Geological excursion guide to the sea cliffs north of Sydney

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University of New England
1976

Cover. Tertiary lateritic podzolic palaeosol (foreground) formed on both deltaic sediments of the lower Newport and Garie Formations, and underlying superimposed grey-brown podzolic palaeosols (ferrods) of the Bald Hill Claystone, in the southeast wall of Long Reef.

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INTRODUCTION

The theme of this excursion is uniformitarianism – the geological principle that natural processes were more or less the same in the past as they are at present. Geology students should be encouraged to think imaginatively about their observations and try to relate them to the modern natural world.

Fossils and rock specimens cannot be replaced. So please only collect material you intend to label and keep. Exceptional finds of fish, amphibians or plants should be offered to a museum or university geology department. Near sea cliffs fallen boulders are an erratically replenished source of fossils. Confine your collecting to these and leave the cliff face undefaced for others to enjoy. Your specimens will remain beautiful and valuable if you wrap them carefully in newspaper for transport.

It is best to visit these localities at low tide. This is more critical at Long Reef than at Turimetta Head and least important at North Avalon. For some groups this guide gives too much information for one day. Teachers should make a reconnaissance trip and decide for themselves what to do before taking a class out.

LONG REEF

Turn off Pittwater Road into Anzac Avenue, then drive through Long Reef Golf Club to the end of the gravel road out to the headland.

Stop 1. At the carpark, there is a fine view of beaches, sea cliffs and lagoons to the north and south. The sea cliffs to the south are formed of Hawkesbury Sandstone, which also caps the general plateau level to the west and north. The sea cliffs to the north expose the older underlying Narrabeen Group sandstones and shales. These rocks are of Triassic age (200 to 240 million years old) and part of a large sedimentary basin centred on Sydney – the Sydney Basin.

The headland you are standing on is largely Triassic bedrock connected to the rest of Australia by low land of recent sand deposits called a tombolo. An even better tombolo in the area, which you may be familiar with, is the sand spit connecting Palm Beach to Barrenjoey. Such a structure can be formed when the sea level falls to expose dry land between an offshore island and the mainland. How else could it form?

Walk eastwards over recent sand dunes and down the track descending towards the rock platform. These dunes are strewn with tubular calcareous root concretions and land snail shells, *Meridolum middenense.*

Stop 2. Siltstone and shale beside the track contain fossil lycopod leaves *(Sigillariophyllum)* with a clear double vein and small round lycopod cones *(Cylostrobus,* fig. 12). These sedimentary rocks were probably finer sediments deposited in front of the old "Gosford Delta" within the Newport Formation of the Narrabeen Group (figs. 1,2). What sort of plant remains would you expect on a lake bed progressively further away from a delta?

These rocks are variably leached (lighter in colour) and iron stained (reddened). This is an eroded portion of a lateritic podzolic palaeosol (fossil soil) which will be seen later.

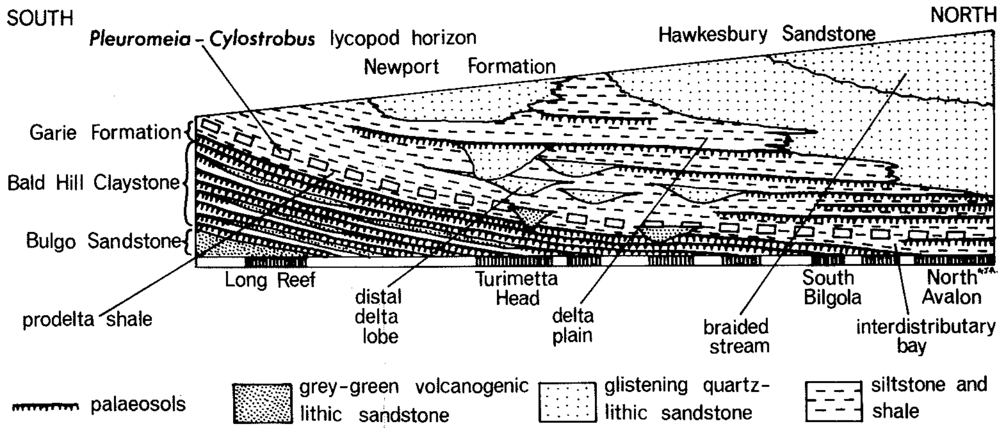

Figure 1. Schematic representation of the Triassic geology of the sea cliffs between Long Reef and Avalon (from the *Journal of the Geological Society of Australia,* with permission).

Continue down the track to a flat grassy area about a metre above the rock platform and beach level.

Stop 3. The dark earth bank on the northern edge of the grassy flat contains layers of recent sea shells. These could be an aboriginal kitchen midden or an older shoreline from a time when the sea was higher or the land lower than at present. Kitchen middens are generally mound shaped. Often they show evidence of fire and rare stone implements. Aborigines seem to have preferred Sydney cockle *(Anadara)* to other shellfish. They prized the valves open with a stick after smashing one corner of the shell on a rock (fig. 3). Old shoreline shell accumulations contain a variety of sea shells including less satisfying periwinkles (*Austrocochlea* and *Melanerita*) and unpalatable barnacles, fine worm tubes and corals. Is this a shoreline shell accumulation or a kitchen midden? Can you think of other ways of telling the two apart?

Walk out over the rock platform heading just south of the higher platform at the point.

Stop 4. Protruding a little above the rock platform is a NW trending dolerite dyke. It is slightly offset in places where the intruded joint system is discontinuous. Does it have a chilled margin or are there other grainsize patterns? The surrounding country rock is very little altered. Why is there no aureole of contact metamorphic rocks as around other igneous intrusions?

Many such dykes in the Sydney area intrude and are therefore younger than the Triassic sedimentary rocks. Judging from the way some are very deeply weathered, they are probably older than the lateritic podzolic palaeosols of the area (see later). So they could be Jurassic to early Tertiary in age.

Walk back to the low red rock outcrop 100 m south of stop 3.

