COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION
DIVISION OF APPLIED GEOMECHANICS

COASTAL EROSION, NORTHWEST PORTLAND BAY, VICTORIA, AUSTRALIA

TECHNICAL REPORT NO. 94

by

EDMUND D. GILL

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ABSTRACT :

Portland Bay is a long curved sandy beach anchored at each end to a basalt promontory. It is in dynamic equilibrium with the high energy S.W. swell. Immediately after the construction of the present Portland Harbour, erosion was initiated along 4 km of beach, and deposition on 6 km east of that. A retrogradation rate of 3.6 m/yr was measured. Erosion is by waves, especially large waves at high tide. A new wave pattern has caused this erosion N.E. of the harbour in the former equilibrium parabola. The erosion is remarkable for its severity, its localized occurrence, and its presence on a coast practically devoid of longshore drift.

Study of natural basaltic underwater seawalls east of Portland Bay has led to the proposal of a submarine discontinuous seawall as a possible remedy. Methods for reducing construction costs are outlined.

KEYWORDS :

Coasts; engineering geology; sediments; coastal processes; Portland-Warrnambool coast, Victoria.

CSIRO,
P.O. BOX 54,
MOUNT WAVERLEY, VIC. 3149
AUSTRALIA

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The west end of Portland Bay is anchored on the solid basalt of the Portland Promontory, while the east end is anchored on the solid basalt of Cape Reamur. The high energy waves from the S.W. swell have shaped the intervening sandy shore into a wide parabola. Because these swell waves have a long period (10 to 20 seconds), they feel the seafloor well out to sea, so that by the time they reach the shore they are accommodated parallel to it. By contrast, the short period storm waves in W. Europe and N. America often arrive oblique to the coast, and so contribute to longshore drift.

The coast of Portland Bay is in a delicate high energy equilibrium, any disturbance of which can have quite pronounced results. This high energy and its delicate equilibrium is the basis of the marine erosion in N.W. Portland Bay.

3. THE HISTORY OF EROSION

The following relevant events have been pieced together from local information:

1956-8	South wall of harbour constructed.
1959	Erosion at Henty Bay Estate first noticed.
1960	Harbour opened.
c.1962	Low rock cover (basalt) placed on the back beach area from the west end of the defined area to a short distance west of Rosslyn St. (Figs. 2, 3).
c.1963	Loss of the uncovered part of the beach admitted waves closer inshore, and erosion occurred through over-splash. To counter this, the height of the basalt wall was increased in 1963. However, spray erosion has continued to be a nuisance, and large amounts of seaweed are from time to time deposited behind the wall. Further raising of the wall was carried out in 1979.
1964	The first house lost by erosion.
1970	The Ports and Harbours Branch of the Victorian Public Works Department suggested experimental groynes. These were put in but did not collect sand, showing virtual absence of longshore movement of sand in that area. Cr. Colin Freeman suggested "a reef of old car bodies and tyres" to protect the shore; this was not implemented.
1970-1979	Sand erosion has continued from the east end of the basalt wall to Monaghan's, while east of that area progradation has occurred (Fig. 2).

Fig. 3.- The basalt wall placed on the back beach to halt erosion. The sea removed the sand on the seaward side of the wall, admitting the waves further inshore, and so facilitating back-wall erosion. The wall was raised in 1963 and in 1979 is being further raised. Loss of a beach seaward of a seawall is the usual result. I am informed that the stumps in the photo are of an experimental groyne

4. THE AREA OF EROSION

The cutting back of the shore (retrogradation) along the west sector as far as Monaghan's, and the building out of the shore (progradation) east of Monaghan's to the east side of Schnapper Point can be established by examination of the Victorian Government air photographs taken in 1947/1948 and 1977 respectively, and by measurements on the Parish Plan, and the loss of a road and houses. Further evidence is provided by iron pipes, formerly used as freshwater wells on the properties, but now standing in the sea (Figs. 4-5). It is informative to note that they extend below sea level, showing that a hydrostatic pressure existed sufficient to maintain a supply of fresh water at that level.

The erosion is effected by waves. Maximum erosion occurs when the largest waves coincide with the highest tides.

The original condition of this shore is shown by the 1947/1948 air photographs. Two features are noteworthy (see Fig. 6):

