3.—THE GEOLOGY AND GEOMORPHOLOGY OF POINT PERON, WESTERN AUSTRALIA.

BY

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Read, 13th April, 1948.

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I.—INTRODUCTION.

Point Peron (also known as Cape Peron*) is situated at 32° 15′S. by 115° 42′E. on the West Coast of Australia, about 15 miles S.S.W. of Fremantle. It was named by de Freycinet in 1803, in honour of Francois Péron who was a naturalist to the French expedition under Baudin, which explored the western coasts of Australia in the " Géographe " and " Naturaliste " between the years 1800 and 1804.

The following quotation from the journal of M. Louis Freycinet is taken from Peron and Freycinet (1807–16, Vol. 2, p. 194) ; " Le 10 mai, à midi, je me trouvois à peu de distance d'une pointe saillante et très aigue, que je désignai sous le nom de Cap Péron." Near here Freycinet hoped to pass

*There is a second Cape Peron in Western Australia, in Shark Bay (Lat. 25° 31′S., Long. 113° 30′E.).

between the islands and the mainland and so to the mouth of the Swan River, but an attempt to do so soon involved him in "les plus pressans perils." Eventually, "A 5 heures du soir, la brise s'éleva et je me hâtai de fuir en doublant les récifs par le Sud." The islands here (Garden I., Rottnest, Carnac, etc.) were named as a group "Les Iles Louis Napoleon," during this expedition, though the term has fallen into disuse.

Geologically and geomorphologically, Point Peron and vicinity does not yet appear to have been accorded any detailed scientific description or mapping, with the exception of a short note on the lime possibilities by Miles (1945).

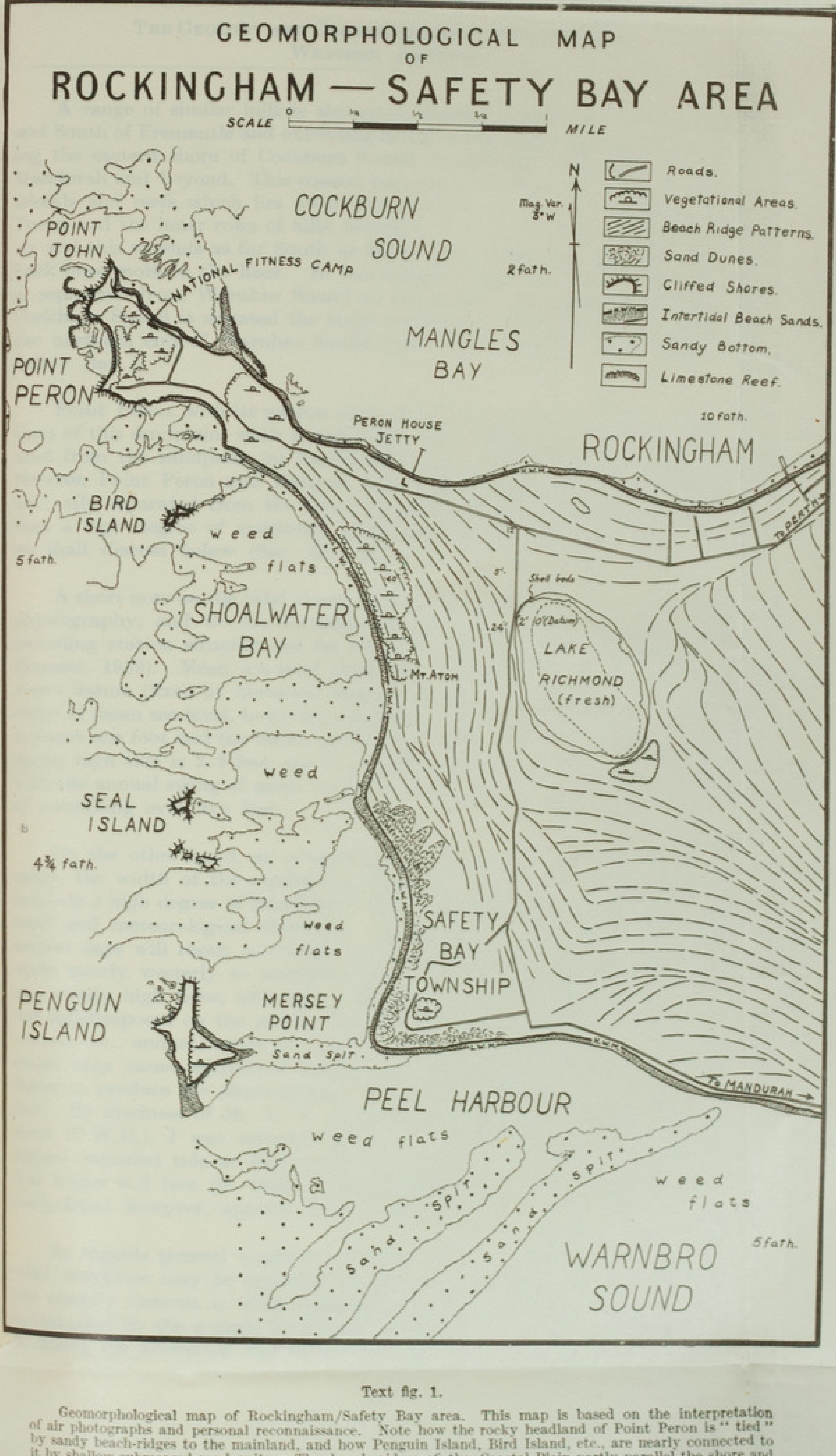
The proximity of this picturesque headland to the populated centres of Perth and suburbs with their educational establishments makes it particularly desirable that a fairly detailed description of the spot should be made ; for Point Peron appears to hold in microcosm a fair proportion of the geological and geomorphological features of the coastal belt of Western Australia which extends in a remarkably uniform way for many hundreds of miles.

In November, 1946, a combined survey by the Geology and Biology Departments of the University of Western Australia was made of the area and a detailed map was prepared by means of ground traverses with the assistance of air photographs. The author has subsequently visited the spot on numerous occasions with student excursions, and a special excursion for the Perth meeting of the Australian and New Zealand Association for the Advancement of Science was made here in 1947.

The present study will be restricted mainly to a description of the broad geological and geomorphological features. It must be emphasised that there is still an abundant scope for comparative palaeontological and sedimentary petrographic investigations. Hitherto nothing has been published on the various aspects of reef ecology, either plant or animal, and even the essential description of living species is still very incomplete.

Point Peron represents an isolated rocky headland in the nature of a tombolo—a former rocky island now "tied" to the mainland by a series of low sand-banks and beach-ridges (*see* text fig. 1 and Plate I.). As noted in the Admiralty "Pilot" (vol. V., p. 327) it may give the impression of being a true island when seen from a distance. The headland is 950 yards long from North to South and about 400 yards across from East to West. It is "tied" to the mainland in the South-East and is exposed to the open sea in the South and West and to the rather protected waters of Cockburn Sound to the North-East (Mangle's Bay). The northern extremity is known as Point John, a tiny promontory in the North-West is called Fisherman's Head, while the main feature of Point Peron projects to the South-West with a large isolated "stack" 50 yards long lying in front of it. The broad sweep of sand to the North of Point Peron we call Long Reach, and a small bay of particular interest about 300 yards South-West of Point Peron our biologists have called Haliotis Bay. From here to the South-West there is a broad sandy sweep which represents the northern end of Shoalwater Bay, which runs down as far as Safety Bay.

The rocky headland at Point Peron is only one of a series of rocky ridges, or islands, and reefs which parallel the coast in a North-South line from just East of Rottnest Island through Carnac Island, Garden Island, Point Peron, Bird Island, Seal Island, Penguin Island and the Murray Reefs—a distance of over 30 nautical miles.



Text fig. 1.

Geomorphological map of Rockingham/Safety Bay area. This map is based on the interpretation of air photographs and personal reconnaissance. Note how the rocky headland of Point Peron is " tied " by sandy beach-ridges to the mainland, and how Penguin Island, Bird Island, etc., are nearly connected to it by shallow submerged sand spits. The beach ridges of the Coastal Plain partly parallel the shore and are partly cut off obliquely, and thus antedate the present erosive cycle. Major changes in the coastline about Peel Harbour have occurred during the last century (*see* Sec. III. (e)).