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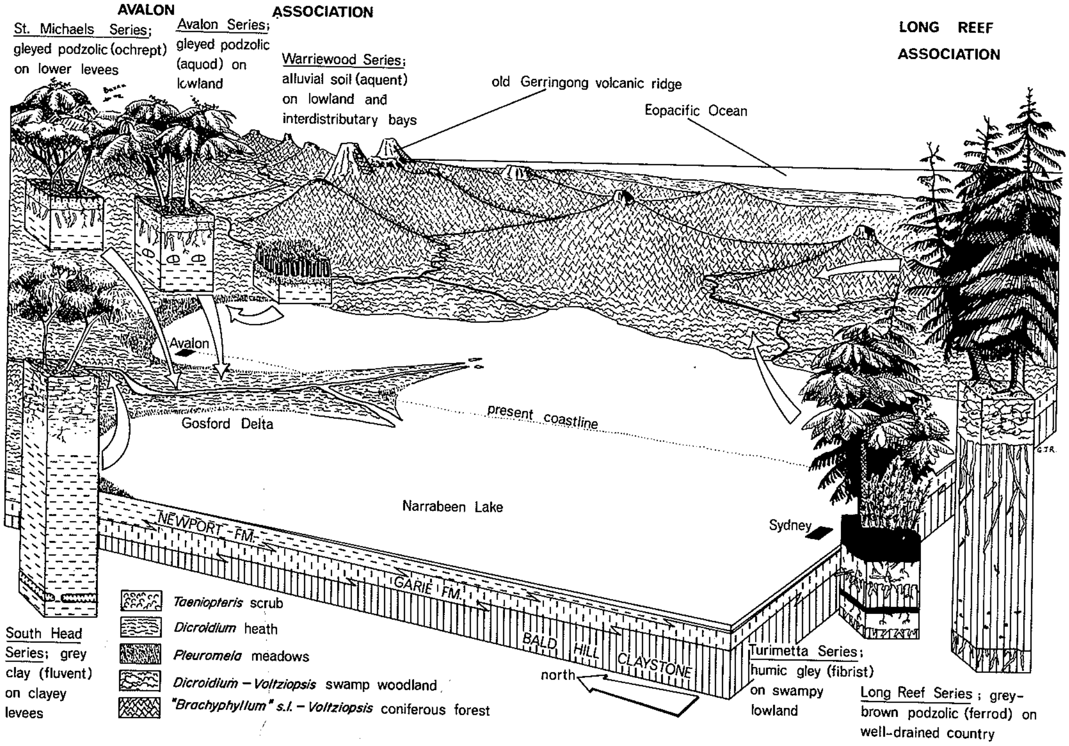

Figure 2. A reconstruction of the Triassic environment looking east from high in the sky near Parramatta (from the *Journal of the Geological Society of Australia,* with permission).

Stop 5. The yellow-grey claystone layer in the low cliff is the A horizon of a Triassic palaeosol (extreme right fig. 2). The B horizon below it has been strongly reddened by ferric iron oxide as haematite. Many soils show a layered structure. In its most complete development there may be a surface organic horizon of leaf litter and animal remains. Clay, iron and aluminium are commonly leached out of the A horizon and accumulate in the underlying B horizon. The C horizon is weathered parent material. Iron is in the grey ferrous oxide state in the A horizon and in tubular mottles around fossil roots extending down into the B horizon. Pea-sized red concretions at the base of the B horizon were formed in the A horizon of an older palaeosol and ferruginized in the overlapping younger palaeosol.

Grey-green lithic sandstone parent material underlies the palaeosols and forms part of the rock platform here. In these old river sediments ferrous iron has not been oxidized red by weathering. The lithic sandstone is the top of the Bulgo Sandstone; the oldest rock unit exposed in these sea cliffs. This sandstone was derived

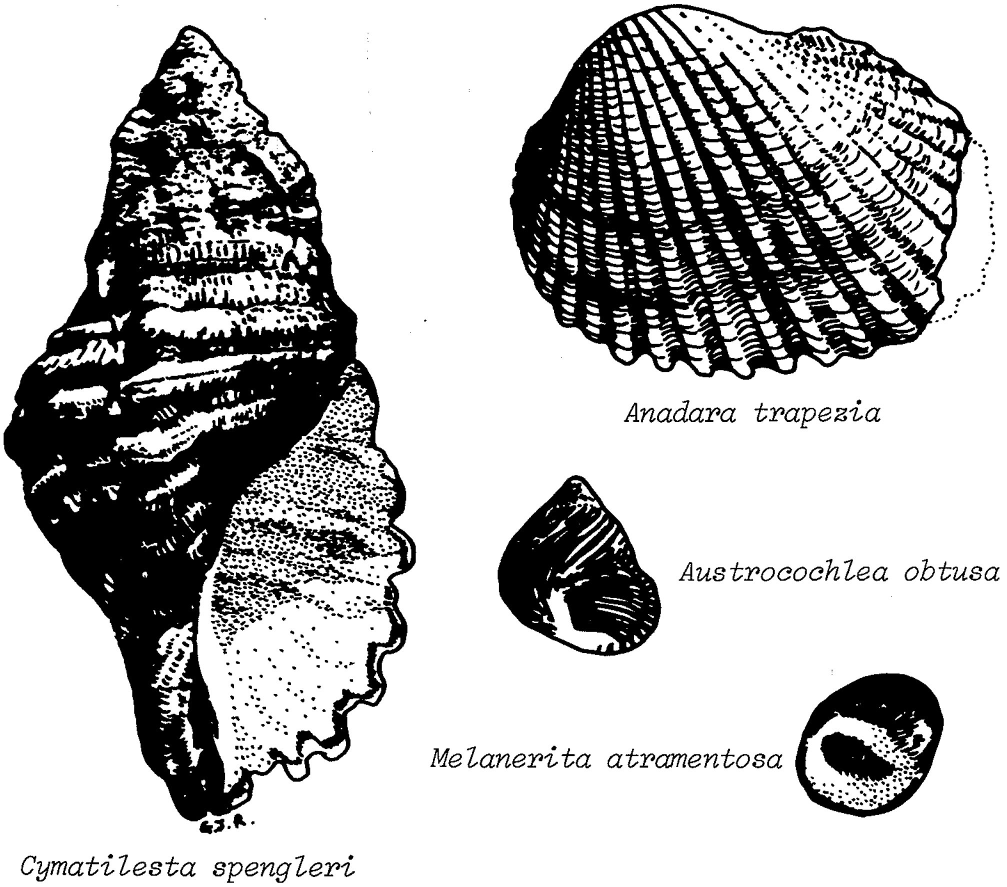

Figure 3. Common sea shells found in recent shell accumulations; all natural size.

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from an old Permian volcanic ridge to the east (fig. 2). Red claystone is interbedded with the sandstone in places. What does this mean?

Stop 6. The rock platform and the higher cliff south of stop 5 show many interesting features.

In the more extensive platform exposures of yellow-grey A horizons there are nodules, large burrows and fine clay illuviated cracks defining soil peds. Peds are clumps of soil material separated by cracks which form naturally in dry soil. The joints exposed as prisms in the cliff and tesselated pavements on the rock platform are not peds. They are infilled with calcite and barites crystals rather than soil material, so they probably formed during compaction of the original soils and sediments. No recognisable plant fossils have yet been found in the redbeds. However fossil pollen in the redbeds suggests that the palaeosols developed under coniferous forest. It is difficult to assess the number of superimposed palaeosols in this cliff as some overlap and their tops are often eroded away. This could be done by studying the microscopic textures of the rocks throughout the section. How many palaeosols do you think there are here? Modern soils of this type take at least 2,000 years to form. What is the likely minimum time taken to form the redbed sequence exposed in this cliff?

