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EVOLUTION OF THE OTWAY COAST, AUSTRALIA, FROM THE LAST INTERGLACIAL TO THE PRESENT

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ABSTRACT: The Otway Ranges consist of uplifted non-marine Lower Cretaceous arkoses (greywackes) and siltstones. The Southern Ocean swell supplies a strong energy input, which is concentrated within a tidal range of 1.52-1.75 m. The Last Interglacial sea cut platforms and built boulder beds, which were covered with colluvium when the sea retreated during the Last Glacial. The return of the sea in the Holocene cut the platforms existing now, and produced the modern generation of boulder beds. Some quantified data are provided for the rocks and their rates of erosion. These have engineering applications. When the sea cuts away the toe of the steep coastal slope, it creates instability and slips occur. The same happens when the toe is removed in roadmaking. The history of a slip at Eastern View from the Last Interglacial to the present is outlined.

ORIGIN OF OTWAY ROCKS

'A study of change as opposed to a description . . . . . . events of change rather than events in change'.
(A. R. H. Baker, 1972)

Events that occurred over 100 million years ago when Australia was still attached to Antarctica (Gill 1975) have determined important aspects of the geochemistry, lithology and structure of the Otway rocks, influencing how they react in the present shoreline situation. In the Lower Cretaceous over 2 km thickness of sediments were laid down rapidly in a basin or rift valley to which the sea had no access. These sediments are highly feldspathic because: (i) Derived from feldspar-rich rocks, e.g. granodiorite, pieces of which occur in the sediments. (ii) Buried rapidly in the sinking basin, so permitting but minimal weathering, as also did (iii). The low ambient temperatures (probably seasonal freezing).

The flatland ecology was dominated by lakes and swamps. No paleosol has been found in the Otways. The sediments were of two main types:

1. Sand-sized, yielding the present arkose or greywacke (the classification depends on the definition accepted for these terms). The amount of arkose falls off northwards, suggesting a source to the south.
2. Silt-sized, giving the present siltstone, which on the present coast reacts quite differently from the arkose.

These two lithic types represent two energy levels. Both are stratified, with the higher energy beds having current bedding. Fern-conifer forests covered land surfaces and swamps, yielding a rich record of fossil plants, which in places form coal. Animal fossils are rare, especially vertebrates, which reflects the nature of the environment (Waldman 1971, Gill 1972a). According to the geochemistry of the environment, concentrations of calcium carbonates, iron carbonates and such occurred while the rocks were still horizontal. These produced the characteristic concretions of the Otway Group that presently influence the course of marine erosion on parts of the coast.

This Otway Basin system was terminated by the uplift of the rocks into a massive elongate dome (Medwell 1971) with marginal folds and faults accompanied by much jointing (Pl. 2, fig. 1), except where large lenses of arkose proved too competent to allow these to develop very far. The earth movements concerned appear to be part of a series that led to the separation of Australia from Antarctica.

A journey along the coast gives the impression that the arkose completely dominates the stratigraphic succession, but bores have proved otherwise (Edwards & Baker, 1943). The reason is that the siltstone is eroded at twice the rate of the arkose (Gill 1973a), so that the former occupies the negative geomorphic structures such as the valleys and bays, and is therefore largely out of sight. A siltstone quite different from the usual one occurs at Cape Otway. It is darker, harder, and does not decrepitate, forming coastal platforms more like those of arkose. Dr. E. R. Segnit kindly examined slides of this rock, and pointed out that it is predominantly quartzose, and has 'feldspar (near albite) and

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PLATE 1

Aerial view of Otway coast from Big Hill Creek (top) north-east towards Point Castries (Grassy Creek). The Great Ocean Road follows high ground to Big Hill Creek, then continues along beach in front of Cathedral Rock (top of photo) towards Cross Springs and Lorne. The view spans about 1.5 km of coast. Note shore platforms, often with beaches. (Keith Cecil photo.)

chlorite, with some calcite and mica'. It lacks cleavage. The formation is separated from the normal Otway rocks by a fault; it is considerably faulted, jointed, and secondarily infilled with calcite. Fossils to check its age were sought but only fossil wood too decomposed for identification and a seam of coal about 1 cm thick were found.

PALAEOECOLOGY

The extensive flatland, with its accumulation of km^3 of sediments in the sinking basin, infers an extensive highland as source. The abundant feldspar infers considerable outcrops within that highland of feldspar-rich rocks, such as granodiorite. To provide transport of such great quantities of sediment from the highland to the lowland, and to form such extensive lakes, a high effective rainfall must have existed along with large rivers.