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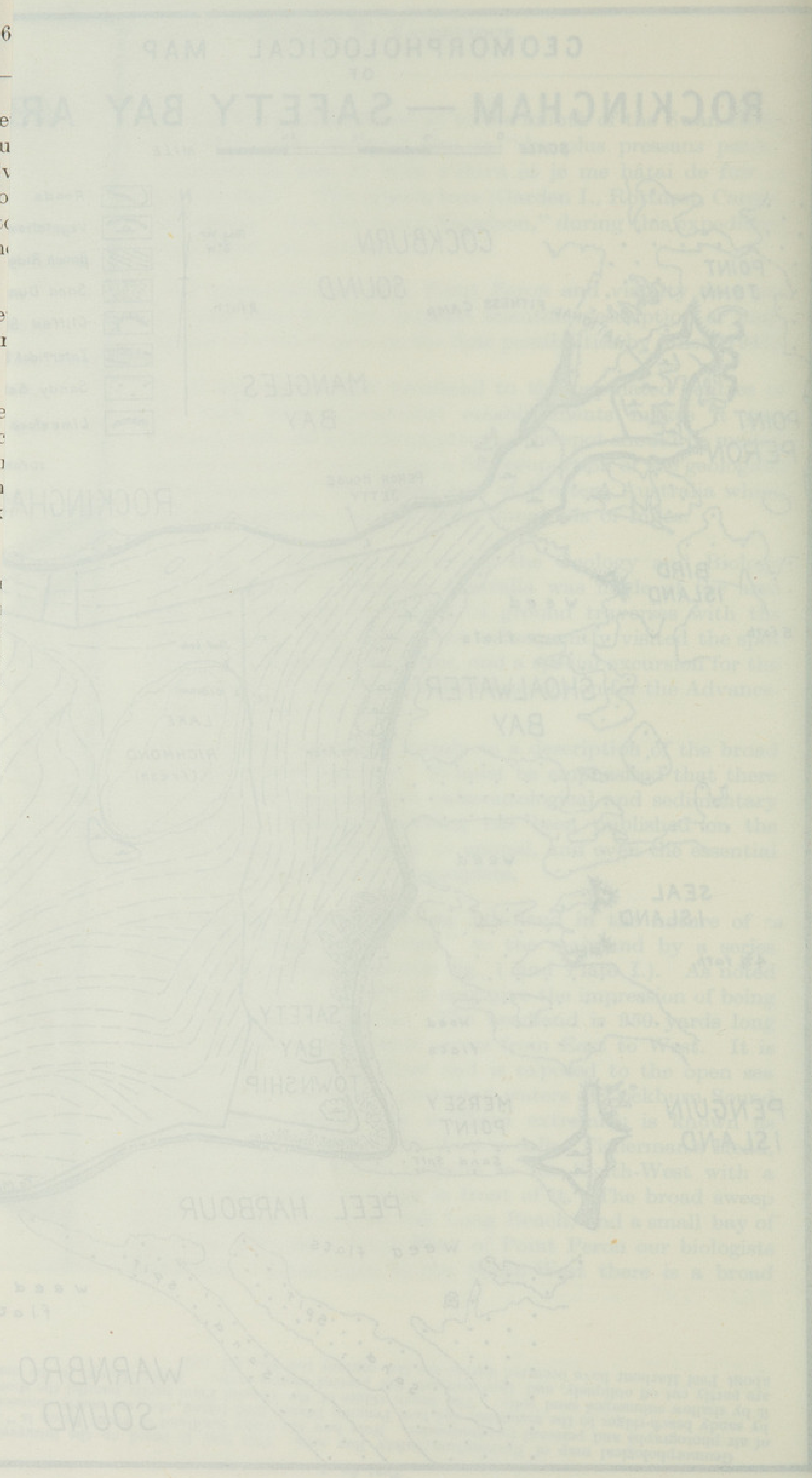


A range of similar hills is also encountered forming the coastline North and South of Fremantle and extending South of Woodman Point, where, forming the eastern shore of Cockburn Sound, it continues southwards as far as Mandurah and beyond. This coastal range is parallel to the off-shore line of islands and reefs which lies about five miles to the West. Between Point Peron and the inner rows of hills, however, a broad sandplain has been built up and this extends as far South as Safety Bay, whereupon the shore swings back once more to the East. In this manner Cockburn Sound to the North is separated from Warnbro Sound to the South. At the southern end of Cockburn Sound is situated the large seaside town of Rockingham, while at the northern end of Warnbro Sound there is the growing seaside resort of Safety Bay.

Point Peron, with its narrow neck of sand, thus forms the north-western limit of this sandplain, while to the South-West, Penguin Island is only separated from the sandplain (at Safety Bay) by a very shallow sand spit. In between Point Peron and Penguin Island, Bird Island and Seal Island are also only separated from the shore by rather shallow sand spits. There is thus a high degree of symmetry about the area, the explanation for which we shall discuss below (Sec. III, (e)).

A short note on the tidal characteristics is essential in the study of coastal physiography, and we are fortunate at Point Peron in having an official recording station situated not far off at Fremantle (*see* recent work by A. Bennett, 1939). Mean sea-level there was determined in 1933 at 2.27 feet above datum (fixed by harmonic analysis at lowest low springs) ; the annual range of mean sea-level, however, was found to be 2.26 feet. The neap range is about one foot and the mean spring range about three feet. Thus the mean spring high tide is 3.8 feet and the mean spring low is 0.8 feet. However, with the annual swing of mean sea-level, we get an overall mean spring range of something over five feet.

On the other hand, as pointed out by Curlewis (1916), the small tidal range, the width of the continental shelf and the open nature of the coast involves a high degree of interference in the tidal characteristics by prevailing wind and meteorological elements. In this way a land wind blowing for several days will result in exceptional and almost unchanging " low " tides, while steady westerly to southerly gales will result in days of exceptional and steady high tides, although a diurnal rise and fall is often identifiable but superimposed on the general banking up of the water. In this way the overall, *i.e.*, annual, range of about five feet is even further increased and swash may cause additional banking on an exposed headland like Point Peron to produce the physiographic effects of a tidal range of more like six feet. By kindness of Mr. L. A. Jones of the Harbours and Rivers Department (P.W.D.), I was informed that owing to this "banking effect," the highest recorded tide at Fremantle was 6.25 feet (in 1910) and the lowest was minus 0.5 feet (in 1896). The physiographic effect of such rare abnormalities, however, appears to be negligible.

As regards general weather conditions, the southerly or south-westerly wind directions may be regarded as prevailing, but in the summer months the easterly element is often experienced during the early part of the day, accentuated by the normal land breeze, while the sea breeze generally comes in during the afternoon and blows with considerable force for a few hours.

For the examination of reefs the lowest tides are desirable, and a combination of these with easterly winds is often experienced about the times of the equinox and in the early mornings in October and March.

The rainfall at Point Peron is somewhat variable, but generally falls between April and October, and ranges from 30 to 40 inches per annum.

The vegetation on the sand-dune and coastal limestone country is very uniform all along the temperate coastal belt of Western Australia. Mr. G. G. Smith, of the Botany Department of the University of Western Australia has been kind enough to identify the following flora from Point Peron :—

Mesembryanthemum aequilaterale Harv.
Olearia axillaris (D.C.) F. Muell.
Frankenia tetrapetala Labill.
Suaeda australis (R. Br.) Moq.
Lepidosperma gladiatum Labill.
Clematis pubescens Hueg.
Scaevola crassifolia Labill.
Acanthocarpus Preissii Lehm.
Scirpus nodosus Rottb.
Spyridium globulosum (Labill.) Benth.
Tetragonia expansa Murr.

The only common native species of land-shell found at Point Peron is *Bothriembrium bulla* Menke, 1843 ; curiously enough it is only found subfossil, and bleached white, in a light brown soil, which has formed over some of the older, vegetated sand-dunes. It is found living at Rockingham and on the Swan River, in damper localities, which suggests a very recent deterioration of climate at Point Peron. A much less frequent land-snail in this fossil soil is the delicate *Austrosuccinea contenta* Iredale (= *Succinea oblonga* Menke). The only living snails here today are *Cepaea pisana* and *Cepaea acuta*, both European introduced forms (personal communication : Mr. L. Glauert).

Below high tide level a wealth of marine flora is encountered. Since this vegetation almost certainly plays an important part in the physiographic development of the reef itself, as will be seen in the discussions below, it is worth while listing the principal representatives. Again, we are indebted to Mr. G. G. Smith for his assistance.

(i) Algae forming a green mat in the ramp-notch-splash zone :
Ulva lactuca Ag.
Entromorpha compressa Link.
Chaetomorpha area (Dillw.) Kuetz.

(ii) Algae of the basal carpet on the reef flat :
Ceramium clavulatum Ag.
Jania fastigiata Harv.
Polysiphonia sp.
Hypnea musciformis (Wulf.) Lamour.
Lithothamnion sp.
Caulerpa cylindracea Sond.

(iii) Large algae anchored in basal carpet :
Sargassum spp.
Cystophyllum muricatum (Turn.) J.Ag.
Ecklonia radiata (Turn.) J.Ag.
Pterocladia capillacea (Gmel.) Born. and Thur.

There are numerous other green, brown and red algae contributing to the flora of this carpet and also down in the undercut off the reef margin and in the deeper habitats offshore.

An analysis of the shelly marine fauna will be found in Appendix I. and II.

II.—GEOLOGICAL BACKGROUND.

(a) General.

The oldest rock of the headland consists of a calcareous dune rock locally known as the Coastal Limestone formation and taken to be late Pleistocene in age. In many places in Western Australia, intercalated in the dune rock (or "eolianite") at about present sea-level, there are isolated lenticles of beach and shallow marine deposits, which presumably indicate a temporary submergence during the otherwise mainly eolian sedimentation ; no example, however, has been recognised in the Point Peron area as yet. The Coastal Limestone is also intercalated by horizons of travertine and fossil soils which likewise appear to represent temporary interruptions in the eolian accumulation. Well-marked fossil soils have been recognised both on Point Peron and on Penguin Island.

The whole Coastal Limestone Formation is comprehensively affected by solution phenomena resulting in further travertine crusts, solution pipes, root structures and other characteristics. The bulk of these karst features may be seen at various points to disappear beneath sea-level and are therefore to be regarded as pre-dating the present erosion cycle. On the shore the Coastal Limestone forms high cliffs in many places and broad reef platforms extend seaward.

Overlying the old consolidated dune rocks of the Coastal Limestone there are series of loose Recent dunes which rise to a height of 88 feet. In places incipient travertinization may be recognised in these Recent dunes.

Around the beaches there are fair-sized deposits of contemporary beach sands and in the beach-ridges of the broad sandy plain, which connects the headland of Peron with the hills five miles to the East, there are very extensive accumulations of earlier Recent beach sands, the height of which has been partly augmented by wind action.

The Coastal Limestone is the main rock type which forms the two parallel ridges described in the Introduction, the outer one through Garden Island and Point Peron being rather dissected and partly inundated, so that it is only represented by reefs today ; and the inner one forming the first range of coastal hills some five miles to the East.

Relatively little is known of the basement which underlies the Coastal Limestone of the Western Australian coastal plain hereabouts, but a deep artesian bore put down by the Army authorities at Point Peron in 1944 (Bore No. E16) reached 1,412 feet and provided an artesian flow of water measured at 14,000 gallons per hour. The water is fairly hot (just over 100°F.) and is rather sulphurous, with a high percentage of dissolved salts. The percussion bore used naturally gives a rather poor indication of the strata penetrated, but the broad features recorded by the driller indicate shaley sands (with marine bands) to 120 feet, below which are sands and sandy limestone to 200 feet ; all of which sounds like the lower parts of our Coastal Limestone. From 200 to 700 feet is a calcareous limestone with marine shells of unknown age ; from 700 to 900 feet there are black pyritic shales with sandstone and glauconite bands. I have been fortunate enough to see some specimens of these, and the bright green glauconite bands may possibly be compared with the Upper Cretaceous glauconites of Gingin and Dandaragan. The black pyritic shales are also of a type found associated commonly with Cretaceous rocks in the artesian bores of Perth. From 824 to 1,230 feet there are pyritic black shales alternating with fine grey sandy shales which contain foraminifera between 824 and 930 feet and may also be compared with the Cretaceous (possibly Lower Cretaceous) below Perth. At 1,230 feet there is a conglomeratic grit horizon passing down into loose sand and sandstone to 1,412 feet, carrying water. This again, we may compare with the so-called " Claremont " water horizon below Perth, which may be of Upper Jurassic age.