The thin grey-green lithic sandstone beds often scour out underlying palaeosols in places. These were probably old sandy stream beds running through the coniferous forest.

Green streaks of copper minerals (paratacamite, atacamite) and rarely native copper specks are associated with coaly plant material in the lithic sandstones and in the tubular grey root mottles of the palaeosols.

Several small faults disrupt the redbeds in this cliff. Work out the movement on the faults by tracing individual rock layers. Some of the faults show good striated and polished glide surfaces (slickensides).

These redbeds, known as the Bald Hill Claystone, can be traced under Sydney in drill holes all the way from similar outcrops near Stanwell Park on the south coast. The grey shales and lithic sandstones overlying it are called the Garie Formation. Above that, the grey shales and glistening yellow and white sandstones belong to the lower Newport Formation (fig. 1).

Consider the rock platform; so well developed here as elsewhere on the New South Wales coast. Some scientists have thought these were excavated at the base of the wave zone and exposed by uplift or a lowered sea level. However there are no benches like this forming below the present wave base. Rock platforms are probably formed by "water-layer" weathering. Water saturated rock of the platform is protected from more intense weathering of the cliff. What erosional agents are involved here?

Continue south from the rock platform past a small beach to a prominent red knobbly rock outcrop low in a sandy cliff.

Stop 7. The strongly outcropping ironstone probably formed on the boundary between the A and B horizons of a lateritic podzolic palaeosol (fig. 4). It separates the yellowish sandy A horizon from a white soft clay B horizon. The greyish sandy surface layer is a modern soil unrelated to the lateritic podzolic palaeosol. The

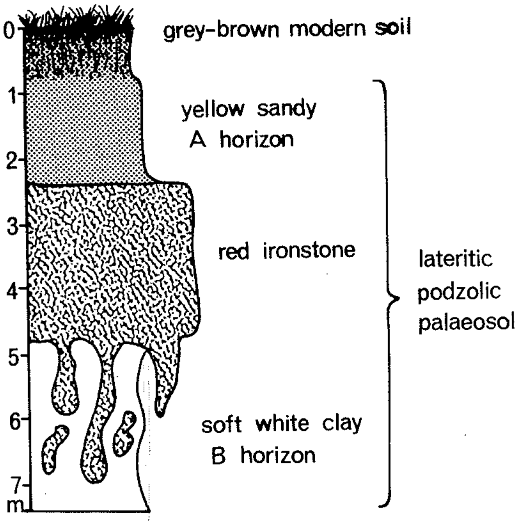

Figure 4. Profile of the lateritic podzolic palaeosol at Long Reef.

palaeosol was developed over all the bedrock of Lond Reef headland but has been eroded away in places. This explains leaching and reddening of the normally grey Garie and Newport Formations, overlying the Bald Hill Claystone in these cliffs. The ironstone dips eastward following the old hill slope. It can be traced under the sea by isolated outcrops between waves and patches of red muddy water. What does this indicate about sea level now compared to when the lateritic podzolic palaeosol was formed? Most of the red surface rocks found so commonly around Sydney are related to lateritic podzolic palaeosols.

Laterites (the red rocks) and lateritic soils are among the most controversial topics of geology and soil science. The orthodox local explanation is that they are residual soils formed under Miocene rainforest growing in a warmer humid climate than at present. Tertiary floras of eastern Australia appear to have been softer and larger leaved (mesophytic) than the dry sclerophyll *Eucalyptus-Angophora* forests today. Small stands of cabbage palm (*Livistona australis* – at Bilgola and Palm Beach), figs and other gulley dwelling mesophytes may be remnants of this older flora. However some scientists doubt that laterites necessarily form in a particular climate. They also feel that these soils could have formed continuously from the Jurassic and, in some cases, up to the present.

Walk south around the ironstone and along the beach to a low outcrop of peat overlying soft grey clay.

Stop 8. About 17 cm of peat overlies soft grey clay containing vertical carbonaceous roots. The peat and clay overlie the lateritic podzolic palaeosol. The carbon 14 age of the peat is 3980 ± 150 years (2030BC). Fossil pollen within the peat and clay record an interesting sequence of changing vegetation. The lowest clay was deposited in a lake fringed by she-oak *(Casuarina).* This was replaced by gums *(Eucalyptus),* then "ti-tree" *(Leptospermum, Melaleuca* and *Kunzea).* With further shallowing peat accumulated under a sedge *(Cyperaceae)* swamp. All these vegetation types can be seen on the New South Wales coast at present. Can you imagine what it was like? The present level of the peat does not necessarily indicate that the sea level was relatively higher than at present when it was formed. The depth to the water table (saturated soil) varies greatly from mean sea level. Why and how does it vary?

TURIMETTA HEAD

Park the cars in Narrabeen Park Parade overlooking Turimetta Beach. Walk down the bulldozed track to the northern end of the beach and up the low angled rock layers to a slightly elevated rock pedestal at the southern end of the cliff line. **Stop 1. From the pedestal** consider carefully the different sedimentary rock layers exposed in the whole length of the cliff. These were delta lobe sediments of the Newport Formation (figs. 1,2). The glistening quartz lithic sandstone in the middle distance was an old meandering stream deposit. It grades into levee deposits on the left and on the right has eroded into older sediments (as in fig. 5). Try to imagine this place in the Triassic; the low cliff of the cut bank, the gently sloping sandy point bar and the low mounded levee top. Point bars build out on the inside of meanders following the erosion of the outer or cut bank. Natural levees are formed where the rushing sand-laden waters of the flooded channel are slowed up against ponded water on the floodplain. Many modern levees are built up and strengthened by man to prevent flooding. Flood waters often break through natural and artificial levees and leave miniature delta deposits, called crevasse splays. Watch out for the other features depicted in fig. 5 as you proceed. The coarser channel-lag conglomerates and shale breccia of this channel may be seen (by the more energetic) where this channel deposit is exposed on the north facing wall of Turimetta Head. Shale breccia is formed by the undercutting and slumping of floodplain silts from the cut bank of the stream. Channel-lag conglomerates probably formed riffle bars between the meander bends where the stream was shallower and slower. The lower channel sandstone right at the point of Turimetta Head was probably an earlier distributary of the delta.