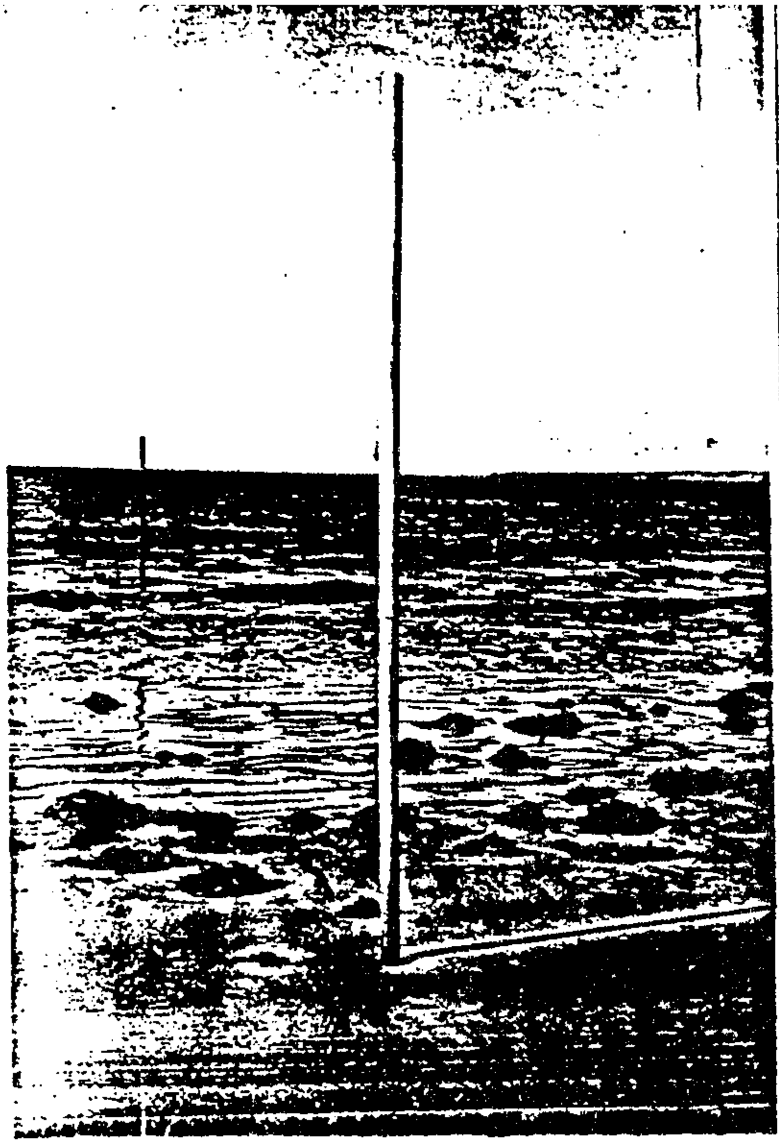

Fig. 4.- Freshwater pi
of properties now erod
away.

Fig. 5.- Freshwater pipes now in the sea. East end of the basalt wal
and continued erosion in foreground.

(a) The beach is wide, as it is east of the basalt wall at present. After the basalt wall was emplaced on the back beach, the remainder of the intertidal sand was washed away. The building of a sea wall usually results in the loss of the beach in front of it. This loss of the beach has allowed the waves to break directly on the wall, so causing erosion behind it, and the deposition of weed.

(b) At intervals along the beach outcrops of hard rock show in the 1947/1948 air photos. This is calcarenite (limestone), like that which forms the Minerva Reef offshore. When the sand is washed away at the eastern end of the basalt wall, an outcrop of this rock can be seen. It is yellow to light brown in colour. Pebbles of this rock are found on the beach; many of them have organisms attached that show they come from the reef offshore. The sand of this coast thus has a firm substrate, which may prove to be of engineering importance.

5. THE RATE OF EROSION

Rapid erosion occurred in the first three years (between 1959 and 1962), resulting in the loss of the road along the coast, and (I am told) of three houses. I understand that the stumps seen in Fig. 3 are of an experimental groyne. At the east end of the wall the retrogradation was measured as the distance between the landward side of the wall (since the wall was placed on the back beach zone) and the present clifflet at the back of the existing beach (Figs. 7, 8). This distance was surveyed in May 1979 and was about 62 m. From 1962 (when the wall was built) to 1979 is 17 years, which gives an *average rate of erosion of 3.6 m per year*. This is an exceptionally high rate. Mean erosion rates over a period of time such as this are usually measured in centimetres and not metres. That the erosion is extraordinarily rapid is shown by the fact that for most of the distance from the east end of the wall to Monaghan's house, the beach below the clifflet is lined with fallen sods with the grass still alive (Figs. 7, 8). That the sand being deposited in the eastern sector is from the shore being eroded east of the basalt wall, and virtually nowhere else, is established by the fact that no sand has accumulated on the basalt groynes jutting out from the basalt wall. The area of sand eroded is also within 2% of the sand deposited.

Two other features should be noted:

(a) *A uniform soil* up to 0.5 m thick caps the sand in the clifflet at the back of the beach (Fig. 7). It thins as it passes over the tops of ridges (Fig. 8), as expected. A similar soil at Cape Reamur and on the coast near Tower Hill has given radiocarbon dates of about 2800 years. The soil is certainly old historically. It has been suggested to me that the shore built out (prograded) in the recent past, and is now just returning to the original shoreline. This is not true. *The soil proves that the shore here has been stable for 2000 years at least.*

(b) Figure 2 shows a number of lines more or less parallel to the shore. These are *beach ridges* drawn from the air photos (Figs. 2, 6, 8) and studied on the ground. The inner edge of this array of ridges is the shoreline of 6000 years ago, dated by radiocarbon. Thus previously the shore has been a prograding one.

Fig. 6.- 1948 air photograph showing the original wide beach, and the calcarenite outcrops. The dark ridges behind the outcrops are seaweed. The lines on land roughly parallel to the beach are ancient beach ridges.

Fig. 7.- Eroding clifflet with established soil and vegetation; fallen sods with living plants line the base of the clifflet.