(b) Coastal Limestone.

(i) *Eolianites.*—The Coastal Limestone of Western Australia has been known for more than a century and a half; its discovery dates back to before the foundation of the Colony, having been observed in the vicinity of King George's Sound by Vancouver on his voyage around the world in 1791. It was described in more detail by Peron and Freycinet (1807–16, pp. 75, 168–73). While Vancouver and others had taken the rock to be mainly of coral origin, Peron and Freycinet recognised it in all its essential features, *i.e.*, as a subaerial deposit originally consisting of wind-blown beach sands and containing shell debris from the beach together with terrestrial snails, bones and vegetable remains. The term " eolianite " was only relatively recently applied to this type of rock by Sayles in his work on Bermuda (1931) ; in America and Australia the older spelling of " æolian " is now often discarded.

It is not necessary here to go into a long report on the history of this formation, as it has recently been summarised by Teichert (1947, pp. 182–185). We may merely confirm his conclusions and emphasise that all the evidence points to the formation of this wind-blown rock during one or more of the Pleistocene glacial periods when the low eustatic sea-level exposed broad areas of continental shelf sands to eolian erosion.

Similar rocks are now recognised around practically all of the more gentle sloping coast lines of the world in warm-temperate and arid latitudes. The rock itself consists of rounded grains of quartz and other resistant minerals with a varying percentage of calcium carbonate consisting of fragmental remains of mollusca, echinoidea, foraminifera, bryozoa, calcareous algae and smaller quantities of coral and other calcareous invertebrates.

The proportion of calcareous to insoluble minerals varies very greatly from place to place, but a characteristic sample collected by Miles from just South-West of Point John showed 80 per cent of soluble carbonates (Miles, 1945). The whole mass is more or less cemented together by carbonate material which has been dissolved out of the higher layers by rainwater and reprecipitated lower down in the old dunes. Very great local variations are thus encountered in the degree of hardening and in the amount of calcareous enrichment.

It is generally considered that the superficial layers of the old sand dunes which had lost the bulk of their calcium carbonate under this leaching process, were reduced already in Pleistocene times to the character of loose siliceous sands which were then blown away once more to be deposited further inland where today there are extensive plains of white siliceous sands quite devoid of calcium carbonate (Crocker, 1946).

In the cliffs at Point Peron today we observe a cross-bedding of these old dunes very nicely exposed with steep dips in places up to 32°, and in the general way dipping East or North-East, *i.e.*, away from the prevailing wind. It will be noticed how the individual stratification planes are more hardened by calcareous enrichment than the intervening accumulations (*see* text fig. 2). It has been suggested that each plane was thus hardened by a shower of rain during its accumulation, but the uniformity of the stratification through hundreds of feet forces one to reject this explanation. It seems more likely that trickling calcareous solutions penetrating the former dune from the original surface would tend to be deflected down the old planes of accumulation, and would thus provide this striking banded effect.

Text fig. 2.

Typical section of steeply bedded eolianite from an exposed position just south of Fisherman's Head where secondary travertinization is well developed along the bedding planes and vertically in the "pencil structures." Note the honeycombed weathering of the non-indurated parts. Hammer with 18 inch handle indicates scale.

A second feature of this calcareous enrichment is a network of vertical pencil-like structures varying from one quarter inch to two inches in diameter, and running vertically through the rock from top to bottom (*see* also text fig. 2). These appear to pass straight through the diagonal hardened planes and may be due to precipitation of calcium carbonate from *vertical* trickling solutions which took place contemporareously with the oblique hardening.

Under wind and rain erosion the less resistant pockets of the old eolianite lying between the above-described features tend to be scooped out and washed or blown away. In this way a pronounced honeycomb effect is produced on the rock surface. Owing to the hardening of the surface by travertine crusts, the tops of the cliffs tend to be well preserved, while eolianite lower down, being much softer, tends to be scoured out by the forces of wind and rain, producing large cavernous structures and " natural bridges " (*see* photos by Gentilli, 1948).

Macro-fossils are hardly known in the eolianites of the Coastal Limestone, but in places large shells have been carried up by sea birds (Teichert and Serventy, 1946), and in other places aboriginal kitchen middens may be mistaken for marine deposits associated with the eolianite. In other exposed places quite large shells may be blown up a moderate distance (say 50 feet), to be incorporated in the eolianite, but this is distinctly unusual and normally the only intact shells found in the eolianite are the foraminifera, which, with their light structure and air chambers, are very easily carried by wind. No comprehensive study of the foraminifera of the Coastal Limestone of Western Australia has yet been carried out, but as far as has been recognised they appear to be mainly living species, but not always of local occurrence today (*see* Appendix II).

(ii) *Soil Horizons.*—At various heights around Point Peron and on Penguin Island in the old eolianite formation, there are layers of very hard travertine varying in thickness between three and 12 inches. The upper surface of these layers is rather smooth and the lower side merges indistinctly into the underlying eolianite. Such travertine horizons have the appearance of being relics of former " hard pans," which normally form at a few feet beneath the surface of the ordinary ground level.

Resting on the travertine surface is a thin or sporadic layer of reddish to chocolate to greyish-brown sandy soil which has the character of some of the more sandy " terra rossa " residual soils of the Mediterranean, in particular those forming on the coastal belt of Palestine. This soil horizon is found to pass downwards to partially fill some of the former solution pipes which are initiated in the travertine horizon and penetrate the underlying eolianite. In this way certain of the solution pipes are almost or completely filled by alternating layers of this reddish soil and coats of travertine. The soil, on analysis, was found to be a calcareous sand with traces of phosphate : $CaCO_3$ 16 per cent, clay 2.5 per cent ; sand 78 per cent (including small amounts of heavy minerals) ; organic matter, etc., up to three per cent. In one sample there was six per cent Fe_2O_3.

In many places in the soil, particularly next to the walls of the solution pipes, are small sac-like or egg-shaped fossils from one to two inches in length, preserved in travertine. These have been compared at times with turtle eggs, wasp nests, etc., but Mr. L. Glauert of the Western Australian Museum, has kindly drawn my attention to a paper by A. M. Lea (1925) referring to them as calcareous insect puparia, the majority of recently formed specimens found in South Australia being correlated with the large weevil (*Leptops duponti* Boisd.). No doubt other large insect larvae form similar cocoons, but since all our Western Australian examples are only in fossil form, no soft parts remain to indicate the precise form of their original inhabitants.

Overlying this obviously fossilized soil horizon follows a higher sequence of cross-bedded eolianites. Soil horizons of this type are found very well developed in the eolianites on the islands of Bermuda (for example, *see* Sayles, 1931), Bahamas, and elsewhere, as well as elsewhere on the coast of Western Australia, *e.g.*, at Hamelin Bay. At Hamelin Bay, however, the soil horizons are more numerous and thicker than at Point Peron, and it appears possible that during the arid low sea-level phases of the Pleistocene the frequency and development of such soil horizons decreased from South to North.

Land snails, such as *Bothriembryon*, are generally associated with these fossil soils, but none were found in it at Point Peron, except in the youngest soil, formed on the vegetated dunes. These youngest soils are clearly older than the freshly-formed, moving dune sands of today and, judging by the thickness of soil (one to three feet), may have been in existence many centuries. Incipient travertinization is to be seen in them in the form of some weak " root structures," but no hard pan has developed yet. As noted above, bleached shells of *Bothriembryon bulla* Menke, are found in this soil, but are not found living on the surface today. Rare specimens of *Austrosuccinea contenta* Iredale are also encountered in it.

(iii) *Karst Features.*—As indicated above, the entire Coastal Limestone Formation, including both eolian and marine members, was subjected, during what was probably the last glacial period of low sea-level, to intense subaerial erosion. In the course of this attack by rainwater, the calcareous eolianite reacted in very much the same way as a pure limestone, such as is so well known in the classic localities of the karst country of Europe. Running water trickling through the porous sands produced impoverishment of calcium carbonate in the upper layers and produced enrichment below, with hardening along the bedding planes and along vertical pencil-like structures (*see* text fig. 2).

These vertical solutions, however, went further, and open pipes were dissolved out, some of these " sink holes " ranging up to 10 feet and more in diameter, but the bulk averaging only one to two feet (*see* text fig 3 ; *see* also photos of pipes near Moore River, Fairbridge, 1947). In places these pipes are found in great profusion, there being almost more pipe hollows than solid rock, while in others there are practically no pipes at all.

A preliminary examination of the distribution of these pipes at Point Peron and elsewhere along the Western Australian coast seems to indicate that the maximum concentration of the pipes coincides with the depressions in the old dune surfaces, as indicated by the depressions in the surface travertine crusts. To begin with there was the formation of a fairly massive layer at some distance below the surface of the dune, a horizon coinciding most probably with the average height of the water table, where occurred the major redeposition of the calcium carbonate which had been dissolved out of the dune sands higher up.

We may imagine now that when this travertine crust became so thick and massive that it was no longer pervious to water like the porous dune rock, the descending solutions would be deflected laterally to flow down over the surface of the crust until they reached depressions between the dunes. As is well-known with irregular dune landscapes, such depressions are often closed basins from which there is no escape of water except downwards. With the accumulations of swampy pools of water in these basins a powerful solvent concentration would be developed, which would seek out any lines of weakness in the underlying crust, penetrating it in many places like a sieve and flowing downwards eventually to reach somewhere about sea-level.

Text fig. 2.

A solution pipe or "chimney" overlooking Point Peron, almost completely exposed by the erosion and removal of the surrounding country rock. It is almost hollow as may be seen through the broken section of the travertine wall near the top. The "hour-glass" constriction appears to be due to an obstruction caused to the downwards working solutions by a hard horizontal band of pre-existing travertine crust. Traces of small root structures may be seen on the outside of the wall.