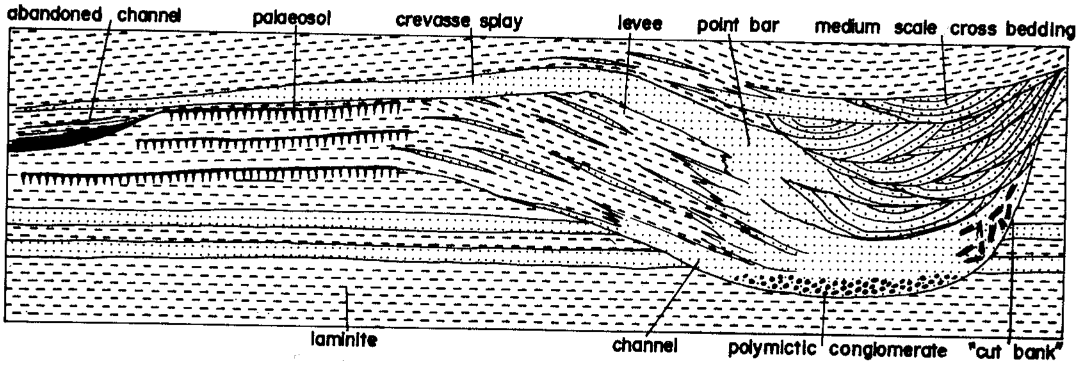

Figure 5. Idealized river sediments of the lower Newport Formation.

Ripple marks of several kinds are exposed on bedding planes around the pedestal. The direction of the wind or water flow can be deduced from asymmetrical ripples, which behave like miniature sand dunes. Symmetrical or "lumpy" ripples may be caused by surface waves in overlying water or by interference of subsequent currents from two different directions. A lot of the short more or less parallel markings on these bedding planes are prod, skip and tool marks of wood and small stones washed over the original sandy sediment. The less marked fine lineation of the bedding planes was formed in transition flow regime when the surface sand grains moved as a single unit with the fast smooth-flowing water. A set of large depressions on the pedestal are probably the tracks of a labyrinthodont (fig. 6). These are extinct lizard-like amphibians. Which way was it going?

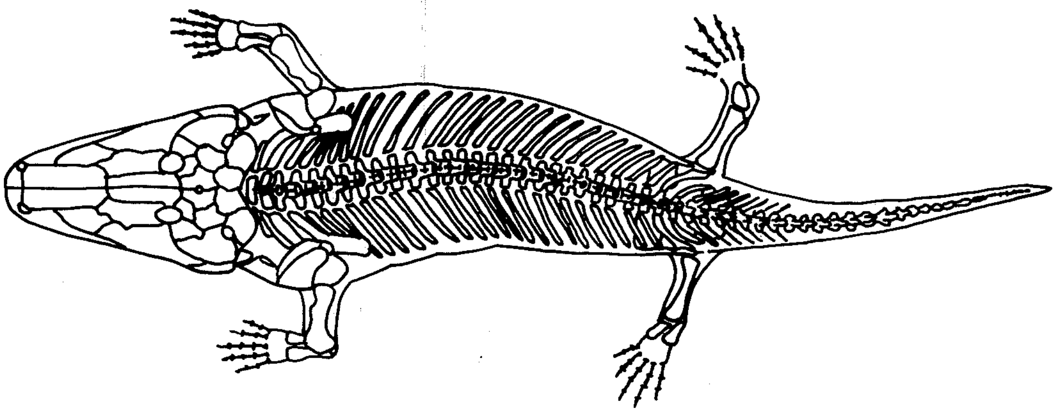

Figure 6. A reconstructed 2.25 m long labyrinthodont skeleton from St Peters brickpit near Sydney (after Watson).

A little above eye-level in the cliff nearby is an interesting forked carbonaceous layer. It could have been an old log stranded in the sandy stream bed. It could also have been a small hollow in which peat accumulation was interrupted at one end by a low sandstone dune (now a cross bed) before more peat was deposited (a seam split). Can you tell whether it is a log or seam split without defacing it?

Walk northwards over the rock platform for a few hundred metres.

Stop 2. At a small alcove in the cliff line there are two superimposed Triassic humic gley palaeosols (right side fig. 2). These are best inspected in the rock platform exposures near here.

Gley soils are characterised by largely bluish to greenish grey colour produced by organic matter and the anaerobic reduction of iron to the ferrous state in waterlogged or poorly drained conditions. Both palaeosols have a thick dark carbonaceous organic horizon. This is underlain by a grey clay A horizon and an irregularly red to purple mottled B horizon. Good examples of fossil carbonaceous roots are exposed in the rock platforms south of the alcove. These have a concertina outline due to compaction of the clay around the roots by the weight of overlying sediments. Some show a central carbonaceous vascular bundle and a thin carbonaceous epidermis separated by claystone replacing the decayed cortex. There are also some tubular burrows and sideritic clay filled holes. How would you explain these? The parent material of these palaeosols was a grey-green lithic sandstone like that at Long Reef.

Walk northwards for 100 m to a slightly elevated rock platform south of a large fallen rock.

Stop 3. The rock platform displays beautifully the organic horizon of one of these Triassic humic gley palaeosols. Much of the fossil plant material is very decayed and unrecognisable. However there are some seeds, fern-like fragments and a long pyritised log. These remains suggest a swamp woodland vegetation, probably a lowland equivalent and partly mixed with elements of the coniferous forest which grew on the red palaeosols at Long Reef. Where the clayey base of the organic horizon is exposed horsetails *(Neocalamites)* are locally abundant. These plants are ancient relatives of the modern *Equisetum* which thrives near lakes and streams. There is no living *Equisetum* in Australia. Its introduction is prohibited because it has proven a noxious weed in overseas waterways. Some species of *Equisetum* are superficially very similar to the cladodes (leafy stems) of the shrubby she-oak *(Casuarina distyla)* which is very common on top of this headland. It is possible that in the Triassic partially submerged *Neocalamites* thickets trapped sediment and organic matter as an initial stage in the ecological succession towards swamp woodland.

Shales low in the cliff here show strong spheroidal or onion skin weathering. These shales also contain fossil lycopod leaves *(Sigillariophyllum)* and cones *(Cylostrobus* fig. 12).

Continue northward.

Stop 4. Just south of Turimetta point the cliff face shows a good section of upper Narrabeen Group sedimentary rocks. The red claystones of the rock platform are the top of the Bald Hill Claystone. The Garie Formation can be arbitrarily mapped here by the lowest and highest grey-green lithic sandstone. In river and delta sediments it is often hard to draw precise boundaries between rock units. Where would you place the boundaries of the Garie Formation here? The Garie Formation includes some old palaeosols, shales with lycopod leaves *(Sigillariophyllum)* and cones *(Cylostrobus)* and a small lithic sandstone channel deposit. Overlying these are shales and glistening white quartz-lithic sandstones of the Newport Formation. Study the profile of the lower weathered-out sandstone and overlying siltstones; conglomerate and shale breccia, cross-bedded sandstone, siltstone, shale and finally a clay palaeosol. This sort of sequence, called a point bar cycle, is very common in sedimentary rocks laid down by rivers.