Fig. 8.- Clifflet with soil thinning as it passes over beach ridge; sods and sand from rapid erosion of the clifflet. Here some fill has been placed over the original surface to level the ground.

At the back of the coastal plain are steep slopes which are former sea cliffs. The sea was there about 125 000 years ago, dated at Port Fairy by the uranium-thorium method. The Port Fairy Calcarenite is a geological formation of sand and shells laid down at that time. The sea was then about 7 m higher than now. The formation can be recognized by its fossils, and these have been identified in the Princes Highway cutting on the west side of the Surry River at Narrawong. The Minerva Reef and the outcrops of limestone seen in the 1947/1948 air photos (Fig. 6) belong to this formation. This is mentioned because an old resident claimed that last century the sea reached the former cliffs at the back of the coastal plain. This is not true. Misconceptions of this kind have been clouding thought concerning this shoreline erosion.

A third misconception is that the erosion at the Henty Bay Estate is simply part of a recent worldwide increase in erosion. I accept that this erosion has occurred, but it is so small that many experts are still not convinced that it has happened. It is of so small a scale as to be lost in a retrogradation rate of 3.6 m/yr. In any case, the *fact that the 4 km of retrogradation is matched by 6 km of progradation immediately to the east shows that it is a local realignment and not a global change.*

6. THE DESTINATION OF ERODED SAND

When Mr. A.J. Buckland was drafting Figure 2, he noticed that the erosion in the western sector is matched by deposition in the eastern sector. This observation from the air photos neatly accords with observations that I had made in the field, viz:

(a) From the end of the basalt wall to Monaghan's house:

- there is a clifflet 1.5 - 2 m high;
- fallen clumps of sand line the foot of the clifflet (Figs. 7, 8);
- the sand is compact;
- a uniform soil up to 0.5 m caps the sand;
- in the soil there are native snails (*Austrosuccinea australis*);
- the natural ground surface is smooth;
- it follows a regular series of beach ridges (Figs. 2, 6, 8);
- the natural vegetation is mature;
- truncated roads, freshwater pipes now in the sea, a boatshed wreck (Monaghan's), and such attest active erosion of exceptional severity.

(b) By contrast, from east of Monaghan's to east of Schnapper Point:

- there is no clifflet;
- the sand is loose;
- no soil caps it;

- all the numerous snails observed were the introduced European snail *Theba pisana*;

- the ground surface is hummocky;

- no beach ridges occur, but they are to be found behind the hummocky sand;

- the vegetation is immature; a few species are in process of colonizing the area;

- the fishermen's Red Hut that used to be on the shore is now some distance from it, attesting progradation.

So it is simply a matter of observation that *the sand eroded in the western sector is being deposited in the eastern sector*. However, it is not part of a general longshore drift. It is very localized. The basalt groynes associated with the basalt wall have not collected sand.

As oblique waves are virtually absent, the longshore movement is a function of the changed wave pattern that is also causing the erosion. For such a process to occur, *two components are essential - a supply of sand and energy to transport it.*

(a) Sand Supply

The N.W. shore of Portland Bay was in equilibrium until recently. It was not prograding, because there was virtually no sand supply. Cliff erosion at Portland supplies a negligible quantity of sand. The Port Campbell limestone, which forms the bedrock, has only silt-size sediments and so provides no sand. Similarly, the basalt does not provide sand. Any sand has to come into the Bay. Dr. George Baker of CSIRO Mineragraph Section (1956) investigated sand movements on the coast in connection with the planning of Portland Harbour. Three experiments were conducted at different times, consisting of the dumping at different places of large loads of sand of the same size range as the local sand but consisti of a foreign mineral, e.g. red pyrites. Samples were taken at set intervals along the beaches, and grain counts done to ascertain what movement had occurred (viz. how much and where). Among Dr. Baker's findings were that:

- the main drift is from west to east;

- the sheltered N.W. part of Portland Bay (Fig. 1) has negligible sand movement. A dump of garnet on Narrawong Beach hardly moved, but this was partly due to the time of year when the experiment was done.

- the sand moving by longshore drift from the west by-passes N.W. Portland Bay.

The results are graphically summarized in Baker's Figure 22, which is herein reproduced as Fig. 9.

(b) Longshore Current

Wind shear on the surface of the sea causes currents. In Western Victc most movement is from west to east, driven by the prevailing S.W. to W. winds. In the summer, east winds blow at times, reversing the current.