Horizontal channels which would eventually connect many of these vertical pipes with the sea, as underground rivers, have not been identified above the present sea-level at Point Peron, but are believed to exist somewhere below our present stand. Analogous channels have been recognised in operation today in the karst-affected raised limestones of Middle Island in the Abrolhos Group (Fairbridge, 1948) and horizontal channels have been identified beneath some of the reefs at Point Peron, and these are believed to have been caused in this manner during the Late Pleistocene karst cycle.

After these pipe structures were hollowed out by moving water very reduced quantities of solutions supersaturated in calcium carbonate (possibly under conditions of reduced rainfall) trickled down the walls of the pipes and redeposited layer upon layer of travertine. These layers are often discoloured by various shades of red and orange by the contemporary dust and soil formations. The walls thus formed are generally much harder than the surrounding country rock, and now when re-exposed to subaerial erosion they stand up like chimneys (*see* photos in a recent article by Gentilli, 1948). The fact that they were formed during an earlier cycle is clearly indicated at Point Peron headland, especially at the northern end of Long Reach and on the northern side of Point Peron itself, as evidenced by the fact that pipes may be seen disappearing straight down below sea-level ; in places they may be seen to extend more than 30 feet up and down. It is also apparent that these pipes at certain times, at any rate, were in contact with the open air, because in very many places down in their walls may be found the little sac-like protuberances which have been identified as fossil insect cocoons of the same type as in the soil horizons. The exits from these cocoons are now in many cases covered by layer on layer of travertine.

Associated with the travertine bands and the solution pipes are fossil root structures (the "rhizomorphs" of Northrop in the Bahamas, 1890), which wind and twist about just like the roots of contemporary scrub, except that they are almost completely replaced by travertine. In places only the rough pseudomorph is recognisable, but in others almost cell by cell replacement of the woody material has occurred.

(c) Recent Beach-rock.

In places at Point Peron, apparently plastered on to and embedded in pockets in the already eroded Coastal Limestone shore at or about the present sea-level, there are deposits of calcareous sand consisting of broken shell debris, foraminifera and quartz grains, but of rather more angular nature than the rest of the eolianite, and in places containing complete shells as fossils. This formation in contrast to the eolianite is generally found dipping seawards, *i.e.*, to West or South-West, and at a gentle angle (about three to seven degrees). The bedding, furthermore, lacks the parallelism of the big dune deposits and shows fine cross-bedding in places. It also exhibits evidence of water sorting with coarse and fine bands alternating. It is completely indurated by calcium carbonate in a very uniform manner and contrasts thus very strikingly to the irregular induration of the normal eolianite. Thanks to its gentle seawards slope and uniform lithology, it tends to joint and break up into rectangular blocks. One has, therefore, little hesitation in identifying this formation as a "beach-rock." It is well exposed on the shore of Long Reach and again in Haliotis Bay.

This beach-rock, as is well known, forms by calcium carbonate precipitation in contemporary calcareous beaches around all warm-temperate and tropical shores today (*see*, for example, Fairbridge and Teichert, 1948). The process is not yet thoroughly understood, but the formation of the rock appears to be due to the percolation of lime-rich solutions carried down through the porous upper parts of the beach by rainwater and reprecipitated in the inter-tidal zone where the acid rainwater becomes neutralized by alkaline sea-water. The factor of heating under the sun's rays when the beach is exposed at low tide, would also assist such precipitation (there is a bulky literature describing these effects and processes which we need not refer to further at this juncture). Contemporary beach-rock is exposed from time to time by changes in the overlying beach sands at certain seasons.

(d) Contemporary Beach-sands, Muds, etc.

Small to moderate amounts of beach-sands are accumulating today along the broad sweep of Long Reach, Shoalwater Bay and Mangle's Bay and a small amount in Haliotis Bay. This beach material averages about 90 per cent calcium carbonate in the form of broken fragments of all types of molluscan shells, echiniodea, bryozoa, froaminifera, corals (which are unimportant) and of calcareous algae of the *Lithothamnium* type.

The bulk of this material is broken down into rather flat flaky fragments averaging half to one millimetre diameter. The material is rather angular with little rounding. Of the insoluble fraction the most important mineral is quartz, and this is in the form of extremely well-rounded grains. Only one to two per cent of the whole consists of the resistant heavy fractions. It appears that the insoluble members are of re-worked origin, while the calcareous material is derived from recently fragmented organic sources.

An additional sediment found on the protected North-East shore, *i.e.*, facing Mangle's Bay, is a whitish mud which is extremely fine-grained and appears to be an inorganic precipitate of calcium carbonate of the type commonly recognised in certain coral reef lagoons, *e.g.*, Houtman's Abrolhos (Fairbridge, 1948), and in similar regions where calcareous eolianite is being eroded, such as the Bahama Banks and the Florida Keys.

(e) Recent Dune and Beach-ridge Sands.

During periods of neap tides, especially during the long dry summer season, the beach sands accumulated under the influence of storms and high tides tend to be dried out and are blown up into coastal dunes, which at Point Peron headland reach a height of 88 feet. These dunes are mainly vegetated today by dune grasses and scrub, which suggests possibly wetter climatic conditions in most recent times. The sand material in these dunes is much the same as that of the beach but quickly becomes reduced in size and much more rounded. I have seen quite heavy shells up to three inches in diameter rolled up the beach to a height of 50 feet in these dunes, but they never seem to reach far inland. Other shell deposits are attributable to the agency of bird and man (*see* Teichert and Serventy, 1947), but in the general way the only intact shells found in these dunes are the very small mollusca and foraminifera.

Parallel to the broad sweep of the shallow, gently shelving shores of Shoalwater Bay, etc., we find numerous parallel rows of beach-ridges. Like the sand-dunes, these too are well vegetated today. Such beach ridges are usually quite quickly overgrown where they have been thrown up above the normal limits of waves, and blown sand caught in this vegetation tends to build them up higher still, so that, strictly speaking, most of the sand beach-ridges have an element of dune ridge about them. The material of these beach-ridges is analogous to that of the present beaches and their adjacent dunes, but all analyses to date indicate a rather low percentage of calcium carbonate near the surface. It would appear that considerable downward leaching had taken place over the last few centuries.

At no point in the region of the Peron headland was I able to demonstrate the formation of a contemporary beach-ridge, or even one formed during the historial period. The height of the beach-ridges and their geomorphological features suggest, in any case, that these formations pre-date the contemporary cycle at the present stand of the sea-level (*see* further, Sect. III, e). It will be seen that the main group of ridges rise from a sand plain averaging somewhat over 10 feet in elevation.

At Point Peron, immediately South of the point itself, a most interesting section is visible, illustrating the relationship of these early-Recent beach-ridge sands to the 10-foot bench of the coast. First a hard beach-rock plaster, full of shells, is found grading up from the 10-foot bench to about 15 feet above datum, and from here up to 24 feet is a typical " raised beach " of loose shell sands. The shells include many gastropoda, but also pelecypoda, echinoderm spines, foraminifera, fragmentary bryozoa, cirripedes, chitons, serpulae, spirulae, etc. The assemblage differs in some respects from that of the present beach (*see* Appendices I and II.)

Other shell beds may be seen in various cuttings and sand pits, mostly between 10 and 20 feet above datum, between Rockingham and Safety Bay. None, however, have been found to be nearly so prolific as that at Point Peron itself. A more interesting section is exposed along the shore of Lake Richmond at about six feet above present datum (and thus well below the low tide level of the 10-foot sea). Here, somewhat crusted by lake travertine, is a somewhat similar assemblage but possessing in addition pelecypoda such as *Katelysia scalarina* (Lamarck), with both valves in place, suggesting undisturbed sedimentation in a protected spot. Geomorphological observations indicate a possible explanation (*see* again Sect. III, e), that this area was formerly a bay open to the North, but cut off to the South and West by successive beach-ridges.

III.—GEOMORPHOLOGICAL FEATURES.

The general geomorphological aspect of the Point Peron headland and vicinity was indicated briefly in the introduction. It is a rocky headland of Pleistocene eolianite, " tied " in the form of a tombolo by a large number of successive beach-ridges to the adjacent mainland, the rocky parts of which lie five miles to the East across a flat plain ridged only by these parallel rows of ancient beaches. Of this feature I will have more to say below.

Around the cliffs of the rocky headland of Peron, Garden Island, Penguin Island, etc., there are a number of interesting erosional features both belonging to the contemporary marine cycle and to previous periods when somewhat higher sea-levels existed. I shall describe first those of the present cycle :—

(a) Contemporary Marine Platforms.

