level and, for most of the Tertiary Period, the Mount Lofty Ranges formed a peninsula bounded on three sides by the extensive marine embayments of the Murray and St. Vincent Basins.

The Birth of the Southern Ocean

The final rifting of Australia from Antarctica was complete by about 45 million years ago, when basaltic magma welled up to form the mid-ocean ridge system between the continents and marked the birth of the Southern

Ocean. The actual boundary of the first contact between the new oceanic crust and the edge of the Australian continental crust exists beneath the lower continental slope of southern Australia, extending from about 80 kilometres south of Kangaroo Island.

Sedimentation and Uplift

In the early Tertiary Period, about 65 million years ago, after an initial phase of non-marine sedimentation (estuarine sands), limestones were deposited in warm shallow seas and the numerous fossils they contain are evidence of the abundant life which then existed. Fossils can be found in the coastal cliffs from Christies Beach to Maslin Beach and Port Willunga where the Tertiary rocks are beautifully exposed.

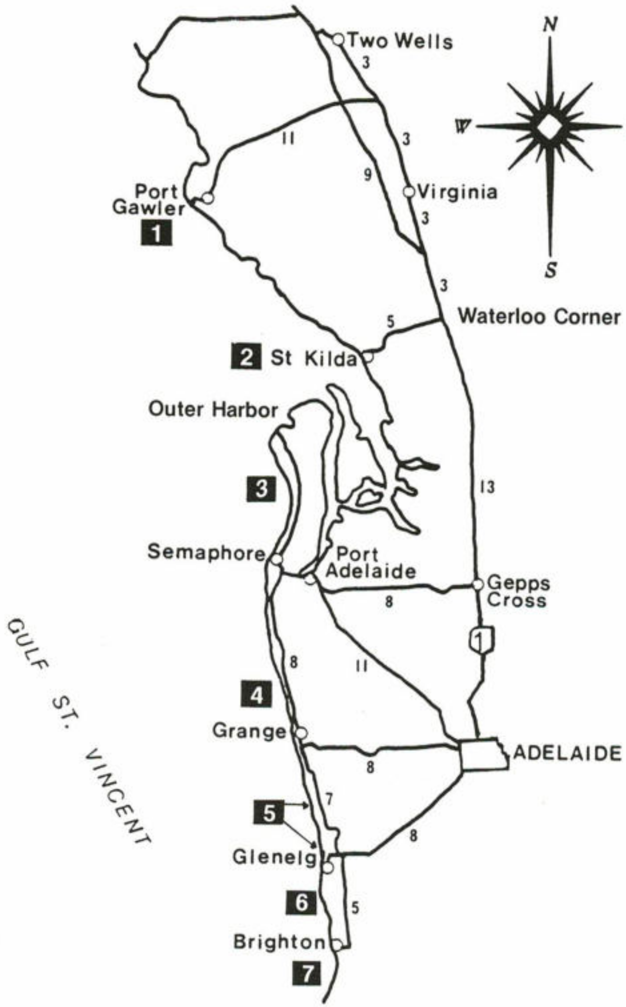
Further uplift took place towards the end of the Tertiary Period, and sea-level has fluctuated many times up to the present day. World-wide sea-levels are affected by glacial periods, when water extracted from the oceans becomes frozen and locked-up in the ice caps. When the ice melts during an interglacial phase, large quantities of water return to the ocean basins and sea-level rises.

One effect of an ice age is that at times of low sea-level, wide expanses of sea-floor are exposed. During the last period of very low sea-level, about 18,000 years ago, the sea retreated to the edge of the continental shelf and it is probable that the sands which now form the Adelaide coastal dunes were derived from material swept off the eroding floor of the gulf by strong westerly winds.

Since the last glacial advance, about 10,000 years ago, sea-level has risen progressively. This means that our dunes and beaches are unlikely to be replenished by sands from the sea bed — hence the need for vigorous attempts at conservation by our coastal management authorities.

The Present

As the Southern Ocean widens along the length of the mid-ocean ridge, Australia continues to move northwards at a rate of several centimetres each year. Movements still continue along the active fault zones in the Mount Lofty Ranges, but at a much diminished rate, and the processes of erosion and deposition continue to shape our landscape. Today, as we observe the forces of nature at work we know that these were the same forces responsible for the dynamic events of the past and by using our interpretation of those events we can try to predict the shape of things to come.



Locality Map 1, Port Gawler to Brighton

CHAPTER 2

PORT GAWLER TO BRIGHTON

The Adelaide and Fleurieu Peninsula coast displays strata of many geological ages, from sediments currently being deposited to rocks of great antiquity. By coincidence, but fittingly, this chapter deals with the youngest deposits. Unfortunately, most of the coastal geology of metropolitan Adelaide is hidden from view. Geological processes, however, are active along the coast and have been responsible for most of the depositional as well as erosional features. Careful observation of beaches and coastal swamps will reveal features that may be observed in older rocks to the south, thus providing a clue to their formation. It is a proven geological axiom that 'the present is the key to the past'.

Locality 1. Port Gawler

Port Gawler is the most northerly point to be visited and provides a good example of Gulf St. Vincent coastal geology to the north of Adelaide. It is more protected from west-south-west winds than the metropolitan beaches, and the sheltered conditions have produced coastal mangrove swamps with tidal flats, interspersed with extensive beaches, backed by low sandhills which contrast with the once continuous dune system of the city beaches.

To reach Port Gawler travel north from Adelaide on the Main North Road to Gepps Cross and then take the Port Wakefield Road to the clearly signposted Port Gawler turnoff, beyond Virginia. Follow the bitumen road to the end (some 10 km after the turnoff) and, taking a hard right turn, drive along the track to the beach. Exploration should be made on foot, wearing waterproof waders or sandshoes, and examination of the coastal sediments requires a shovel rather than the traditional hammer.

A shallow excavation on the beach will reveal that the sand and dead seagrass is only a surface veneer over a multi-layered sedimentary system. The first layer beneath the surface sand consists of a thin stratum of living blue-green algal filaments. Algae belong to the most primitive group of plants, the Thallophytes, plants that lack true roots, stems, leaves and flowers. They have world-wide distribution and form the chief aquatic plant life in both fresh and sea water. In their simplest form, algae are single celled, but most species are filamentous with many cells grouped together in a hair-like structure. Algae are important for their binding or cementing action which helps to preserve structure within the sediment and such structures may assist in identifying the original depositional environment of rocks of much greater age.

Below the layer of blue-green living algae is a dark grey layer of decomposing organic matter rich in hydrogen sulphide. This gas is produced by the decomposition of algal layers below the living layer. Underlying layers vary in colour according to their organic content and the amount of bacterial activity. These colours may also be influenced by tidal conditions and seasonal variations. With increasing depth, oxygen is again present, having been brought from deeper levels, and colours change to reddish brown indicating the presence of limonite, resulting from the oxidation of iron sulphide.

Another interesting feature on the beach is the small wave-like undulations, called ripple marks, which have been formed by waves selectively sorting sand particles of different sizes. The crests of the ripples consist of the finer material, the coarser grains being deposited in the troughs. The size of the ripples is a function of both the sediment size and the wave energy present during formation. Ripple marks are often preserved in sandstone and this feature will be observed in sections further down the coast. Because of the sorting, they are useful in determining which way was 'up' at the time of formation, and thus establishing whether the strata have been overturned by subsequent tectonic activity.

In low areas to the rear of the beach, shallow depressions have been filled with muddy water containing finer sediments. Upon drying, the mud (composed of silt and clay particles) shrinks and forms mud-cracks, a feature also preserved in rocks further to the south. (Pl. 1)

Wading out from the beach, beds of sea-grass *(Posidonia australis)* are encountered. Sea-grass is a vital factor in the depositional cycle of trapping and holding particles and allowing sediment to accumulate. Without sea-grass, the sediment would be much more mobile and susceptible to erosion, thereby exposing the coast to increased damage from storm waves.

The mangroves also may be inspected by those willing to brave the mosquitoes and other insects. The coastal mangrove *(Avicennia marina)* is the only species to flourish in South Australia, which is near the southern limit of growth of the plant (Pl. 2). Mangroves cannot tolerate frost. They create an environment where very fine grained sediment can accumulate as opposed to the coarser sand particles of the beach environment. The fine sediments are trapped among the mangrove roots and will eventually form siltstones and mudstones in contrast to the sandstones produced from

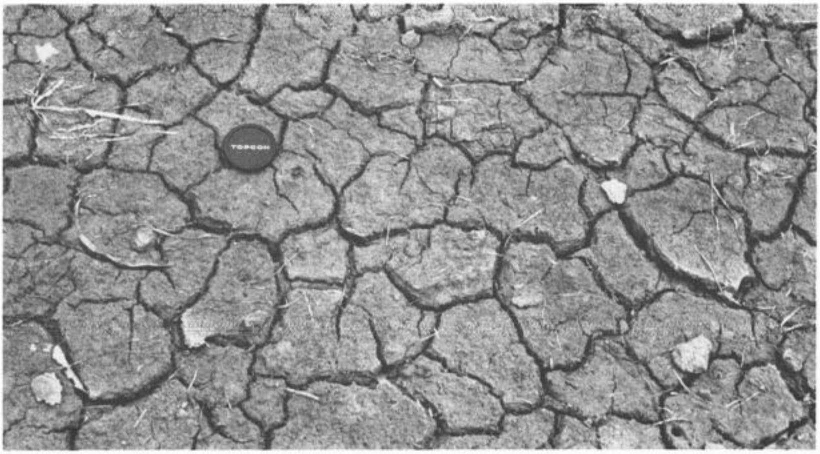


Plate 1. Modern mudcracks

coarser beach sediment. Gastropod and small bivalve shells may be observed in the channel floors during low tide. Anyone who wants to spend a longer time examining the mangrove area in detail is advised to undertake the guided tour along the St. Kilda Mangrove Walkway conducted by the S.A. Department of Environment and Planning. Contact the Salisbury Council for details.

Plate 2. Mangroves showing aerial roots

Returning to the beach, it is worth driving north along the track which follows the coast just inland from the tidal zone. The area to the east is an extensive deposit of broken shells which has accumulated along the coast over the last 6,000 years. It has been extensively mined for shellgrit and is now used by motorcycle and off-road vehicle enthusiasts. Climbing one of the few sandhills to have escaped the pulverising effect of motorcycle and go-cart wheels, it becomes clear that the deposit is composed entirely of shells. A handful readily yields many specimens including bivalves and gastropods.

Bivalves are shells consisting of two parts, a left and a right hand, held together in the living animal by a flexible ligament, e.g. cockles. Gastropods have univalve shells typically coiled in a helicoid spiral, snails being a common example. Most of the shells are from five to 30 mm in size and have obviously been deposited under higher energy conditions than presently exist along the coast which is now largely fringed with mangroves. If preserved, these shells could become fossils in a rock formation of the future. Alternatively, the shape of the external form of the shell could remain as an imprint (mould) in the rock, or the internal cavity, filled with sediment, may be preserved to form a cast.

The Port Gawler area forms an interesting and complex depositional environment where a wide range of sediment sizes is actively being deposited and acted upon by chemical and physical processes, and it provides a useful model for postulating similar environments of deposition for older sedimentary rocks with equivalent features.

Locality 2. St. Kilda

The seaside town of St. Kilda is reached by turning west, off the Port Wakefield road, at Waterloo Corner. The turn-off is well sign-posted when driving from the city. St. Kilda offers an opportunity to look at the tram-car museum, to take a guided tour on the Mangrove Walkway and to inspect the relatively young and only hard rock along this section of the coast. This rock formation is called the Glanville Formation and is thought to be about 125,000 years old. Although not known to crop out at the surface, the Glanville Formation was exposed during excavations for the St. Kilda boat channel. Fragments may be examined on the lower sections of the breakwater running along the north side of the channel, or in the several large blocks of rock situated on the landward end of the channel near the tram stop and parking area (Pl. 3). The Glanville Formation, largely composed of shell-beds, was deposited during the first of two Quaternary marine transgressions (periods between ice-ages when the sea was at higher levels than the present, due to melting polar icecaps).

The second transgression is represented by the St. Kilda Formation, described below, which consists of an assemblage of algae, foraminifera (mostly microscopic animals which play a vital part in geological dating) and shells of animals which lived in a climate considerably warmer than that of today. Many of these organisms are now confined to tropical and sub-tropical seas to the north. During the last ice-age the Glanville Formation was

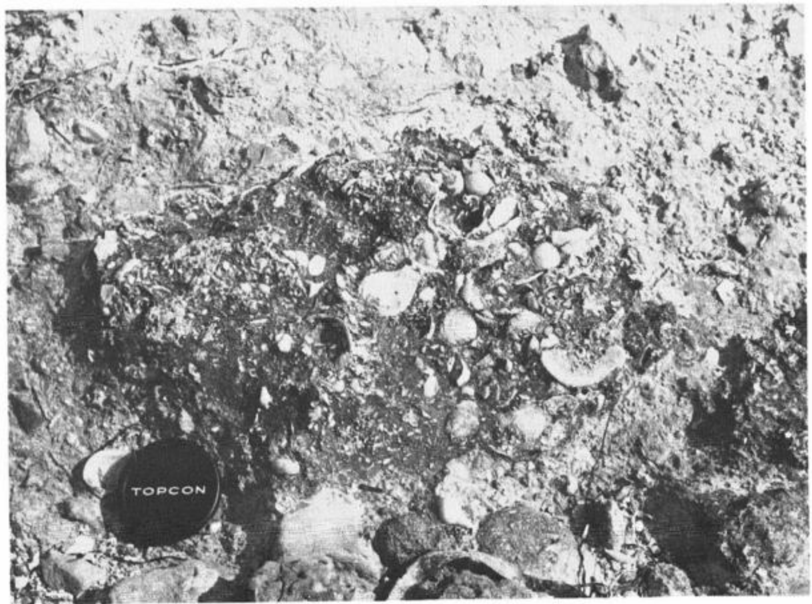


Plate 3. Consolidated shell deposits

exposed as a result of the drop in sea-level, and a lime-cemented crust was formed over the deposit.

Metropolitan Beaches

Adelaide's metropolitan coastline consists of a continuous coastal beach and dune system which provides an opportunity to observe coastal processes in a moderately high-energy environment. Inland from the coastal sands (Semaphore Sand) is a low lying swampy area, or back-dunal swamp of shells and finer sediments (St. Kilda Formation). Isolated dunes of red aeolian sand (Fulham Sand) overlie the St. Kilda Formation in places. While many of the formations near the coast have been hidden from view by urban development they may still be observed in a few locations. Driving west along Grand Junction Road towards Port Adelaide, remnants of the St. Kilda Formation may be seen to the north of the road from west of the railway overpass at Kilburn. Surface sediments are fine grained and dark grey, suggesting a marine origin. Delfin Island and the West Lakes development were formed by dredging the swampy St. Kilda Formation.

The remaining locations to be discussed are situated along the metropolitan coast. Although specific areas are mentioned, the beach system is continuous and conditions can be observed and assessed wherever the beaches are visited.

A brief summary of the beach building process is desirable before looking at specific areas. The beach system consists of the near-shore area, the beach itself and the sand dunes located inland from the beach. During winter storm periods of high wave energy, sand is removed from the beach and the front of the dunes, and deposited off-shore thus reducing the depth of water and helping to dissipate wave energy impinging on the beach and dunes further inland. During periods of calm summer weather, sand is moved back on to the beach and blown inland where it rebuilds the dunes prior to the next year's storms. The dunes are stabilised (fixed) by specialised dune vegetation. Thus sand in a natural or undeveloped area is continually being moved on and offshore by successive seasonal weather patterns. When urban development takes place on the dunes, the sand is locked in place and effectively removed from the cycle. Successive storms can thus progressively erode the beach, as the dunes are not replenished during the summer season.

The loss of the metropolitan beaches is also being aggravated by a combination of rising sea-level and falling land level, or subsidence, which produces a natural recession of the shore. Due to these processes alone, it has been calculated that some 15 m of coastline has been 'lost' since European settlement.

Another process operating along Adelaide's beaches is the littoral, or longshore drift of sand along the coast. This occurs as a result of the predominant south-west winds and a wave pattern which has a tendency to push sand in a northerly direction. Unfortunately, water depths increase south of Brighton so that there is no new supply of sand coming into the system from further south. This has resulted in a gradual depletion of the southern beaches, with a corresponding accumulation of sand towards the northern end of the metropolitan coastline. The process is, however, far from uniform and local reversals of the general pattern occur wherever structures are built which interrupt the flow of sand, such as the Glenelg breakwater.

Locality 3. The Le Fevre Peninsula

This excursion starts at the northern end of the beach system. Join the coastline at any convenient point, such as by following the Old Port Road and Bower Road to the coast at Semaphore South, and then travel north along the Esplanade and Lady Gowrie Drive towards Outer Harbour. The northern end of the Lefevre Peninsula is geologically very young, having been formed over the last 6000 years by the northward littoral drift of sand. Air photos taken before extensive development of what are now the suburbs of Taperoo, Osborne and North Haven, show a fan-shaped succession of beach ridges extending north. Each of these sub-parallel ridges represents the dunes of a former coastline and illustrates how the tip of the peninsula has grown northwards and, less rapidly, to the west (Fig. 8).

This land-building process is still going on. It is interesting, for instance, to observe the gradual increase in beach width between the road and the sea as one travels north from Semaphore, an indication that a significant amount of sand has accumulated since construction of the roads. The rate of sand movement is even more dramatically observable at North Haven and Outer

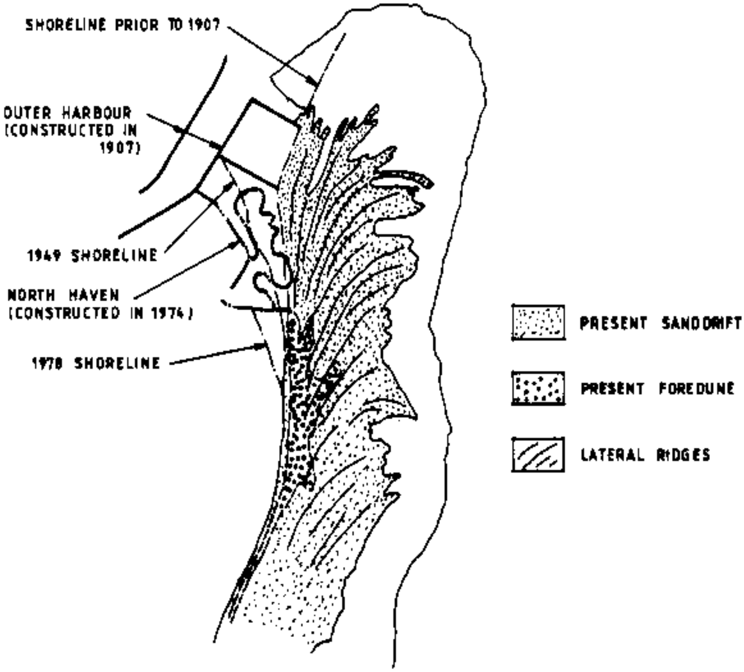


Figure 8. Northern Le Fevre Peninsula

Harbour where, since the building of Outer Harbour in 1907, sand has accumulated against the harbour's southern shore. Seaward accumulation of sand from the intersection of Lady Ruthven Drive and Lady Gowrie Drive, which, presumably, was built initially quite close to the shore, was some 400 m between 1907 and 1949, i.e. about 10 m per year. More recently the southern breakwater for the entrance to the North Haven Marina, which runs west from the end of Marmora Terrace, has also restricted the northward movement of sand. In less than a decade the sand accumulation is already about 100 m wide.

Locality 4. West Lakes Sand Dunes

Returning south along the Esplanade and then along Military road, there is, to the north and south of Estcourt House, one of the few remaining areas of intact dunes. These dunes were purchased by the Coast Protection Board and set aside as an example of the dune system that once fringed the entire shore of the Adelaide Plains. They may be reached from the carpark to the south of Estcourt House.

As heavy recreational use of the area could damage the delicate ground cover of coastal plants, access through the dunes has been restricted to walkways in order to protect them. A number of coastal plants may be seen in the dunes, including Spinifex Grass *(Spinifex hirsutus)* and the introduced Marram Grass *(Ammophila arenaria)*. These and other plants, if buried beneath blowing sand, may become fossils of the future. In the meantime, they act as stabilisers and hold the dune surface together. As an adjunct to the naturally occurring and introduced plants, the Coast Protection Board and Woodville Council have constructed fine mesh fencing to further trap blowing sand.

Locality 5. River Torrens and Sturt River Outlets

Two areas worth noting are the artificially created outlets for the River Torrens just north of Burbridge Road at West Beach, and the Sturt River which feeds into the Patawalonga boat harbour at Glenelg. This entrance also includes a breakwater at the end of Anzac Highway. In both instances, to the north and south of these artificial breaks in the dune system, conditions have been altered, with sand accumulating to the south because of the interruption to the northerly drift, while the beaches to the north are depleted of sand because of a lack of replenishment. The situation at Glenelg is particularly severe because sand has built out to the end of the breakwater and now continually flows around it to block the channel.

Locality 6. Minda Home Sand Dunes

Travelling south from Glenelg, an interesting section of beach may be observed in the suburb of North Brighton between Holder Road to the south and Somerton Surf Lifesaving Club to the north (just off Repton Road, Somerton Park). Here a series of largely intact dunes separates Minda Home from the beach.The section is best approached from the south via Holder Road or the Esplanade from Brighton.

It is immediately evident that the beach is much narrower here than to the north. The back of the beach is formed by a steep cliff in the foredune. Signs of erosion and slumping are evident in the cliff, which suggests that it is eroding. The reason for this may be an inadequate supply of sand from the dune system further inland or, more likely, the removal of sand to the north due to littoral drift, coupled with the gradual rise in sea-level.

The dune face is particularly interesting as it contains several features which clearly indicate the rapid rate of erosion possible in a dune system. Looking northward, along the dune, a thin horizontal line of darker material is evident running toward the Somerton Surf Club. It is the remains of a road, constructed in what was then a more extensive dune system. Careful examination also reveals a line of nearly buried fence posts running along the inland edge of the road. The sequence of events is thus, construction of the road and then the fence, subsequent burial from blowing sand, and, most recently, erosion, which has exposed the road section.

Returning to the beach, it is possible to collect numerous shells incuding several bivalves and gastropods. Transitory ripple marks are also evident on the beach, and these are continually being affected by wind erosion. Two processes of erosion, wind and water, will arrange the sand in layers or beds of different sized sand grains. Such layering is seen in most sandstones.