The shales and siltstones of the Newport Formation provide the more richly fossiliferous boulders on the rock platform. The most common fossils are fern-like leaves of *Dicroidium* (pronounced Dye-crow-iddy-um). *Dicroidium* belongs to an extinct plant group, the seed ferns or pteridosperms (fig. 7). These plants had some features of true ferns, conifers and cycads, but are quite distinct from all these modern plants. How? True fern fossils found here have a more delicate leaf without so much black coaly material. When found fertile, which is rarely, the true fern

Figure 7. Reconstruction of *Dicroidium zuberi;* leaf (black), pollen organ (left), pollen (upper inset), seed organ after shedding seeds (right) and seed (lower inset); one half natural size unless otherwise indicated (after specimens in the collection of the Geology Dept. University of New England).

fossils have many small spore sacs (sporangia) attached to the surface of the leaf. *Taeniopteris* leaves (similar to fig. 14) probably belonged to a further group of extinct plants allied to modern cycads. The venation of *Taeniopteris* is very simple. How does it differ from most modern angiosperm leaves? Fossil conifer shoots (fig. 8) found here may be the same species which grew on the red palaeosols at Long Reef. A pseudofossil found here has so fooled people in the past that it was even given a proper biological name (fig. 9). These were probably small plastic mud balls aggregated by local microbial activity and flattened and radially slickensided during compaction.

When collecting fossil leaf compressions it is usually only necessary to keep the side with the most black carbonaceous plant material. This is usually more attractive

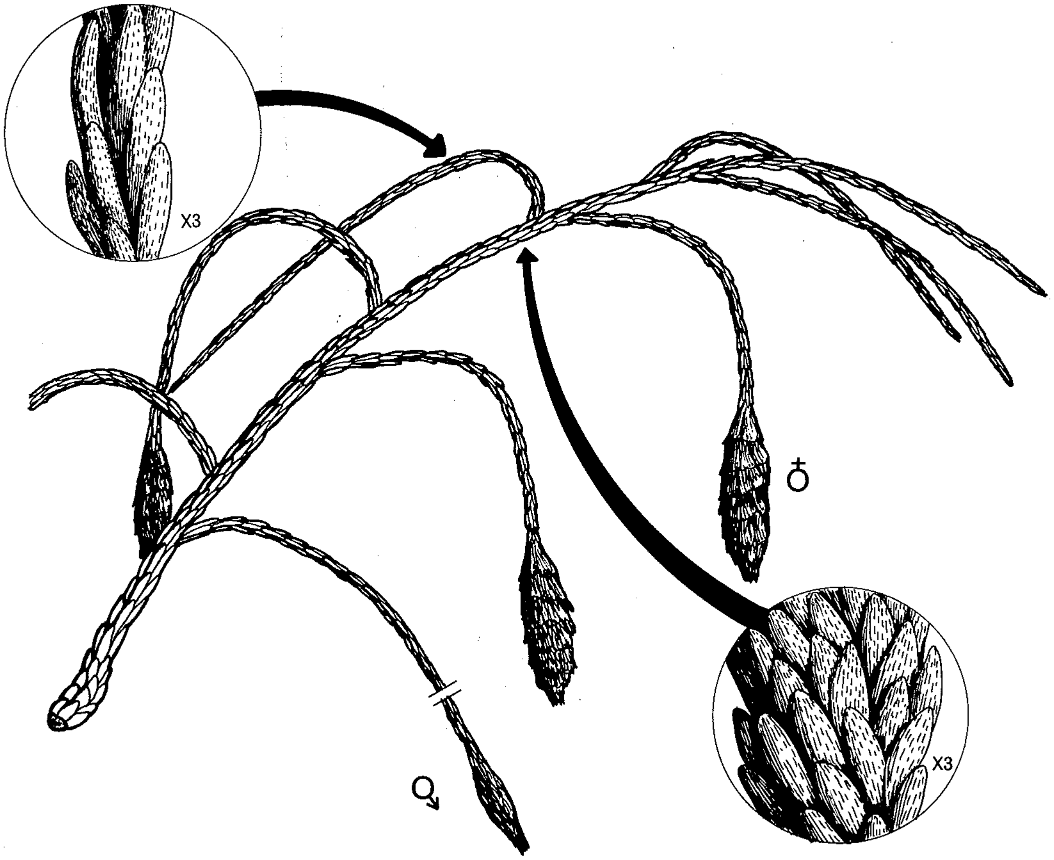

Figure 8. A reconstructed foliar spur of *Voltziopsis angusta;* natural size (after Townrow and specimens in the collection of the Geology Dept., University of New England).

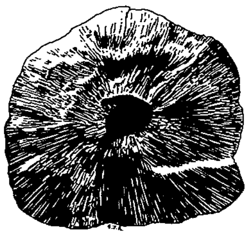

Figure 9. A *Guilielmites* concretion; natural size.

than the counterpart. The carbonaceous material can be treated chemically to show the epidermal cell outlines, stomates and hairs of the original plant. However fructifications may be difficult to interpret unless both sides are carefully saved.

NORTH AVALON

Park the car in a vacant lot off the east side of Marine Parade between North Avalon and Urara roads. Walk down the track towards the rock platform. Care may be needed over a few natural steps in interbedded sandstone and shale. Walk south across the large boulders of the rock platform to a large cave high in the cliff wall.

Stop 1. St Michaels cave was probably formed by the deep weathering of a post-Triassic dolerite dyke. Examine the dark material which has replaced the dyke in the roof. Some fragments of volcanic material have been found but this is largely a dark grey pebbly sand with some larger siltstone blocks and charcoal. Dolerite dykes exposed above sea level are commonly more deeply weathered than those on rock platforms, as at Long Reef. At cave level the walls are much wider than the original dyke, probably due to wave and wind erosion accompanied by rock fall. Can you think of other ways this cave and sedimentary dyke could have formed?

Stop 2. On the rock platform the old dyke line is a much larger fissure filled with large fallen blocks which are cemented by hard beach rock. Beach rock is shell grit firmly cemented by calcite. It may only take ten or twenty years to form. Some second world war planes which crash landed on sandy beaches of tropical islands are now firmly cemented in beach rock.