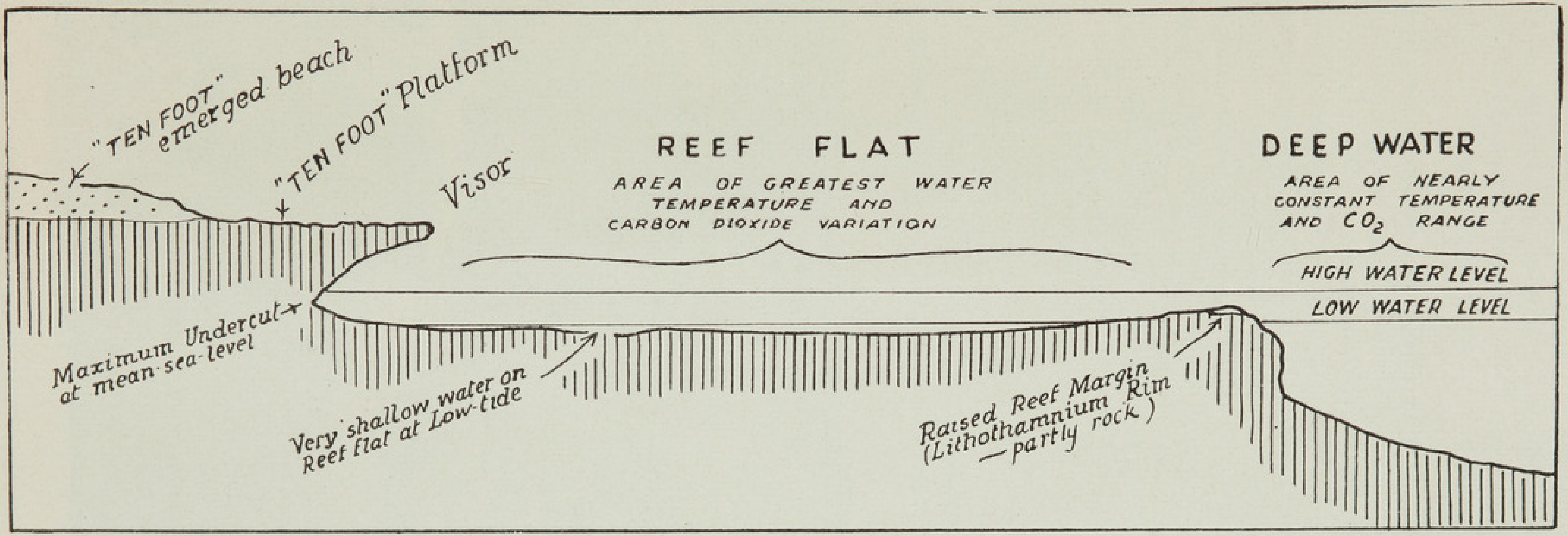
The present marine cycle is observed to be in the process of cutting out a series of broad marine platforms otherwise known as "water-level benches," or, quite simply, "reefs." The expression "reefs," however, should not be taken to imply that these features are coral reefs. The occurrence of corals in this region is quite a rarity, and they are better described as "limestone reefs," though sometimes, but less accurately, named "sandstone reefs."

(i) *General.*—These contemporary marine platforms extend out to sea for a distance of up to 200 yards where the main force of the waves is spent. Their outer edges follow an almost North-South line from West of Point John for over 1,000 yards to somewhat South-West of Point Peron itself. However, all is not one massive reef but there are many "bays" and indentations in the reef flats where quite deep water comes close in to the shore. Isolated "stacks" and small islets rise off-shore from the surface of the platform. The general level of the platform is about the height of datum (low water springs), but in certain areas the surface is irregular and several feet below datum, while on the outside edges there is generally a somewhat raised rim. Nevertheless, the average height of the reef is within a few inches of datum.

The reason for this planation of the limestone to form a horizontal bench or reef at about the level of low water spring tides has never been explained on the West Australian coast. I indicated something of the nature of the process in a paper on the Abrolhos (Fairbridge, 1948) and the subject is still under research. Briefly the problem is this : as Macfadyen (1930) in the Red Sea, Kuenen (1933) in the East Indies, and several other authors quite recently have pointed out, limestone coasts, particularly in the warmer waters of the world, are undeniably being subject to chemical solution by the surface layer of sea-water. Normally speaking, sea-water is supersaturated in calcium carbonate and cannot dissolve further quantities. There is no evidence of solution going on at depth as has been postulated by Murray to account for coral reef lagoons.

In a thin layer, restricted to the surface of the sea near the shore, sea-water is believed to act as a powerful solvent which attacks and undercuts limestone cliffs and reduces them to horizontal reef platforms, at a level which corresponds both to the lowest limit of subaerial erosion and also to the lower limit of this superficial marine solution, *i.e.*, the level of low spring tides (*see* text fig. 4, page 49). It is observed that mechanical and biological forces assist the chemical, but that the latter is the controlling influence. It is suggested that, with a sharp rise in temperature and loss of CO_2 (both raising the pH) in the shallow water (especially just on the surface) on the reef flat on a hot sunny day, there will be a precipitation of calcium carbonate from the supersaturated sea-water. In the night there will be a considerable drop in temperature in the shallow water of the reef flat, reducing the pH and making the water relatively "acid." In addition at night, the photosynthesis (with absorption of CO_2) by reef plants will be interrupted, and additional quantities of CO_2 will be liberated by animals and plants, further reducing the pH. The role of surf in taking excessive quantities of CO_2 into solution may also be considered.

The deeply etched and jagged surface of the limestone at the undercut cliff edge is plain for all to see. In striking contrast are the smooth, polished surfaces occasionally found where mechanical abrasion (by sand) has been operative. Biological action, by boring worms, pelecypoda, echinoids, algae



Text fig. 4.

Section across an idealized reef-flat cut in limestone rocks. It will be seen how the bulk of the reef is reduced to the level of low water spring tides, or a little below. It is here on the reef flat and especially in the undercut notch that maximum solution effects are experienced. These features are normally protected from powerful wave action by the reef rim. The latter is generally somewhat higher than the rest, being exposed to the continual splash of waters of even temperature, and, in addition, is often further protected by incrustations of *Lithothamnion*. It is remarkable how resistant this outer rim is to mechanical erosion.

and so on, is also recognised as assisting the destruction of the reef. Nevertheless, on the one hand, the zone of maximum erosion, in the undercut and swash area, is marked by a minimum of biological agents, while on the other, the area of maximum biological attack, from the level of the low-water springs downwards, is precisely that part of the rocky coast which is best preserved.

(ii) *Raised Rims.*—The outer edge of the contemporary reef flat, whether or not it is exposed to a moderate amount of wave action and splash, is almost always raised somewhat higher than the rest of the platform ; the height of this rim is generally between six and 18 inches, according to exposure. Paradoxically enough, the greater the exposure, the greater the height. The rim is generally found to be coated with incrustations of calcareous algae and is analogous on a small scale to the well-known *Lithothamnion* rim of Charles Darwin, found on the great coral reefs of the Pacific and Indian Oceans.

In some of the most exposed outer parts of the reef the *Lithothamnion* rim is ranged somewhat in the form of steps with intermediate rims between each step, the highest terrace being to the exterior. Being surrounded with a low rim of growing calcareous algae, each of these terraces is perpetually covered by a shallow pool of water no matter what its height (up to 18 inches) above low tide line, since here on the outer edge wave splash keeps it filled with water and thus keeps the rim-building algae alive. The over-flow towards the interior fills successively lower and lower terraces.

Text fig. 5.

The low reef rim off Fisherman's Head, seen at low tide when the upsurge is spilling water over the rim onto the reef flat. The horseshoe opening is a former " blow-hole " now broken through on one side.

Text fig. 6.

The same reef rim, seen a few minutes later, when the back-surge is allowing the water thrown onto the reef flat to drain back into the sea. Note the reversed role of the rim in holding the water up on the reef.

The inner reefs, where wave action is much reduced, are bounded simply by a single rim about six inches in height (*see* text figs. 5 and 6). At low tide in calm weather the water is thus seen to surge up over the edge of the rim, but being prevented from flowing directly back, flows sideways to escape into one of the deep channels which cut the reef. On the sides of these channels, where there is practically no surge at low tide in calm weather, the rims are very reduced or even absent and consequently allow this escape. There is thus an almost perpetual current crossing the reefs from the outside and swinging away laterally near the shore.

It has sometimes been thought that the *Lithothamnion* rim had grown up from the outer edge of a horizontal reef platform, but when this rim is broken into with sledge-hammer and crowbar it is generally found that the *Lithothamnion* only forms a thin coating or incrustation over the surface and that the interior of the rim is calcareous eolianite like the rest of the reef. Only in exceptional places is the *Lithothamnion* incrustation more than a few inches thick. This observation appears to demonstrate that the reef platform has in fact been eroded (by solution) downward below the rim level, the latter being preserved from chemical erosion in the zone of wave splash.

In certain places, particularly at the reef edge facing the transverse channels where there are very reduced amounts of wave splash and where the water current is generally flowing out from the reef back into deep water, there are traces of a very small rim which is purely of the country rock material with no *Lithothamnion* at all. These rock rims are broken in many places, but they are nevertheless very interesting because they are raised and sharp, projecting from the steep reef edge out over deep water. They clearly demonstrate with their lack of rounding that it is chemical erosion which is going on in the interior, for in such exposed positions sharp pinnacles of this sort would soon be rounded off. The rock rims of this character are generally not more than about three inches in height.

A third, but very unusual type of rim, is encountered on the protected North-East side of the Point Peron peninsula. Here, in Mangle's Bay there is a considerable amount of white, sandy and marly calcareous sediment extending over and out beyond the reef, so that there is very shallow water for a considerable distance off-shore. Rising, however, in a few places near the shore to a height of nearly two feet above datum, are a number of micro-atolls, ranging up to three or four feet in diameter, each with a miniature lagoon in the middle (*see* text fig. 7).

Text fig. 7.

A micro-atoll coated with Mytilus, nearly four feet in diameter, found on the shore of Mangles Bay just north of the National Fitness Camp.

The rims of these micro-atolls are coated with dense clusters of a mytilid, *Brachyodontes erosus* (Lamarck), a common mussel which is found widespread in the shallow waters of Cockburn Sound. These micro-atolls are much the same type as those described on the Bermuda Reefs by Agassiz (1895), though the incrusting animal in Bermuda, according to Agassiz, was more commonly *Serpula* ; still *Mytilus* micro-atolls are also known there. These Bermuda micro-atolls, like those of Point Peron, are built of calcareous eolianite with rock rims merely coated, or incrusted, with a protection of *Mytilus* or *Serpula*. The interior, or miniature lagoon, has, in both cases, been reduced below the rim level by erosion, presumably both chemical and physical. Since, however, their protected position in Mangle's Bay prohibits any excavation by scouring due to violent wave attack, it seems most likely that it is chemical erosion which is the most important feature in the etching out of these shallow lagoons.

(iii) *Blowholes and Under-Reef Channels.*—At various points on the reef at Point Peron, but most easily observed at Fisherman's Head, there are vertical pipes or holes in the reef which, in some cases, are directly connected to the sea either in the under-cut outer margin of the reef or by means of a longer under-reef channel. In this way the breaking wave near the reef margin is followed a few seconds later by an up-surge in the blowhole and the water spills out over the reef flat. With the back-surge the water runs back into the hole.

Since the level of water is thus repeatedly raised and splashed around the rim of the blowhole, there is generally an active growth of *Lithothamnion* over the raised rim just as there is on the outer edge of the reef (*see* text figs. 5 and 6). In ordinary weather the hydraulic thrust is not enough to shoot water high into the air, but in times of exceptional storms at low tide, a miniature geyser effect is sometimes produced.