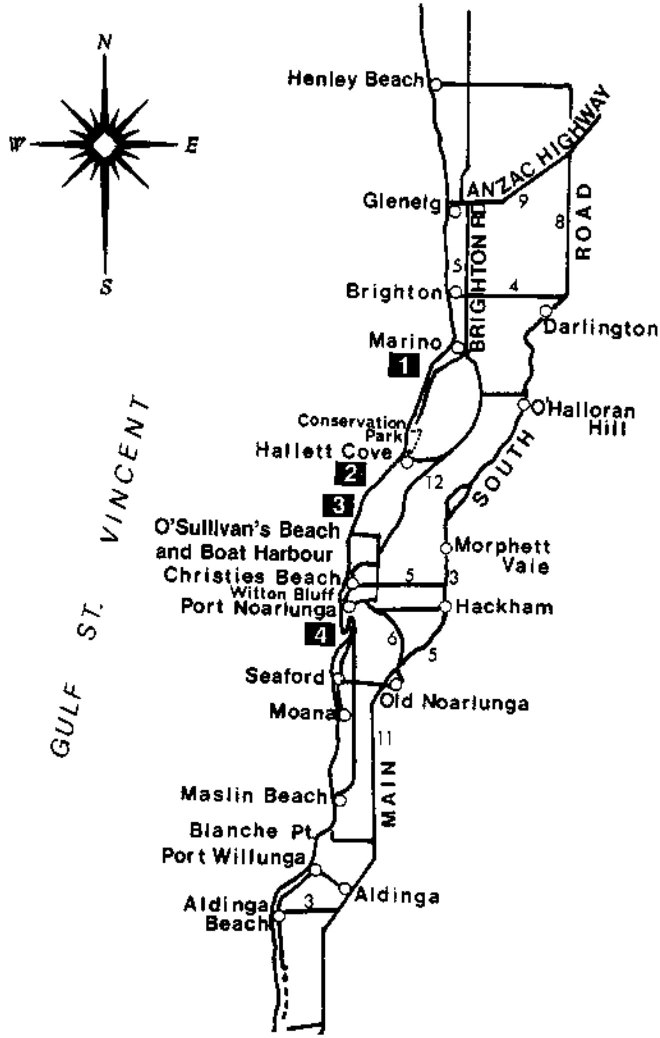
Locality 7. Brighton Beach

The beaches at Brighton have been badly affected by erosion resulting from urban development on the dunes coupled with littoral drift of sand to the north. Much of the beach is backed by dumped rock (rip-rap). Whilst necessary to protect the road and buildings fronting the sea, the rocks also reflect wave energy instead of absorbing it as a natural dune would. This reflected energy removes sand further offshore and consequently lowers the beach. Without replenishment the Brighton beach would eventually disappear.

N.B. Rip-rap has been used to back many local beaches as far south as Christies Beach. The rock used is Brighton limestone from the Linwood Quarry at Brighton and it is worth examining for the many sedimentary structures it contains.

The Coastal Management Branch of the Department of Environment and Planning (previously The Coast Protection Board) currently transports some 20,000 cubic metres of sand per annum to maintain the southern beaches. This sand is brought from Semaphore and other northern beaches. Although various options are continually being assessed by The Coastal Management Branch, it is clear that South Australia must continue to pay the price of past coastal development carried out without due understanding of the processes acting in this most changeable of natural environments.

Since this chapter was first drafted, two of the areas described, Port Gawler and Minda Home Sand Dunes, have changed significantly thus highlighting the dynamic and fragile nature of coastal geological processes. The wide beach and dune system at Port Gawler has been disturbed almost beyond recognition by off-road vehicles and sand sailers. The beach near Minda Home has been widened by importing sand, and fencing has been added to the base of the sand dune to help stabilise it. The reader is invited to look for other examples of change in the coastal environment.



Locality Map 2, Marino to Onkaparinga Mouth

CHAPTER 3

Marino to the Onkaparinga Mouth

The flat sandy metropolitan beaches end at Marino, where the sea washes on to hard rock layers. From here to Port Noarlunga and beyond, cliffs have developed behind rocky or pebbly beaches with occasional sandy bays. The coastline can be divided geologically into two distinct parts. Between Marino and O'Sullivans Beach resistant Precambrian rocks form the coastal cliffs, while from Christies Beach to the Onkaparinga River mouth and further south, the cliffs are composed of rocks of Tertiary and more recent age. These rocks have all been raised by earth movements along the Eden Fault which has a north-east trend and intersects the coast near Seacliff. When driving southwards along Brighton Road, the fault scarp is clearly seen ahead, marking the uplifted edge of the Eden Block, which slopes southward towards Port Noarlunga.

This section of the coastline contains the Hallett Cove Conservation Park where some of the best preserved Permian glacial features in the world can be inspected.

Locality 1. Marino

The area is approached by taking the right fork at the southern end of Brighton Road, following signposts to Marino, and crossing the railway at Marino Rocks Station into Jervois Terrace, which leads to the boat ramp.

Walking down the ramp to the beach, slaty rocks can be seen, showing distinct layers, which are tilted inland. These layers do not represent the original bedding of the rocks but are due to cleavage which resulted from compression caused by metamorphism and folding during the Delamerian orogeny, about 500 million years ago. Careful inspection shows that the bedding is nearly vertical, dipping steeply westwards towards the sea (Fig. 9).

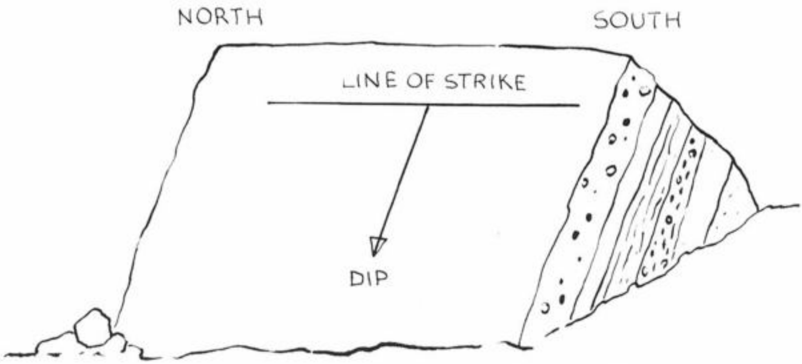


Figure 9. Beds striking north-south and dipping to the west

On the shore platform, north of the ramp, sandstones are seen with a lower angle of dip. An anticlinal fold can be observed in the cliffs, the higher strata being almost horizontal, indicating that the axis of the fold has been reached. There are ripple marks on some of the bedding plane surfaces (Pl. 4). These rocks are rich in pale pink feldspar grains and are known as

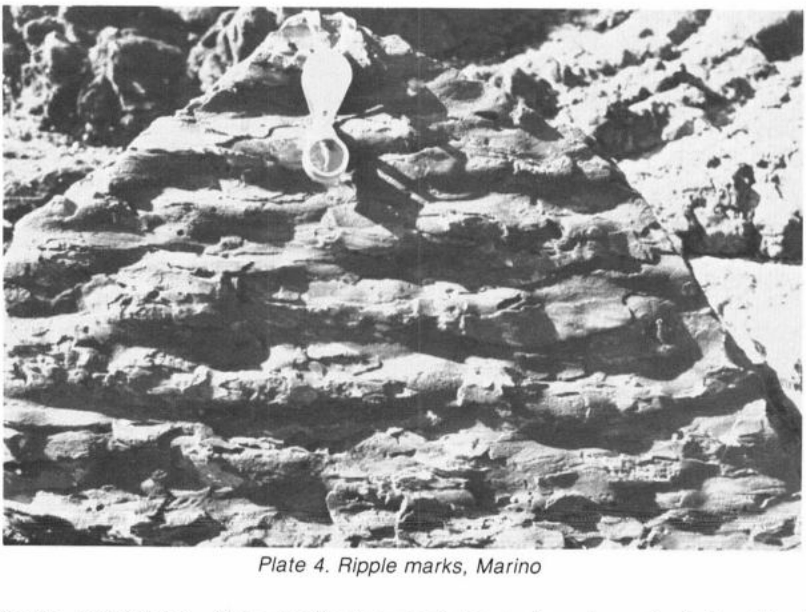


Plate 4. Ripple marks, Marino

arkosic sandstone. This particular rock formation is called the Marino Arkose. It is calcareous ('fizzes' when tested with dilute hydrochloric acid) and exhibits slump structures and cross-bedding. This sandstone can be followed along the rocky shore platform to the north until it comes into sharp contact with a younger darker-coloured, finely laminated siltstone about halfway between the ramp and the Esplanade.

To the south, the rocks near the sea still dip steeply to the west, but the bedding in the cliff is again nearly horizontal. On the foreshore erosion has truncated the western limb of the anticlinal fold, the axis of which is aligned north-south and tilted downward to the south (Fig. 10). The rocks here are Precambrian sandstones and siltstones deposited in Marinoan times, approximately 600 million years ago.

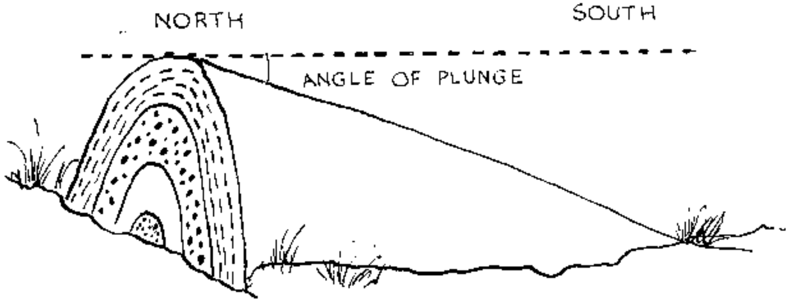


Figure 10. Anticline plunging to the south

Locality 2. Hallett Cove

Hallett Cove first attracted the attention of scientists in 1877 when Professor Ralph Tate of Adelaide University discovered glacial pavements there. He related these to the Pleistocene 'Ice Age' which affected large areas of the Northern Hemisphere between 1.5 million to 10,000 years ago. In 1893, the Adelaide meeting of the Australian Association for the Advancement of Science provided 'the largest scientific excursion ever held in the Southern Hemisphere' to investigate the discovery. In the same year Professor Walter Howchin concluded that the glacial sediments were much older and that they were probably deposited in the Permo-Carboniferous age. This view has since been supported by other scientific evidence.

When the ancient glaciers passed over this area the exposed land surfaces were smoothed and polished by the erosive force of the ice. At the same time, the debris which was carried on the margins of the ice-mass left tell-tale scratches and gouges on the Precambrian bedrock showing that the ice was moving in a northerly direction. Hallett Cove is one of the few places in the world where such markings have been so well preserved. Glacial pavements, upon which striations and gouges are clearly etched, can be seen easily along the cliff tops on Black Cliff and to the north beyond Waterfall Creek. These pavements roughly mark the western wall of a partially exhumed Permian glacial valley of which the eastern boundary can only be postulated as it is hidden beneath more recent sediments.

The area as a whole is like a precious cameo because it shows at a glance many of the significant events of the geological history of South Australia over the past 600 million years. There are three major unconformities apparent in the area. The first, between the Precambrian and the Permian, represents a period of about 330 million years during which the

Precambrian sediments were uplifted, folded and eroded. This unconformity is quite easily observable. The second break occurs between the Permian Ice Age and the Pliocene, a gap of about 265 million years. This is more difficult to recognise without explanation. During this time there was a long period of erosion after which Australia and Antarctica began to separate, about 55 million years ago. However, it was not until very much later, approximately 5 million years ago, that the area was submerged beneath the sea and the next sediments were laid down. These sediments are represented by the Hallett Cove Sandstone which outcrops discontinuously throughout the area. The third unconformity, between the Pliocene and the Pleistocene, is of about 3 million years duration, after which large quantities of alluvium washed down from the uplifted Mount Lofty Ranges and buried the underlying rocks. In relatively recent times the whole area was uplifted and erosion took place to form the present shoreline and landscape as we know it. Hallett Cove has been declared a Geological Monument of international significance and is regularly visited by scientists and students of geology from all over the world.

HALLETT COVE CONSERVATION PARK—All the important geological features of the area can be observed within the Hallett Cove Conservation Park and the National Trust's adjoining Sandison Reserve. A self-guided walk has been laid out by the National Parks and Wildlife Service and an explanatory leaflet is available at the northern and southern entrances to the park. Each station along the walk has multiple figuring. Letters A to H refer to the coloured leaflet available at the park entrances, whereas numbers 1 to 18 refer to an earlier students' guide which is reproduced in Fig. 11. It is emphasised that because the area is a conservation park, no collecting of specimens is permitted.

Access to the park can be confusing due to the maze of streets in the subdivisions, so a street directory may be useful. The northern park entrance is 500 m from Hallett Cove Railway Station, down South Avenue. From here, a track leads directly westwards, downhill to the coastal cliff where the self-guided walking route can be joined. The southern park entrance is off Heron Way, north of the Life Saving Club, which is on the beachfront of the Cove proper. The turn-off to Hallett Cove and the Conservation Park is clearly marked on the Lonsdale Highway. Cove Road also links the northern and southern access points.

WATERFALL CREEK AND BLACK CLIFF — Approaching Waterfall Creek from the northern entrance of the park, there is a good example of a glaciated pavement showing parallel striations and crescentic gouges, at post 10. Nearby on the higher path at post 11 the white, fossiliferous, calcareous Hallett Cove Sandstone can be seen as a horizontal layer 1 m thick, overhanging the path (Pl. 5). This is the type section for this formation. The rock was formed in a shallow sea with sufficient turbulence to break up fossils and incorporate them with pebbles, boulders and sand of reworked Permian rocks, which were exposed at the time.

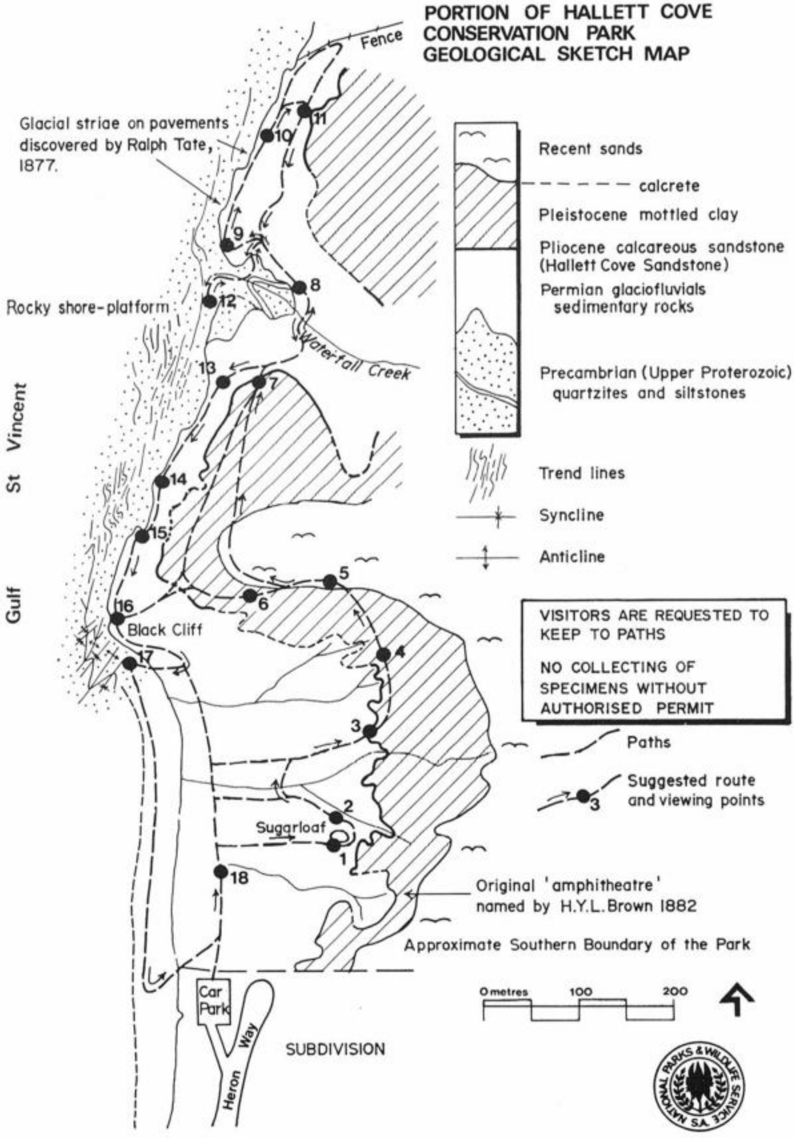


Figure 11. Portion of Hallett Cove Conservation Park. Geological sketch map. (Reproduced courtesy South Australian Department of Environment and Planning)

Plate 5. Hallett Cove Sandstone, Post 11, Hallett Cove Conservation Park

From the cliff top above the mouth of Waterfall Creek, looking southwards, there is a wonderful view of the folded reddish-purple Precambrian siltstones and sandstones of the Marinoan Series, which form Black Cliff and the shore platform. The individual beds on the shore platform show as a series of parallel lines bending around occasionally due to the presence of small eroded and truncated folds. The unconformity between the Precambrian and the overlying paler Permian sediments is well defined along the cliff top and on the southern bank of the creek. The old land surface formed by the Precambrian rocks dips to the east indicating that this is the western side of the glacial valley referred to earlier, while the overlying paler Permian sediments, broken by reddish bands, follow this old land contour and also show a shallow dip to the east. Below this unconformity at a small waterfall in the creek, just east of post 8, a small anticlinal fold can be seen in the blocky Precambrian sandstone (Pl. 6).

Plate 6. Anticline, Waterfall Creek, Hallett Cove Conservation Park

On the shore platform and at the mouth of Waterfall Creek, a variety of pebbles and boulders can be found which are not locally derived. They are erratics which have fallen from the glacial sediments above as the cliff has eroded away. Rocks of varied lithology are included, some of granitic material, others are sandstones displaying small-scale cross-bedding.

Walking towards Black Cliff along the shore platform, note how the folds in the Precambrian rocks are emphasised by the differences in texture and colour of the sedimentary layers. Observe how prominent bands in the cliff can be traced along the wave-cut shore platform, often showing 'S-bends' or fold pairs (Pl. 7). These folds all plunge south. White quartz infills tension

Plate 7. Wave-cut platform with 'S' folds, below Post 15, Hallett Cove Conservation Park

gashes which are associated with the hinges of the folds, and occasionally slickensides (parallel scratches often infilled with green chlorite) indicate how the beds have moved relative to one another during folding. These small folds are 'wrinkles' or parasitic folds indicating that the Precambrian beds are on the western limb of an even larger anticline. This folding occurred during the period of orogeny associated with the end of the Adelaide geosyncline approximately 500 million years ago, and has been modified very little by subsequent movements.

A close study of the Precambrian rocks will show that an axial plane cleavage (see Fig. 22) which has developed into fine grained siltstones, as the result of the folding, is not apparent in the harder sandstones. Where the cleavage and the bedding make a low angle to each other the combined effect has produced a wrinkled bedding surface. This effect combined with wave ripples is seen on the steep rock face of Black Cliff.

From Waterfall Creek there are two paths leading to Black Cliff along the cliff top. The lower path leads through the soft clays and sands of the glacial sediments, while the higher path is situated on Pleistocene clays. The Hallett Cove Sandstone crops out as a hard buff-coloured band between the two paths.

Along the lower path, at post 3, three large quartzite erratics can be seen and from post 14 an 'aerial' view of the shore platform reveals some 'S' folds. At posts 15 and 16, erosion of the Permian sediments has uncovered good examples of polished and striated glacial pavements. These pavements are those first described by Professor Tate in 1877 (Pl. 8).

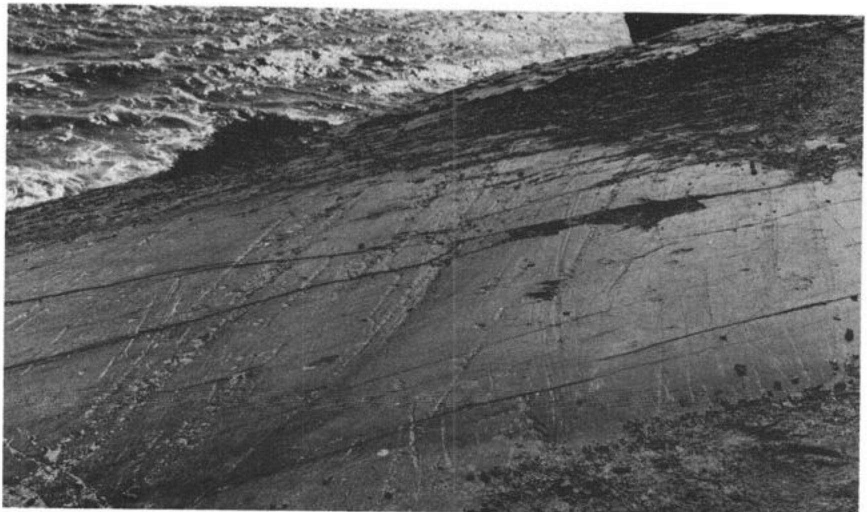


Plate 8. Striated pavement, Post 16, Hallett Cove Conservation Park (photo J.A. Salas for The National Trust of SA)

From the top of Black Cliff, note the absence of the Precambrian rocks along the swimming beach and their reappearance as cliffs at the southern end of the cove. This shows the uneven nature of the old Precambrian surface upon which the glacigene sediments were deposited. Several large erratics can be seen on the beach (Pl. 9). Looking down onto the shore

Plate 9. Erratics on the beach at Hallett Cove

platform immediately south, there is a splendid view of a series of eroded and truncated synclines and anticlines which are further examples of the small folds in the area. The pattern formed by these folds indicates that they all maintain a plunge to the south.

THE AMPHITHEATRE — The area to the east of Black Cliff, behind the sandy beach, is called the Amphitheatre, so named by the geologist H.Y.L. Brown in 1882 (Pl. 10). Here the Permian and Cainozoic features can be studied in detail. The nature of the Permian sediments within the Amphitheatre suggests that they were deposited in a lake formed by 'meltwater' trapped behind retreating ice, towards the end of the glaciation.

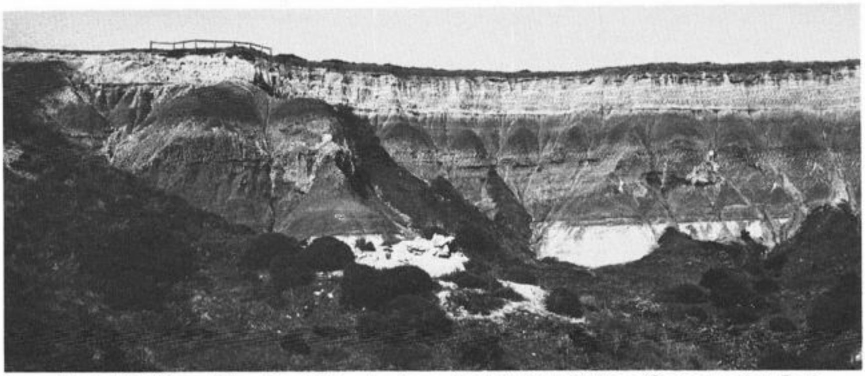


Plate 10. View of the Amphitheatre from Post 1, Hallett Cove Conservation Park

A panoramic view of the area seen from the top of Black Cliff, reveals the pale Permian sediments overlain by the thin discontinuous band of hard Hallett Cove Sandstone, undercut by erosion, and overlain by the thick sequence of red-white and green-red silts and clays of Pleistocene age. There is a great thickness of these alluvial sediments which were washed down as fans and flood plain material when the Mount Lofty Ranges were uplifted. This sequence contains several fossil soil horizons which have developed a concentraton of red-coloured iron oxides. These Pleistocene sediments are capped by a hard white nodular calcrete horizon that weathers into small marbles, the Ripon Calcrete, a common surface formation in southern South Australia. Erosion since Pleistocene times has produced the landforms visible within the Amphitheatre and the soft sediments are still eroding rapidly today.

The Amphitheatre can be approached by a path leading from the top of Black Cliff or by walking down to beach level and taking one of the lower paths. The path nearest to the southern entrance leads directly to the 'Sugarloaf' (Pl. 11), a rounded hillock composed of whitish Permian sandstone capped with Pleistocene clay (the Pliocene Hallett Cove Sandstone is here missing). Erratics of various sizes are found in the glacial beds and several large examples can be seen weathering out of the brownish sediments at the base of 'Sugarloaf' hill on its northern side.