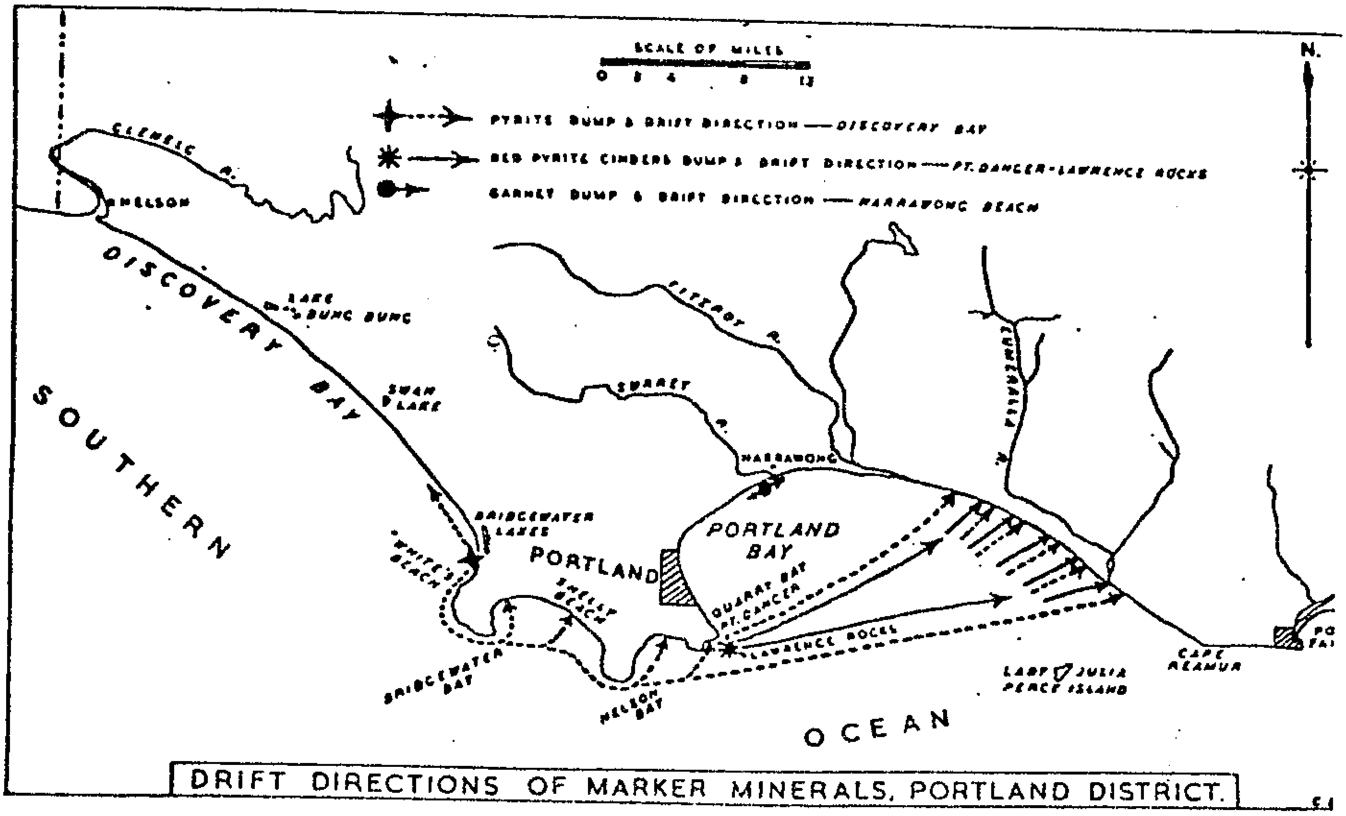

FIG. 9. —Sketch map of the Portland District showing direction of drift of (1) pyrite from the dump on Discovery Bay beach, (2) brown garnet from the King Island scheelite tailings dump on Narrawong Beach, and (3) red-pyrite-cinders from the dump on the sea floor between Point Danger and Lawrence Rocks.

Thus all the harbours in this area face east, and there are considerable build-ups of sediment on the west sides of promontories, e.g. Bridgewater Lakes and Cape Reamur. At Warrnambool I have calculated the proportion of eastward to westward drift from the meteorological data, using the formula *frequency x velocity*^{2}. This gave a *predominance of eastward over westward drift of 6.6 to 1* (Gill, 1978a). This is why the resultant sand movement in Portland Bay is from west to east. However, longshore drift is practically absent in the N.W. sector of Portland Bay, which is sheltered by the Portland Promontory. On the other hand, it is strong in N.E. Portland Bay where 93 000 000 m^3 of sand have been piled on Cape Reamur.

The absence of a coastal sand dune in the study area is evidence of sand under-supply. Since 1958 the equilibrium of 10 km of coast has been changed. The western 4 km has suffered erosion, and the eastern 6 km deposition. This is very localized for a coastal process. It is not normal longshore drift, but re-arrangement of sediment by a new wave pattern. A new profile of equilibrium is in process of being established. A matter for further investigation is how long it would run, if permitted to continue, and how far it would go. *Within the broad parabola of Portland Bay, a secondary parabola is being established because of a re-orientation of wave forces. This is local and man-induced, because it is unrelated in time and space to the broad natural processes.*

Mr. A.J. Buckland measured from the 1947/1948 and 1977 air photographs that 135 600 m^2 of sediment have been eroded west of Monaghan's (Fig. 2), while 138 300 m^2 have been deposited east of Monaghan's. These figures are within 2% of each other. It is estimated that the volume eroded and that deposited are of the same order of magnitude, i.e. there is no reason to think that any significant quantity has been carried out to sea, or carried further along the coast.

7. THE CAUSE OF EROSION

The cause of erosion is the building of the present Portland harbour. The structure has caused a change in wave action, resulting in the erosion and deposition already described. The link with harbour construction is given by:

(a) *The time of commencement of this exceptional erosion.* As soon as the harbour was built, the erosion began.