The under-reef channels, referred to above, actually connect the two sides of the narrow headland called Fisherman's Head, and a few seconds after a wave breaks on the South-West side there is a considerable up-surge of water on the North side of the Head. There appears to be a tunnel about 25 long which must be of considerable diameter, since the amount of yards water displaced in this way is quite impressive.

On the low cliffs, 150 to 200 yards South of Fisherman's Head one may observe vertical solution pipes which have been produced during an earlier cycle of karst erosion going straight down from the top of the cliffs to below sea-level. Some of these pipes, too, are in direct connection with the sea somewhere below and the water naturally surges up and down with the prevailing swell.

From our knowledge of similar karst developments with solution pipes and horizontal channels observed elsewhere above sea-level, it seems very likely that a well-developed network of former underground rivers and solution channels is connected to many of our vertical pipes. Some of these are still sufficiently free from blockage by sediment that they are open to the sea beyond the reef edge, where the water is about 10 feet deep on the average.

We thus have a system of " drowned " karst caves and channels beneath Point Peron. A somewhat similar case of " drowned " karst development of probably similar age has been described from the Abrolhos Islands (Fairbridge, 1948).

(iv) *Submarine Under-cut.*—The outer edge of the reef is what sailors call " steep-to " and the bottom drops immediately to 10 feet or more where it forms apparently a lower platform of an average depth of about three fathoms, beyond which it drops again to about five fathoms. Insufficient amounts of sounding data are available for this region to make perfectly sure of these relationships, but the present material appears to indicate that, just as there are a number of horizontal platforms on the land, there are also a number of submerged off-shore platforms.

It is perfectly clear, however, that the outer edge of the reef flat is overhanging with a visor-like projection of the reef rock. Beneath this overhang, except in places where obviously it has recently been broken off, there is almost always a deep " under-cut " which may extend back for distances between three and 15 feet.

It was noticed immediately that this under-cut is analogous in appearance to the intertidal under-cut, which we recognised at the inner edge of the present reef flat and which separates the latter from the higher reef platforms, *e.g.*, the 10-foot bench. It would not require a great stretch of fancy, therefore, to imagine the present contemporary bench inundated to a depth of 10 feet, in which case our 10-foot platform would be the new water-level reef and off-shore there would be a deep under-cut.

We might, therefore, without further ado explain the submarine under-cut at Point Peron as a phenomenon caused by inter-tidal erosion during a former lower sea-level, the height of which would have been between about 10 and 20 feet below the present sea-level. This phenomenon of the under-cut reef margin is not restricted to Point Peron. It is not by any means a local feature, and I have recognised it in many places in Western Australia and I am informed that it is commonly found elsewhere, in South Australia, etc.

There are, however, certain alternative explanations which have been presented. To begin with, we recognise the inter-tidal belt and a short distance above and below it a special zone of chemical activity in which alternate solution and redeposition of calcium carbonate is in progress. In this way, although rock material is continually being removed down to low tide level, the rock surface there is so indurated and hardened by precipitated calcium carbonate that it is extremely difficult to break, even with a sledge-hammer. Boring operations which have been carried out in search of water, etc., in the coastal limestone, generally indicate that hard crusts of this sort do not extend to any great depth and after a few feet the rock becomes quite soft again. In some places the old dune material is so unconsolidated that it simply powders in the hand. It is conceivable, therefore, that beneath a layer two to three feet thick occupied by the reef flat and its overhung rim, there is a softer horizon of old eolianite which is subject to more rapid erosion by mechanical scouring of the waves. In this way, the under-cut would be a contemporary product of mechanical wave action.

Alternatively it has been demonstrated that just below low tide line the activities of boring mollusca, worms, sponges, etc., reach their maximum intensity, and in this way the under-cut might be loosened and honeycombed by biological attack.

In answer to both these alternative proposals, however, there are a number of very serious objections. In the first place the surface of the under-cut is coated in large fleshy seaweeds and all manner of more delicate marine growths, both plant and animal. It is often plastered with pink *Lithothamnion*. Very close by I have even found specimens of the delicate coral *Cyphastrea* which could not possibly stand any great mechanical erosion. The entire surface of the under-cut is thus protected by a thick coat of living materials, and it is quite apparent that if major erosive activities were in progress bare surfaces of rock would be exposed. It is true that in places segments of the overhang have broken off and are seen to lie in the clear water at the foot of this submarine cliff. In exactly the same way large segments of the overhang between the 10-foot platform and the present bench may be seen to have broken off. This would seem to be a natural result of the tremendous hydraulic power of waves, possibly aided, to some extent, by the activities of boring animals and plants. Nevertheless, the scars left by the broken off segments are quickly covered again by a mat of living organisms, and it appears to be most improbable that a contemporary mechanical form of erosion is responsible for the under-cut itself.

As for biological attack being solely responsible, we have the evidence of particularly large blocks which we have broken off the edge of the reef by means of crowbars and sledgehammers. It was only with the greatest difficulty that these segments of the reef were obtained, and in the resultant cross sections of the reef rim it was found that boring animals only reached a depth of six to nine inches, to the interior of which was found a pure eolianite rock, the grains of which are cemented together in the most massive and resistant manner. Thus we must reject also the explanation of biological attack as the sole factor in producing this under-cut, and the conclusion reached is that the under-cut was formed during an earlier cycle of erosion under intertidal conditions when the sea-level was at least 10 feet lower than it is today.

(b) Emergent Platforms and Shell Beds.

We have seen above how there are extensive contemporary marine platforms around the promontory of Point Peron, and stepping back up the shore and cliffs of the rocky parts we find a succession of emerged platforms which exhibit many of the same features which we have recognised in the ones forming today. We recognise their horizontal indurated surfaces although in many cases they are deeply dissected ; nevertheless, in the same way that a " Gipfelflur " in mountain geomorphology enables us to recognise a former peneplain, the conformity of heights over a broad area (all across steeply dipping rocks) also indicates a former erosion plane.

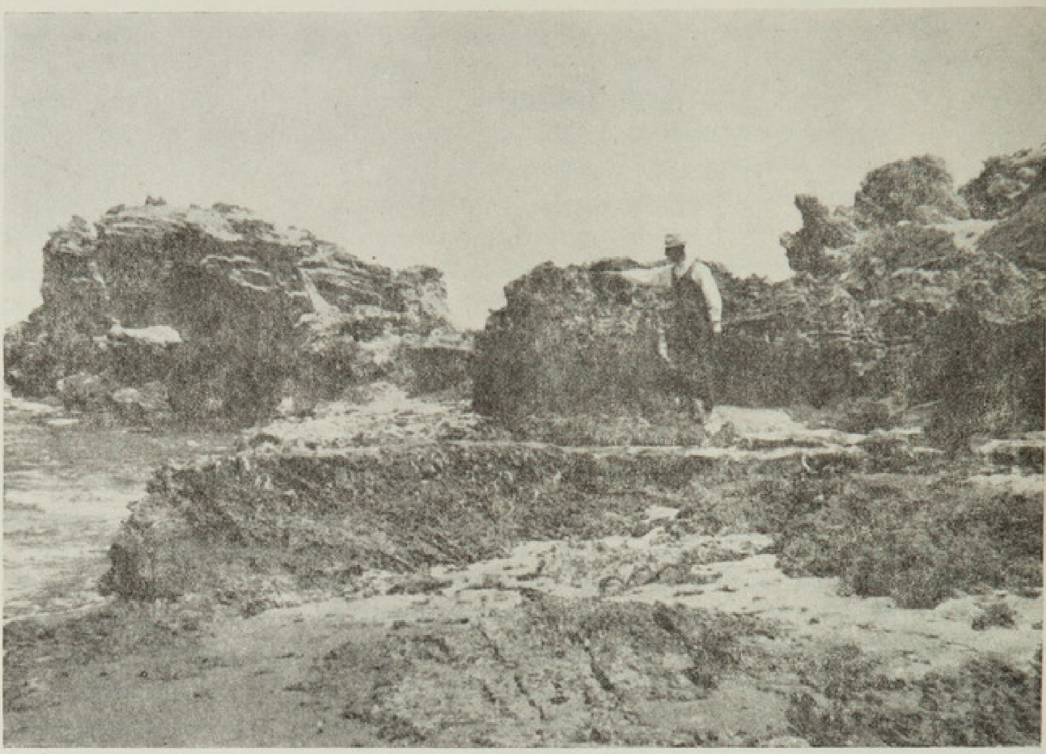
We do recognise patches of *Lithothamnium* incrustation in places, but so far I have never found even the relic of the raised marginal rim which is so characteristically associated with the contemporary reef ; which is hardly surprising since the outermost edge would be the first to suffer active erosion with emergence.

On the other hand, we recognise "fossil " blowholes, " fossil " cliffs and the former under-cuts or notches at the bases of these cliffs. All these features, of course, are in varying stages of degradation.

Three characteristic emerged platforms with their associated beach accumulations may be observed at approximately 10, five and two feet above datum (*see* text fig. 8 and 9). It is unusual to find all three preserved in one and the same place for the obvious reason that the formation of each younger one tends to destroy the immediately preceding one. On the other hand, around the limited compass of the Point Peron peninsula, all three are found in varying conditions of preservation.

In age, the 10-foot platform is the oldest, while the five- and two-foot platforms represent intermediate still-stands of the sea in its drop to the present level. From the dimensions of the 10-foot platform and of the contemporary reef, we may presume that these features were formed during long periods of stable sea-level, while the five- and two-foot platforms, being very much smaller than either the oldest or the present features, must have represented relatively brief periods of stability.

The fact that the low cliffs between the respective platforms are even preserved almost intact as steep abrupt features, clearly indicates that the sea-level changes between the periods of stability were accomplished with great rapidity, allowing only a minimum of time in which intermediate erosion could take place. Had the sea-level been gradually lowered over a long period, we would expect a broad sloping bench rather than a series of short sharp steps.



Text fig. 8.