Plate 11. View of the Sugarloaf from Post 3, Hallett Cove Conservation Park

CONSERVATION OF HALLETT COVE — This area was nearly lost to us when housing development began to spread to the south as Adelaide's population increased. The first moves to conserve it were taken in 1957 by Professor A.R. Alderman of The University of Adelaide who asked the Marion Council and the newly formed National Trust of South Australia to attempt to preserve the glacial pavements. Since then many individuals and organisations have added their support to move the Government to acquire and maintain a reserve large enough to protect, not only the geology, but also the features of botanical and anthropological interest. Through these efforts the Sandison Reserve, which is held by the National Trust, was increased in size and about 50 hectares of adjoining land was purchased by the State Government and dedicated as the Hallett Cove Conservation Park on 1st July, 1976.

Locality 3 Field River to Curlew Point

Walking south from Hallett Cove Beach, note the erratics which have collected at the mouth of the Field River (Pl. 12). From here the coastline no longer runs parallel to the strike of the rocks and rock outcrops slant across the beach. The dip is still very steep, the rocks becoming younger towards

Plate 12. Granite erratic, south of Field River, Hallett Cove

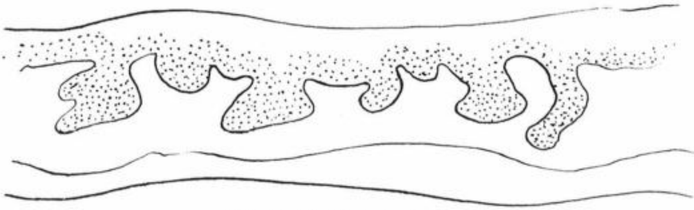


Figure 12. Load casts

the south-east. They are mainly reddish-brown siltstones with interbedded thin sandstones of the Brachina Formation. The sandstones show such features as load casts (Fig. 12), herring bone cross-bedding and ripple marks. These rocks are still part of the western limb of an anticline earlier observed at the Conservation Park. This limb is itself occasionally folded with smaller subsidiary folds trending north-south. Near Curlew Point, on the northern side of the Port Stanvac boundary fence and about three-quarters of an hour's walk from Hallett Cove, spectacularly folded quartzites can be seen (Fig. 13). The massive zig-zag pattern on the cliff face and on a rock stack is due to the reclined nature of a series of successive subsiding folds. These structures were illustrated by Walter Howchin (1929) in his book 'The Geology of South Australia'.

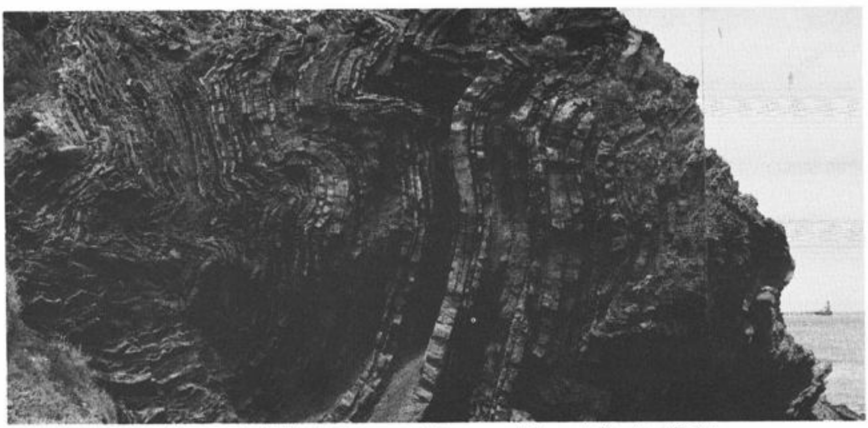


Plate 13. Folds in Precambrian quartzites at Curlew Point

Location 4 Christies Beach to Port Noarlunga

At Christies Beach, the sandy beach was once backed by low dunes, few of which now remain. To the north, the remains of a prominent outcrop of Precambrian light-coloured, fine-grained quartzite can be found each side of the entrance to the new boat harbour. Howchin referred to this area as 'Rocky Point'. The strike is north-east to south-west with a dip eastwards. It was once possible to see, before much of the outcrop was removed, the slight westward curve at its summit indicating that it is the eastern segment of a minor anticlinal fold.

To the south is Witton Bluff, now almost completely masked by artificial screes in an attempt to preserve a road which runs along the top of the cliff (Pl. 14). The rocks, mostly hidden, are of early Tertiary age, the headland being formed mainly of the Blanche Point Formation, a fossiliferous limy clay and siltstone containing conspicuous casts and shells of the spiral-shaped gastropod, *Spirocolpus* ('Turritella') *aldingae*. This formation is underlain by the glauconitic Tortachilla Limestone. These rocks can be inspected much more easily further to the south and will be described in detail in Chapter 4.

Plate 14. Witton Bluff

From Christies Beach to Port Noarlunga the coast road runs along the top of the Bluff. At Port Noarlunga, north of the jetty, a platform shelf has developed due to the presence of a hard siliceous rock horizon (the Gull Rock Member of the Blanche Point Formation). This is the unit seen at Witton Bluff where it contains fragments of mollusc shells in the lower layers. Above the shelf, Quaternary sandy deposits form low cliffs

South of the jetty a sandspit runs along the bank of the Onkaparinga River. The river in its last three kilometres meanders over plains, finally reaching the sea about one and a half kilometres south of the jetty. To examine the cliffs around the river mouth more closely, drive inland through Port Noarlunga, turning right to cross the bridge, then follow Weatherald Drive along the left bank towards the mouth. From the footbridge, follow the left bank, where the uppermost beds of the Blanche Point Formation are seen, overlain by a succession of younger rocks. These sediments are known as Chinaman's Gully Beds and crop out about 100 m south of the footbridge. The vari-coloured clays and cross-bedded sands are about two metres thick and were deposited in a non-marine environment. Beyond and above this unit are the Port Willunga Beds, a sequence of bryozoal sand, marl and limestone (see Chapter 4). Other fossils include *Spirocolpus* ('Turritella') and mollusc fragments. It is noticeable that beneath the harder layers, the lower softer beds have been eroded by the sea producing overhanging ledges in several places. Much of the cliff is made of alluvial material with conglomerate bands washed down to river level, but as the river bends round the end of the sandspit to reach the sea, the Port Willunga Beds again appear. They are more easily seen along the beach, just south of the river mouth, by descending the steps from the carpark at the end of the esplanade. Fossils that can be seen here include *Spirocolpus* ('Turritella'), Pecten and other mollusc fragments, as well as echinoid spines.

CHAPTER 4

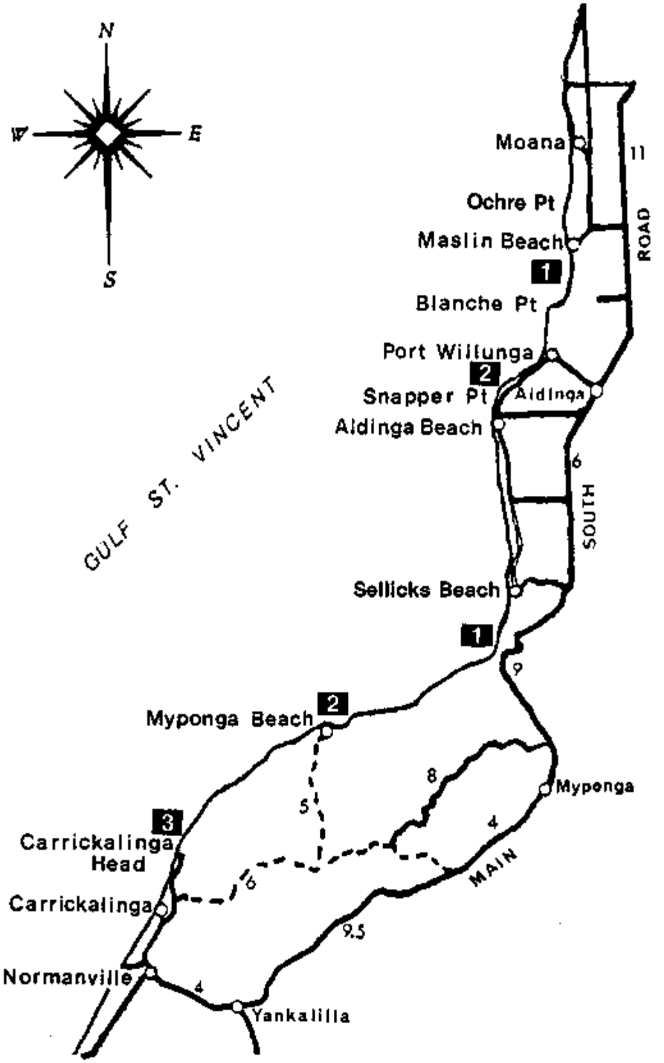
MASLIN BAY TO SNAPPER POINT

The strata to be seen in the cliffs of Maslin Beach and Port Willunga constitute the type section for the Tertiary rocks of the St. Vincent Basin. These sedimentary rocks were laid down between 45 million and 5 million years ago and infilled the Willunga Basin which had been created by the block faulting of the Mount Lofty Ranges in early Tertiary times (Fig. 7). Later, in the Pleistocene, these sediments were covered by outwash from the ranges. A close inspection of the coastal cliffs in this area will reveal the many environmental changes which influenced the deposition of these sediments, including several transgressions and regressions of the sea.

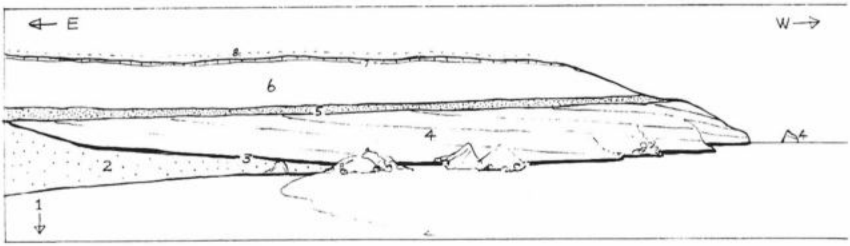
Winter is the ideal time to explore the geology of this area as the rock exposures are fresher and brighter and the loose sand, which piles up against the cliff during the summer, has been carried back into the sea beyond low-tide level by stronger waves. It is worth noting that when the moon is new or at the full, the beach is well exposed around mid-day, also that nude bathing is permitted at the southern end of Maslin Beach.

Locality 1. Maslin Bay

The history of the sequence seen at Maslin Bay began in a river delta, represented by the North Maslin Sand (1), which was inundated by a deepening sea followed by the deposition of the South Maslin Sand, the Tortachilla Limestone and the Blanche Point Formation (2, 3, 4). Later there was a break in deposition and tilting occurred, followed by further shallow marine sedimentation, as represented by the Hallett Cove Sandstone (5). The sea eventually retreated and was replaced by river flood-plains in the Pleistocene (6). (Numbers refer to Fig. 13.)



Locality Map 3 (Chapters 4 and 5), Maslin Beach to Carrickalinga Head (see also maps 4 and 5)



8. Recent .... Soil
7. Mid Pleistocene .... Calcrete
6. Late Pleistocene .... Mottled clay and sand
5. Late Pliocene.............. Hallett Cove Sandstone
4. Late Eocene .... Blanche Point Formation
3. Late Eocene .... Tortachilla Limestone
2. Late Eocene .... South Maslin Sand
1. Mid Eocene .... North Maslin Sand

Figure 13. Geology of coastal cliffs Maslin Bay
Based on diagram by University of Adelaide Geology Department

Looking towards Blanche Point, a panoramic view of the coastal cliffs of Maslin Bay is obtained from the car park near the mouth of Bennett Creek, just south of Maslin Beach township. On the southern side of the creek the weathered cliff-top rises from the old river terraces and remnant dunes, to the Tortachilla Trig. Point, about 800 m to the south. The lowest beds exposed on this section of the beach are the mustard-coloured South Maslin Sands which slope gently to the south and disappear beneath the beach in the southern corner of the bay. Above the sands and lying at the same angle, pale pink and white fossiliferous limestones and marls form the lower half of the cliffs ending in Blanche Point and Gull Rock.

Lying conspicuously and unconformably on top of the older beds, is a horizontal bed of yellow sand grading into hard white limestone which forms a narrow platform half way up the cliffs. This is the Hallett Cove Sandstone described in Chapter 3. Above the sandstone are red, green and brown mottled clays of Pleistocene age topped by a thin layer of recent soil which shows a white calcrete horizon on the exposed face of the cliff. The material is slowly moving downslope to mingle with the underlying clays (Pl. 15).

THE BASE OF THE TERTIARY SEQUENCE — To examine the rock sequence in order (Fig. 14) it is necessary to start at Ochre Point, 1,200 m north of Bennett Creek. Here a reef of Precambrian quartzite forms a natural groyne across the beach. This is the edge of the Clarendon Fault Block which is tilted to the south-east towards the Willunga Fault. Immediately south of the quartzite there is a small cliff face, some 100 m long and 5 m high, consisting of an unbedded purplish clay. A blocky smoke-stack type of weathering suggests that blocks may crumble and fall at any moment. Occasional polished pebbles and erratics indicate that it is Permian clay, similar to that seen at Hallett Cove. The cliff-face then swings inland and the

Plate 15. General view of Blanche Point and Gull Rock from cliff top with Pleistocene beds in foreground

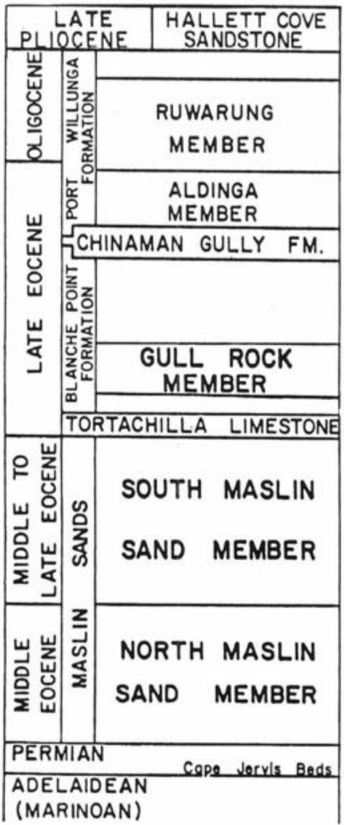


Figure 14. Composite columnar section of Tertiary units Maslin Bay — Port Willunga Type Sections (after B.J. Cooper)

area behind the beach is fenced off and used by the Readymix Sand Quarry for waste disposal.

THE NORTH MASLIN SANDS — Evidence of deposition, after a long period of erosion, is found in the Readymix Sand Quarry which is excavated in the oldest Tertiary rock unit, the North Maslin Sands. This quarry is privately owned and not freely accessible to the general public. (It may be possible for parties to make arrangements for a visit with the quarry manager.) The quarry has been in operation for many years and the worked-out areas have been graded and grassed so that the original appearance has been lost. The deposit ranges in grain size from pebbles to very fine, cross-bedded sands with the coarser grains and pebbles in the lower part of each bed. The base of the formation is marked by a band of polished quartz in a conglomerate which lies on a whitish clay base known as 'pipe clay'. This clay is Permian glacial material similar to that which appears in the small cliff on the beach. The sands are predominantly white with yellowish and reddish bands near the top, and are about 19 m thick. About 3 m above the base, dark laminated clay bands with creamy nodular lenses occur. These clays yield occasional plant remains including myrtle and fern leaves which appear to have been dropped in stagnant pools and covered by fine layers of silt. Pollen spores and plant cuticles indicate a sub-tropical flora at that time. The cross-bedding and the absence of marine fossils indicate terrestrial deposition.

THE SOUTH MASLIN SANDS — The North Maslin Sands of Middle Eocene age, are overlain by the South Maslin Sands, the first marine beds in the sequence. Though variable, they are generally coarse and, unlike the North Maslin Sand, consist of a 50-50 mixture of well rounded quartz and limonite grains which give them a predominantly brown colour. The limonite is thought to have been deposited first as glauconite, an unstable hydrated potassium iron silicate, and later changed by oxidation. Using a hand lens, small patches of dark greenish glauconite can still be seen in these remnant sands. Glauconite is distinctively marine in origin and formed in shallow water under moderately reducing conditions, consistent with slow sedimentation. Laminated limonite, capping the successive layers of cross-bedded sands, is noticeable in the face of a gully (The Canyon) which breaks out to the beach about 300 m north of Bennett Creek (Pl. 16). This limonite also caps the small hilly slopes for about 250 m south of Bennett Creek after which a thin talus, formed from the overlying clays, disguises the South Maslin Sands until the Tortachilla Trig. Point.

The land rises gradually to the Tortachilla Trig. Point 46.6 m above sea level, and spectacular gullies are being eroded in the cliff face which appear like hanging valleys when the winter tides wash the beach sands away. Seen from the water's edge the spur below the Trig. Point stands out, the white clay base streaked with stains from its red mantle. The steep gully north of the Trig. Point shows the typical mustard yellow-brown South Maslin Sands reaching up to the weathered Pleistocene clays. This is the highest point of the formation, which has been estimated as 30 m to 48 m thick.

Fossils are uncommon in the South Maslin Sands but detailed examin-

Plate 16. Cross bedded sands north of the steps at Maslin Beach

ation reveals that foraminifera, echinoid spines, sponge spicules, polyzoa, molluscs and shark teeth do occur and brachiopods are more common in the higher beds. This fauna, together with the evidence provided by cross-bedding, indicates estuarine marine conditions. From the Trig. Point spur, the South Maslin Sands plunge down to disappear beneath the beach in the southern corner of Maslin Bay.

THE TORTACHILLA LIMESTONE — first appears south of the Trig. Point in a wide, spectacular gully with several spurs and numerous red and brown clay hillocks. The southern side of this amphitheatre ends in a bluff with two bands of Tortachilla Limestone clearly exposed. The total thickness here is only 2 m increasing to 3 m in the southern corner of the bay where there has been some irregular erosion of the underlying South Maslin Sands.

The appearance of the Tortachilla Limestone marks a change of environment. No longer do we see signs of cross-bedding, while animal life, as represented by the fossil fauna, has increased enormously. Deposition occurred in shallow sheltered seas. The formation begins with sands rich in limonite grains and grades into a hard fossiliferous pink-white limestone with a little glauconite. Above, a thin friable band shows an increase in glauconite, so that the rock takes on a predominantly green colour. The limestone can be traced around the bay to just east of Blanche Point where the upper section forms a platform and the lower, a reef. The best place to examine this formation is at the steps north of Blanche Point (Pl. 17,17a). The contact with the underlying South Maslin Sands can be seen where the harder limestone has been slightly undercut.

Plate 17. Contact between South Maslin Sands and Tortachilla Limestone at steps north of Blanche Point

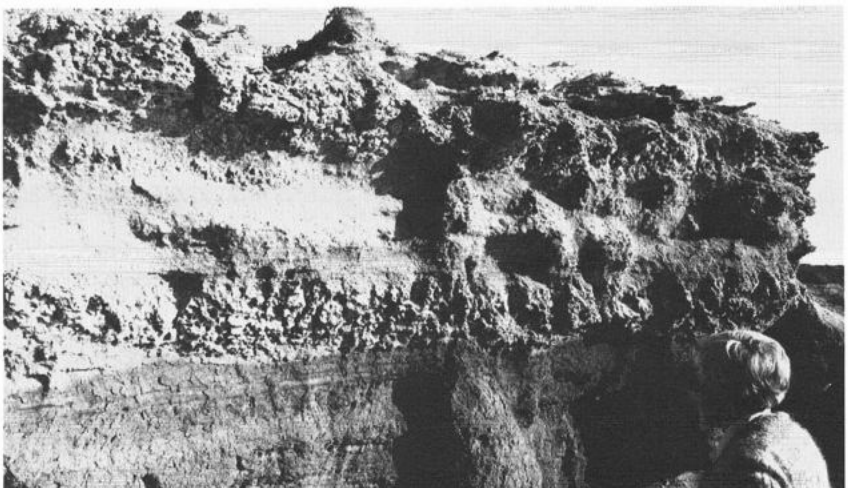


Plate 17a. Detail of contact between South Maslin Sands and Tortachilla Limestone

THE BLANCHE POINT FORMATION — (Previously called the Blanche Point Marls), conformably overlies the Tortachilla Limestone, forming the main mass of the cliffs around the southern end of the bay (Pl. 18), including Blanche Point itself and Gull Rock, which is an eroded remnant of the cliff and a good example of a sea-stack. Marl is a limy clay and the first bed (the Transitional Marl) 3.5 m thick, is soft, friable and richly fossiliferous. A few centimetres of the lower beds can be seen above the underlying

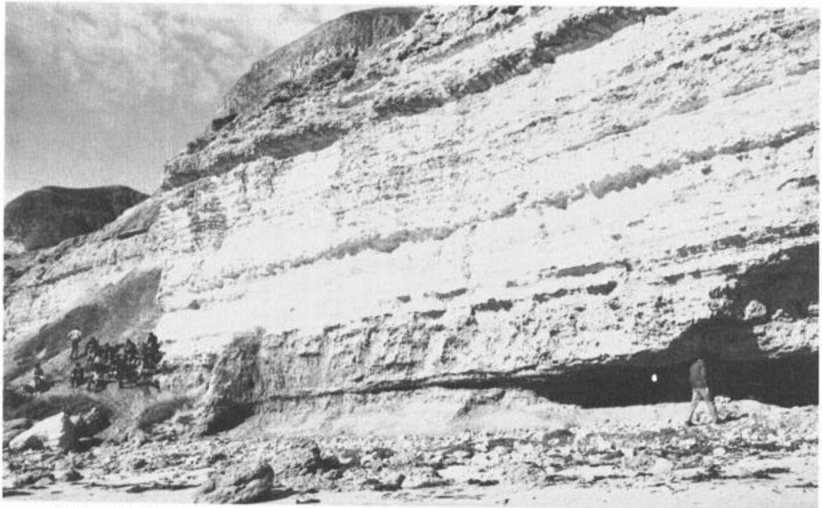


Plate 18. Northern face of Blanche Point showing Blanche Point Formation

Tortachilla Limestone, where they are cut by the Hallett Cove Sandstone, south of the Trig. Point. The top of the soft marls disappears where it has been eroded at sea-level on the northern side of Blanche Point and forms a long shallow cutting beneath the overlying Gull Rock member (banded marls).

About 100 m south of the steps, the Blanche Point Formation begins with a hard calcareous and glauconitic layer. This is succeeded by 11 m of alternating bands of hard and soft marls known as the Gull Rock Member, which forms the vertical cliffs on the northern side of Blanche Point. The Gull Rock Member is characterised by resistant hard bands composed of opaline silica. Its presence supports palaeontological evidence of deposition in bodies of water with restricted circulation and limited access to open oceans. The sediments are comprised of a mixture of volcanic ash (from extensive volcanism associated with the separation of Australia and Antarctica), sponge spicules and calcareous fossil remains. The hard layers were produced later by selective silicification.