Australia was then still attached to Antarctica, and the palaeomagnetic measurements show that the south pole was south-east of Tasmania (Wellman, McElhinney & McDougall 1969). Palaeontologic and oxygen isotope evidence show that the temperature gradient moved from very cold in the south-east to tropical in the north-west of Australia (Gill 1972a). The presence of extensive forests is consistent with a cold but not frigid climate. The occurrence of drop pebbles, of masses of unsorted gravel, of rock slabs up to many metres in diameter with sharp edges and broken pieces floating in a matrix of different rock, indicate ice transport from seasonal freezing followed by thawing. Waldman (1971) has so interpreted varves at Koonwarra in South Gippsland which have plants, insects and fish but without bioturbation. A climate with seasonal freezing would reduce weathering, and so help to preserve the high percentage of feldspar; it would also depress evaporation and so make the rainfall more effective.

I have seen no paleosols in the Otways, no stumps in position of growth (except one in a transported block, which is not relevant here) and no tree trunks, although all of these occur in rocks of the same age in Gippsland. These facts are consistent with a greater development of lakes in the Otway region of the Lower Cretaceous, and of swamps in the South Gippsland region. This could account for the development of coal in economic quantities in South Gippsland but not in the Otways.

The widespread occurrence of siderite in the Otway region, but not (as far as I know) in the Gippsland region, is of ecologic significance in that this mineral occurs only where the pH is about neutral and the Eh just below 0.0. Probably the greater amount of vegetal matter (as shown by the coal) in South Gippsland kept the pH too low for siderite to form.

PRESENT OTWAY COAST

'The problem of reconciling both aspects of time – as setting and as sequence'. (A. R. H. Baker, 1972)

As the Otway Range is a horst, the hills come down to the sea, forming cliffed headlands and extensive shore platforms (Pl. 1). Sandy beaches occur in bay heads where the larger rivers debouch. The spring tidal range increases from west to east, viz. 1.52 m at Apollo Bay to 1.75 m at Lorne. Siltstone shore platforms consist of a low ramp graded to L.W.L. Arkose platforms consist of intertidal and supratidal planated areas with irregularities caused by ramparts (Gill 1972b) and 'islands' of higher rock often steep-sided or stepped (Jutson 1949, 1954). Shore platforms are well developed because:

1. The south-west swell provides a high energy input.
2. The energy is concentrated in a small tidal range.
3. The Flandrian Transgression reached its peak about 6,000 years ago in Australia (Thom & Chappell 1975) thus providing a greater time for formation than in some other areas which had the Holocene sea level peak at 3,500 years or even later.

Where the spurs transect the coast, two-storied cliffs usually occur. Indeed the hinterland is an important aspect of coastal organization because its elevation can determine whether cliffing occurs or not, and so affect

(a) The rate of coastal retrogradation

(b) The degree of weathering of the rocks sectioned by the sea, i.e. if the sea is below the weathered zone. On a low coastline the sea sections the weathered zone. But on the Otway coast most of the platforms are in unweathered rocks with oxidation only in the large joint planes. Local weathering is usually due to the oxidation of pyrite, which occurs both as nodules and as plates in open joint planes.

(c) The amount of rainfall. The Otway Ranges are a rain trap, with much water available to erode sediments and to transport them.

Four unusual features of the Otway coast are:

1. *Tafoni,* both honeycomb weathering (on sloping to vertical and overhang surfaces usually), and cavitation weathering (recesses in cliffs and such). Honeycomb formation can occur with exceptional rapidity in Otway arkose in that it has developed in sea walls built of this rock in 1943 and 1949 respectively.

2. *Concretions:* These are cemented by calcite, siderite and siderite/ankerite. Some occur in heavy mineral bands (which oxidise to limonite). Nodules of pyrite (which oxidises to goethite) also occur. See Gill, Segnit and McNeill 1977.

3. *Boulder formations:* Significant accumulations of boulders occur at many places. There is some correlation between the occurrence of rivers and the incidence

of boulder beds, showing that the rivers are a source of supply. Boulder ramps occur in the following situations: (a) At the back of present beaches and platforms, usually in a trap consisting of a jutting headland or smaller rock mass (Gill 1973b, Pl. 6).
(b) In back beach locations, where they are covered with sand capped by a thin soil and vegetation (Gill 1972b, Fig. 3). (c) In ramps now emerged and vegetated, but containing shells (Gill 1972d, Figs. 10-11). (d) In Last Interglacial boulder ramps on emerged shore platforms, sometimes weathered, and often covered with colluvium capped by soil (Gill 1972d, Figs. 13-14, Plates 2-3).
4. *Ramparts:* These are explained as a function of marine differential erosion (Gill 1972b).

LAST INTERGLACIAL COAST

The shaping of the coast during the Last Interglacial appreciably influences the development of the present coast, since in all coastal evolution there are marked inheritance factors. The best recorded past shoreline in Australia (and indeed in the world) is that of about 125,000 years ago, which in stable areas stands at about 7.5 m above the present. On the exceptionally stable coast to the west at Warrnambool, where even the Miocene marine strata are still horizontal, this shoreline stands at 7.5 m, and can be traced for long distances along the coast of Western Victoria. It has been traced through to the Otways where there are numerous emerged shore platforms and boulder beds at approximately this elevation. On the Otway coast from Eastern View to Apollo Bay 19 such sites are listed (Gill 1974) and others are known to the author, e.g. from the Parker River, Cape Otway and Point Flinders areas.