Three former marine benches cut in the Pleistocene eolianite, dipping steeply landwards Locality just south of Point Peron itself. Man is standing on the lower part of the notch—of the 5-foot bench and is indicating the rather worn surface of the 10-foot level. The 2-foot level in the foreground is partly obscured by beach sand and plastered by contemporary beach-rock. The sea is nearly at low tide.

Text fig. 9.

Former notch cut in indurated eolianite and filled with beach-rock conglomerate and shell plasters of the 5-foot sea-level, exposed in vertical section by quarrying just north of Fisherman's Head and producing the paradoxical situation of a younger deposit almost completely enclosed in undisturbed older rocks

Detailed features of the respective platforms are as follows :—

(i) *Ten-foot Platform.*—This is the highest platform encountered at Point Peron, or, for that matter, anywhere so far in the Coastal Limestone rocks of Western Australia. It is found very well preserved around the Point Peron peninsula at a number of points : 150 yards South-East of Point John in a small protected cove ; at Fisherman's Head (200 yards South-West of Point John) ; 150 to 250 yards South of Fisherman's Head ; bevelling some earlier beach-rock at the northern end of Long Reach; on the North and South sides of Point Peron itself ; 100 to 200 yards South-East of Point Peron and on the pointed headland between Haliotis Bay and the northern end of Shoal-water Bay.

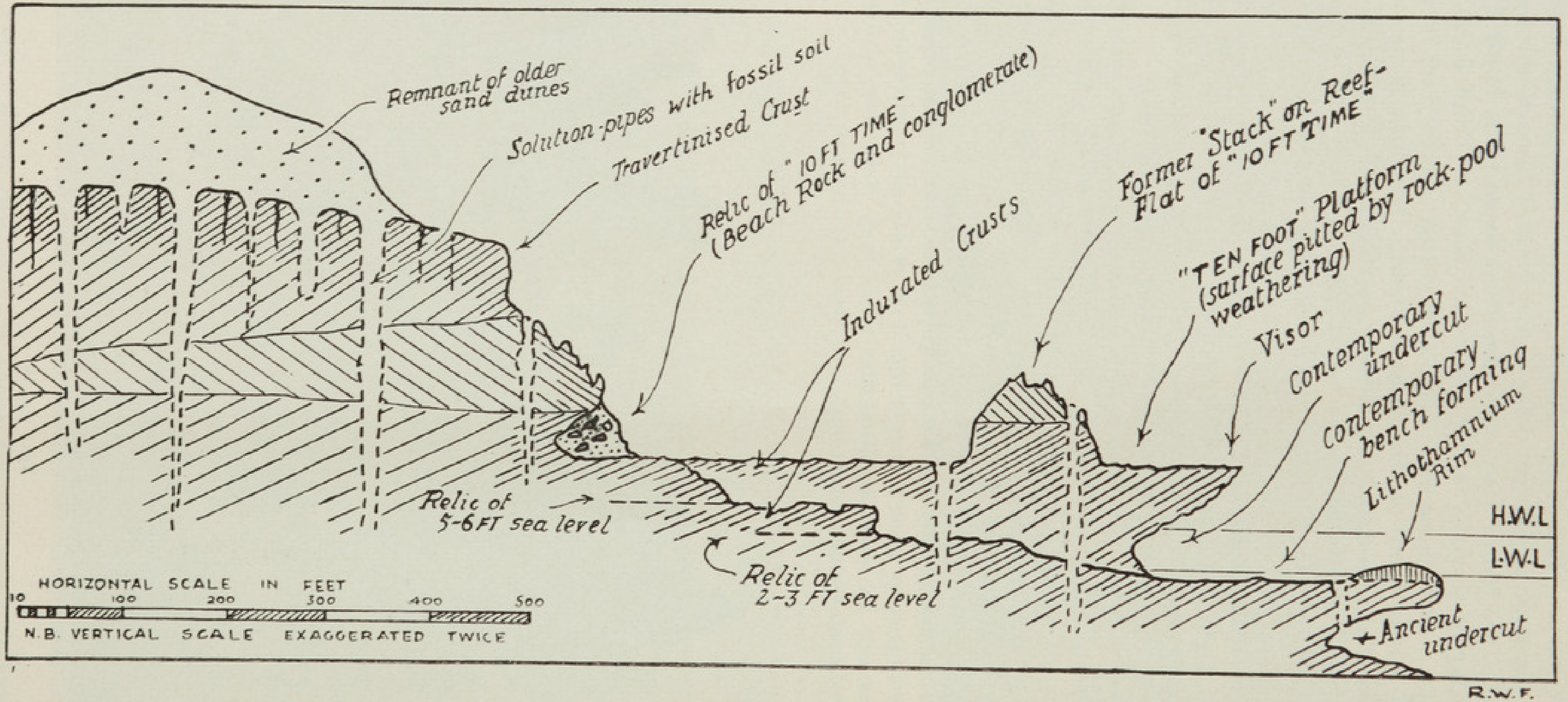
All these traces of the 10-foot platfoım are all the more impressive because they truncate the steeply dipping eolian bedding of the Coastal Limestone, and there is thus no chance of differential weathering producing apparent platforms which are not true products of former high sea-levels.

Certain of these 10-foot benches, as for example at Fisherman's Head, are subject to contemporary pool-level weathering (by spray-filled rock basins). However, this type of weathering has not carried the surface of the platform down more than two or three inches. The nature of this process has recently been described in California by Emery (1946).

Elsewhere, only rainwater and spray are apparent as erosive forces. These tend to cut up the surface of the platform into short sharp jagged pin-nacles, but, nevertheless, it is still surprising how relatively unaffected many of these platforms are by erosion since the time they first rose above low tide level some thousands of years ago.

Text fig. 10.

Fisherman's Head, looking north-west, showing the 10-foot bench, crowned by honey-combed pinnacles representing former sea stacks. The cross-bedding of the eolianite (dipping landwards at 20°) may be seen running right through the whole cliff. In this exposed position all traces of the 5- and 2-foot benches have been effaced in one big con-temporary notch, while blocks of the formerly overhanging " visor " have fallen down in the right-hand side. There is about one foot of water on the reef.



Text fig. 11.

Idealized section through Fisherman's Head, indicating the relationship between the four marine benches (contemporary, 2-foot, 5-foot and 10-foot) which bevel the old eolianite. Associated with them are under cut notches and their contemporary beach deposits. The problematical " ancient undercut," beneath the present sea-level, is also indicated. Note how the cross-bedding in the eolianite and the vertical solution pipes (reaching below sea-level) are older and independent of any of the benches.

At Fisherman's Head, and in a more dissected way at Point Peron itself, there are former sea-stacks which existed somewhat in their present form, even at the time of the 10-foot level. In this way the stacks at Fisherman's Head are seen rising up (with slightly under-cut sides in places) from the 10-foot platform for another 10 feet or so. Again, the cross-bedding of the eolianite may be seen running up into the stack (*see* text figs. 10 and 11).

The impressive development of beach-rock, rising from several feet below sea-level to be bevelled off at 10 feet above, found in Long Reach, is probably attributable to the period of rising sea-level immediately preceding this 10-foot period. The situation there is complicated by the plastering of more recent beach-rocks on the surface of the old in places.

(ii) *Five-foot Platform.*—With this lower platform we are already within reach of direct wave action when the tide is at its highest and the waters reach of a direct wave action when the tide is at its highest and the waters of the continental shelf are banked up by on-shore storms, so that the highest waves and swash may actually attack the five-foot platform. The tendency, therefore, is for this platform to be more dissected, curiously enough, than the older 10-foot platform.

In any case, however, as indicated above, it is a platform of much smaller extent than the 10-foot and is consequently more easily effaced. Nevertheless, it is found at a number of places on the Point Peron peninsula : 75 yards South-West of Point John ; 20 to 50 yards North-East of Fisherman's Head ; in traces 200 yards South of Fisherman's Head ; bevelling outcrops of old beach-rock at Long Reach, on both sides of Point Peron itself and on both sides of Haliotis Bay.

The finest occurrences are thus on either side of Point Peron itself, which, for some reason, appears to be more protected than elsewhere. These are amongst the best preserved traces of the five-foot sea-level of the mainland of Western Australia, though much more extensive traces of it are found at Rottnest (Teichert, 1950) and the Abrolhos Islands (Fairbridge, 1948). At Point Peron it is found cutting into the edge of the 10-foot platform with a nicely developed under-cut, but is generally only about three to 20 feet in width.

No emerged shell beds or beach-rock have been so far actually identified with this platform at Point Peron except for one small patch South-East of Fisherman's Head where quarrying activities have apparently removed the five-foot platform. Plastered into under-cuts and crevices in the eolianite to the interior there is a typical shell deposit of the type commonly associated with pockets of beach-rock (*see* text fig. 9). Owing to the removal of the platform which formerly lay in front of this under-cut, these shell deposits today appear in a very paradoxical position, since they are both overlain and underlain by diagonally bedded eolianite and at first sight appear to be intercalated stratigraphically in that eolianite, for their grain-size and cement is practically identical. Only careful examination discloses that, in fact, we have only a shell "plaster."

(iii) *Two-foot Platform.*—The traces of this most recent intermediate still-stand come well within the compass of the present tidal range and are thus almost daily subjected to wave attack (both chemical and physical). It is not, therefore, in the least surprising that the relics of this bench are very obscure except in the most protected places.

Were it not for the fact that we recognise traces of this sea-level very clearly in Rottnest, the Abrolhos and elsewhere on this Western Australian coast, it might be easy to pass over the evidence at Point Peron without noticing it ; nevertheless, there are certain traces of conformable levels which occur undeniably at this elevation here, especially to the North-East side.

Associated with this level, particularly at Haliotis Bay and Long Reach, there appear to be some formations of beach-rock which are unquestionably younger than the eolianite and yet rise to a height somewhat above contemporary limits of beach-rock formation (*see* Sec. II (c)).

(c) Shore Ramps.

In most places along the coast the junction between the horizontal contemporary shore platform and the shore itself is marked by a low under-cut cliff or by a sloping sandy beach. However, in certain places such as Haliotis Bay and certain spots on Rottnest, there is short ramp, which is bevelled across the be lding planes of the eolian rock material.