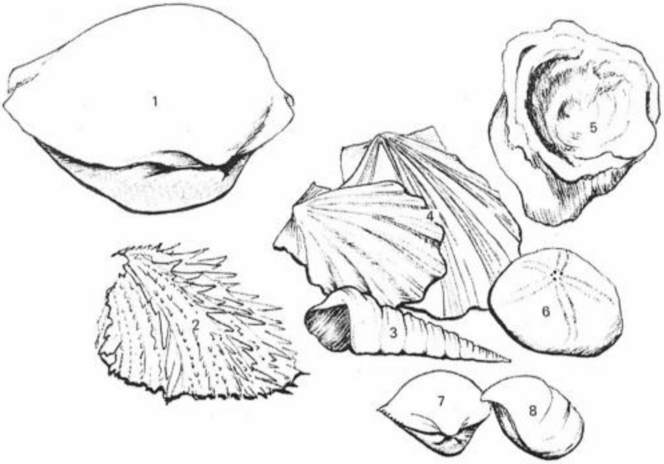
The sequence passes upwards into softer marls and eventually into strata which contain hard opaline bands like the Gull Rock Member. These first appear under the Hallett Cove Sandstone about 400 m east of Blanche Point. The unconformity is well marked by the harder bands at the head of the bay. There the wedge of softer marls has been eroded, and the hard top of the Hallett Cove Sandstone forms a conspicuous secondary platform.

It is impossible to walk round Blanche Point, even at the lowest tides, so it is necessary to approach the southern portion of the sequence from the south. The car park at Port Willunga is the most accessible location to start from. However, before leaving Maslin Bay, the great variety of fossils which may be found in the rocks there should be considered.

FOSSILS FOUND AT MASLIN BEACH — With a little practice one can learn to distinguish the various formations and a wide variety of fossils can be found. Near the steps there are fallen blocks of Tortachilla Limestone where fossils can be safely and easily found. Shark teeth have been discovered in the sands above the steps.

Geologically, the foraminifera, used for dating, are some of the most important fossils but their shells are usually very small and only just visible to the naked eye. The bryozoa (a group of the Polyzoa which means 'many animals') are also microscopic, but they live in colonies and their connected calcareous body-coverings take many forms, from the encrusting 'sea mats', to the elegant genus *Retepora* ('lace coral'). Well over 200 species have been listed from Australian Tertiary rocks. Bryozoans are common in the Tortachilla Limestone. Fossil brachiopods, commonly called 'lamp shells', from their resemblance to the old Roman oil-lamps, are also conspicuous in this formation. The local name 'cocky's beak' is an apt description of some of the larger species. Brachiopods are solitary animals with bivalve shells, dorsal and ventral (back and belly), unlike the bivalve molluscs, clams, cockles and mussels, which have their valves on the sides, left and right. The brachiopod has a hole in the beak of the ventral valve through which a muscle (or pedicle) projects to anchor it to a rock.

A group of organisms which has left abundant remains is the Echinodermata (sea-urchins, starfish, etc.). The bodies of spiny sea-urchins, heart and biscuit urchins and sea-eggs are most common and their spines are abundant. Sea-lilies (crinoids) also belong to this group and fragments of their stems can occasionally be found.



Actual size
1. 85mm
2. 60mm
3. 35mm
4. 50 and 70mm
5. 60mm
6. 43mm
7. 32.5mm
8. 32mm

Figure 15. Some common fossils found at Maslin Beach and Port Willunga

1. *Anodontia sphericula*
2. *Spondylus spondyloides* (Tate)
3. *Spirocolpus* ('Turritella') *aldingae* (Tate)
4. *Pecten palmipes* (Tate)
5. *Pycnodonte* (Phygraea) *tarda* (Hutton)
6. *Echinolampus posterocrassus*
7. *Internal mould of a bivalve*
8. *Magellania sp.*

The molluscs are the most common invertebrate group found around the coast today. In the earlier Eocene beds the molluscs are represented by *Ostrea* (oysters), *Chlamys* (fan shells), *Glycimeris* and univalve gastropod casts. In the Blanche Point Formation, the gastropod *Spirocolpus* ('Turritella') *aldingae* is abundant and the soft marls have been called Turritella Beds. The Hallett Cove Sandstone is noted for its oyster beds, and some slabs fallen from the upper platform at the southern end of Maslin Bay may be found on the beach. Some common fossils are shown in Fig. 15.

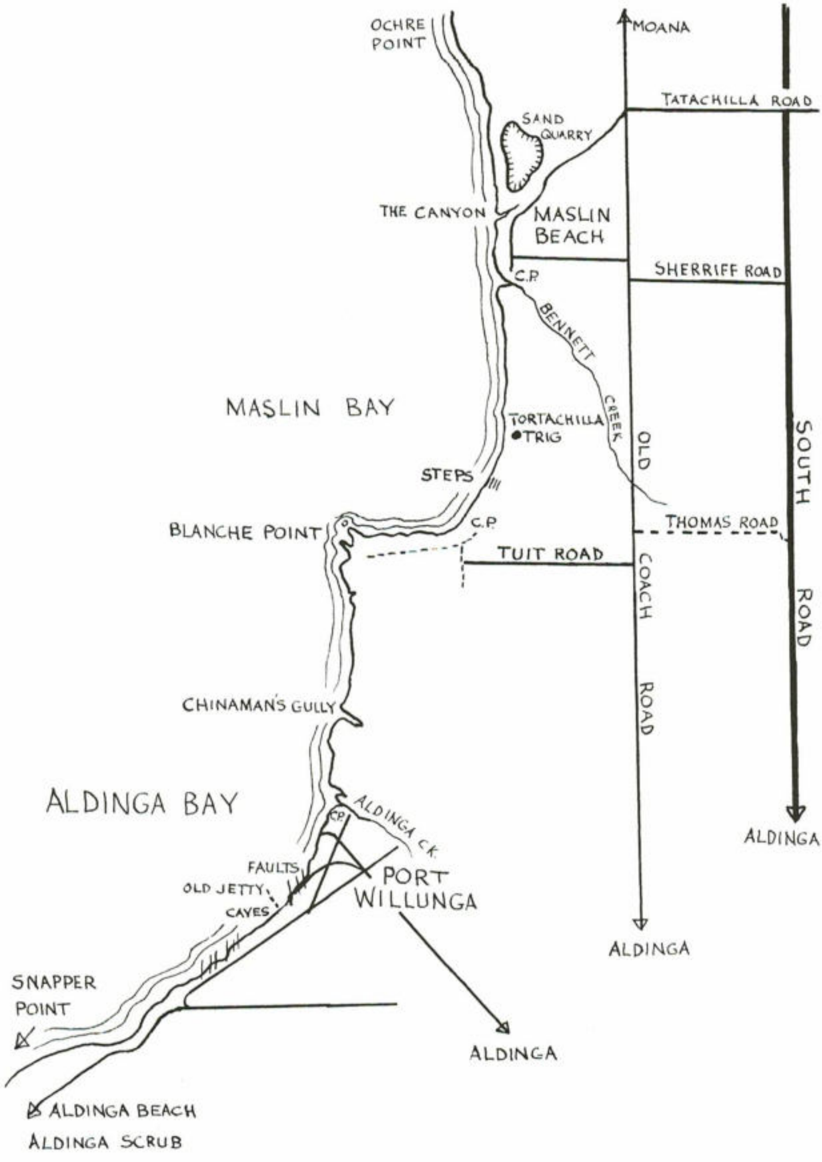
Locality 2. Port Willunga

The top of the banded marls, so prominent in Maslin Bay, reaches sea-level 150 m south of Blanche Point and about 1,400 m from the Port Willunga car park. The uppermost hard bands form a series of platforms across the beach from the most southerly bluff of Blanche Point.

From there an abrupt change in the foreshore occurs. The cliff top swings inland in an arc. Behind the beach is a line of low vegetated dunes, truncated by high storm tides. Behind the dunes, for about 500 m, a segment of the cliff has dropped several metres. As the lower part is composed of the soft marls it is easy to visualise that the cliff has been undercut, causing a slippage, probably rotational. The soft marls, though poorly exposed, continue in the cliff to about 50 m north of Aldinga Creek. The uppermost beds are dark greenish-grey and contain abundant *Spirocolpus* ('Turritella') *aldingae*. The presence of the pelecypods *Limopsis chapmani* and *Chione* sp. suggests a change of environment, probably towards shallower seas.

THE CHINAMAN GULLY FORMATION — A thin lens-like formation of colourful clays and sands, reaches a maximum thickness of 1.5 m and extends for about 700 m. The unit can be seen near the top of two small water-courses north of Chinaman Gully, but the best outcrops are in the gully itself (map 4). The brightly coloured beds form the bottom of the water-course and are freshly exposed where the water falls over them after rain. Here green, brown and yellow laminated clays are overlain by inter-bedded yellow to white and blue-grey sands and thin silt. The sand and clay beds are topped with yellow and red clays and grits. Some sandy layers show cross-bedding and the beds are believed to have been deposited in a non-marine environment. White marly nodules in the underlying *Spirocolpus* ('Turritella') *aldingae* bed suggest that there was some erosion before the Chinaman Gully Formation was laid down.

THE PORT WILLUNGA FORMATION — The Port Willunga Formation which overlies the Chinaman Gully Formation is made up of sandy polyzoal limestone with soft clayey bands, a combination which tends to form a vertical cliff face. It was deposited in the late Eocene to Middle Miocene and is divided into a lower Aldinga Member of bryozoal sandstone and limestone, and an upper Ruwarung Member of bryozoal limestone with chert. The beds run from about 260 m north of Chinaman Gully to almost 2 km south of the old jetty piles on the foreshore, reappearing as Middle Reef which is exposed at low tide north of Snapper Point. The formation represents a



Map 4. Detailed map of Maslin Beach and Port Willunga

distinct change in environment. The polyzoal remains are broken and there is evidence of cross-bedding indicating vigorous wave action.

A feature of this section of the coast is the minor faulting north of the old jetty, with a prominent fault 25 m north of the piles (Pl. 19). Most of the faulting occurred before the Hallett Cove Sandstone was laid down, although one fracture, about 450 m south of the piles, indicates that there was some movement after Pliocene sedimentation. All the faults are normal and due to tension. It has been suggested that the Pliocene reef, south of Snapper Point, is the crest of a small anticline. The faulting here in the Port Willunga Formation could be associated with an earlier movement of this same anticlinal fold.

Plate 19. Minor faulting north of the old jetty piles, Port Willunga

THE HALLETT COVE SANDSTONE — After the deposition of the Port Willunga Formation there was a time break during which erosion took place. Sedimentation resumed in the Pliocene and the Hallett Cove Sandstone was laid down unconformably on the older strata (Pl. 20). The formation is well exposed in the cutting leading down to the site of the old jetty where it is about 5.5 m thick. Here it consists of seven hard fossiliferous bands with white to yellow sands in between, although pebbles from higher bands mingle with and disguise the sands. The hard bands vary from sandy limestone to calcareous sandstone. (North of Blanche Point, in Maslin Bay, the upper hard limestone forms an intermediate platform between the beach and the top of the cliff. Further north again it becomes less fossiliferous, and at the top of the steps which once led to 'Uncle Tom's Cabin', there is a band of green to brown clay 1 m thick between the upper portion and the lower sands. North of the Trig. Point, the formation thins to sands about 3 m thick and the only fossiliferous limestone in this section is the capping on the small bluff north of the car park at Bennett Creek). South of Blanche Point the rock is highly fossiliferous, containing numerous molluscs, some

Plate 20. Hallett Cove Sandstone north of Snapper Point. Port Willunga Beds form the bottom third of section, overlain by cavernous Hallett Cove Sandstone, topped by unconsolidated Pleistocene clays

resembling present day species, despite the fact that seas were warmer in Pliocene times.

While many fossils can be seen only as casts, *Ostrea arenicola, Spondylus spondyloides, Chlamys consobrina* and *C. antiaustralis* occur in the Oyster Beds. Large slabs of these are seen at the south end of Maslin Bay. Some fossils, restricted to the Pliocene, are the large foraminifera *Marginopora vertebralis,* the gastropod *Diastoma provisi* and the pelecypod *Anodontia sphericula* (usually found only as weathered casts). The formation disappears beneath the beach just before the first path up the cliff at Snapper Point, reappearing as a reef at low tide south of the point (Pl. 21).

THE PLEISTOCENE BEDS OF MASLIN AND PORT WILLUNGA BAYS — The Pleistocene deposits which cover the underlying Tertiary rocks are all terrestrial. The oldest are clays and in this section reach their maximum thickness of 18 m between the Tortachilla Trig. Point and the steps to the south. They are best seen at the heads of these fan-shaped gullies where there are both mottled and red clays 12 m thick, overlain by greenish sandy clays weathered to picturesque beehive-shaped knobs. Further north, the hard, distinctive Pliocene Hallett Cove Sandstone disappears and the clays rest on sands, tending to merge into them so that the contact line is lost. South of Blanche Point the red clays are not visible and the deposit thins towards Chinaman Gully, but then approaches its maximum thickness again between Port Willunga and Snapper Point. The clays are of Lower Pleistocene age but to the south, where they form an alluvial deposit, deposition continued into the Middle Pleistocene.

Plate 21. Reef of Hallett Cove Sandstone at Snapper Point

RECENT DUNE SANDS — From Snapper Point the beach runs south to Sellicks Beach and the Willunga Fault Scarp. Below the cliffs at the Point, a row of vegetated aeolian dunes lies behind the beach and continues for the length of the beach, protecting the coast from tidal erosion. These probably represent the 6,000-year-old backdunes and the 2,000-year-old foredunes that characterise the eastern Gulf St. Vincent coast in the Adelaide area. South of Aldinga Beach township the sands have been carried inland for some distance and form the soil of the forest reserve (Aldinga Scrub).

South of Snapper Point the cliff profile gives way to a low-lying area behind Sellicks Beach, roughly following the inclination of the Pliocene strata. Movement along the Clarendon and Willunga Faults continued well into the Pleistocene when clays were washed down from the rising Willunga scarp. Over much of the area they have been protected by a later covering of limy loess possibly blown from the exposed floor of Gulf St. Vincent during low sea-levels in the later Pleistocene. It is assumed that the loess had been leached and the calcium carbonate redeposited as a limy marl with marble-like concretions cemented together to produce a calcrete (or kunkar). The calcrete follows the contours of the river valleys where the older clays have been eroded and is clearly a younger deposit of Upper Middle to Upper Pleistocene age. This calcrete capping has also provided a hard surface which has protected the clays on the coastal cliff tops, helping to retain their generally steep profile.

N.B. An excellent display of the stratigraphy and fossils of this area and other parts of South Australia, can be seen in the Tate Museum at The University of Adelaide's Department of Geology and Geophysics in the Mawson Laboratories, which is open to the public from 2-5 pm Mondays to Fridays.

CHAPTER 5

Sellicks Beach to Carrickalinga Head

Locality 1. Sellicks Beach

Sellicks Beach is situated at the southern extremity of the Willunga Embayment, and is bounded by the Willunga Fault scarp. (The present profile evolved during the Pleistocene and is the geomorphological expression of the Willunga Fault.)

Along the beach can be seen Cambrian, Tertiary and Quaternary sedimentary deposits, representing a time span from about 500 million years ago to the present. Turn left at the bottom of the ramp leading to the beach, and proceed south. On the left are clay and gravel cliffs, gradually increasing in height. They are unconsolidated and of recent formation. To understand the sequence of geological events in chronological order, it will be necessary to continue to the end of the beach, about three kilometres, and start with the oldest rocks in the area. These are of Cambrian age (Fig. 16) and are first encountered in the multi-coloured cliffs where the coastline veers to the south-west, and the beach is littered with fallen rocks.

The cliffs are formed of Heatherdale Shale, a mudstone, containing irregular small black nodules of calcium phosphate and calcium carbonate, usually aligned along the bedding planes. They can be seen in the large pebbles on the beach, and in the wave-cut platform beneath the fallen rocks. The Heatherdale Shale extends inland in a north-easterly direction along the north-western side of the Willunga scarp, and to the south-west along the coast to near Myponga Beach. There is an outcrop on the southern side of Myponga Beach, and at Carrickalinga Head.

Numerous crush zones (the result of fault movements), which have been infiltrated by iron oxide, occur in the cliffs at Sellicks Beach. Bedding in the shales is ill-defined, but on the wave-cut platform below, the different coloured bands clearly differentiate between the beds, which are vertical as the result of movement along the adjacent Willunga Fault. Subsequent

Map 5. Detailed Map of Sellicks Beach to Carrickalinga Head

CAMBRIAN	KANMANTOO GROUP	PETREL COVE FORMATION
		BALQUHIDDER FORMATION
		TUNKALILLA FORMATION
		TAPANAPPA FORMATION
		TALISKER CALC - SILTSTONE
		BACKSTAIRS PASSAGE FORMATION
		CARRICKALINGA HEAD FORMATION
	NORMANVILLE GROUP	HEATHERDALE SHALE
		FORK TREE LIMESTONE
		SELLICK HILL FORMATION
		WANGKONDA FORMATION
		MT. TERRIBLE FORMATION

Figure 16. Cambrian sequence—Normanville and Kanmantoo groups

flexure was responsible for the shattered condition of the rocks in the cliffs, which are easily eroded by marine action. Pebbles are buried by storm waves at the base of the cliffs, undermining them, and eventually causing collapse and retreat.

The varied colours are the result of weathering. The fresh rock is black. Some of the larger fallen blocks show hieroglyphic or honeycomb weathering. Being in the littoral zone (between high and low tides) these rocks are subject to constant wetting and drying, causing the oxidation of iron compounds and subsequent case-hardening of the exterior by the precipitation of minerals. Penetration of this layer by salt and other minerals from seawater allows the softer rock beneath to be eroded, resulting in the etching of fascinating surface patterns (Pl. 22). Among the fallen rocks will be seen some mottled grey/buff coloured limestones of the Sellick Hill Formation. These limestones do not crop out in this area, so they must have been transported by longshore drift from Myponga Beach, where they are exposed (Pl. 23).

After traversing a hundred metres of fallen rocks on the wave-cut platform, the cliffs show a change from the blocky pink and purple mudstone

Plate 22. Weathering patterns on fallen rocks of Heatherdale Shale

to finely bedded, yellow ochre-coloured bryozoal limestone. (Bryozoa are small colonial organisms, somewhat resembling coral; in these beds however, the fossil remains are fragmental). It is here that the Cambrian shales are in contact with Tertiary limestones of the Port Willunga Formation (previously described from the type-section at Port Willunga.) At Sellicks Beach however, the upper beds of the formation occur and are several million years younger (early Miocene).

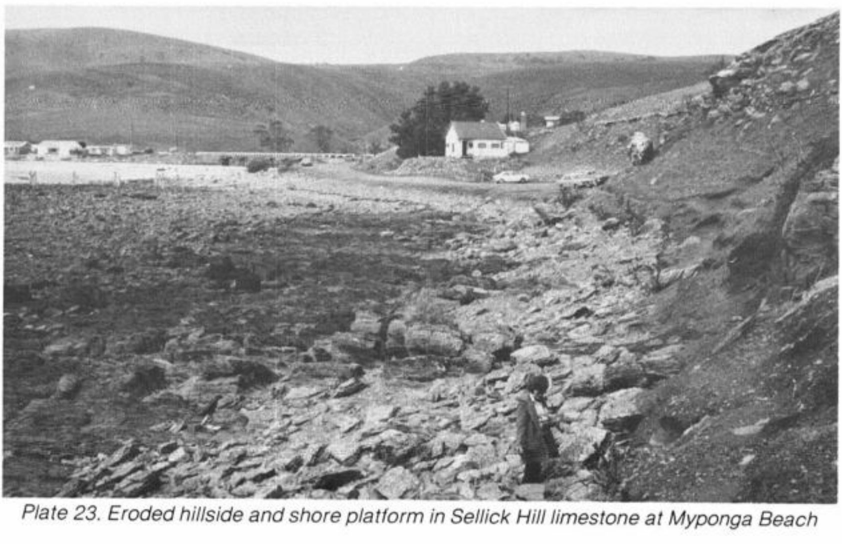


Plate 23. Eroded hillside and shore platform in Sellick Hill limestone at Myponga Beach

The contact between the Cambrian and the Tertiary shows no evidence of faulting but the Cambrian rocks are very crumbly and irregular, evidence that weathering had taken place at the surface before the Tertiary limestones were deposited (Pl. 24). The limestone fills pockets in the eroded

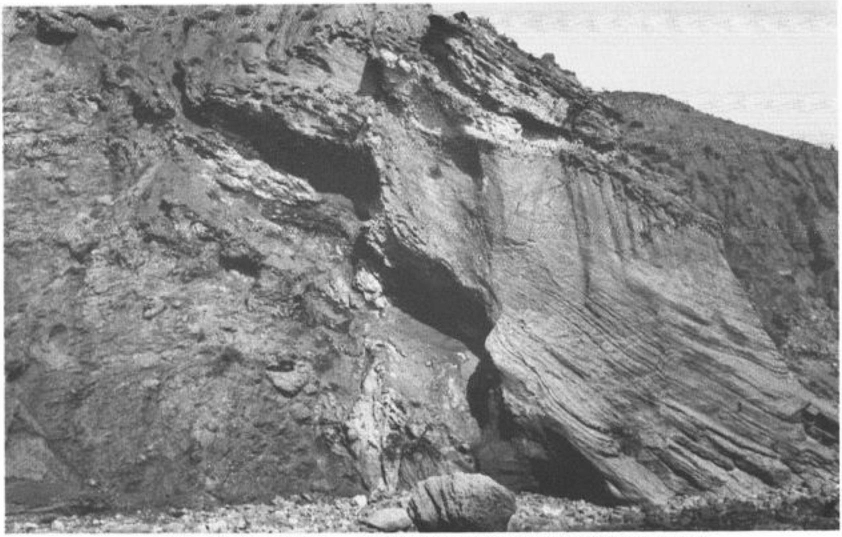


Plate 24. Cambrian—Tertiary contact, Sellicks Beach south

surface of the shales. The Cambrian shales are parallel to the erosion surface and thus were horizontal when the limestone was deposited. As both sets of rocks are now tilted 50 degrees to the north-west, it can be inferred that uplift occurred in post-Miocene time. Note how the limestones have been dragged up by the vertical movement of the Willunga Fault.

Weathering prior to deposition indicates an unconformity, representing a break in sedimentation which in this case lasted about 475 million years. The type of unconformity shown here with no angular discordance between the two sets of beds is known as a disconformity. The Tertiary beds have been levelled to a serrated wave-cut platform parallel to the cliff face, with free standing stacks which have remained resistant to erosion (Pl. 25).

A few metres south-west of the contact, well defined limestone beds have been up-turned almost vertically. Overlying them with angular unconformity is a metre of horizontally bedded, partially consolidated conglomerate. Among the boulders of conglomerate is a variety of fossil mollusca, similar to some species found on the beach today. Overlying the conglomerate are several metres of fine beach sand. The boulders, sand and shells are indicative of an ancient beach, which has been raised to a platform about three metres higher than the present beach (Pl. 26). In geologically recent times, the whole sequence has been covered by the clays and gravels and unsorted slope wash which form the cliffs above. A short distance further

Plate 25. Serrated platform in Tertiary limestone, Sellicks Beach south

along the beach, caves formed by marine erosion occur in areas of weakness, i.e. in joints and between strata. The collapse of cave roofs has produced arches, and where an arch has collapsed a stack remains. The Tertiary limestone continues in the cliffs and serrated wave-cut platform to the west-south-west, until contact is again made with the Cambrian shales.