The platforms on the Bass Strait part of the Otway coast are usually covered with colluvium which can be as much as 20 m thick. The colluvium is capped by a dark grey to black sandy loam up to 0.5 m thick. The colluvium is Last Glacial because it accumulated after the retreat of the Last Interglacial sea.

An example of emerged platform, boulder bed and colluvium is now described from the long roadcut on the Ocean Road on the north-east side of the Cumberland River (Pl. 2 and 3). Part of this section fronts the ocean and part the small estuary of the Cumberland River. The roadcut is 3 to 21 m high, and descends slowly from the Lorne end to the river end, so that the section progressively passes through the fossil pebble bed, and then the platform with pebble bed above. The surveyed section is about 366 m long and finishes at the edge of the concrete ford where the old road crossed the river. In the middle of the section the road turns into the estuary, and at this point bedrock rises through the section; it is a small headland or a former rock stack. The total fall of the section line is 21.5 m. As the energies on the river front are less than those on the ocean front, the boulders there do not reach so large a diameter. The Cumberland River boulder bed is the longest seen so far, and as it covers various lithologies (arkose in thin and thick beds, and siltstone) and two environments (open coast and estuary), it can be deduced that the Last Interglacial sea made its impress on the shore in much the same way as does the modern sea. There is variation of platform height and lithology as on the existing coast. Taking this into account, the emerged platform is of the order of 7.5 m above the present ones. Numerous platforms occur at about 4 m and some near Warrnambool have *Ninella torquata,* showing they are Last Interglacial (Baker & Gill 1957, Gill & Amin 1975). Since the platforms were formed, river channels have been incised below sea level, showing that these platforms are older than Last Glacial. Gill and Amin (1975) dated such platforms at Sandy Bay as about 110,000 years old, and interpreted

PLATE 2

FIG. 1—Coast south-west of Boggaley Creek, south-west of Lorne. Note strong jointing of arkose shore platform and its effect on geomorphology. The platform continues under the beach. On the left, at the foot of the cliff is a miniature embayment with vegetated deposits of boulders, shells and calcarenite. The deposit is a few hundred years old, but is now being eroded by the sea.

FIG. 2—Road cut facing sea on north-east side of mouth of Cumberland River. Note (a) 3 m of Last Interglacial shoreline boulder bed covered by (b), over 1 m of fine colluvium with angular rock fragments, and covered in turn by (c) a thick bed of colluvium with large angular blocks. At the top is fine colluvium (d) and again with some rounded boulders, apparently derived from a higher shoreline. A uniform sandy loam (e) covers the colluvium. Height of section above road is 21 m.

FIG. 3—Close up view of boulder bed at foot of section shown in Fig. 2. The seaward facing section has boulders up to 1 m diameter, which is much larger than the maximum size for the bed facing the estuary, because of higher energy status.