Try to work out the geological succession near here from fig. 10. On the low level of the rock platform and low in the cliff a palaeosol organic horizon contains abundant *Pleuromeia* stems (fig. 11). Some of the stems are preserved flattened lengthways, some as oval outlines of upright stems and there are also some pitted-looking root-bearing bases (rhizophores). The cone of *Pleuromeia* was probably *Cylostrobus* (fig. 12) which is not found here but is common in shales of the Newport Formation deposited in front of the old delta further south. *Pleuromeia* grew here as dense monospecific thickets in an interdistributary bay of the delta (figs. 13, 1, 2). How is *Pleuromeia* different from the well-known fossil *Lepidodendron,* forests of which formed the Carboniferous coal measures of Europe and North America? How does it differ from modern lycopods *(Lycopodium, Selaginella, Isoetes)*? For those not familiar with modern lycopods, *Lycopodium cernuum* is very common on the upper parts of a road cutting on Wakehurst Park-

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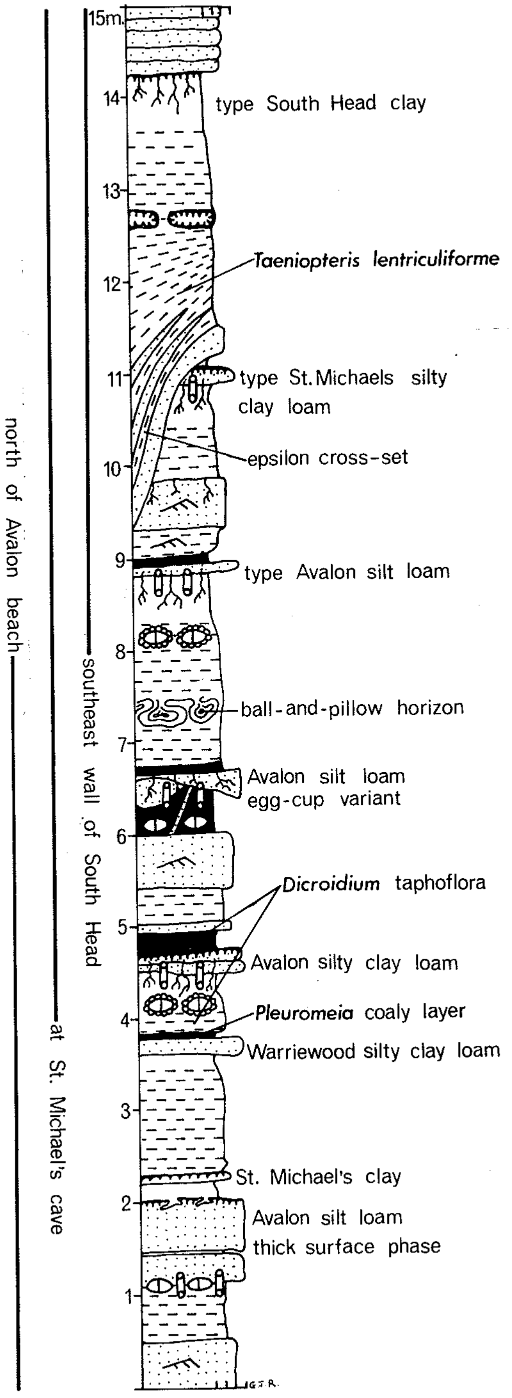
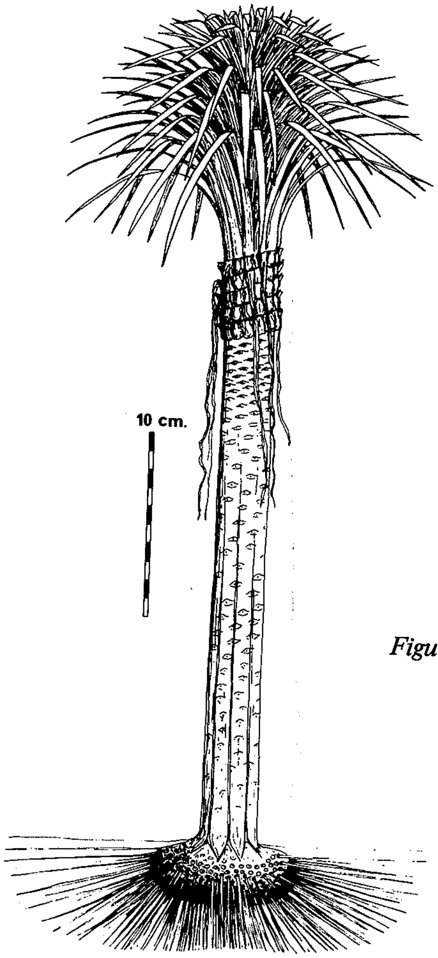


Figure 10. The sequence of palaeosols at North Avalon (from the *Journal of the Geological Society of Australia,* with permission).



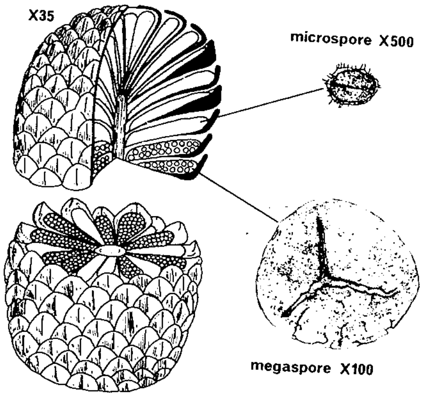


Figure 12. Reconstruction of *Cylostrobus sydneyensis* and its two kinds of spores; cone at natural size (from *Alcheringa,* with permission).

Figure 11. A reconstructed *Pleuromeia longicaulis* plant (from *Alcheringa*, with permission)

way just west of Deep Creek, Narrabeen.

The ball-and-pillow structures were probably formed by slumping of sandy layers into shaly layers when the sediments were soft and wet. This was possibly triggered by a slight earth tremor. The shaly layers within the pillows have weathered out in a honeycomb pattern.

Examine some of the immature and gleyed podzolic palaeosol A horizons in the rocks here (figs. 10, 1). The thin hard sandstones near the top of the profiles are similar to so called ganisters of coal measure sequences. They were probably silicified by plant opal from the *Dicroidium* flora. Egg-cup podzols are local thickenings of the sandy A horizons, presumably formed under individual long-lived trees. The common vertical sandstone tubules are probably old insect burrows in which sandy material from the A horizon has fallen down into the clayey B horizon. The siderite nodules were probably formed at the level of the old water table. What evidence can you see for these interpretations?

These palaeosols supported a *Dicroidium* heath association (fig. 2). The fossil leaves are thick and leathery and the palaeosols are also similar to those of modern heath lands. No large tree trunks can be seen and radiating root systems in the palaeosols are only small.

Walk northwards over the fallen boulders.

Stop 3. Examine the large boulders on the rock platform as you go. Even very large boulders may be moved about or disappear during severe storms.