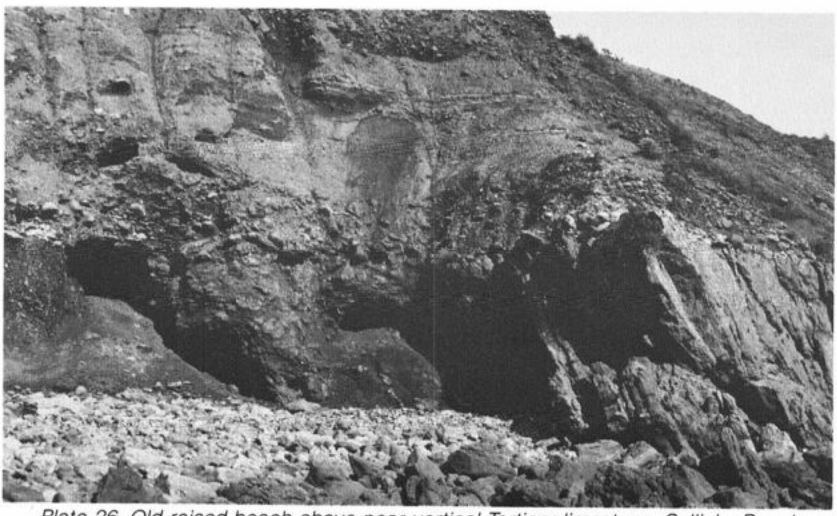


Plate 26. Old raised beach above near vertical Tertiary limestone, Sellicks Beach

Return northwards to the sand beach and the slight bend in the coastline where on the right is a short, steep-sided gully (Pl. 27). At the entrance lies a storm ridge of flattened water worn rocks, banked high at the back of the beach and sorted according to shape by wave action. The large flat rocks are easily swept to the top, and due to their shape, do not roll down. The rounded ones remain underneath. For a short distance, the gully cuts through Quaternary clays and gravel—the fanglomerates—which form the high cliffs to the north. A few metres along the creek bed, a small outcrop of fossiliferous limestone can be seen and it is also exposed in the north bank, a short distance beyond, dipping at about 20 degrees to the north-west. In it are fragments of reddish-brown ironstone, believed to have been washed down from an older lateritised surface of the Fleurieu Peninsula.

Plate 27. Cliff showing bedded Cambrian strata with Tertiary beds in foreground, behind storm ridge

High to the right, but better seen from the beach, Cambrian shales are in contact with the Pleistocene fanglomerates. The sheer wall of well-bedded Heatherdale Shale at the end of the gully has been tilted over the limestone, another indication that uplift was post-Miocene. In the shale banks near the terminal wall of the gully, there is an abundance of black phosphate nodules on each side of the watercourse. They are aligned along the bedding planes of the shale, emphasizing the dip.

Continuing north along the beach the cliffs are formed of fanglomerates which are unconsolidated and have been eroded into weird shapes (Pl. 28). After the uplift of the Willunga scarp, which was originally much higher than it is today, climatic conditions during the last Ice Age, which caused a lowering of sea-level, favoured rapid erosion. The colder climate, with ice and frost shattering rocks on the adjacent ranges, produced vast quantities of rubble. Storms and heavy rains washed it down with mud and clay to form

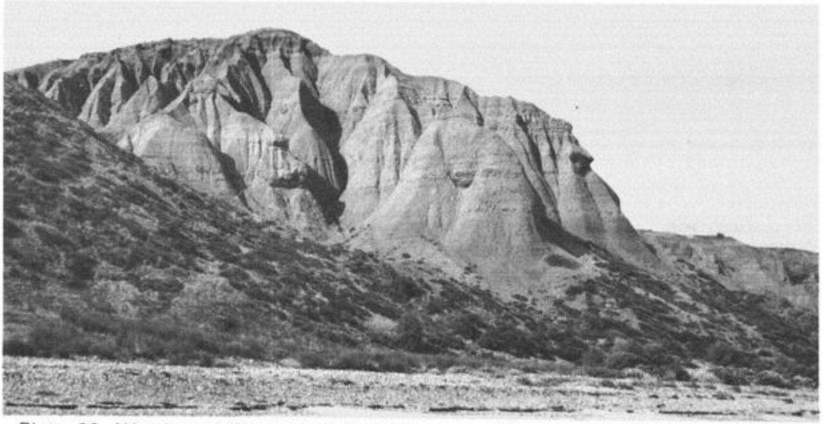


Plate 28. Weathered Quaternary fanglomerate cliffs along Sellicks Beach to the south

the alluvial fans and fanglomerates. Radiocarbon dating places the last activity at 30,000-40,000 years ago. Vegetation subsequently covered and prevented much further spreading of fans, which were cut through by streams with the formation of deep gullies. Coastal erosion has subsequently cut back the fanglomerates, forming high cliffs.

The fanglomerates are the source of the pebbles which litter the beach, especially in winter, when heavy seas and outgoing high tides drag them across the littoral zone. The incoming tide flings them against the base of the cliffs, so initiating the notch and cave formation (Pl. 29).

Plate 29. Notch and cave weathering in horizontal limestone, Sellicks Beach

Underlying the fanglomerates, low limestone cliffs, more resistant to erosion, form a slight bend in the beach, and continue seaward on the wave-cut platform, which is covered with sand at the base of the cliffs but visible at low tide. A complete progression of erosional forms can be seen, from notch and cave to arch and stack (Fig. 17). The limestone beds are horizontal, both in the cliffs and on the smoother shore platform. Here, away from the Willunga Fault zone, the Tertiary beds are not flexed, but have remained horizontal since the time of deposition.

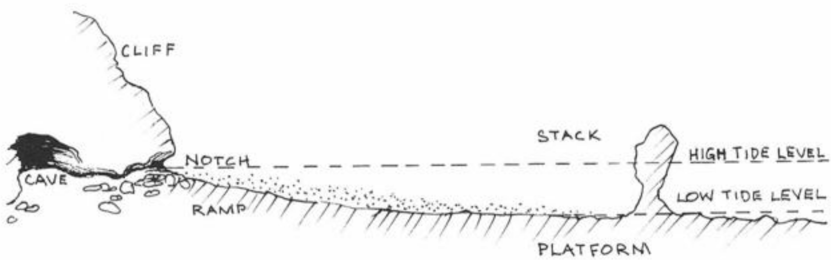


Figure 17. Coastal erosion forms

Locality 2. Myponga Beach

Leaving Sellicks Beach, the South Road is rejoined at the Victory Hotel, Sellick Hill, where a right turn leads to Myponga. Soon after the road turns inland, a good cross-section of early Cambrian rocks has been exposed by excavating the hillside to accommodate the new road. A Highways Department sign draws attention to the fact that here is a geological section of significance. It comprises a thick sequence of well-bedded sedimentary rocks, dipping steeply to the north-west. These rocks are known as the Normanville Group. The road passes progressively older beds within the group from the Carrickalinga Head Formation downwards (Fig. 16). The complete section in the Normanville Group can be seen on the old Sellick Hill Road, above the Victory Hotel, where the overturned contact with Precambrian siltstone and quartzite is exposed.

Before reaching Myponga township take the first road on the right to Myponga Reservoir. Descending to cross the spillway, the road cuts through Precambrian slates and joins the gravel road to Myponga Beach. (An alternative route is to by-pass the reservoir and take the road to Myponga Beach about 5 km south of Myponga town.)

After a steep descent to Myponga Beach, with magnificent views of the Willunga embayment to the north, turn immediately left, without crossing the bridge over the Myponga River outlet. The road ends in a small car park from which a narrow track leads to a rock platform above sea-level. On the left, above the track and beside it, massive beds of limestone dip 50-55 degrees to the south-east. This is the Sellick Hill Formation, composed of mottled and banded fine-grained limestone and calcareous siltstone (also present in the Sellick Hill Road cutting). The banding in these limestones is believed to be secondary, formed just prior to, or during, lithification, rather than being sedimentary in origin. A distinctive feature of these limestones is differential weathering (Pl. 30), where the softer, less resistant, more soluble grey limestone is eroded, leaving ridges of siltstone.

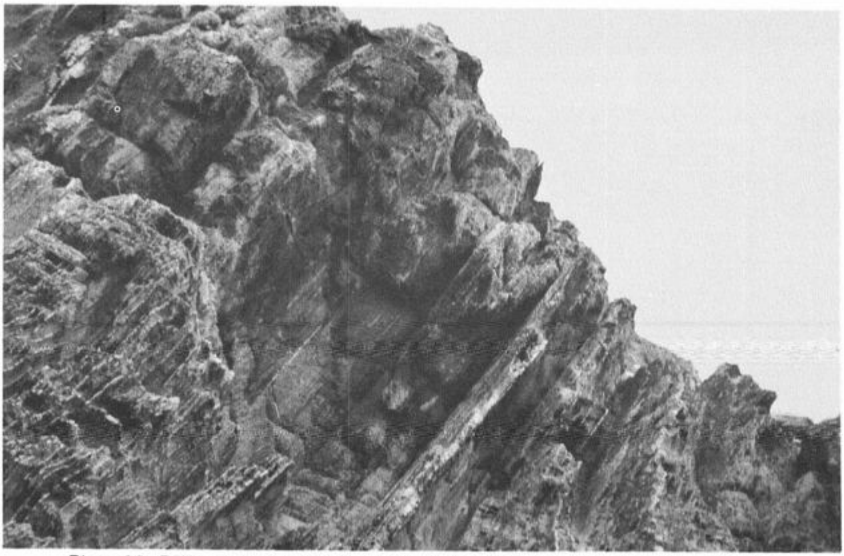


Plate 30. Differential weathering in Sellick Hill Formation, Myponga Beach

To the right of the track, weathering and marine erosion have reduced the limestones to a serrated rocky platform, the dip of which is parallel to the cliffs. Interbedded with the limestone are ochre-coloured non-calcareous siltstones. The platform continues and becomes higher at the seaward end of the track striking in a north-easterly direction.

Narrow bands of intraformational conglomerate with nodular pebbles of Lower Cambrian age are prominent. They were formed by the break-up of limestone, already lithified, and its incorporation in successive sedimentary deposits. At the same time, the shells of hyolithids were collected by the ocean currents and deposited in thin bands within the conglomerate. The fossilised remains of these animals, now resembling small black elongated cones somewhat like thick pencil leads, can be seen in some places between the bands of conglomerate although they are a little difficult to find without close scrutiny of the beds. Sometimes, they are aligned with the direction of the current which deposited them, otherwise they are jumbled at random. The largest may be up to two centimetres in length. Some authorities believe *Hyolithes* was a mollusc, others have expressed the opinion that it may be a worm tube. Its zoological affinities remain unknown. It consisted of a tube, capped with a lid which was hinged at the rear of the shell, and the animal was able to extend its soft parts through this opening. *Hyolithes* is very common in early Palaeozoic rocks.

Around the point, light coloured, coarse sandstone is interbedded with grey, calcareous sandstone. On the large, flat, tilted and weathered surfaces of the latter, worm burrows and foraging tracks can be seen. They can be easily distinguished from the pitted weathering of the rocks. The fossil burrows stand out in relief, having been infilled in ancient times with finer, silty material which is more resistant to weathering than the host rock. Some burrows may show meandering or 'feather stitch' patterns. All rock types seen in this area are part of the Sellick Hill Formation.

Beyond the beach, to the east, a walking track extends along the base of the hillside. The track passes over a small exposure of older, very hard quartzite before skirting a small pebbly beach. It then rises on to Cambrian shales which can be traced north-eastwards along the coast back to Sellicks Beach. At the top of the path, both 'onion' and 'cannon ball' weathering has produced some remarkable shapes. The return to the main road may be made via the reservoir or Myponga. Alternatively if time permits, do neither. Instead, at the hilltop junction, turn right and proceed six kilometres to Carrickalinga Head.

Locality 3. Carrickalinga Head

As the road descends on the approach to Carrickalinga, there is a small disused quarry on the left. In it the now familiar mottled limestones of the Sellick Hill Formation show characteristic differential weathering. This quarry is the site of the discovery of the first Cambrian fossils in South Australia. *Archaeocyatha* were found here by Professor Edgeworth David and Walter Howchin in 1897 and provided the first proof of Cambrian rocks in the Mount Lofty Ranges. *Archaeocyatha* have a worldwide distribution in Lower-Middle Cambrian rocks and are the predominant fossil in the South Australian Cambrian sequence. The name means 'ancient cup' and they have the appearance of two concentric cones separated by a type of radial structure. They are difficult to place in the animal kingdom and have been given their own distinct phylum. They had a relatively brief evolutionary history of 30 to 40 million years from the beginning of the Cambrian to the end of the Middle Cambrian.

If a northerly (right hand) direction is maintained, the esplanade eventually ends in a car park. The track which skirts the new houses above the beach can be followed for about 100 metres. It is best to do this section at low tide, or at least avoid high tide, as it becomes difficult (though not impossible) to reach the small, sheltered, sandy cove. Alternatively walk along the beach; the tide will dictate the amount of gentle rock scrambling necessary.

The black, deeply weathered limestone at the northern boundary of the cove shows bedding planes dipping to the south-east. This is the fossiliferous Fork Tree Limestone which overlies the Sellick Hill Formation. It can also be seen in the road cutting near Sellick Hill where the rock is pale grey in colour and contains the same Cambrian index fossil *Archaeocyatha*. It is considered that the presence of fossils and the paler colour are due to deposition in shallower water with better circulation. This limestone is being quarried at Sellick Hill for road metal. At Carrickalinga Head, the darker coloration is possibly due to carbon forming in a deeper, stagnant reducing environment.

Overlying the Fork Tree Limestone, and forming a backdrop to the little bay, is a thick deposit of Heatherdale Shale showing fine ribbon bedding and dipping to the south-west (Pl. 31). The pink colouring is due to weathering; to the south it is black. Some of the shales and siltstones are calcareous and some contain small black nodules of phosphate, strung out in roughly parallel rows along the bedding. An interesting feature of the shales here is the formation of 'cannonballs'. They can be seen protruding from the rock face at the south-eastern end of the bay from high in the cliff to quite low,

Plate 31. Heatherdale Shale overlying Forktree Limestone, near Carrickalinga Head

ranging from golf ball to cannonball size. They have been described as intraformational nodules.

The southern end of the cove is bounded by greywacke of the Carrickalinga Head Formation. The greywacke at this location is the unaltered equivalent of part of the metamorphosed Kanmantoo schists which occur widely along the south coast of Fleurieu Peninsula as far as Cape Jervis, and in the eastern Mount Lofty Ranges. This rock unit can be readily distinguished from the finely-bedded Heatherdale Shale, which it overlies, by the massive beds and blocky jointing.

The greywacke sediments were swept rapidly into the subsiding Kanmantoo Trough, which developed on the eastern side of the Adelaide geosyncline prior to the tectonism which raised the Mount Lofty Ranges. They are therefore composed of an unsorted mixture of detrital rocks and minerals including quartzite, slate, limestone, shale, amphibole, chlorite, sericite and plagioclase, which are irregular in shape and size, and cemented together with clay and fine-grained quartz. The formation has the appearance of an impure feldspathic sandstone, dark grey to green in colour. There must have been quieter periods during the chaotic deposition of the greywacke, as is evidenced by interbeds of shale (Pl. 32).

Returning south along the beach (tide permitting) through the fallen greywacke blocks, note on the left, just past the southern end of the cove, the absence of a shale bed which has been eroded out of the greywacke sequence leaving a shelf about one metre deep. On the beach below the car park, remnants of an anticline and syncline can be seen in the wave-cut platform. Honeycomb or hieroglyphic weathering, similar to that seen at Sellicks Beach, has been produced by the alternate wetting and drying of the rocks as the sea advances and retreats.

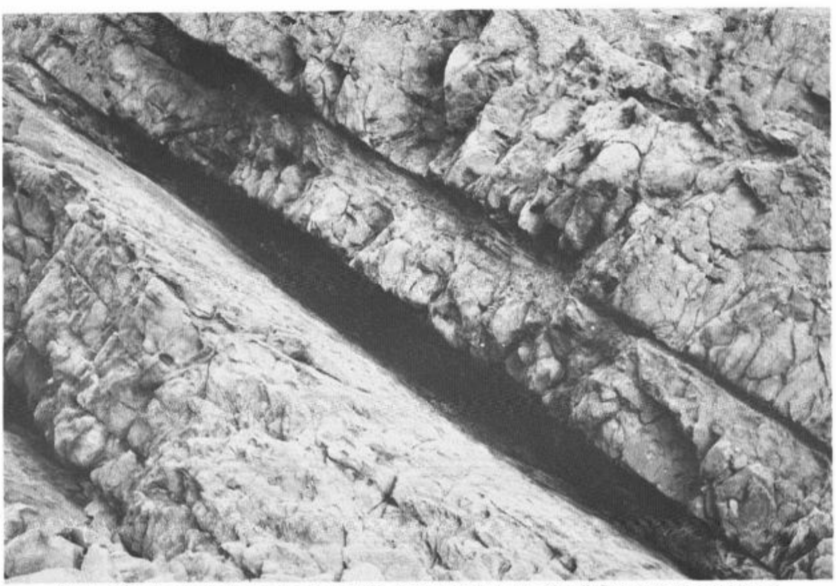
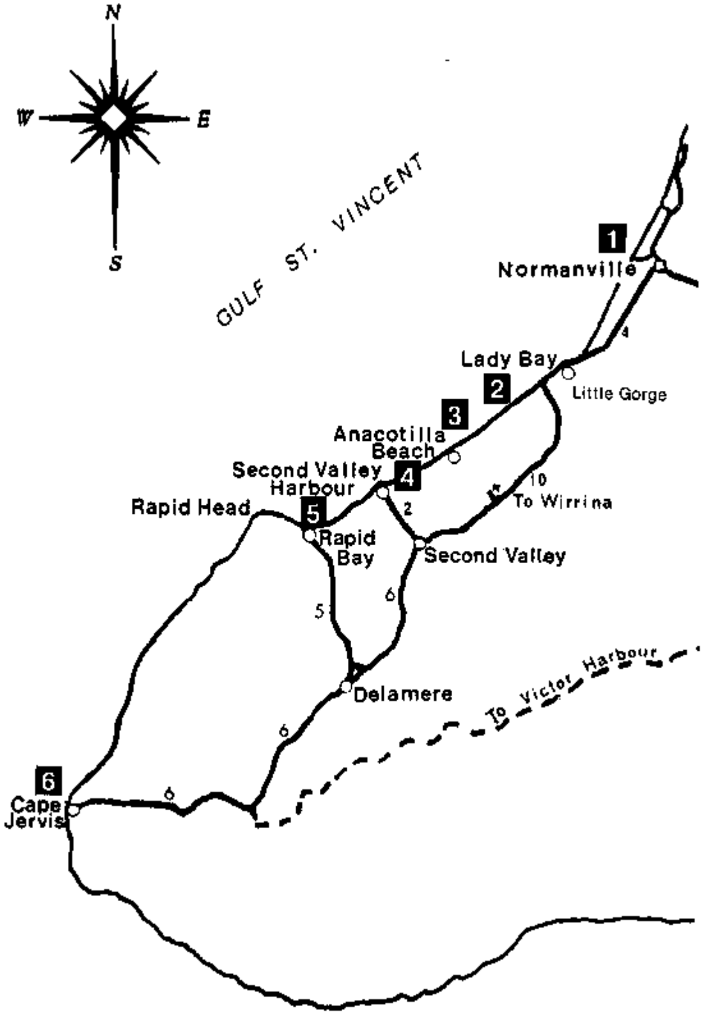
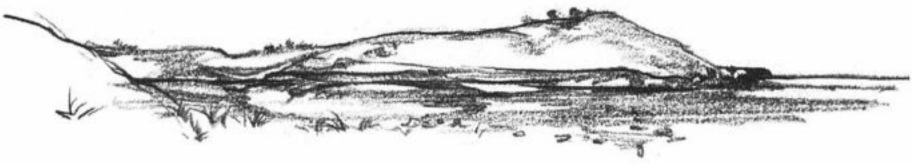


Plate 32. Eroded shale beds within greywacke, south of Carrickalinga Head



Locality Map 6 (Chapters 6 and 7), Normanville to Cape Jervis



CHAPTER 6

NORMANVILLE TO ANACOTILLA BEACH

The rocks seen in the coastal exposures along this part of Fleurieu Peninsula are representative of some of the oldest known in South Australia. They are part of the crystalline basement which forms the core of the Mount Lofty Ranges, and have been so altered by heat and pressure due to burial, and folding and fracturing caused by earth movements, that it is generally impossible to determine their original composition. The schists and gneisses at Normanville and Little Gorge belong to this group of rocks (Pl. 33).

A major unconformity exists between the crystalline basement and the next younger group of rocks (Adelaidean), which crop out at Little Gorge, Anacotilla Beach, Second Valley and Rapid Bay (see Fig. 21). This sedimentary sequence comprises conglomerate (rounded, waterworn fragments cemented together by finer-grained mineral particles), sandstone (rocks formed mostly of sand-sized silica grains), limestone and dolomite (carbonate rocks) and tillite (rocks formed during periods of glaciation, often containing quite large 'erratic' pebbles). The Adelaidean sequence of rocks was uplifted, folded and partly metamorphosed by the strongly compressive earth movements of the Delamerian Orogeny, which continued for many millions of years, starting about 500 million years ago, and which played a major part in determining the structure of the Mount Lofty Ranges. For a discussion of the subdivision of the Adelaidean see Chapter 1.

The elevated mountain chain built by this orogeny was slowly reduced by erosion for about 200 million years, but the landscape was still rugged when the glaciers of Permian times (about 270 million years ago) ground their way down the valleys. Evidence of this glacial episode can be found in the valleys of many of the rivers and creeks in this area. The main watercourses, the Carrickalinga, Yankalilla, Bungala, Anacotilla and Congeratinga Rivers are thought to flow along ancient glacial valleys where they are rapidly eroding the soft Permian till.

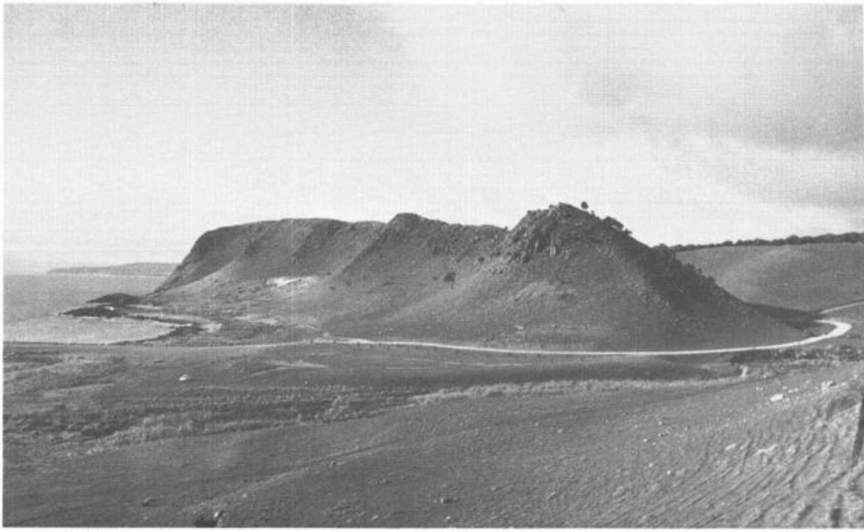


Plate 33. Looking north, across the mouth of the Congeratinga River to the basement inlier

Much younger than the rocks mentioned above are the unconsolidated alluvial sands and muds deposited by the rivers, and the sand dunes which line the coast at Normanville. These have formed only during the last few thousand years, and are part of very recent geological history.