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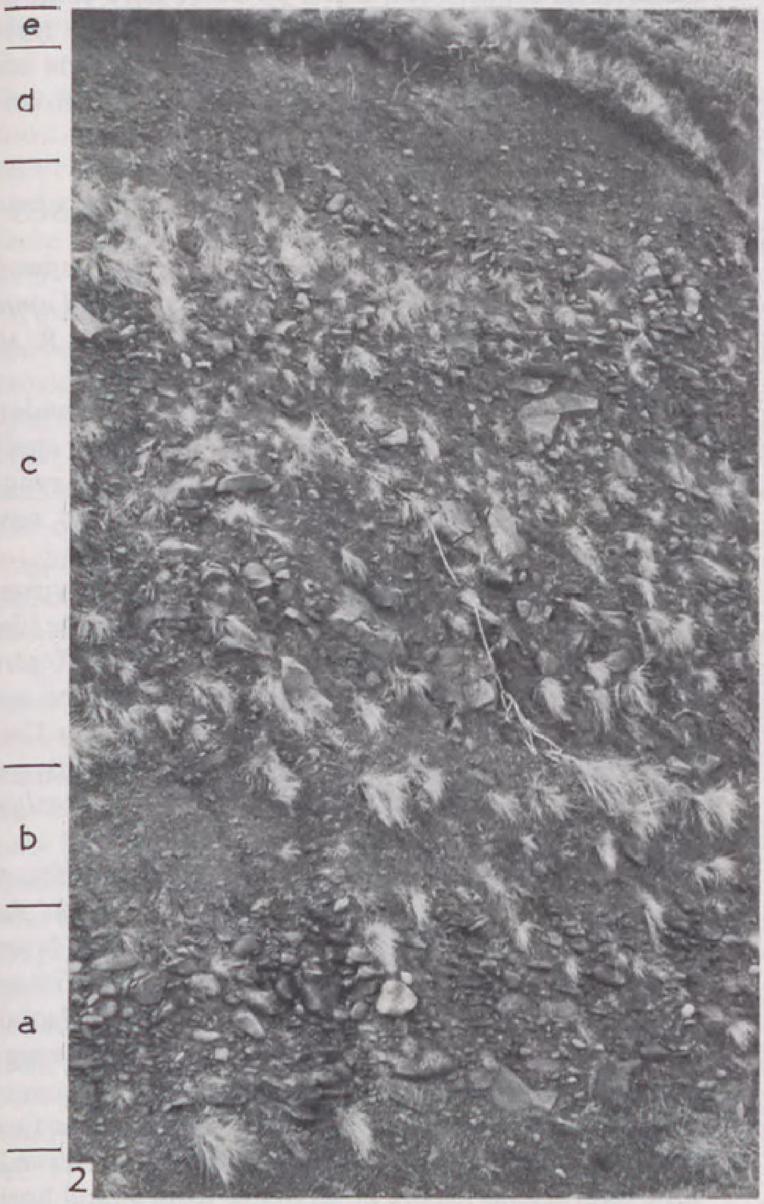
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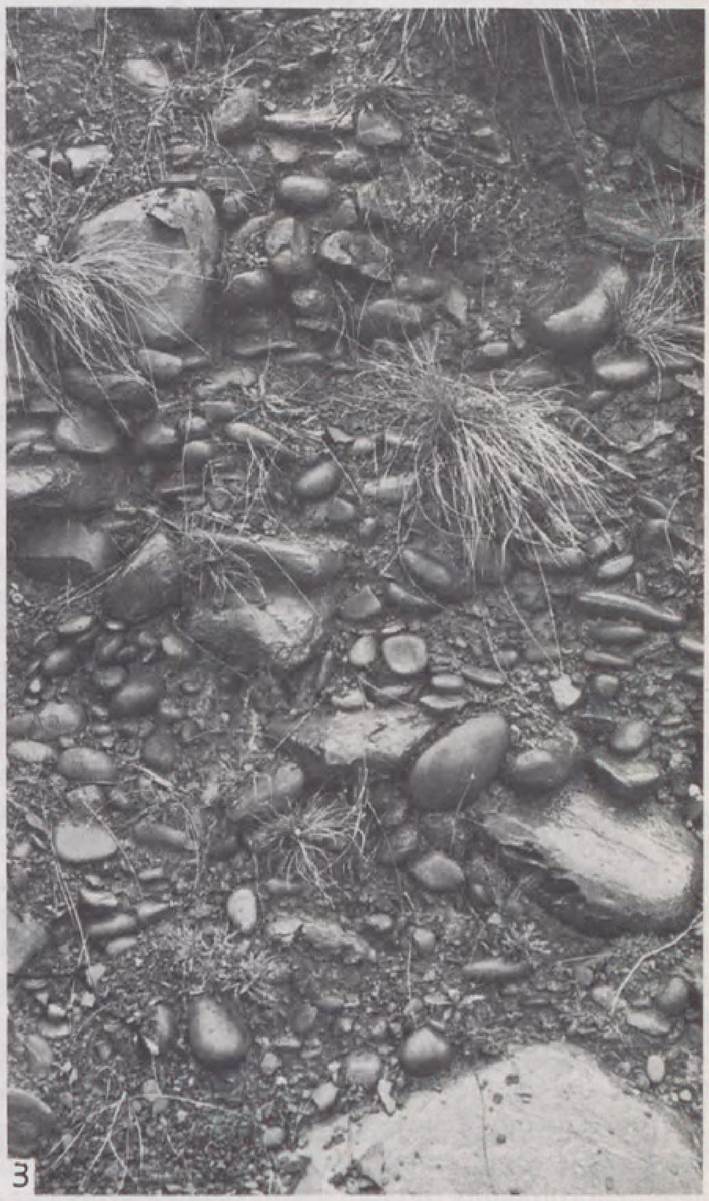
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them as a stage in the retreat of the Last Interglacial sea.

CHRONOLOGY

The chronology of the platforms has been investigated by three approaches:

1. *Eustasy:* The platforms and associated deposits are emerged beyond reach of the present waves, yet are related to the present coast and constitute the previous major cycle. After this shoreline was established, the sea retreated below the present level, so that river channels were cut deep below it.

2. *Stratigraphy:* The Holocene shorelines contain carbonate shells whereby they can be dated. They are considerably younger than the emerged platforms and boulder beds from which all carbonate has been leached, except in the Cape Otway area where they are covered with aeolianite. It is hoped eventually that shells suitable for U/Th assay will be found under this formation. The aeolianite is immature, but with a mature terra rossa at the surface, now commonly eroded to reveal the calcrete B horizon. The immaturity of the aeolianite capped with a mature terra rossa are the characteristics of the Last Interglacial aeolianite at Warrnambool (Dennington Sand) which has been dated at 125,000 years (Gill 1967).

3. *Extrapolated chronometry:* The series of emerged platforms under discussion can be traced from Port Fairy near Warrnambool round the Otway coast to Eastern View at approximately the same level. At Port Fairy this platform has been dated by U/Th at 125,000 years (Gill 1967), and also proved to be beyond the range of radiocarbon dating. The continuity of this shoreline at about the same level round the Otway coast shows that little or no tectonic movement has occurred in that period of time.