(b) *The area affected.* The spatial relationship of the harbour structure to the erosion area is as expected. For example, the construction of the Apollo Bay harbour at about the same time had the same effect - erosion to the N.E. and accumulation of sand in the zone of low energy on the landward side of the harbour. A dune has been built along the shore opposite the shopping area at Apollo Bay. At Portland sand under-supply means that no dune has been built, but divers have informed me that sand has accumulated underwater on the lee side of the harbour.

(c) *The degree of erosion.* Many causes of erosion exist, but it is rare for erosion of this magnitude to occur. When it does, it is usually due to man's interference, or to some rare event such as a volcanic eruption that alters the orientation of the coast and so its dynamic equilibrium.

(d) *The pattern of erosion.* It is significant that although the erosion is so extreme in magnitude, it is nevertheless so localized. This indicates a local cause and not a general one. The beach ridges shown in Figs. 2, 6 and 8 mark the retreat of the sea from the 6000 yr shoreline of a slightly higher sea. The erosion has not followed this pattern, i.e. the pattern of the parabola established by the equilibrium of coastal forces in Portland Bay. The erosion pattern at the Henty Bay Estate is a new one (inconsistent with the previous one) that truncates the beach ridges (Fig. 8).

8. POSSIBLE REMEDY

(a) The proposals set out below follow *two important principles: To take action compatible with the natural processes* operating in the area. To work contrary to nature is to court failure. One difficulty in treating this erosion area is that the ecosystem is very unusual. This will be described presently.

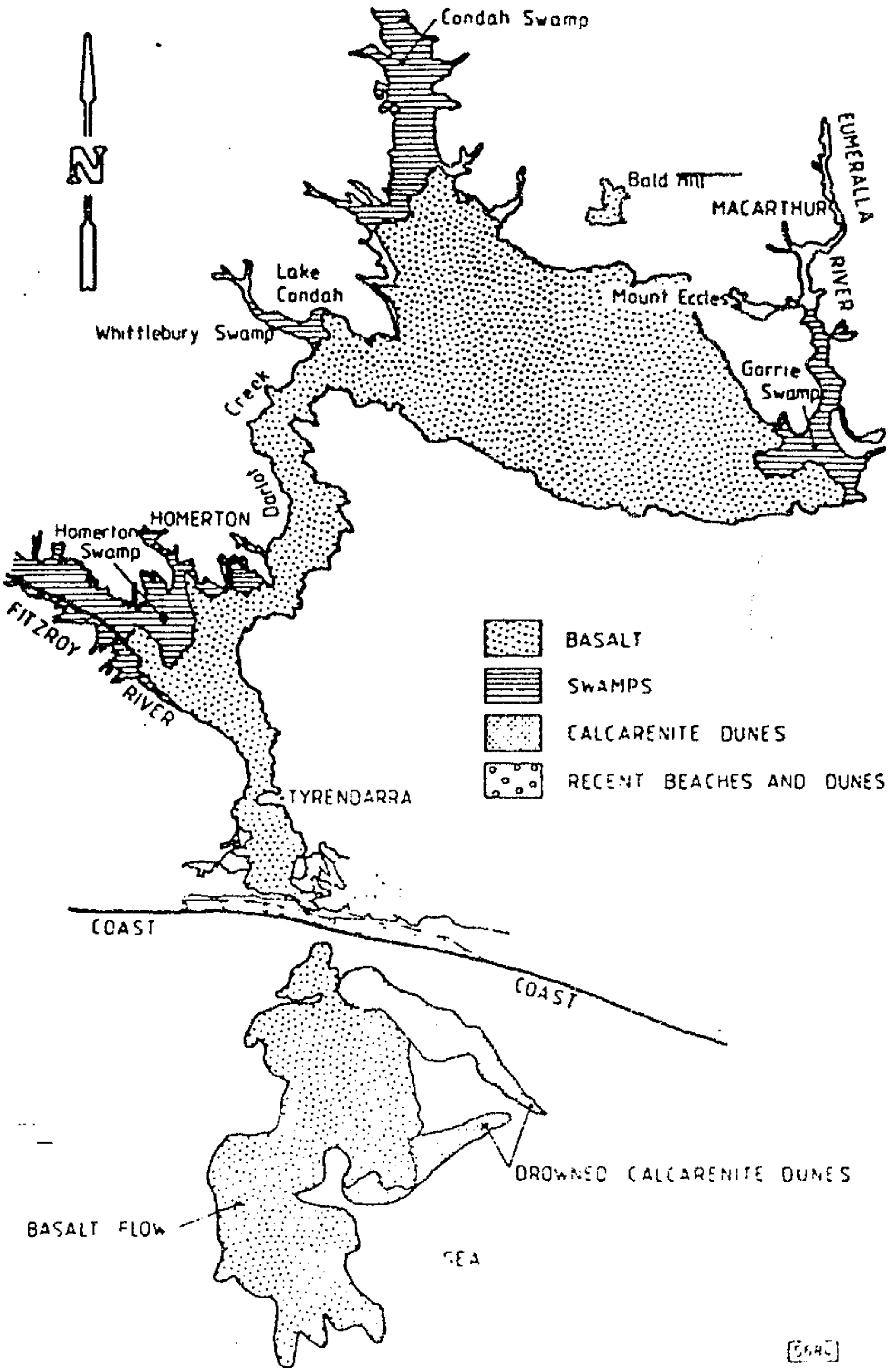

Fig. 10.- Plan of Mt. Eccles eruption and Tyrendarra flow (adapted from Boutakoff, 1963).