Locality 1. Normanville

Travelling south, the Normanville area can be approached from two directions. Either of the roads which skirt the Myponga Reservoir can be taken, the more westerly (a gravel road) traverses Carrickalinga Hill, while the eastern road (bitumen) passes through Yankalilla. If the Carrickalinga road is taken, notice the well-developed river terraces of Carrickalinga Creek; and further south, those of the Bungala and Yankalilla Rivers. These flat areas may indicate a higher stand of the sea, and were formed several thousand years ago. They are composed of red alluvium and sand carried by rivers which are part of the drainage system of the southern Mount Lofty Ranges. The physiography of the river-terrace and sand dune system can be clearly seen from the car park at the old Normanville jetty.

The Normanville dunes are one of the last remnants of the local dune system which once extended southwards from Outer Harbour (see Chapter 2). They not only constitute an area of natural beauty but are ecologically significant as they support an assemblage of plants typical of the old dune system, including several species of trees and large shrubs which are confined to isolated pockets of the dunes. They are also of particular interest as a site where Aboriginal relics occur.

The long belt of sand dunes (about 4 km), between the road and the beach are fixed dunes, well stabilised by vegetation. The quartz-rich sands have been mined for glass-making in the northern section. This activity may cause future re-mobilisation of the dunes, with consequent problems of beach erosion. A dune system forms naturally on an exposed coast and protects the sandy beach and the land behind from coastal erosion. Even along the comparatively calm Gulf coasts near Adelaide, some local councils are compelled to spend large sums of money to maintain the foreshore in an attempt to minimise damage to urban development, once natural dune systems have been disturbed (see also Chapter 2).

Locality 2. Little Gorge

After leaving Normanville, travel south along the Rapid Bay—Cape Jervis Road (Willis Drive), across the Bungala River towards Little Gorge, noting the change of rock type from the Carrickalinga area where the rocks are predominantly Cambrian sandstone and shale underlain by limestone (see previous chapter), to the ancient Precambrian gneisses of the crystalline basement. Other outcrops of the crystalline basement occur at Houghton and between Crafers and Aldgate. These areas of older rock surrounded by younger strata, often exposed as the result of erosion of the crest of an anticline, are known as 'inliers' and are usually more or less circular or elliptical in shape.

Copper was found in the hills 2.7 km south of Normanville, and traces of mining activity can be seen in the hillside to the south-east of the road (Gorge Copper Mine, c. 1863). Nodules of copper pyrites were found, but the mine was not economic and was never developed. It is situated on private land and therefore cannot be visited without obtaining prior permission.

The Yankalilla River is crossed 3 km south of Normanville and from there the road crosses scree slopes below steep cliffs which were probably coastal cliffs during the higher sea-level mentioned above. At that time the sea washed right up to their base and an erosional surface developed. Large amounts of talus have since been deposited, which is evidence of the rapid erosion which is taking place at the present time. Boulders of Precambrian crystalline basement rocks, which form the scree, can be examined by the roadside. These are gneisses containing pink feldspar, milky quartz and black biotite, with epidote (pistachio green) and dark, greenish-black hornblende. Some boulders show veins of quartz and of pegmatite (pegmatite is a coarse-grained igneous rock containing very large crystals of quartz and feldspar), and thin mica-rich layers (schist). These rocks frequently have a banded appearance which is typical of gneiss. Excavation of the scree slopes is carried out at some points, probably for road metal.

Approximately 5.7 km from Normanville, the Little Gorge car park is reached and the road turns abruptly inland (Fig. 21). The car park is actually built on creek alluvium deposited on the 'bench' formed during a higher sea-level (about 10 metres above present sea-level at this location).

Walking south along the beach to the first outcrop of rocks (about 200 metres), note that the white sand contains some areas of blackish grains. These come from the 'heavy' minerals titaniferous haematite and magnetite which occur in the basement gneiss and are released by the weathering and erosion of the rocks which form the steep cliffs behind the beach.

Here, the Adelaidean rocks can be seen for the first time in this section. The oldest unit is a basal conglomerate, overlain by coarse sandstone and dolomite. These rocks were laid down in the Adelaide Geosyncline and later folded by compressive earth movements which probably began in late Precambrian times and continued through the early Cambrian, occurring as pulses of activity and culminating in the Delamerian Orogeny which commenced about 500 million years ago.

In this part of southern Fleurieu Peninsula the folds formed during these earth movements were so strongly deformed that they became 'overturned' (Fig. 20). Continued pressure from the east caused this large overturned anticline in the Normanville-Second Valley area to develop several thrust faults which are thought to be present in the vicinity of Anacotilla Beach to the south.

At the base of the cliffs, notice the rocky outcrops of banded gneiss composed mainly of milky quartz and pink feldspar with very coarse-grained developments of muscovite, some black titaniferous haematite (slightly magnetic) and black magnetite (strongly magnetic). The combination of metamorphism and shearing in these basement rocks has resulted in the 'oyster-shell' appearance of some outcrops where micaceous minerals have wrapped around aggregates of quartz.

A few metres seaward of these metamorphic rocks is an outcrop of the basal conglomerate of the Adelaidean. This is a sedimentary rock which, at other localities in the Adelaide region, is seen to overlie the gneiss unconformably. The sedimentary beds dip towards the east and they contain prominent black layers of ilmenite which has come from the basement rocks and has outlined and highlighted such features as cross-bedding within the rock. The sedimentary rocks are younger than the gneiss but because they are part of the lower limb of the overturned anticline they lie below it. This lower limb is greatly 'thinned' due to the intense pressures which deformed the beds at the time the fold was formed. It can be proved that these sedimentary beds are 'upside-down' by looking for the inversion of the cross-bedding and the graded beds (Figs. 18, 19).

The basal conglomerate contains pebbles which were originally spheroidal. They have been flattened and 'stretched' so that they are greatly elongated and lie with their long axes parallel to the dip of the beds, i.e. to the east. Elevated temperatures and pressures caused the whole sequence of rocks to be metamorphosed and folded, and a schistosity or cleavage to develop in them. This can be recognised as planes along which the rocks will split and is parallel to the flat ended and elongated pebbles. At low tide a greyish dolomitic rock can be seen seawards of this basal conglomerate, i.e. stratigraphically above it.

Returning to the car park, drive into Little Gorge which cuts through the cliffs formed by the basement rocks. A small quarry can be seen on the south-western side of the road and the basement gneiss can be examined here in greater detail.

Locality 3. Anacotilla Beach

Three kilometres south of Little Gorge there is a turn-off to the Wirrina Holiday Resort. Upon reaching the hotel-motel, veer to the right and 200 metres further on there is a gate. The public may proceed through this gate which, however, must be shut as there are sheep grazing in the area. The

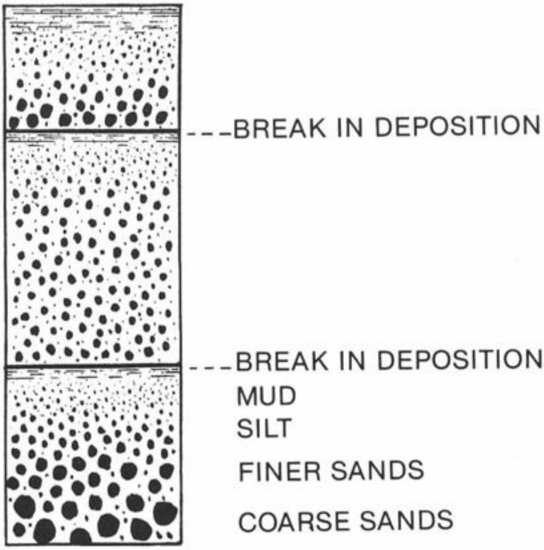


Figure 18. Graded bedding

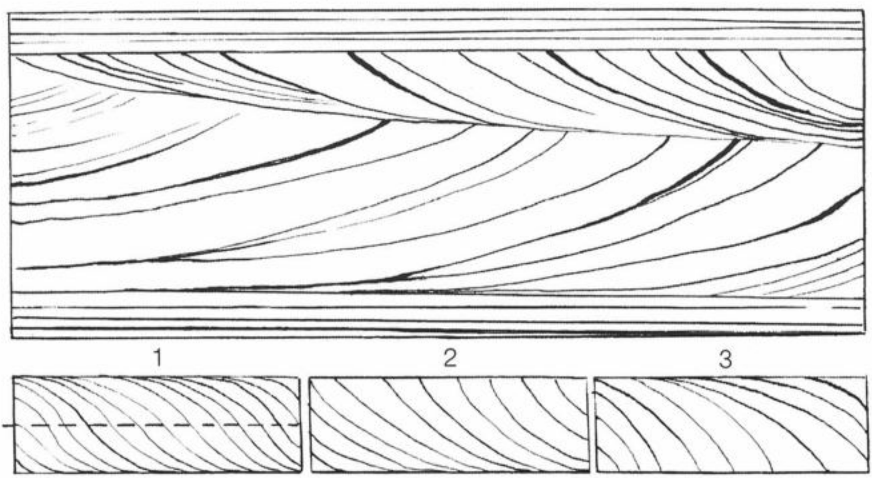
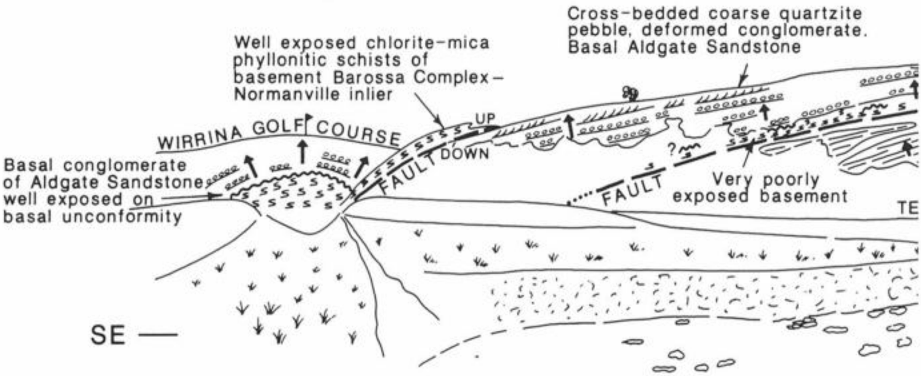


Figure 19. Use of cross bedding in determining whether a bed is the right way up or upside down.

1. *Complete cross-bedding*
2. *After the top has been removed by erosion*
   Right way up
3. *Upside down*

SKETCH SECTION OF THE NORTHERLY FACING CLIFFS
SOUTH OF THE CONGERATINGA R



road crosses the Anacotilla River several times and finally reaches Anacotilla Beach after about 1½ km. There is a large parking area near the boat ramp.

Approximately 200 m from the sea is the confluence of the Congeratinga and Anacotilla Rivers. Note the river terraces which form the extensive flat bordering the river, below the cliffs. These terraces probably formed at the same time as those south of Normanville and are very steep with well developed scree slopes.

Walk across the mouth of the river to the area adjacent to the south-western sea-cliff (Pl. 34). The rocks here are blackish-grey phyllites formed from the metamorphism of mudstone, and show well defined bedding, 'picked out' by thin pyritic, gritty layers. These layers are resistant to weathering and are slightly raised on the surface of the rock. In this small

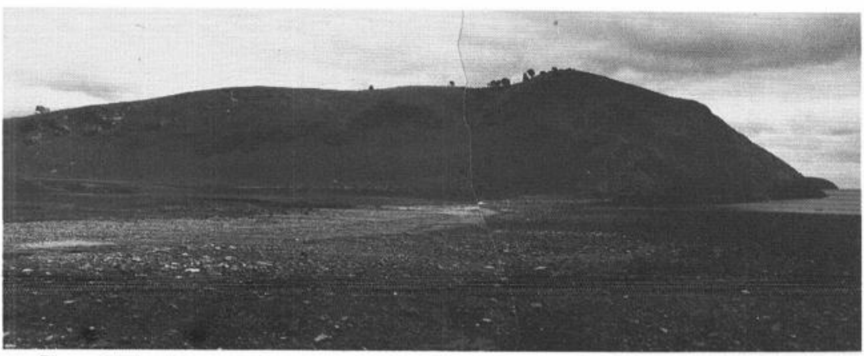


Plate 34. Looking south across the mouth of the Congeratinga River, Anacotilla Beach (see Fig. 20)

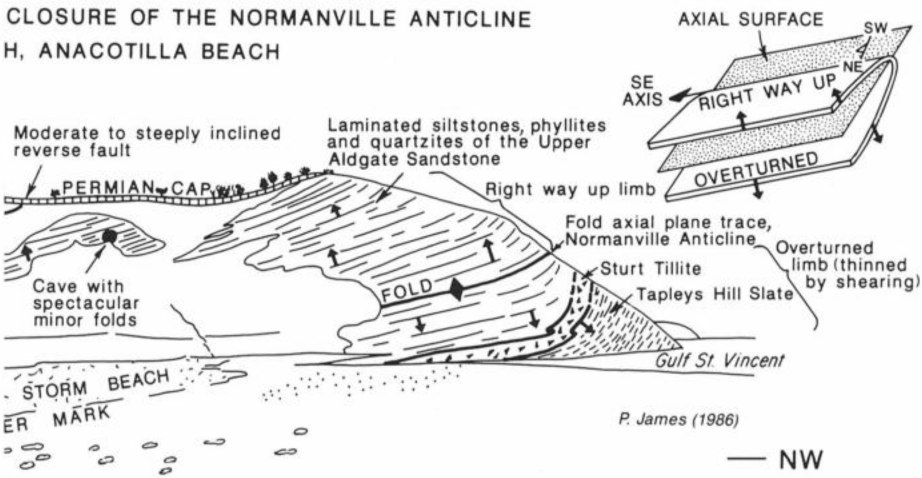


Figure 20. Section—South bank of the Congeratinga River, Anacotilla Beach

area the bedding is quite variable, often steeply dipping, and wavy or undulating. The dark grey colour of the rocks may be due to the presence of carbon, and the tiny pyrite grains shine in the raised laminations.

Near the base of the cliff there are Precambrian glacial rocks (Sturt Tillite). The erratic pebbles and rock fragments of all sizes, contained in this dark grey tillite, are deformed or elongated in approximately a south-easterly direction. They are 'stretched' in a similar fashion to the pebbles in the basal conglomerate at Little Gorge Beach. The tillite is thought to be approximately 750 million years old, and to have been formed on the sea-floor from material dropped by melting icebergs which floated out to sea from an ice-covered continent. The erratic rock fragments and pebbles consist of rock types quite different from the matrix in which they are now found. They are mainly quartzite and granitic gneiss and come from the bedrock over which the glacier moved.

It is interesting to consider the age differences between this very old tillite (consolidated till) and the much younger (270 million years) soft Permian till (unconsolidated), which occurs at Hallett Cove and underlies the Tertiary sediments of the Myponga Basin, Inman and Back Valleys. Remnants of this till can be seen on the wave-cut platform or, better still, further inland in the valley of the Congeratinga River as well as in many other river and creek valleys south of this area. The Sturtian and Permian glaciations were both major events in the history of the earth.

Further to the south the contact between the Sturt Tillite and the Tapley Hill Slate can be seen on the shore platform. Above it in the cliff section which faces the sea, the nose of a small fold can be observed about 10 metres up.

The outer limbs are formed of the dark-grey Tapley Hill Formation while a lighter member of the Sturt Tillite forms the core. The trace of the axial

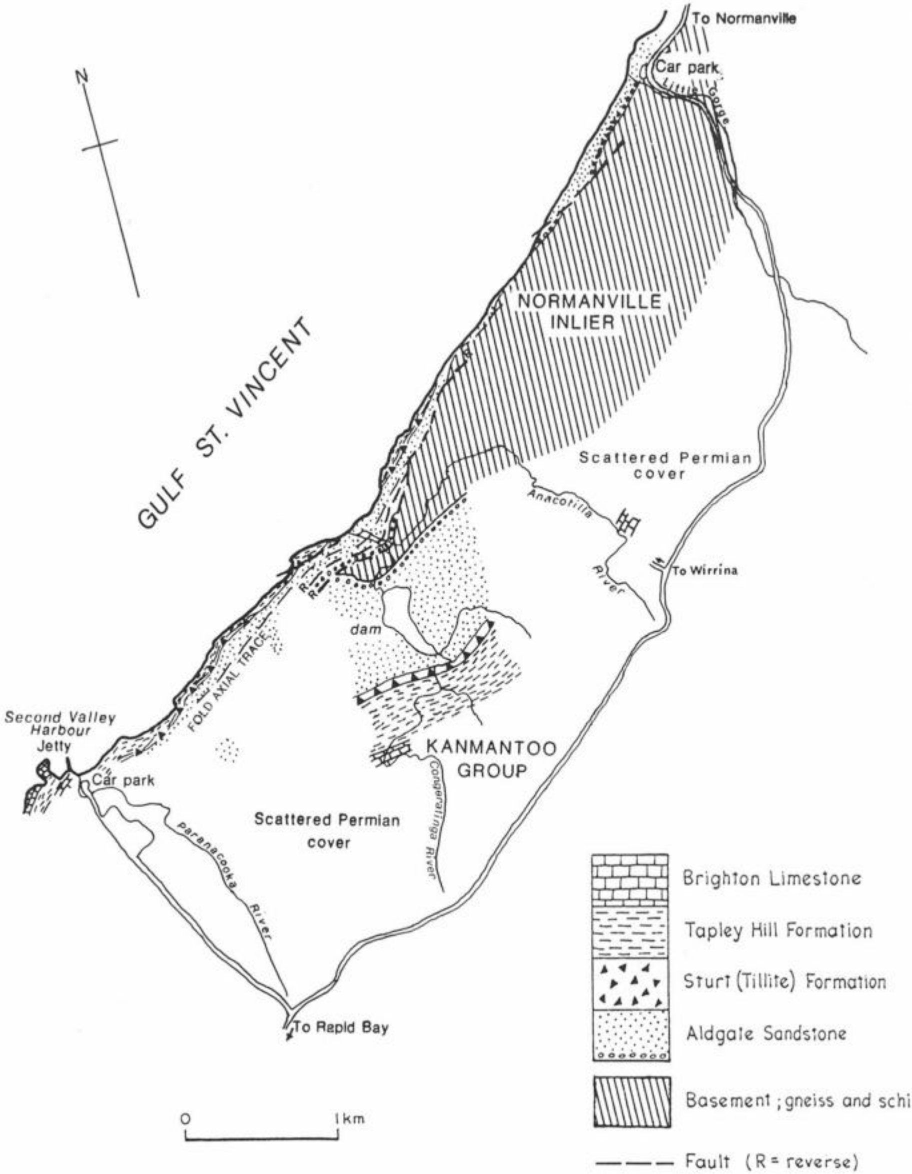


Figure 21. Geological map of the area between Little Gorge and Second Valley (Modified from Anderson, 1975)

surface plunges away to the south-east at about 25 degrees. This fold is part of the lower limb of the much larger fold described above and the rocks here are overturned as they were on Little Gorge Beach.

Now walk back towards the mouth of the river, and along the rock exposures high on the southern bank. The 'nose' of the anticline is actually crossed here. A small cleft in this rocky outcrop shows good exposures of smaller folds, which are well defined by thin layers of rock of different colours. These are caused by variations in the sediments which were laid down sub-horizontally when the rock was forming. The beds are oriented 'right way up', as the upper limb of the overturned anticline has now been reached. Further to the south-east is a small exposure of basement schist (the 'oyster-shell' rock described on Little Gorge Beach), and then an outcrop of basal conglomerate with many stretched pebbles. This bed contains black heavy-mineral bands (probably titaniferous haematite), with well defined cross-bedding, showing that it is oriented 'right way up', also. The appearance of these two older beds means that there is probably a steep reverse fault between the greyish and buff-coloured slates and the basement schist, as the two formations are obviously out of sequence; but no trace of the fault can actually be seen. It is believed that the basement and the basal conglomerate have been 'thrust up' over the tillite during deformation.

Continuing in a south-easterly direction another outcrop of basement schist is reached on the ridge which runs down towards the Congeratinga River just below the dam. This probably indicates the presence of another reverse fault.

Cross the river and walk back towards the beach. In the north-east bank another small exposure reveals the contact between the basement and the overlying conglomerate. Here, the rocks are 'right way up' and the contact is a good example of an angular unconformity.

From the parking area, a short walk can be taken in a north-easterly direction along the beach past the boat ramp to examine the water worn outcrops. The first rock encountered (at reasonably low tide) is a basal conglomerate which contains abundant pinkish feldspar as well as quartz grains and heavy-mineral bands. Next a gritty quartzite is reached which is probably the basal bed of the tillite. Some outcrops contain erratic pebbles and also an occasional lens of blue-grey dolomite.

The first dark grey rock outcrop which juts into the sea is formed of tillite and slate and these, once again, are in a reversed position (the slate appears below the tillite although it is younger). This orientation of the beds indicates that they are part of the lower limb of the overturned anticline seen at the southern end of the cove.

About a metre above sea-level there is a deposit of 'beach rock' covering part of this small rocky headland. It is made up of rounded, unsorted pebbles with cobbles and boulders of the above formations bonded together by a calcareous cement and is probably related to the higher sea-level described in the Normanville area when the river terraces were formed.

Note that small patches and strips of sand still remain at the foot of the cliffs. These are remnants of the once continuous belt of coastal dunes described at Normanville. Remains of quite large tree trunks can occasionally be seen eroding from the dunes probably indicating a former substantial cover of natural vegetation in this area when sea-level was lower, some thousands of years ago.

Along this part of the coast, from Little Gorge southwards, the rocks show a relatively well-developed cleavage (Fig. 22), indicating low-grade metamorphism, whilst those north of Normanville do not appear to have been metamorphosed. The metamorphic effect increases in a southerly direction demonstrating that deformation and more intense folding occurred in this part of Fleurieu Peninsula during the Delamerian Orogeny.

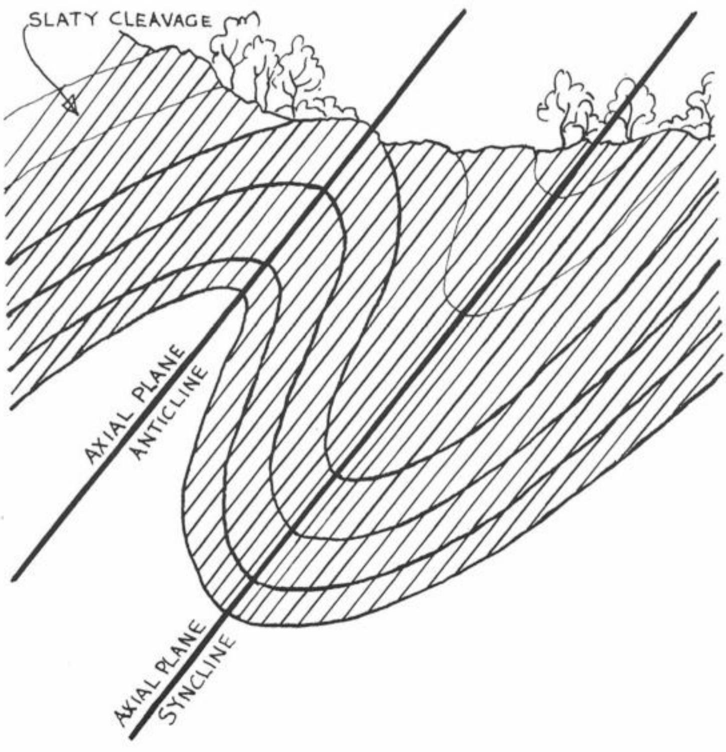


Figure 22. Relationship of slaty cleavage to fold axes

CHAPTER 7

SECOND VALLEY TO CAPE JERVIS

Locality 4. Second Valley (locations continued from Chapter 6)

Second Valley is approximately 102 km from Adelaide and 2 km from the main Normanville—Cape Jervis Road. The region is dominated by the major overturned anticline described in the previous chapter. The core of this overturned anticline, the Myponga-Little Gorge Inlier, is an elliptical area of basement rocks surrounded by Adelaidean and Cambrian rocks of the Adelaide Geosyncline, exposed as a result of the erosion of the crest of the anticline. The nose of the inlier, which has proved difficult to map because of the complex geology, occurs north of Second Valley, and the continuation of this fold nose passes through the Second Valley Harbour area. This has resulted in good exposures of folding, and examples of foliation and linear features, rarely seen so easily in the Mount Lofty Ranges. Second Valley Harbour is regularly used as a teaching area for geology students and has been declared a Geological Monument by the South Australian Division of the Geological Society.