Many of the sandstone boulders show good examples of honeycomb weathering. Try to work out the shape of the original sand dunes which formed the cross bedding exposed in several faces of the boulders. There are also good examples of shale breccia and conglomerate. The conglomerate consists of a variety of pebble types; red and green jasper, siderite nodules, vein quartz and various sedimentary and volcanic rocks. These were probably transported by streams all the way from the New England Fold Belt to the north. Fossil leaves found around here are predominantly *Taeniopteris lentriculiforme* (fig. 14).

100 m north of the track down to the rock platform there may be some large slabs covered by groups of radiating sandstone tubules. These are trace fossils (fig. 15). They generally protrude downwards from a sandy layer into a shaley layer (these slabs are upside down). Were they formed by crabs or worms feeding in a radiating pattern? Were they a ritual shovelling in a mating ceremony of fish? Or what?

A little further on, the rock platform exposes the siderite nodule horizon of a palaeosol in plan. Fossil roots penetrating the nodules are weathered out as small

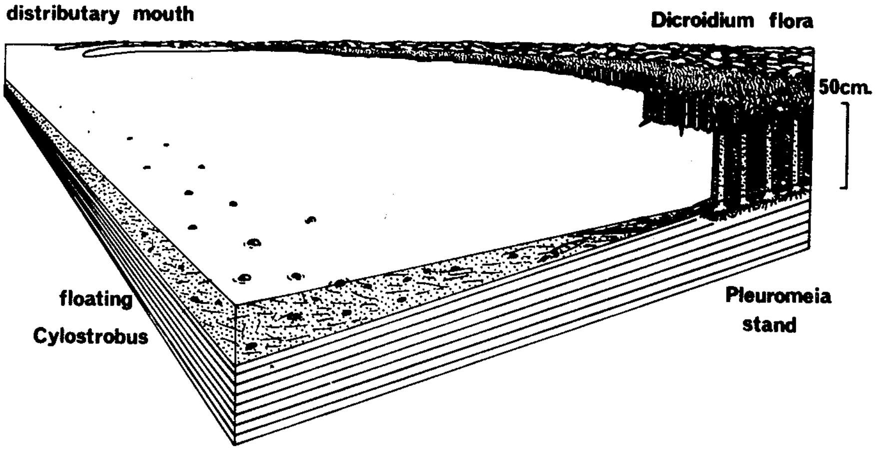


Figure 13. Reconstructed *Pleuromeia* meadows in an interdistributary bay of the Gosford delta (from *Alcheringa,* with permission).

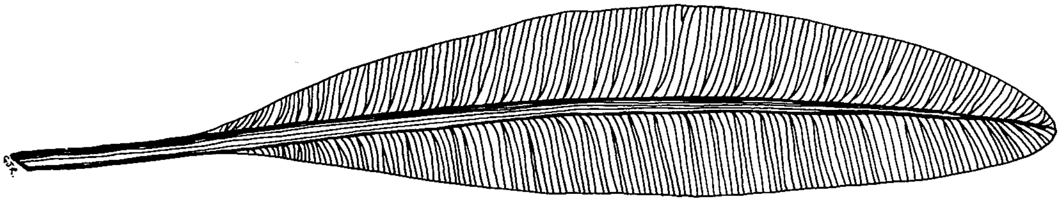


Figure 14. A leaf of *Taeniopteris lentriculiforme;* natural size (after Etheridge).

pits. Many of the nodules are joined to form a broad thin network. They could not have been transported like this. This and other lines of evidence indicate they formed in place.

Continue walking north to a thick shaley layer underneath an overhanging ledge of sandstone.

Stop 4. Two metres of shaley rock exposed here is part of an epsilon cross set. This name is from a classification of cross bedding types named by letters of the Greek alphabet. Epsilon cross bedding generally dips at a low angle and is made up of alternating beds of sandstone and shale. These are quite common in the lower Newport Formation where they probably formed natural levees.

On top of the epsilon cross set a grey clay palaeosol has developed. It shows

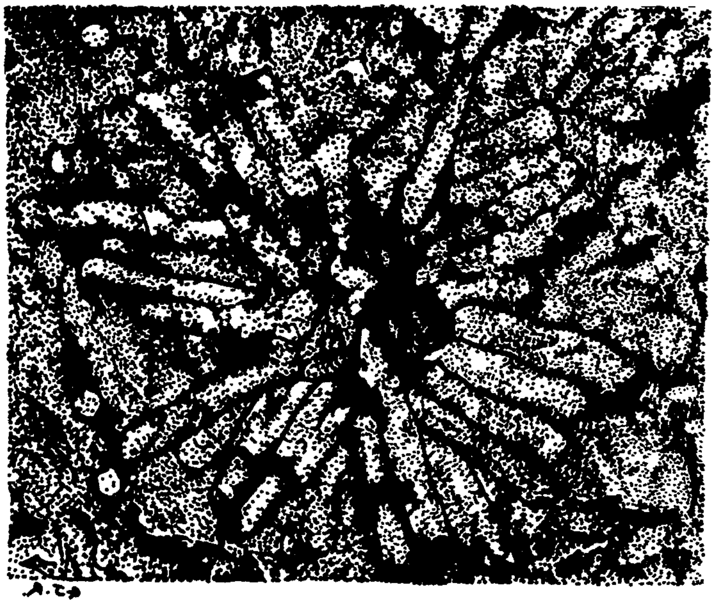


Figure 15. The trace fossil *Subglockeria;* natural size.

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well defined rough faced blocky soil peds and carbonaceous roots.

Walk back up the track towards the cars.

Stop 5. Just above a short climb over interbedded sandstone and shale the rocks and soils are variably leached and red mottled. This is related to the lateritic podzolic palaeosol, seen more clearly at Long Reef.

Walk north along the top of the cliff line, then follow a track to the top of South Head.

Stop 6. The sandstone benches around the trig station belong to the Hawkesbury Sandstone which overlies the Newport Formation. These sandstones are generally whiter because they contain less clay and rock fragments than the Newport Formation sandstones. The largest particles are scattered vein quartz up to a few centimetres round. How does this compare with conglomerate in the Newport Formation? Cross bedding in the Hawkesbury Sandstone is generally larger than in the Newport Formation. The Hawkesbury Sandstone was probably deposited by a broad river with several channels. The size of its sedimentary structures indicates that it was large and powerful, at least when in flood. Some of the structures are idealised in fig. 16. How many of these can you locate? In furious or double cross bedding the sets of cross strata as well as the individual layers dip at an angle. Antidunes are formed when the water is flowing so fast and shallow over sand that the surface waves break into foam and move upstream. Convolute lamination may be formed by the slumping of wet sand. At the bottom of large cross sets this and small ripple marks are also formed by turbulent eddies in the lee of the original sand dune. These structures are not common here, but may be seen in the sea cliffs of the southern beaches and in road cuttings around Sydney and on the Newcastle Expressway. Where would you place the boundary between the Newport Formation sandstones and the Hawkesbury Sandstone in the cliffs here?