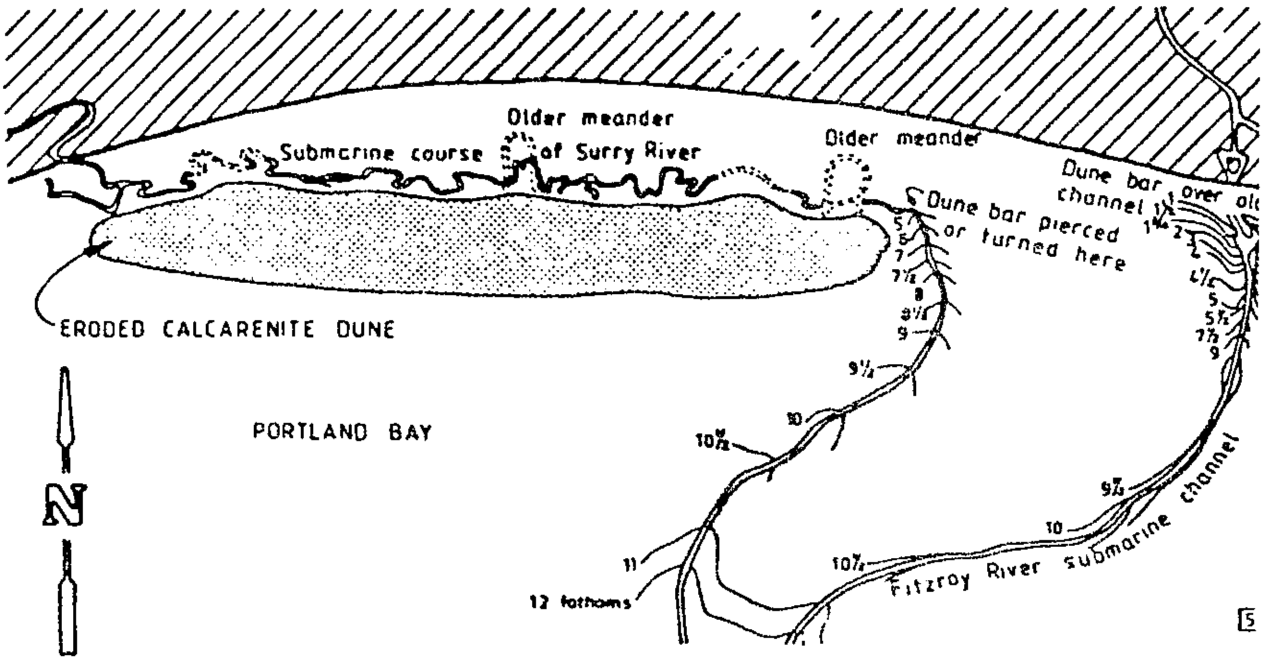

Fig. 11.- Undersea course of the Surry River, still not filled in by longshore drift. Even the billabongs are still clear in the air photos. Seaward of the course is a submerged dune planed off by the rising sea (adapted from Boutakoff, 1963).

To treat the cause, and not the result.. Rapid action was necessary when such a exceptional rate of erosion began to cut away the coast. The ecosystem was not known then, so a basalt wall was emplaced, which treated the result and not the cause. For a lasting solution, the cause must be treated, i.e. the waves modified before they reach the shore, and not after they reach it. If this solution is achieved, the erosion will cease, the basalt wall can be removed, and the beach returned to the people.

(b) *The Coastal Ecosystem of N.W. Portland Bay*. The unusual characteristics of this coastal compartment arise from the fact that the sand supply is virtually cut off from both the east and west. This is why no dune borders the beach along the Henty Bay Estate, and why the course of the Surry River can be followed under the sea in great detail, including the billabongs (Fig. 10). In all other rivers in Victoria such old channels have been filled in by sand moving along the coast. The sand supply from the west (the major one) is cut off by the Portland Promontory. In N.W. Portland Bay there are no dune structures such as occur on the west side of the Portland Promontory, but they gradually return as one moves east round the bay. However, the really unusual thing about Portland Bay is that the sand moving from the east is also largely cut off. This is effected by the Tyrendarra basalt flow which I have dated from wood in underlying gravels as 19 600 (± 600) yr old by radiocarbon (Gill 1978b). Figure 10 shows Mt. Eccles and the lava flow from it moving out on to the continental shelf. The continent. shelf was mostly dry 20 000 years ago, because the building of the big ice caps had extracted so much water from the oceans. At the coast the lava flow is covered with shell sand generated in modern times. Two dunes built up against the lava flow can be seen on the east side (Fig. 9). These are on the continental shelf and are now under the sea. Because they are made of lime (shell) sand, they hardened in the presence of sea spray and so survived the advance of the sea. But they show how sand was trapped on the east side of the flow.