EVOLUTION OF THE OTWAY COAST

The Great Ocean Road (Pl. 1) provides an excellent, more or less continuous section of the coastal rocks from Eastern View to Apollo Bay. This reveals the great quantity of Last Glacial colluvium covering this emerged shoreline and filling in old gullies (Pl. 2, fig. 2). From this section three processes in the evolution of this coast since the Last Interglacial can be inferred:

1. The terracing of the steep terrain by the Last Interglacial sea at about 7.5 m above present sea level, and its retreat (probably through a 4 m stage) leaving elatforms and boulder beds.

2. The retreat of the sea far out on the relatively flat continental shelf during the Last Glacial, leaving the old shorelines as part of the terrestrial terrain. The emerged shore face had been weakened because the toe of the steep slopes was cut away. Sub-aerial agencies operated to re-establish stability by combing down the coastal face, so that colluvium covered platforms and boulder beds, filling in also the coastal gullies.

3. From 20,000 to 6,000 years ago the sea was advancing back over the plain of the emerged continental shelf (the Flandrian Transgression), and in the subsequent comparative stillstand has cut the present platforms and cliffs. At the same time a soil was forming on the colluvial slopes. In the past 6,000 years platforms and cliffs have been cut, channels have dissected the platforms and new boulder beds have accumulated. Work has also been done on the boulder budget. The rivers have delivered new boulders to the coast. Erosion has caused some to be inherited from the Last Interglacial deposits (Pl. 2 and 3). Some have come as concretions eroded out of the cliffs, and some have been carried below sea level where they become covered with marine growth and are no longer active.

QUANTIFICATION OF COASTAL PROCESSES

'To a considerable extent, advances in the understanding of processes shaping spatial patterns depend upon our being able to measure these processes.' (A. R. H. Baker, 1972).

Quantification has done more to increase understanding of coastal processes than any other study method. It makes thinking precise, narrows the range of possible interpretations, and itself prompts new ideas.

1. *Rates of retrogradation:* In the common environment of west Victorian climate and marine regime, the mean rates of retrogradation achieved in four different rock types during the past 6,000 years since the sea came to its present level are (Gill 1973a): Lower Cretaceous arkose 0.9 cm/yr; Lower Cretaceous siltstone 1.8 cm/yr; Last Interglacial aeolianite 4.0 cm/yr; Penultimate Glacial basalt 0.

These figures show that we deal with quite different kinds of coast, and quite different profile ages. An Otway siltstone profile changes 100 per cent faster than an arkose one. On the other hand, the profile on the basalt is the same as for the Last Interglacial; erosion has occurred in channels and other high energy areas, but the overall geometry is unchanged because the original basalt flow profile is still there and surface features of the flow (such as tumuli) are still preserved. Last Interglacial fossils lie in many vertical and horizontal joints in the supratidal zone. By contrast, if the average aeolianite platform is 20 m wide, then in the past 6,000 years twelve such platforms have been formed and all destroyed except the existing one, and this is only 500 years old. Present platforms are of course in all stages of evolution, but the foregoing figures give the scale of change. No ancient features are retained on existing aeolianite platforms; they are too young. However, it may transpire that the small differences that do remain are significant, i.e. they may record recent small oscillations of sea level.

2. *Erosion rates:* On March 8, 1971, the arkose ramparts on the south-west side of the mouth of St. George River were surveyed, and yellow oil paint discs about 5 cm in diameter were painted for control on three high points, viz. the top of the highest rampart at 4.7 m above L.W.L. [*x*], the top of a lower rampart behind it at 3.9 m [*y*], and the top of a large boulder on the ramp of debris from roadmaking at 4.1 m [*z*]. This section was published (Gill 1972b, Fig. 5). A year later (March 11) I was surprised to discover that while discs *y* and *z* showed no change, there was a noticeable reduction of the arkose surface at disc *x* on the south side, although this was the highest outcrop and so presumably the most resistant bed. By November 6, 1973, disc *x* was reduced to a series of patches, and reduction of rock surface had occurred all round the disc. By this time there was also some rock reduction on one side of disc *y*. By May 19, 1975, disc *x* was reduced to one irregular patch 2 x 1.2 cm, and the maximum reduction of surface was 3 mm. No site would receive maximum erosion all the time since the Flandrian peak 6,000 years ago, but if it did, the reduction would be of the order of 4.5 m! This is sufficient to show that a considerable reduction of rock surfaces has occurred. At the end of this four years of observation disc *z* was still bright. This indicates that the reduction of the paint and surrounding rock was essentially a function of erosion and not weathering.