There is a car park under shady pine trees near the caravan park and it is only a short walk to the harbour through the little gorge of the Parananacooka River. To the left, in the side of the steep coastal cliff, which is the lower limb of the overturned anticline, there is an exposure of a minor overthrust or reverse fault (Pl. 35), where the higher beds can be seen to over-ride the lower beds, at a very low angle. This results in crustal shortening and is symptomatic of areas subjected to intense compression and folding.

Follow the path around to the seaward side of the cliff, past the jetty, and note the strongly cleaved and layered slates of the Tapley Hill Formation in the cliff face. Also exposed in this area is the Brighton Limestone (marble phase), which is younger than the Tapley Hill Formation but is here overturned and, as a result, appears below it. Both have been subjected to

Plate 35. Minor reverse fault on approach to Second Valley Harbour

low grade metamorphism. A little further on, the slate is interbedded with the buff coloured marble, highlighting exposures of spectacular folds in the cliff face (Pls. 36,37). The geometry of these folds is related to the major fold of the area. They are reclined folds, thinned in the limbs and thickened in the hinge, plunging gently to the south-east (into the cliff). The cliff line is almost at right angles to the axial plane of the folds so that they are seen in profile, allowing their true symmetry to be fully appreciated.

Plate 36. Reclined folds in cliff face, south of the jetty at Second Valley Harbour

Plate 37. Details of folds at Second Valley Harbour

In the cliffs and on the shore platform at the neck of the small peninsula to the south-west, the slates have been metamorphosed to phyllite (with a foliation dipping south-east) and the streaking of mica gives them an iridescent metallic sheen.

Exposed on the tip of the small peninsula are buff coloured marbles, more massive and less thinly banded than those near the jetty and folded on a larger scale. Both phyllite and marble have a prominent axial plane cleavage which develops in bedded rock subjected to stress. In the limbs of the folds the cleavage is parallel to the bedding but in the exposed hinge zones it can be seen to be at a high angle.

From the peninsula, looking back towards the cliff line, the complexity of this area can be appreciated (Pl. 38). From here it is possible to see some of the larger folds in the phyllite, quartzite and marble on the cliff face. Once again they are reclined, repeating the pattern of the smaller folds seen near the jetty and in the marble on the peninsula. In the base of the cliff face, at the neck of the peninsula, there is another thrust fault which disappears into the quartzite above the cave to the south. Not visible from the peninsula is a spectacular fold which 'closes' in the cliff face around the first bluff to the south of the peninsula. It is best seen from a boat but can be seen by climbing around the rather precipitous path near the foot of the bluff. An old beach line can also be observed as a 7.5 metre wave-cut bench and notch on the coastal cliffs between Second Valley and Rapid Bay.

Leaving the harbour, walk north along the small swimming beach and climb the low hill immediately before the first outcrop of rock across the beach. The stratigraphy is once again reversed. The rocks on the beach, which form the base of the cliffs, are the Tapley Hill Formation, while on the cliff tops the older Sturt Tillite occurs. This is almost obscured, except for small

Plate 38. Panoramic view of cliffs at Second Valley Harbour looking from the small peninsula

slivers, by Permian deposits, the two glacial units resting unconformably together. From here a good view is obtained of the coastal cliffs to the north (Pl. 39) and the valley beyond, which is filled with Permian sediments. The shape of the small hills on the northern side of the valley have the appearance of being ice-smoothed and erratics occur in the paddocks below. Small to medium-sized erratics can readily be found on the cliff tops. Most are locally derived but an occasional boulder of Encounter Bay granite appears.

Plate 39. Looking north from Second Valley towards Anacotilla Beach

Walking north, a large isolated erratic, which has split in two is prominent on the south-western side of the next hill-top (Pl. 40). It is dark-grey crystalline quartzite and is clearly an ice-plucked block of the local bedrock. One of the faces is scarred by very clear deeply cut striae and chatter marks caused by the grinding action of debris carried in the base of the ice. This piece of rock was itself broken off, caught up in the ice and eventually dropped amongst the debris when the ice melted. The outcrop above it, on top of the hill, is Sturt Tillite.

Plate 40. Erratic on cliff top at Second Valley showing striae and chattermarks

Locality 5. Rapid Bay

Rapid Bay, 108 km from Adelaide, is reached by a steeply descending road from the main Second Valley-Delamere Road. It was named by Colonel William Light after his brig. *H.M.S. Rapid,* and it was here that he made his first camp on the mainland of South Australia as Surveyor General in 1836. He was so enchanted by the appearance of the country with its 'fine stream of fresh water running into the sea and soil, rich beyond expectation', that he considered it as a possible site for the capital city which he had been sent here to found.

This area, although still beautiful, has been extensively cleared for grazing and now sheet erosion and local gullying are common. Towards the coast the land is deeply dissected, exposing rocky outcrops beneath shallow soil, and terminates in steep cliffs along the coastline. The older rocks, once again, are partly covered by a veneer of younger sediments including fluvio-glacial clay, silt and sand of Permian age.

The mining history of Fleurieu Peninsula dates from 1844 with the discovery of silver, lead and copper in the Rapid Bay area. Several mines were operated between 1844 and 1918, the earliest and most important being the Yattagolinga Mine, named after the small river which flows through the valley. The 'Record of Mines of S.A.' (4th edition, 1908) reports that copper lodes were found cropping out on the surface and showed also in the face of the cliffs fronting the sea. It also noted that some fine white marble was to be found nearby. Several shafts were sunk in the hill immediately north-east of the present jetty and a tunnel at beach level was driven to connect with a 24 m shaft from the top of the hill. This tunnel can still be found 275 m north-east of the jetty but has been blocked off for safety reasons. The ore minerals found there were native silver, silver-bearing galena, chalcopyrite, malachite, azurite and sphalerite. Altogether, 190 tons of hand-picked silver, lead and copper ore were produced. The mine was closed in 1908.

The Olivaster Mine, in the same area, operated from 1912-1918 and at one time was thought to be richer in silver than Broken Hill, the galena containing up to 16 ounces of silver per ton. Some of the ore was smelted at Port Pirie but high running costs eventually forced the closure of the mine.

The fine white marble, mentioned in the publication of 1908 is now the commercial reason for the existence of the tiny settlement on the coast at Rapid Bay. The Broken Hill Proprietary Company Limited established a quarry for the production of metallurgical grade marble in 1940 on the hill immediately adjacent to the one containing the old mines. The rock was shipped to Newcastle, Port Kembla and Whyalla, to be used in the smelting of iron ore.

In 1980 the quarry was purchased as a going concern by Adelaide Brighton Cement Holdings Limited and the marble is now shipped to Port Adelaide for use as cement clinker.

The quarrying operations at Rapid Bay have resulted in some major changes to the landscape. For many years the bay was progressively filled with quarry waste material which altered the shape of the shoreline, creating an artificial beach surface some two metres higher than the natural beach level, and south of the jetty, larger waste was tipped over the cliffs forming artificial screes. The waste has been transported northwards along the coast creating new beaches in some of the small coves between Rapid Bay and Second Valley. Since the dumping ceased, the beach between the jetty and mouth of the Yattagolinga River has become markedly eroded and rocks have been placed there to overcome this problem.

Access to the quarry requires the permission of the quarry manager and, if obtained, inspection should be undertaken with some care. It is always advisable to wear a hard hat in these areas and not to drive or walk too close to the edge of the quarry faces. Visitors are not welcome near the jetty when loading is in progress.

The deposit comprises medium to coarse-grained limestone which has been partially recrystallised to marble. The age of the rock is a matter of dispute. It has been described in the past as unbanded marble of Cambrian age, but in recent years, a Precambrian age has been suggested (Daily 1963). No fossils have been found in the unit and, contrary to some descriptions, examples of banded marble can be seen (Pl. 41). However, anomalies exist for both ages and if you wish to play Devil's Advocate, ask two geologists, familiar with the area, the age of the Rapid Bay marble and sit back!

The marble horizon worked at the quarry, once considered to be an isolated lens, is now thought to be the result of tectonic thrusts along the axis of the major regional overturned anticline discussed earlier and its great

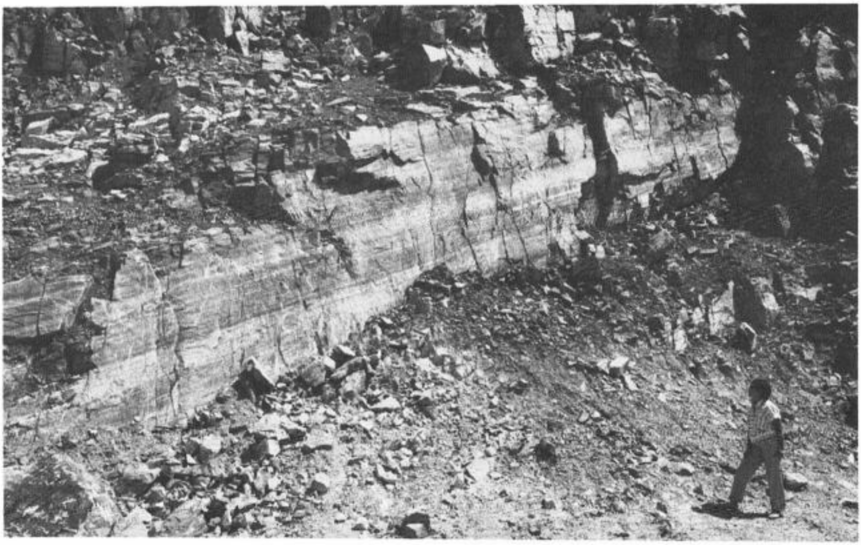


Plate 41. Banded marbles, Rapid Bay quarry

thickness due to the thickening in the hinge of a fold similar to those seen, on a smaller scale, at Second Valley. The marble extends right to the top of Mount Rapid, which rises on the south-western side of the bay to a height of 270 m, and it is broken only by a strong belt of quartzite 75 m thick near the summit. It is intersected by joint planes, fissures and crush zones related to the intense folding, which makes the deposit relatively easy to work. Two

Plate 42. Breccia zone, top bench, Rapid Bay quarry

varieties of limestone can be observed: a dark grey, fine-grained variety, which has a high silica content, and a white to yellow, coarse to medium-grained rock, high in magnesia. This is due to minor amounts of detrital quartz and dolomite within the limestone. Slaty impure limestone forms the hanging wall and footwall of the quarry. Sink-holes and caves that have been filled with clay, soil and travertine also occur.

A fault breccia runs across the floor of the quarry from south-east to north-west (Pl. 42). It can be examined in the face of the eastern corner of the top bench, in an area no longer worked, where massive angular blocks of marble, broken by a crushing or grinding action along a fault line, are exposed. In this case, however, no obvious displacement can be seen on either side of the breccia zone.

A short distance south of the breccia a small cave has formed, large enough to enter with care. Near the opening can be seen the result of leaching of calcium carbonate from the limestone by groundwater with redeposition of botryoidal formations of calcite (from the Greek 'botryoides' meaning a bunch of grapes) on the roof, and the beginning of a shawl stalactite. There are also large crystals of rhombohedral calcite in the fractures.

One of the rewards for carrying a pair of binoculars is to stand on the cliff top behind the office buildings of the quarry and look northwards to Second Valley Harbour. From here, the large reclined fold, which cannot be observed from the peninsula there, can be seen easily.

After visiting the quarry, walk south past the loading jetty and along the foot of the cliffs where the quarry waste has been tipped. Here, the different types of limestone can be closely inspected and the occasional mineral specimen found. A cave, close to the jetty, which has been weathered out by the sea and by groundwater, contains more good examples of botryoidal and rhombohedral calcite.

To the north-east, the now extensive beach ends with a steep cliff of slaty limestone containing a large cave, which exhibits a notice warning of falling rocks. At the top of the cliff, alunite, an hydrated potassium aluminium sulphate mineral of secondary origin, was once worked for potash. **A warning to swimmers:** it is worth remembering that the artificially raised level of the beach ends very abruptly a few metres from the waterline.

Locality 6. Cape Jervis

Cape Jervis is 121 km from Adelaide and 13 km from the turn off to Rapid Bay. It was named by Matthew Flinders in 1802 after Lord St. Vincent, First Lord of the Admiralty, whose family name was Jervis and who was Admiral of the Fleet at the Battle of St. Vincent in 1797. Just beyond Rapid Bay, the road passes through the little town of Delamere which gave its name to the mountain-building episode which formed the early Palaeozoic fold belt on the site of the Adelaide Geosyncline, the remnants of which now form the rejuvenated Mount Lofty Ranges. The approach to the Cape itself is notable for the spectacular view of Kangaroo Island across Backstairs Passage. The

Cape is a comparatively flat area extending about three kilometres back from the coast and the low level is possibly due to erosion by the same ice movement which, it is now believed, scooped out Backstairs Passage during the Permian glaciation. It is covered by Quaternary and Permian material which has been severely eroded following over-clearing and over-grazing.

The early South Australian geologist Walter Howchin wrote in 1911 that the most extensive development of glacial till observed in the State up until that time was at Cape Jervis. The area now contains the type section for the Cape Jervis Beds, and is characteristic of much of the Permian glacial rocks

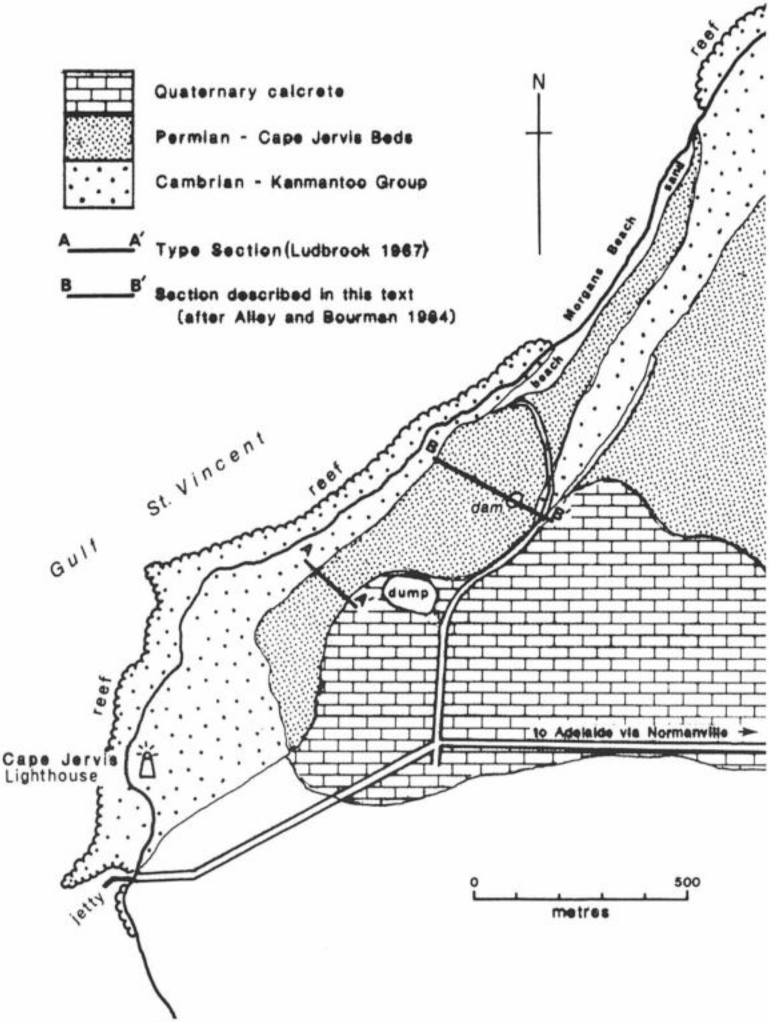


Figure 23. Geological map of Cape Jervis area (Modified from Alley and Bourman (1984) after Ludbrook (1980)

south of Adelaide. The site is a Geological Monument as defined by the South Australian Division of the Geological Society of Australia (Fig. 23).

Evidence suggests that during the Permian glaciation, when Australia was part of the super-continent of Gondwana, the South Pole may have been only 150 km south of Adelaide. The source of the ice-sheets was believed to have been somewhere south-west of present-day Tasmania. Glacial striations on Fleurieu Peninsula generally indicate that the ice moved from east to west. However, although there are no striae visible at Cape Jervis, evidence gained from the analyses of the orientation of pebbles within the glacial till suggests that this area may have been the junction of two ice-sheets, one moving west across the Peninsula and the other moving northwards through what is now Backstairs Passage (Alley & Bourman 1983).

The road down to the Cape ends at the car park near the jetty and the lighthouse. The rocks which crop out around the jetty and along the shoreline to the north-east are the Carrickalinga Head Formation, lowest of the Kanmantoo Group, which comprises the bulk of the Cambrian rocks in south-eastern South Australia. They were formed in a rapidly sinking trough which occupied much of Fleurieu Peninsula and continued into Kangaroo Island and was situated east of the Adelaide Geosyncline. The group attains a thickness of about 9,000 m. Unlike the older Normanville group occurring further north along the coast (see Chapter 5) which is comprised of limestone and shale, the Kanmantoo Group is essentially feldspathic sandstone metamorphosed into meta-sandstone and schist.

At Cape Jervis, grey metamorphosed sandstones occur on the coastal platform and along part of the coastal cliff. The lighthouse, originally built in 1871 and replaced in 1972, stands on the Kanmantoo rocks. Behind and to the north of the lighthouse, glacigene sediments form crescent-shaped hills up to 30 m high. They are easily eroded and water has scoured out many gullies which constantly reveal fresh exposures of the underlying sediments.

Walk down to the beach from the end of the short road which runs behind the lighthouse and look back at the cliff face. The Kanmantoo rocks, which are exposed along the beach and form the lower part of the coastal cliffs, can be seen cropping out through the overlying sediments about half way up. These rocks formed the land surface at the time of the Permian glaciation and now form the western side of a partially exhumed glacial valley. Walk along the base of the cliffs to the second gully north of the fence running at right angles to the beach (approximately 800 m). There is a small dam at the top of this gully. Before climbing the gully, look for some cobble beach deposits about one metre above sea-level. These were thrown against the steep face of the cliff during storms probably during the Holocene (Recent) which commenced about 10,000 years ago. A second deposit occurs at a height of six metres and would have been formed during the late Pleistocene, 100,000 years ago. Look back south to the old rubbish dump and car park on top of the hill, and a third deposit can be seen at 50 metres above the present sea-level. This formed during the early

Pleistocene, about 1,000,000 years ago. Now, climb the gully to where the Kanmantoo rocks dip down sharply to intersect it. You will notice that the sediments, which obscure the Kanmantoo rocks, are of a reddish colour and are composed of comparatively recent material which has washed down from above. The older Permian glacigene sediments, above the Kanmantoo rocks, are easily distinguished by their paler colour. The Kanmantoo Group bedrock is seen to be strongly jointed, and contact with the overlying Permian is obscured largely by a thin adhering layer of calcrete and iron oxides, developed by groundwaters depositing salts dissolved from passage through the Permian sands. This may be one of the reasons why no striae have been found, so far, in this area.

Directly above the contact, there is a compact, non-stratified sandy till approximately three metres thick, containing a few pebbles and boulders. This is the lodgement till or basal debris deposited by ice grinding across the land or directly from the base of the melting ice during de-glaciation. Most of the erratics have been derived from the Kanmantoo Group bedrock; some are Encounter Bay-type granite and others have their origin much further away, in present day Antarctica. The larger ones are commonly polished, faceted and striated. Above the till is 50 cm of coarse gravel, which is interpreted as a residual accumulation, or lag concentrate, deposited during de-glaciation after the finer sediments have been winnowed away by currents, possibly when the till was briefly exposed.

Overlying the gravel deposit are 15-20 m of interstratified sand, silt and clay, containing lenses of gravel and isolated pebbles and boulders. This unit probably extends higher but 10-12 m of debris and soil obscure the sediments above it. These highly variable fluvio-lacustrine beds were probably deposited by melting ice, which filled the present Backstairs Passage, forming temporary and constantly changing lakes and streams. The bottom of these beds displays local slumping which may have occurred shortly after deposition when the ice melted below it. Polished, faceted and striated pebbles are common and it is possible to find dropstones (pebbles or boulders which depressed the sediments beneath them as they fell from the ice).

On several occasions, after the glacial maximum, debris flowed off the top of the melting ice towards the east. These tills are represented by two very pebbly beds in a matrix of coarse silty sand with a concentration of very large boulders which can be seen right across the cliff face at this level. It is the source of the large granite erratics lower in the gully and scattered along the shore platform (Pl. 43). Many come from the suite of Encounter Bay Granites which extend from Port Elliot to Cape Willoughby on Kangaroo Island. At Cape Jervis the tills are thought to have been formed by several debris flows from ice stagnating in Backstairs Passage.

Overlying the flow tills and reaching to the small dam at the top of the gully, is a clay unit topped by massive calcreted limestone from which Pleistocene marine molluscs have been recovered. The presence of marine foraminifera in the clay unit enabled a Permian age for the underlying

Plate 43. Granite erratics on shore platform at Cape Jervis

sediments to be determined (Ludbrook 1967). At the bottom of the unit the silty-clays are homogeneous and display conchoidal fracturing. Above these are bedded clays three to four metres thick containing dropstones and gravel lenses which are indicative of melting ice. The bedding becomes better developed at higher levels. The sedimentary characteristics of this unit suggest that it was laid down in increasingly deeper water which was becoming more and more saline, indicating a gradual transgression of the sea around the melting ice mass and bringing the story of the glaciation to a close.

To the east of the dam site a road has been recently constructed leading north to Morgans Beach. Consolidated Permian beds are exposed on the eastern side of the road cutting and dip westwards from a steep bedrock slope. This is the primary dip caused by deposition on the eastern flank of the Permian glacial valley and these beds are equivalent to those deposited on the western flank, previously described, in the gully. Higher up on the hill and to the north, lighter coloured Permian outcrops can be seen resting unconformably against the Kanmantoo bedrock. These remnant deposits show the north-east trend of this ancient glacial valley.

Another road has also been constructed along the top of the cliffs and leads to a lookout which is an excellent vantage point for viewing the dramatic cliffs stretching northwards along Gulf St. Vincent and also to wonder at the two large erratics perched on the side of the hill nearby.