Further evidence is provided by the course of the Surry River, as shown in Figure 11. In the aerial photographs the river course can be seen quite clearly (Boutakoff, 1963 Fig. 21). It has not been filled in, as usually occurs. There is little eastward moving sand, and the westward moving sand has been largely trapped by the Tyrendarra lava flow. Because of this under-supply of sand, the use of groynes can be of little use, and in some places no use whatever.

(c) *Submerged Seawall.* For the control of the shoreline erosion, I propose that the best method known at present (albeit inadequately tested) is the submerged seawall. *Such structures interfere with the orbiting of the waves, and so reduce their energy.* They "trip" the waves. Waves are still present for recreational purposes, and in some places to maintain necessary sand movements, but the top is removed from their energy graph. These structures are built from the sea floor up to about low water mark so that they are out of sight and do not spoil the appearance or availability of the beach. Moreover, rocks below sea level do not suffer the strong wave attack as those at higher elevations do. The orientation of marine growths on such boulders prove their stability.

More needs to be known about the best design for submerged seawalls in the Australian environment, and how to reduce the cost of their emplacement (cf. Dick and Brebner 1968, Raman *et al.*, 1977).

(d) *The Design of Submerged Seawalls.* Immediately east of Cape Reamur (east end of Portland Bay) is Horseshoe Bay, a small rounded bay resulting from the collapse of a basalt tumulus (dome). The *long-period waves of the open sea do not penetrate the bay because a submerged basalt ridge trips them,* so that small short-period waves replace them. It is a natural submerged seawall. A number of these occur between Cape Reamur and Port Fairy to the east. Such structures are comparable with coral reefs, which are another kind of natural submerged seawall.

Procedures exist for the marking of such seawalls (natural and artificial) so that they are not a hazard to shipping.

Killarney Beach, between Port Fairy and Warrnambool, is a favourite resort for families but not for surf-riders, because the *power of the waves is considerably reduced there by a discontinuous natural seawall of basalt.* Here domes and short ridges of basalt curb the wave energy. A flat basalt flow forms part of the general shallowing of the sea (Fig. 12), but the discontinuous domes and short ridges protruding from it disorganize the waves and markedly modify their energy. My attention was first attracted to the site by the marked contrast between the large waves beyond this natural coastal defence and the small ones landward of it. The easterly part of the Killarney Beach area mapped in Figure 12 almost completely cuts off the waves because there are more impediments. The next step should be to instrument the area in order to define how and to what extent the wave energy is reduced by the basalt protrusions.