In 1961 a cut was made through the supratidal platform north-east of Stony Creek, Lorne, to insert a sewer outlet. It was concreted over level with the platform. A pool with boulders in it beside the outlet but behind the rampart was cemented over, but has now been broken up, and pieces of rock and concrete widely distributed. In the vicinity of the cut, and also near Stony Creek where access was gained by trucks to the platform, blobs of concrete were left. Erosion since 1961 has reduced the surrounding platform so that the concrete stands up like miniature mesas. In this instance wear has increased by the constriction of swash between the mesas. The amount of wear varies, but the maximum is the surprising amount of 2.5 cm. Also survey marks cut in the platform were considerably diminished after one year, so much so that they were difficult to find.

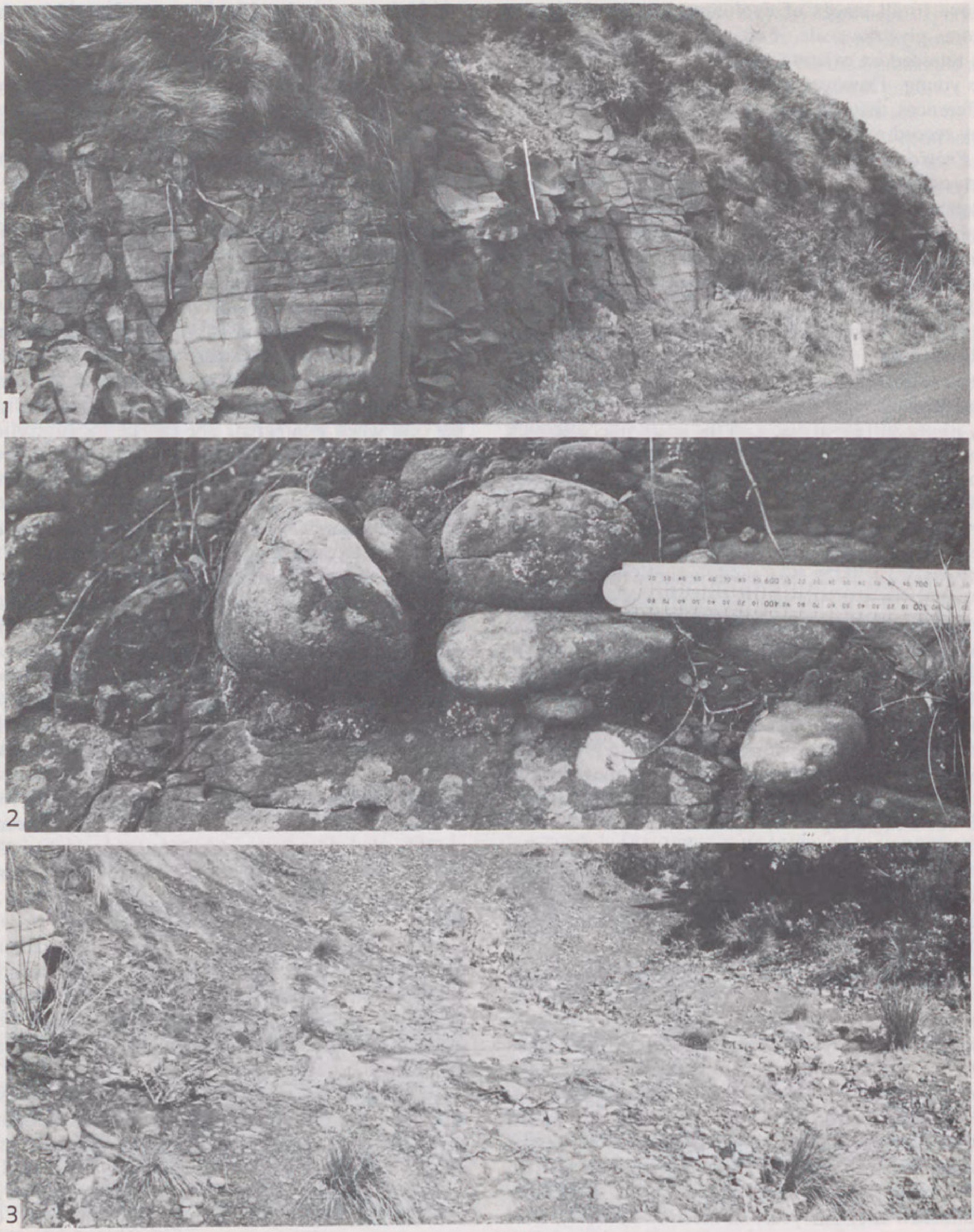
These results show that on exposed sites arkose abrasion is considerable, but very variable. Thus it would be imprudent to propose that existing exposed Otway supratidal platforms preserve the height of a mid-Holocene sea level, unless specific evidence had proved it. Nevertheless, they could be relics of such platforms now reduced in height.

3. *Rate of honeycomb formation:* That this process can take place more rapidly than previously known is demonstrated by two arkose sea walls built in different areas (but in the splash zone) in 1943 and 1949, and now having quite extensive honeycomb (tafoni) on them (Pl. 4, Fig. 3).