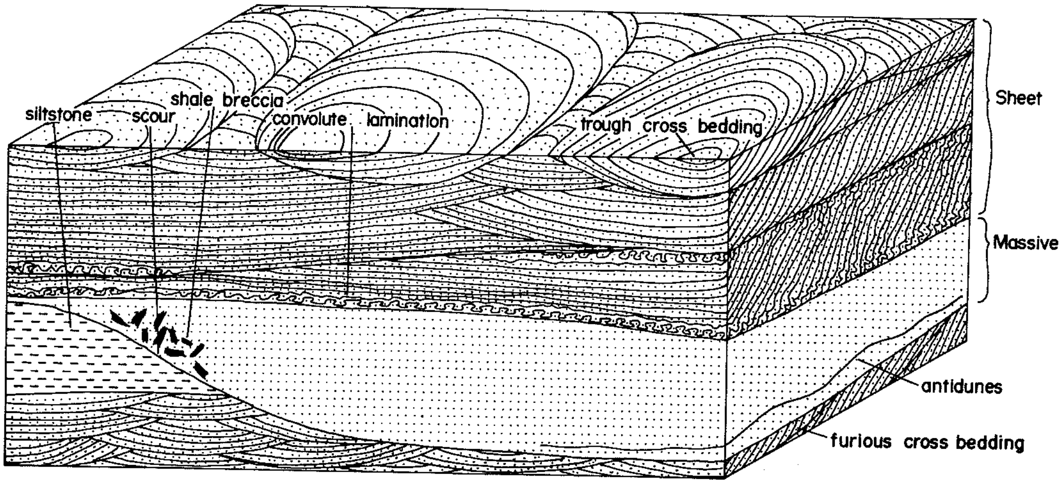

Figure 16. Idealized river sediments of the Hawkesbury Sandstone.

This headland supports some of our more colourful native flowering shrubs. The sandy soils developed on the Hawkesbury Sandstone are difficult for plants because they are low in nutrients and do not hold water well. However nature has responded with one of the most beautiful and diverse floras in Australia, with about 2,000 indigenous species. This interesting flora can be further studied in the Ku-ring-gai Chase National Park and at several commercial native gardens nearby.

The large bay visible to the west and north is Pittwater; the southern arm of Broken Bay. This estuary along with Port Jackson and Botany Bay were formed by the drowning of old river valleys by the sea. Boreholes and studies of the way seismic (shock) waves are reflected from the bottom have revealed old river sediments and drainage patterns at depth. They are not strictly rias, as this term should be confined to simple re-entrant bays perpendicular to the coastline.

FURTHER READING

This list is largely the most recent works on relevant topics from which further references may be gained. It does not include standard science textbooks.

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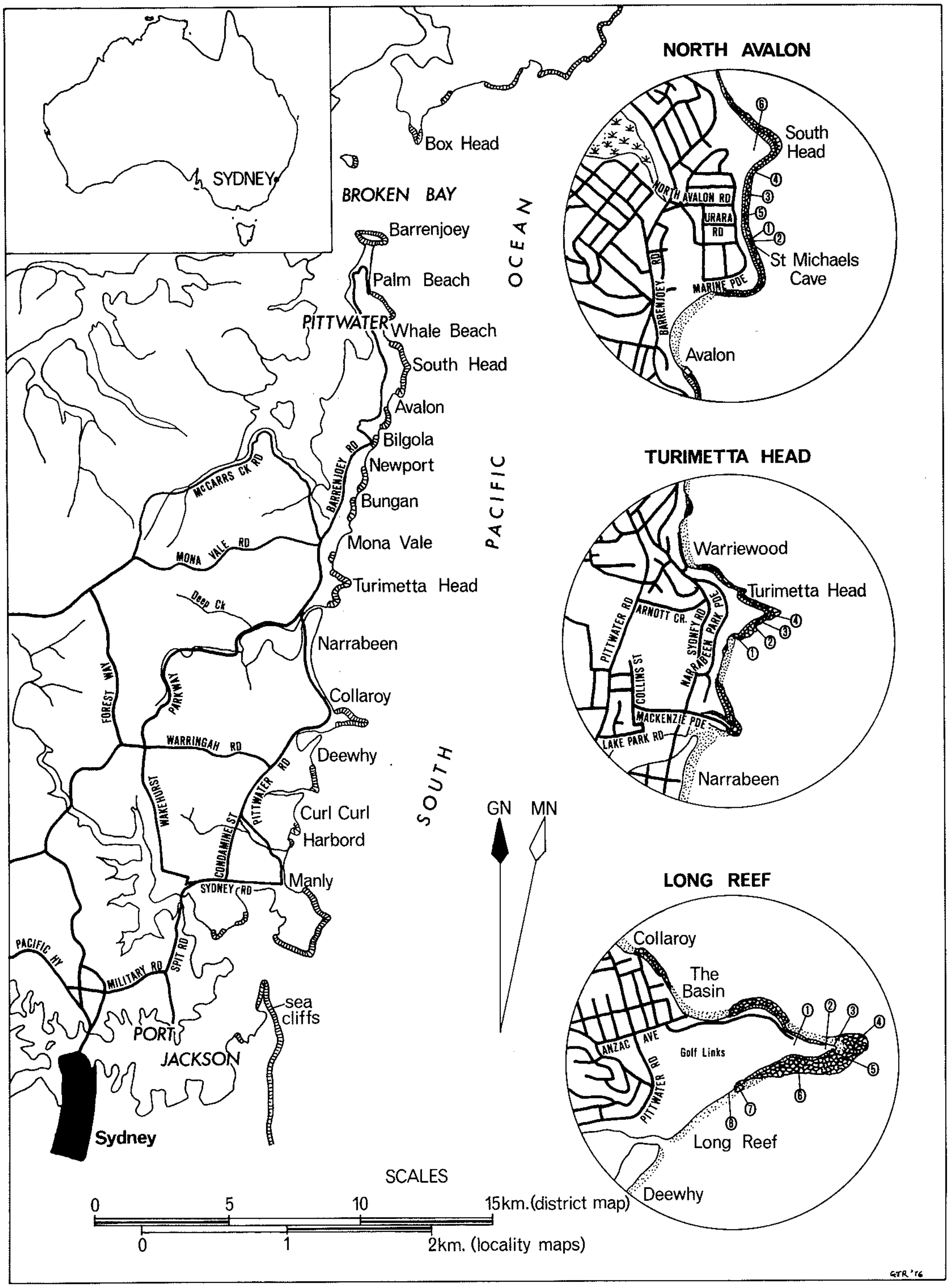

Figure 17. Location of the sea cliffs and excursion stops, north of Sydney.