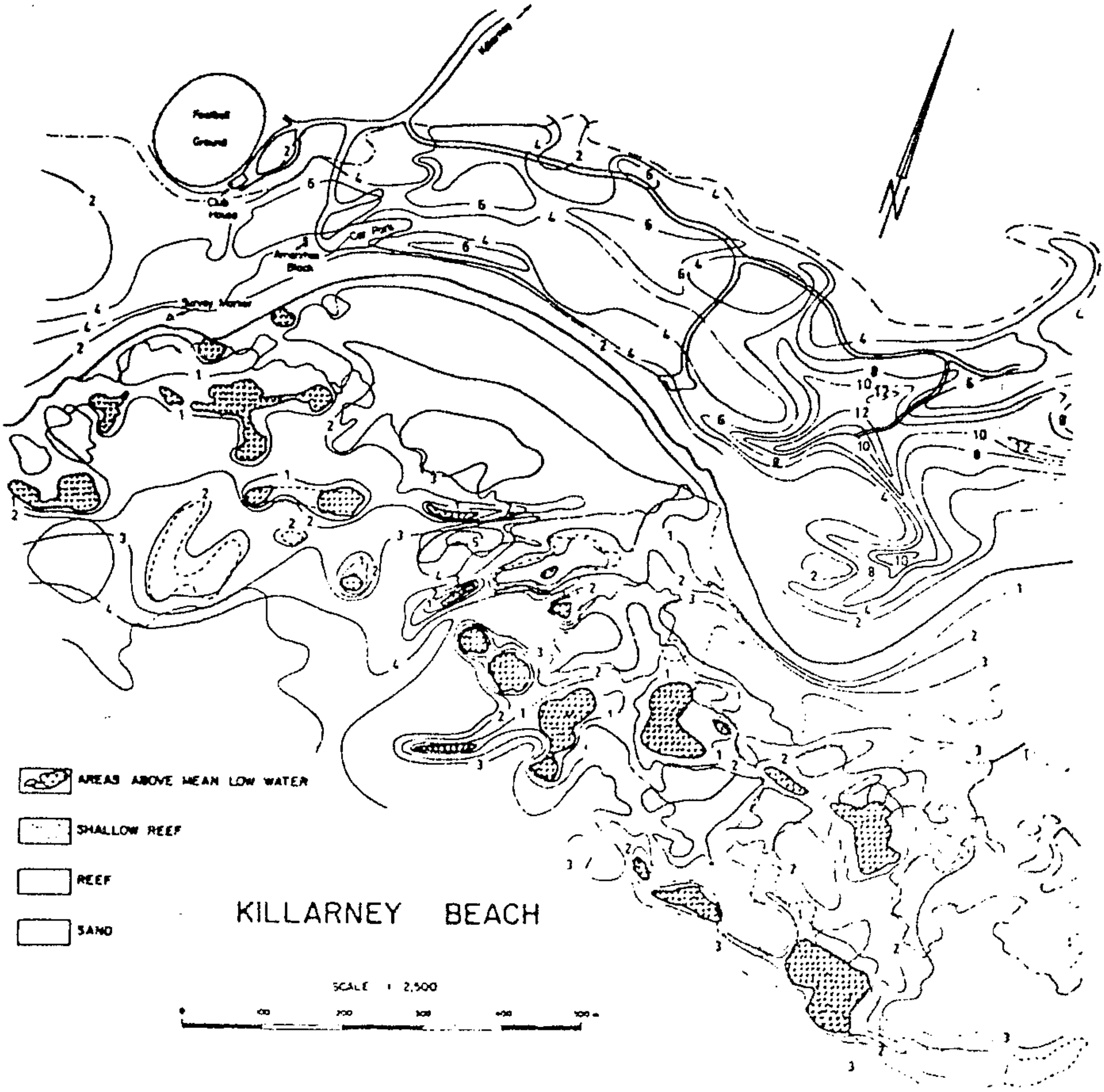

Fig. 12.- The basalt flow forms part of the general shallowing of the sea, but the domes and ridges protruding from it form a discontinuous seawall that markedly dampens the wave energy.

Two inferences can be made from the Killarney Beach site:

1. *A series of mounds of rock can be as effective in damping wave energy as a continuous seawall.* Considerable turbulence is created between the mounds, and this absorbs a great deal of energy. A submerged seawall consisting of mounds of large pieces of basalt placed as far apart as their diameter could dampen wave energy, but *cost only half as much* as a continuous seawall. Only half the amount of material would be needed, and the cost of emplacement would be more or less halved.

2. *Impedence could easily be increased* by emplacing extra mounds between the others and seaward of them (compare the east end of the Killarney Beach site). *As the mounds would be built of loose blocks they could be tailored,* if necessary, to modify their effects.

One clear advantage of the Killarney Beach array is that it is *fully adjusted* to the conditions existing there. An experimental structure can take some time to become fully adjusted to the short and long term changes in the environment. Another advantage is that there are no construction costs.

(e) *Cost Reduction in Submerged Seawall Construction.* While costs can be reduced ~50% by using mounds of rock instead of a continuous seawall, *an even greater percentage saving can be effected by building the structures from the land* instead of from the sea, as is usually done. A setup of launches and barges is very expensive, and in the high energy conditions of the coast of S.W. Victoria much time is likely to be lost due to adverse wave conditions. It is envisaged that one of the largest rock moving machines, fitted with a perspex screen to protect the driver from splash, could do the work. There are other types of apparatus that could be modified for this work. Bulldozers are used to dig trenches and lay oil pipe lines in the seafloor, with a vent to the surface, and either an air pipeline or Scuba apparatus for the driver.

As can be seen from Figure 12 *the basaltic domes and ridges rise from a base only 3-4 metres* at the deepest part, so the mounds do not need to be emplaced in deep water. In N.W. Portland Bay the spring tidal range is only 0.9 m and the neap 0.4 m; also it is a protected area with much smaller waves than at Horseshoe and Killarney Beach. High-standing machinery could dump the rocks from the land in these conditions, and this would be only a fraction of the expense of doing the work from the sea. A discontinuous seawall built from the land could be as little as one fifth of the cost of a continuous wall built from the sea. The very effective Killarney Beach natural seawall shows that it does not have to be as deep as such structures are usually made. The shallow seawall uses less material and is cheaper to emplace.

Another method that could be considered is the use of large concrete tetrahedra with iron rings in the top to facilitate handling. The excess sand deposited east of Monaghan's could be used for this purpose. Being calcarenite, it is not a strong sand, but strength is not needed. The forces below low water mark are very small compared with those in the breaker zone. Groups of tetrahedra could be used instead of rip-rap. If the tetrahedra were set on the beach opposite where they are to be emplaced, and the sites in the sea were marked with buoys, a helicopter could emplace them all in a couple of days.

9. CONCLUSION

Nature has demonstrated an effective means of wave control at Killarney Beach, and this could be applied at the Henty Bay Estate where the wave energies are much less. If mounds are emplaced, as proposed, they could be instrumented to gain a greater understanding of the system. The method could then be adapted to the many sites in Australia plagued with coastal erosion. It may well be that at the hundreds of sites where expensive sand replenishment methods are presently being used in Victoria, this method could dispense with those costs, and so make worthwhile a full scale experiment near Portland. If, as is apparently the case, sealevel is slowly rising, coastal erosion will progressively get worse, and some more satisfactory method is urgently needed to treat the cause, and not the result.

10. ACKNOWLEDGEMENTS

T.G. Ferguson and A.J. Buckland made the survey of Killarney Beach (Fig. 12), and Mr. Buckland prepared Figure 2, and calculated the area of sand eroded and deposited. This skilled help is greatly appreciated. Mr. Buckland made the line drawings.

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Footnote:

An interesting line of future research would be to design apparatus that, in addition to protecting the shore, utilized the energy of the waves to provide electricity to light warning signals on the artificial reef, and run the tourist facilities onshore. Such an apparatus would make a contribution to the much needed energy conservation programme.