4. *Lithology:* Edwards and Baker (1943) record that 60-70 per cent of the Otway rocks are arkose, and although thick beds are rare, the thickest known is 122 m. The mineral grains are mostly 0.25-0.5 mm diameter. The arkose consists of 10-15 per cent quartz, and 23-35 per cent feldspar, i.e. 2-2.5 times more abundant. This is one reason why the rock has a high erosion rate. The porosity is 2 per cent when fresh, 10 per cent when weathered. The calcareous concretions are 25-49.3 per cent carbonate, but the matrix has only a few per cent. The siltstones have about 33 per cent kaolinite.

5. *Rates of marine quarrying and plucking:* The degree to which this occurs depends on the energy of the sea at the site of the process, and the frequency of the bedding planes, joints and faults that facilitate removal. Quarried blocks fall into channels, over the platform edge clifflet, or are thrown on to the platform and moved to the back, whence they usually find their way into a channel. Plucked blocks are lifted out of the surface of the platform, and therefore follow a similar route. These blocks in transit erode the platform, and sometimes the cliff also. During storms, blocks from the intertidal zone are thrown up on to platforms from time to time. These 'rocks out of place' can be recognised by their biota, e.g. calcareous worm tubes (Gill 1972c). Blocks with abraded honeycomb and worm tubes originated in the spray zone, lay between M.S.L. and L.W.L., then were hurled up to the platform. Oxidation/reduction patterns assist tracing the journey of such blocks; also they can be labelled with concretions when they come from a bed with such structures. Blocks from roadmaking are usually fully oxidised, and are unmistakable when they have marks pierced by a jackhammer!

On the platform south-west of Point Sturt, plucked blocks were weighed and it was estimated that since the Flandrian Transgression 300 tons of such material had been removed from that platform (Gill 1971). The weight of quarried rocks would be many times larger because the blocks are usually much heavier. On January 21, 1972, I observed that a block had been quarried from the south-west edge of the supratidal platform south-west of Point Sturt, and had been carried 2 m into an intertidal position. The volume of this arkose was about 0.5 m^3 and so weighed about a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tonne. On November 6, 1973, the block was in the channel, abrading and being abraded. The freshly exposed area from which the block came was occupied by young limpets at an intensity of about 300 per m^2. If for the 6,000 years since the Flandrian Transgression one such block on the average was quarried each year, then 6,000 tonnes of rock that had occupied 3,000 m^3 would have been removed.

Many rocks are cast ashore each year from M.L.W. or below, attached to kelp (*Durvillea potatorum*) holdfasts (Gill 1971, Pl. 1, Fig. 1).

6. *Energy of waves:* One of the most important quantifications awaiting achievement is the measurement of the flux of energy from the open ocean to the shore. A method has been devised, but the instrumentation is expensive. At Lorne on May 16, 1975, big seas were running due to an extra strong south-west swell. A local storm was running at the same time, but was coming offshore and so blew spindrift seaward from the tops of the waves. At the supratidal platform north-east of Stony Creek, huge waves were crashing on the seaward side of the ramparts, then hurling masses of highly turbulent water shorewards. As the platform had been surveyed it was possible to calculate that each large wave loaded the platform with some 12,000 tonnes (12,000 m^3 of water) travelling at over 20 km/hr. When the sea subsided, it could be seen that large blocks of arkose up to a tonne in weight had been ripped from the rampart and hurled to the back of the platform. This energy from a subantarctic storm conveyed by swell modified the coast at Lorne on that day.

ENGINEERING GEOLOGY

1. *Coastal roads:* Limited success with shoreline installations will continue until shoreline processes are understood, in particular until coasts can be mapped in terms of energy. Engineers have asked how close the Great Ocean Road can be built to the shore so as to give maximum views, yet protect the investment. As Otway siltstone has only half the resistance as arkose on the coast, it is an obvious source of weakness. Thus arkose forms all headlands; there is no headland of siltstone (with the special exception of Cape Otway already mentioned). Where the two occur in alternate strata, the arkose has not its usual strength because it has a weak support. Where bedding planes, faults, crush zones, joints and such structural weaknesses occur, the resistance of arkose is decreased; where concretions exist, the resistance is increased (Gill & McNeill 1973). On the other hand, in a roadcut, siltstone decrepitates as a heap of small pieces, while arkose tends to break away in large pieces which are a danger when falling, and a hazard on the roadway.

It was mentioned earlier that colluvium infilling old gullies occupies a great number of roadcuts. But there are two kinds of colluvia. One is sandy, oxidised, contains masses of angular arkose of a great range of size, and is liable to slip when charged with water. The other kind is grey to faintly mottled, i.e. little oxidized, and clayey. The two types are of the same age, and their differences are due to being derived from the two lithic types — arkose and siltstone respectively. Thus the latter is usually in the valleys and the former around the headlands. The sandy colluvium may have seepage issuing from it, but the clayey colluvium is an aquaclude. It can be used for inferring the presence of unseen siltstone bands in the bedrock.