CHAPTER 8

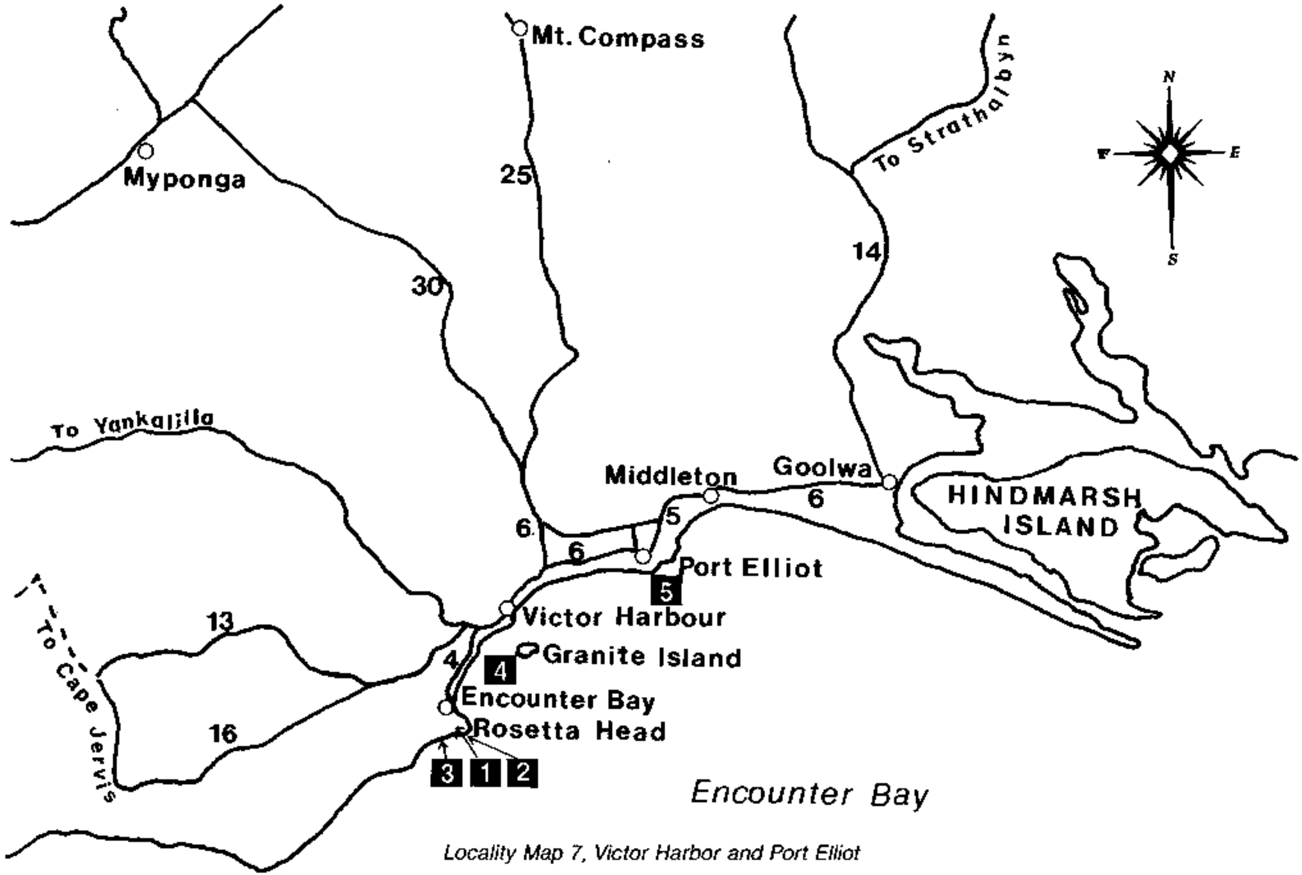
VICTOR HARBOR AND PORT ELLIOT

The principal features of interest in the Victor Harbor-Port Elliot area are the granites which were intruded into the metamorphosed sediments of the Kanmantoo Trough towards the end of the Delamerian Orogeny—about 510 million years ago. The intruding magma solidified deep within the crust perhaps ten kilometres down, and it is only because of prolonged erosion, acting over millions of years, that the rocks became exposed at the surface. Evidence of the Permian glaciation is also visible in the South Coast area in the form of deposits left behind when the ice melted. In a number of places these deposits rest upon granite, indicating that the granite was exposed as part of the landscape around 270 million years ago. Some of the granites must have been completely covered by the glacial sediments but have been re-exposed by erosion which has taken place over the intervening millions of years. The granites can be seen at Rosetta Head (The Bluff), Granite Island and Port Elliot, while the glacial deposits are to be found on and around Rosetta Head and at Port Elliot.

Locality 1. Rosetta Head

Rosetta Head is an important locality where Kanmantoo schist and granite are both well displayed and Permian tillite is known mainly from the foreign boulders present. A key feature is the complex intrusive contact zone between the schist and the granite. Because of the resistance of the granite to erosion, a prominent headland has been formed. Fig. 24 shows the locations of the various rock types.

The smooth rounded profile of Rosetta Head has been attributed by some workers to the erosive action of the Permian ice-sheet which once covered it, but erosion must have extensively modified it since that time. In order to examine the features along the north side of Rosetta Head, park at the 'Whalers' Inn' and walk along the road to the jetty. Several points of interest are worth inspection (Fig. 25).



Locality Map 7, Victor Harbor and Port Elliot

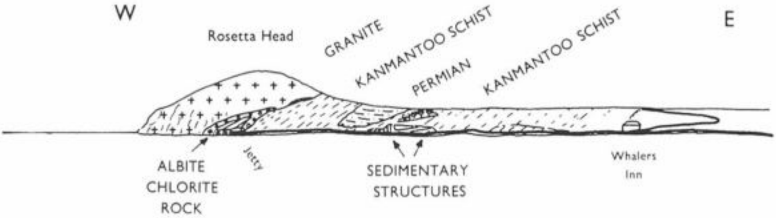


Figure 24. View of Rosetta Head from the beach road looking south-east. (From J.L. Talbot and R.W. Nesbitt, Geological Excursions in the Mount Lofty Ranges and the Fleurieu Peninsula).

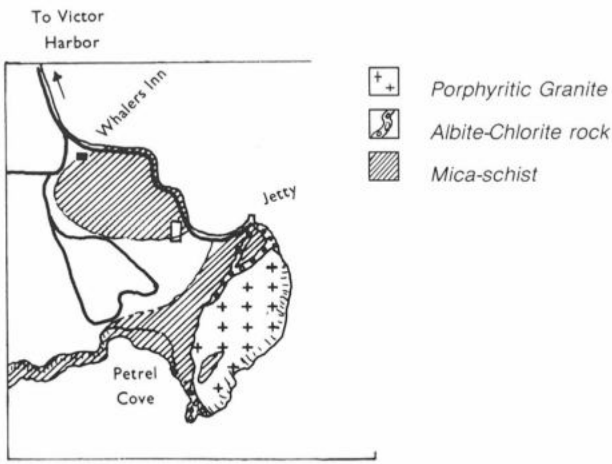


Figure 25. Geology of Rosetta Head (From J.L. Talbot and R.W. Nesbitt)

Visible from the car park are several large granite boulders on the beach (Pl. 44). They are too far from the granite outcrops at the seaward end of Rosetta Head to be products of coastal erosion. They are believed to be glacial erratics which have reached their present position as a result of ice transport. In this case the transport has been minimal if they are derived from the local granites.

The rock exposed on the beach adjacent to the jetty road is Kanmantoo schist which contains numerous layers of mica. This distinct layering (known as schistosity) dips to the south-east. Interesting features in the schist are the delicate sedimentary structures (Pl. 45) which were formed at the time of deposition in Cambrian times. They have been preserved despite the high temperatures and pressures which converted the rock to schist during the Delamerian Orogeny, and good exposures of ripple-marks and load casts can be seen in the cliffs which form the landward side of the road. Notice the difference in inclination between the sedimentary bedding, which is folded into anticlines and synclines, and the schistosity planes, which are steep

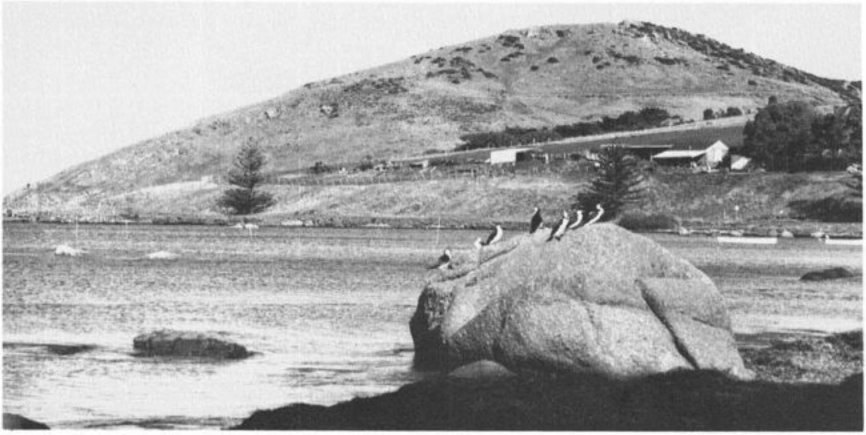


Plate 44. Erratics on the beach, north of Rosetta Head

and relatively constant throughout the area. Where the road turns towards the jetty, the schist gives way, for a short interval, to what appears to be stony soil. This is Permian till and it contains many erratics of granite and Kanmantoo schist.

The zone of contact between the Kanmantoo schist and the Victor Harbor granite lies just behind the jetty at the end of Rosetta Head. This is a very complex area in which a variety of granites and schists are intermixed. The feldspar in the granites, which is close to the contact zone, and which becomes the dominant rock immediately south of the jetty wall, is a white feldspar known as albite. This differs from the more common potash

Plate 45. Cross-bedding in Kanmantoo schist on the side of the Bluff road

feldspar of the typical Victor Harbor granite. A greenish-grey micaceous mineral, chlorite, is also present in this contact-zone rock. There are xenoliths of schist in the granite, indicating that the rock, into which the granite was intruded, had been metamorphosed before the intrusion occurred.

A sharp contact between the albite-chlorite granite and the typical Victor Harbor granite occurs in the cliffs about 65 m south of the jetty. It is not advisable to look for this contact as freak waves are a feature of the coastline, even in fine weather.

Locality 2. The Top of Rosetta Head

The granite is well exposed on the higher slopes of Rosetta Head and an ascent to the summit is recommended. A footpath which leads to the summit can be followed, starting on the jetty road near the Permian till; or alternatively, a short climb can be made from the car park halfway up Rosetta Head overlooking Petrel Cove.

Just above the car park the underlying rock is schist, but ascending the track, grains of quartz and feldspar eroded from the granite become increasingly conspicuous. As in the area behind the jetty, the contact zone is complex, with schist and granite intermingled for a considerable distance. Xenoliths of schist can be seen in the granite along the track.

Many features associated with the weathering of granite can be seen from the shoulder of Rosetta Head. The Victor Harbor granite is extremely porphyritic, containing very large phenocrysts of feldspar. The quartz, another conspicuous constituent of the rock, possesses an unusual blue coloration, which is a characteristic of the granites found in this area. The granite has weathered into rounded boulders, or tors (Pl. 46), and several examples of 'onion-skin' weathering are to be seen. The coarse particles of quartz and feldspar found around the boulders are the result of weathering, and are in the process of breaking down to form the siliceous 'soil' of Rosetta Head.

From the top of Rosetta Head, where a plaque on a large granite tor commemorates the encounter between Matthew Flinders and the French explorer Baudin in 1802, it is possible to see several islands. All these islands are of granite and have weathered to a characteristic smooth shape (Pl. 47). They are steep and rocky on the seaward side; but less steep and covered with vegetation on the landward side. The contact between the granite and the schist, already observed at Rosetta Head, passes across the landward side of Wright Island in Encounter Bay. Granite from West Island was used for the base and steps of Parliament House in Adelaide.

An old mine shaft, recently filled in, is situated in Kanmantoo schist on the landward side of Rosetta Head, above the car park. Following the discovery of malachite on the surface, a shaft was sunk c. 1863 in an unsuccesful search for an economic deposit of copper ore. Traces of malachite may still be found around the top of the shaft. However, this mine, called the Coolamine Mine, or The Bluff Mine, was little more than a venture and produced insignificant amounts of ore.

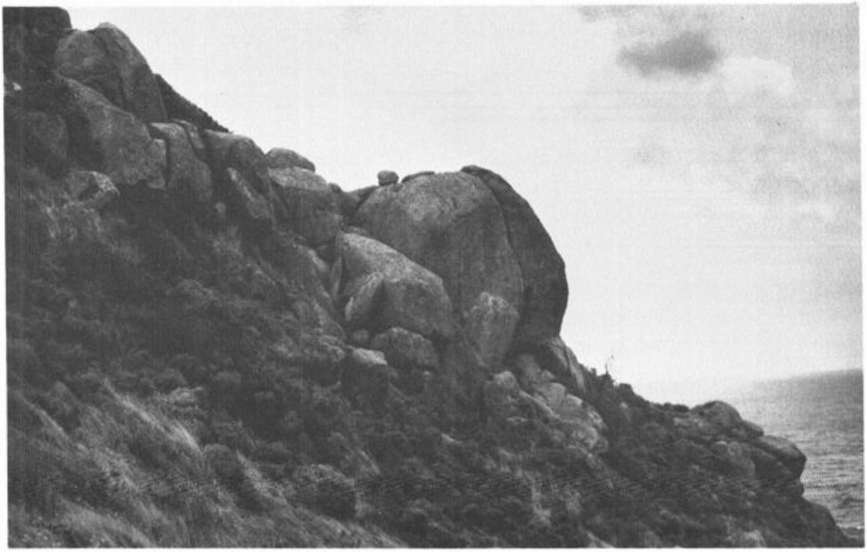


Plate 46. Granite tors, Rosetta Head

Locality 3. Petrel Cove

There is a car park close to the steps which lead down to Petrel Cove. Kanmantoo schist is exposed on the beach. Using a hand lens, an examination of the deeper pink-coloured beach sand around the outcropping rocks will reveal rounded grains of minerals—including pink garnet, black ilmenite, colourless zircon, reddish rutile and brown-stained shell fragments, which have weathered from both the Kanmantoo schist and the overlying Permian till. Granite erratics which are not locally derived and have also weathered from the till can be found on the beach.

The contact zone between the schist and the granite of Rosetta Head is near the south-east corner of the cove, at the end of Rosetta Head. It is well worth a visit and can be approached along a path at the base of the cliffs. Once again the albite-chlorite rock replaces the true granite along the contact which dips, very obviously, to the south-east.

Plate 47. Wright Island, Encounter Bay, with characteristic granite weathering forms on the ocean side (right hand) and Kanmantoo schists on landward side

Locality 4. Granite Island

A causeway connects Granite Island with the mainland at the end of the main street of Victor Harbor. A horse tram runs across to the island during weekends, school holidays and on public holidays.

Close to the Granite Island end of the causeway, there are good outcrops of the porphyritic Victor Harbor granite (Fig. 26). The large potash feldspar phenocrysts showing simple twinning, and the characteristic blue quartz, indicate that it is the same granite already seen on Rosetta Head. A careful examination of the rock with a hand lens will reveal the presence of white plagioclase feldspar and black mica. While some of the xenoliths on Granite Island, like those on Rosetta Head, are of Kanmantoo schist, others are of a fine-grained grey granite.

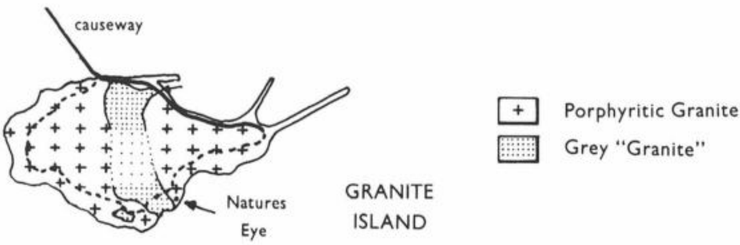


Figure 26. Geology of Granite Island (From J.L. Talbot and R.W. Nesbitt)

This fine-grained granite which forms some of the larger xenoliths in the Victor Harbor granite at the end of the causeway, crops out near the small jetty about 70 metres east of the chairlift. It is enclosed in the coarser-grained Victor Harbor granite containing xenoliths of Kanmantoo schist, indicating the very early formation of the grey granite (Fig. 27).

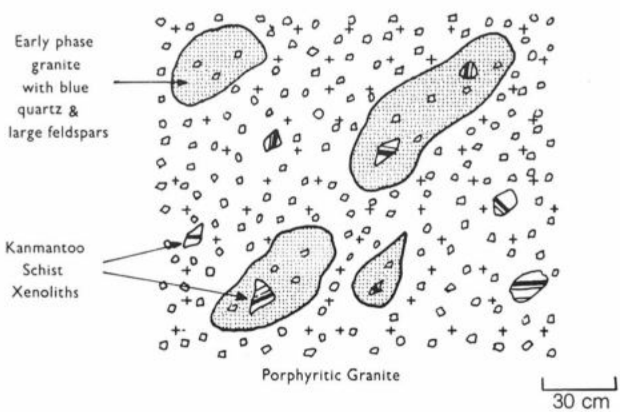


Figure 27. Representation of the xenolith-in-xenolith relationships on Granite Island (From J.L. Talbot and R.W. Nesbitt)

A walk around Granite Island reveals many interesting features associated with granite and granite weathering. Unusual features are 'Nature's Eye', an example of a water-worn pot-hole, and Rhinoceros (or Elephant) Rock on the western side of the island. This rock owes its peculiar shape to weathering caused by salt crystallising in small cavities on the granite surface. Cavernous weathering of the boulders is another feature produced when chemical weathering of the interior of a granite joint-block has proceeded inside a case-hardened and resistant outer skin.

Locality 5. Port Elliot

Granites are again conspicuous at Port Elliot, and a walk eastwards from Knights Beach will reveal many features of interest (Fig. 28).

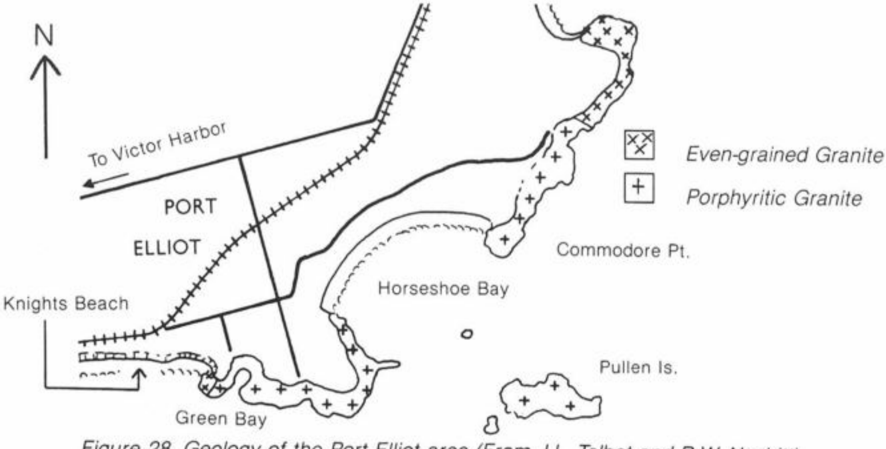


Figure 28. Geology of the Port Elliot area (From J.L. Talbot and R.W. Nesbitt)

The calcareous sandstone cliffs at the back of Knights Beach are of Pleistocene age and reveal several sedimentary structures, including cross-bedding and 'honeycomb' weathering caused by sea spray. Evidence for the much greater rate of erosion of the soft sandstone compared with the resistant granite is provided by the prominent granite headland. This feature, a good example of differential weathering, is well displayed all along the South Coast.

At low to moderate tides, it is possible to examine the three different varieties of granite which are exposed east of Knights Beach. The darkest is the porphyritic Victor Harbor-type granite, which is cut and veined by a coarse-grained pink granite with prominent feldspar phenocrysts. The third granite is pink and even-grained, with no phenocrysts. In both the porphyritic granites, 'mantling' of the phenocrysts can be seen. This phenomenon is caused by precipitation of a different type of feldspar around an already formed crystal during the cooling of the granite magma.

N.B. It is advisable to keep to the higher rocks and path when walking between Knights Beach and Horseshoe Bay. There is a real danger of being washed from the lower slabs by large freak waves.

Along the path between Knights Beach and Green Bay, the unconformity between the granite and the overlying Pleistocene dune sediments is clearly visible. Both the sediments and the overlying calcrete layer (kunkar) can be seen from the path around the head of Green Bay.

Looking across Green Bay, the strong jointing in the granite is evident, the general orientation of the joints being parallel to the direction of Green Bay. The bay is, in fact, the result of extensive weathering along the joint planes in the granite (Pl. 48).

Plate 48. Weathering along joints in granite, Green Bay

Some notable features visible in the granite between Green Bay and Horseshoe Bay are a vein of aplite (fine-grained granite) and quartz (Pl. 49), xenoliths of Kanmantoo schist in the granite (Pl. 50) and pods of a black mineral (tourmaline) which occurs as long, thin, shiny prismatic crystals. These pods were formed by crystallisation from the mineral-rich fluids remaining after most of the granite magma had solidified. The landward edge of the granite abuts against soft reddish-coloured sediments of Permian age. Where the sediments have been eroded away, a polished surface of granite has been exposed.

Beyond the eastern end of Horseshoe Bay, north-east of Commodore Point, there is another contact zone—this time between the porphyritic Victor Harbor-type granite and the even-grained pink granite. Here, the pink feldspar in the even-grained granite has been altered to the white feldspar, albite, (seen at Rosetta Head), and the narrow contact zone is of white granite. This is a similar situation, although less complex, to that observed behind the Rosetta Head Jetty.

This area has been drilled and quarried in some places so that fresh hand-specimens can easily be collected. Patches of pink (garnet-rich) sand occur on the beach between the granite outcrops. There are no Quaternary deposits overlying the granite in this area and recent sand dunes form the surface cover.

Plate 49. An aplite and quartz vein in granite, just east of Green Bay

The last granite outcrop in this area is an un-named bay, where fine mica flakes glisten in the sand. At Basham Beach, between here and Middleton, there is a small outcrop of Kanmantoo schist, interbedded with a conglomerate containing elongated pebbles, the result of directed stress during metamorphism. Beyond this point are the low cliffs of Middleton and the extensive geologically recent sand dunes associated with the Murray Mouth and the Coorong.

Plate 50. A xenolith of Kanmantoo schist in granite at Port Elliot

Postscript

The history of the granites at Victor Harbor and Port Elliot, like that of granites elsewhere in the world, is complex and not completely understood. The abundance of some almost unaltered xenoliths of Kanmantoo schist would seem to indicate that the granites visible today crystallised near the roof of the magma chamber, while the wide variety of granite types indicate that several intrusions occurred, rather than a homogeneous magma crystallising in a simple chamber. It would appear from the xenolith-in-xenolith relationships that new magma intruded into already solidified granite, which contained xenoliths of Kanmantoo schist. Pieces of this granite fell into the intruding magma, forming xenoliths which already had xenoliths inside them.

Other features not yet satisfactorily explained are the 'mantling' of some of the phenocrysts and the reason for the white feldspar (albite) in the granites close to contact zones with schists or with other granites. It is highly possible that mantling is associated with continued growth of crystals under the hot conditions persisting during metamorphism and that the albite is an atom-by-atom replacement of potassium by sodium from fluid passing along the contact zone and along cooling cracks in the granite at the end of the magmatic process.

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