2. *Coastal slips:* Each transgression of the sea has cut away the toe of the coastal slopes and caused slips. Slippage can be slow, in the form of colluvium, or sudden. The cutting of the Ocean Road has removed the toe of coastal slopes in the same way, and so caused slips (Pl. 4). At the same time the clearing of the hillsides has in many areas caused increased instability by increasing rate of water runoff and removing root anchorages. Slips may be in the bedrock (as at Windy Hill between the Sheoak and Cumberland Rivers), or limited to the unconsolidated Cainozoic rocks above (Evans & Joyce 1974, Joyce & Evans 1976). Comment will be limited here to one example of the second type of Eastern View.

In December 1973 the Ocean Road east of Spout Creek was widened and straightened. This work revealed a Last Interglacial shore platform cut in unoxidized Lower Cretaceous arkose, and covered by a boulder bed (Pl. 4, fig. 1). Above this was up to 2 m of thin layers of sediments (the top one with a dip of 15° seaward) which were interpreted as layers of hillwash. Above was some 5 m of slip material, covered with a

PLATE 3

FIG. 1—Ocean Road cutting facing estuary of the Cumberland River. Emerged shore platform with well rounded boulders and pebbles on it. This arkose platform varies in height as modern ones do, but part of it was surveyed as 7.5 m above L.W.L. Scale: 1 m rule with top at platform level.

FIG. 2—Close up view of boulders on platform. Scale: 1 m rule.

FIG. 3—Same roadcut, but near river end on old road. The boulder bed has been quarried for road works. The quarry shows that the platform and boulder bed extend in to a former cliff.

grey juvenile soil such as commonly occurs on Holocene deposits. This section later collapsed, revealing that a number of small slips was involved, i.e. separate unstratified masses of clean running sand, clayey sand, sandy clay, and carbonaceous clay. In the slip material further east are many large pieces of silcrete; five were noted over 1 m in diameter and one about 5 m. This silcrete comes from a lateritic profile at the top of the range 120-200 m high and 3-5 km away (which means a declivity of about 1 in 25).

The history of the slip at the old shoreline is as follows:

(i) The Last Interglacial sea cut a cliff in the competent Lower Cretaceous arkose, and the incompetent Tertiary beds. Slips that occurred while the sea was there were washed away. The large quantity of heavy mineral sand associated with the boulder bed on the shore platform came in part from such sediments.

(ii) When the sea withdrew, hillwash covered the platform and boulder bed. By the time the sea had withdrawn to south of its present position, the area was a terrestrial environment, no longer influenced by the sea. Slips occurred from time to time in a long train from the range capped with a lateritic profile down to the coastal plain formed by the exposed continental shelf. Pieces of silcrete broken away from the ridge capping were rafted seawards by the slips.

(iii) The sea rose in the Flandrian Transgression during the period 20,000 to 6,000 years ago and at its peak it was near the old shoreline. From that level the sea retreated in a series of oscillations to its present level, leaving a narrow sandy Holocene terrace along which the Ocean Road now runs. This rise of the sea once more caused coastal instability. During the succeeding period of comparative stability, the juvenile soil was formed on the surface of the old slips. This stability lasted until the toe of the slope was once more removed, this time by the roadmakers. A more detailed study of this area could greatly improve this history with respect to both space and time.

ACKNOWLEDGMENTS

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PLATE 4

FIG. 1—December 1973 roadworks for widening the Ocean Road at Eastern View east of Spout Creek. The base of the section is Lower Cretaceous freshwater arkose in which is cut a Last Interglacial shore platform, on which is a boulder bed with pebbles and sand (with heavy minerals). Over this is about 1 m of thin layers dipping towards the shore (other side of road), interpreted as hillwash. The remainder of the thick section of Lower Tertiary sediments is a series of slips of varying lithology. Since the roadcut was made the section has slipped badly, revealing the nature of the materials. The marks on the batter are bulldozer scours and not bedding.

FIG. 2—View south of the above locality from the shore platform. In the middle of the photo is (a) the Ocean Road (marked by road posts) in jeopardy from 'Clarke's Slip'. On the left at H.W.L. is (b) a row of piles set in deep concrete and backed by logs, behind which is rock fill. At the north (right) end a stone wall (Fig. 3) extends from the wooden construction to the cliff. This work was done in 1949 to protect the toe of a slip from erosion by the sea, which it has done, and the slip is now vegetated. The large blocks of stone at the north end were placed there recently because of marine attack on the stone wall. On the right side of the photo is the latest slip. On the hillside above is evidence of a long history of slipping. The basic cause is a wide belt of siltstone, which as usual has eroded to give a platform graded to L.W.L. The siltstone suffers wet/dry decrepitation and results in unstable slopes. The road cutting has aggravated a natural instability. There is no Tertiary formation present here.

FIG. 3—Close up of arkose wall built in 1949, but now weakened by a 'nip' eroded by the sea at its base, and by tafoni in the rock. Only walls in the marine spray zone suffer this rapid development of honeycomb weathering.

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