This sloping ramp is a feature which does not seem to have been described before and its origin is rather puzzling. It slopes down from high to low tide level at a more or less uniform angle and then flattens out sharply where it joins the horizontal platform. Above high tide it either merges with a five-foot platform or passes into an under-cut cliff. The angle of the ramp is generally identical with that of neighbouring beach-sands and therefore appears to be a function of the local factors of wave erosion, exposure, etc. In some places the upper limits of the ramp are pock-marked by rain water and spray erosion, and in certain places the lower part of the ramp is being under-cut and dissected with radial channels by marine attack, but the ramp appears to be quite smooth where it has been only recently exposed. It appears to disappear laterally beneath adjacent sand beaches, or into beach-rock.

It may be seen thus that where exposed to continued erosion, either subaerial or marine, the ramp quickly begins to disintegrate. On the other hand, it is not to be confused with a recently cemented accumulative deposit, as for example, a contemporary beach, because we may recognise across the smooth surface of the ramp the basset edges of the truncated eolianite bedding planes.

The impression I have gained, therefore, is that it is an erosion surface which is a function of the local swash zone.

(d) Beaches, Beach-rock, Spits and Dunes.

Contemporary sand-beaches at Point Peron are somewhat restricted except in Long Reach, the broad sweep between Point Peron itself and the cliffs South of Fisherman's Head, and a shorter stretch at Haliotis Bay. Further sand accumulations occur along most of the North-East shore from Point John to Rockingham and beyond, and in the South forming the shore of Shoalwater Bay. The beaches are fairly gentle for the most part and rise sharply inland into dunes. Beach gradients range from seven down to about three degrees.

Contemporary beach-rock appears to be forming today in the normal manner experienced on tropical and warm-temperate calcareous beaches. It is found in Long Reach and Haliotis Bay in particular. On the long sandy sweeps to the East and South, however, it is notably absent. Where it does occur it should be restricted in height in its contemporary development, almost precisely to the limits of the intertidal belt, and thus with the small tidal range at Point Peron could not theoretically have a maximum thickness of more than four to five feet. However, on examination it was found to extend from a few feet below sea-level to somewhat more than 10 feet above low water mark.

Since the beach-rock extends through a vertical elevation of about 12 to 15 feet, it must be assumed that it represents beach formations, formed through a period of changing sea-level, since there is no reason on an open coast like this to assume any fundamental change in tidal characteristics, which, as noted above, would not permit more than four to five feet of beach-rock to form at any one stand of the sea-level. It appears, therefore, that this formation represents a series of beach-rocks which were laid down in bays in the former dune coast, probably during the rise of the sea-level at the beginning of Recent times. Similar examples are to be seen on Rottnest Island and elsewhere along our coast.

Turning now to the sand spits which are another interesting feature of the Point Peron coast, we may comment that they generally tend to develop in the vicinity of islands and headlands where intersecting series of waves tend to " shepherd " sand out into long tongue-like projections. In this way, sand from the beaches of Mangle's Bay is migrating steadily out to the North-West in response to waves which have swung round in the South-West part of the Bay, to break in the opposite direction to the waves coming from the ocean side, *i.e.*, from the West. Representatives of these in their reduced intensity curl around Point John and intersect with the Mangle's Bay wave system about half a mile South East of Point John opposite a slight irregularity in the sweep of the Bay. Once initiated, sand-banks of this type tend to evolve to considerable dimensions, and in this manner a broad sandy spit has now grown out from the shore for over 400 yards in a northerly direction.

Traces of submerged sand spits may be recognised from the air-photographs at various points to the South in Shoalwater Bay, connecting Safety Bay with Penguin Island and separating Peel Harbour from Warnbro Sound (about half a mile South of Safety Bay and four miles South of Point Peron). An interesting historical record refers to these old sand spits which separate Peel Harbour from Warnbro Sound. Peel Harbour was originally surveyed more than a century ago as a suitable loading point for timber ships, but an extraordinary change in the sand spits which formerly protected it from southerly gales rendered this project impossible. The surveyor, J. S. Roe, reported to the Colonial Secretary in 1846, that in the 10 years since the former survey in 1837, a considerable change in the coastline had taken place ; whereas Peel Harbour had been protected from Warnbro Sound by a scrub-covered sandy spit, it was then (in 1846) practically cut off by an extension of this sand barrier over the floor of the Harbour where there had been previously 10 fathoms of water. Of this protection and obstruction there is now but little trace except as may be recognised under water from the air-photographs.

Peel Harbour is today in direct connection with Warnbro Sound and is totally exposed to southerly storms. The air photographs, however, clearly show traces of sand spits extending from the shore about one mile East of Safety Bay township in a south-westerly direction, and these are apparently the sites of the former promontories and spits. It is notable that they represent extensions in the trends of the old beach-ridges on the landward side (*see* below under Sec. III (e)).

Contemporary dunes have been developed and are being actually augmented both on the headland of Point Peron and at many points behind the beaches of Shoalwater Bay and elsewhere along the coast. These dunes are overwhelming and obscuring the pre-existing system of beach-ridges. At Point Peron the dunes rise to 88 feet and further South still higher. The dunes reflect the prevailing wind (South-West) in the general way, being of the parabolic "blow-out" type, pointing more or less to the North-East.

(e) Old Beach-ridges.

As remarked in Section II (c) of this paper, no recently formed beach-ridge has been positively identified at Point Peron or vicinity, but an enormous series of beach-ridges may be followed from the peninsula, stretching away to the next line of limestone hills, about five miles to the East, forming a wide flat plain covered by steep little ridges and swales.

The bulk of the beach-ridges have been measured and range from about 10 to 15 feet above datum in the swales to 20 to 30 feet on the crests. It would appear from these figures that most of the ridges developed during the 10-foot sea-level, when ordinary wave action would build up beaches of seven to 10 feet above that level and additional assistance by winds would account for the rise to 20 feet (above the 10-foot datum) and even higher in isolated cases.

The level of this plain does not appear to drop (according to military surveys) in any noticeable manner in the five miles from the interior to the exterior, and beach-ridges may thus have developed during the long period of stable high sea-level, 10 feet above the present, though on the Cockburn Sound side the outermost ridges are somewhat lower and may have developed during the lower intermediate sea-levels at five and two feet. Further study of this problem might prove instructive.

Study of the air photographs discloses very interesting patterns in these old beach-ridges. It is found that the bulk of the ridges are parallel to old limestone hills and shore-line which lay five miles East of Point Peron, each successive ridge following the former at about 50 to 100 yards. Without counting them carefully, this would make between 80 and 100 beach-ridges across the plain.

In the triangle between Point Peron, Rockingham and Safety Bay, however, the parallelism of the main beach-ridge pattern begins to show interruptions, apparently due to the intersection of the wave systems, on the one hand from Warnbro Sound in the South, and on the other from Shoalwater Bay to the West. As noted above, a lower and somewhat reduced system of beach-ridges is also found forming a belt between one quarter and one half a mile in width around Rockingham forming the southern limits of Mangle's Bay (Cockburn Sound). The three systems reflect somewhat the wave symmetry between West, North and South.

Where these three systems intersect there is a certain amount of erosional truncation of one beach-ridge system by another, and finally in the middle there is a depression occupied by a broad swampy lake (Lake Richmond). Today this lake is fairly fresh, but this may be explained in the light of the high rainfall in this area and the fact that the fresh water table beneath this plain lies at an average depth of less than 10 feet. The level of the lake is generally about six feet above datum, and its floor is at least 10 to 15 feet below. This fact, with the lower beach-ridge pattern to the north, and its calm-water marine fossils (*see* Sec. II., (e)), all go to suggest that the lake was formerly a bay open to the north.

It is to be noted from the attached map (text fig. 1) that the beach-ridge patterns are truncated by the coast in the south-western part of Mangle's Bay, in the middle part of Shoalwater Bay and in the northern part of Warnbro Sound, and it appears that considerable sections of the sandy coastline in these areas have been washed away during the last few thousand years, that is to say, during the period of the Recent successive drops in sea-level.

In a few places contemporary sand dunes are overwhelming the old beach-ridges and everywhere the old ridges are thoroughly overgrown by scrub and even trees. It appears certain, therefore, that no beach-ridge formation is taking place today, and, furthermore, that active erosion of beach-ridges has been taking place for a considerable number of years.

IV.—CONCLUSIONS.

We have seen how the whole of Point Peron and a broad plain connecting it with the limestone hills five miles to the East, on which stand the towns of Rockingham and Safety Bay, are entirely made up of Pleistocene and Recent sediments. The oldest rock type is the Pleistocene calcareous eolianite, the Coastal Limestone, overlain by beach sand, beach-ridge and dune deposits of various ages in the successive post-Pleistocene cycles of sedimentation.

The present limestone shore is bevelled by broad marine platforms forming at low water level today, and the shores are terraced by relics of earlier Recent sea-levels forming platforms or benches at two, five and 10 feet above present datum and associated locally with contemporary shell beds.

Especially interesting features described, include the particular physiographic features of the contemporary reefs and the emerged platforms. The old beach-ridge pattern to be observed mainly from air photographs presents further valuable evidence on the subject of Recent history.

Recapitulating the geological history of the region, we find that two parallel systems of dune-rock formations, five miles apart, run in a more or less North-South direction (there are also parallel rows of dune rocks recognised further off-shore). These two dune systems were exposed to subaerial erosion in Late Pleistocene times and deeply indurated by circulating lime-rich solutions and intersected by complex karst erosion features. The whole landscape was then " drowned " by the early Recent transgression, commonly known as Flandrian transgression (of Dubois). The sea rose to 10 feet above its present low water stand, and since this phenomenon is recognised as a world-wide feature, we are able to compare its age with the accurate observations in Europe, which indicate the time to have been about 4,000 years ago. The sea remained at this level for many hundreds of years, during which time the old limestone hills of hardened eolianite were subjected to wave erosion and benched by horizontal platforms. The shallow sea between the range of limestone hills, of which Point Peron was one, and the inner range lying East of Rockingham became gradually silted up with deposits of sand, and during this long period of stable sea-level, row after row of long beach-ridges grew up in front of the eastern row of hills until, finally, Point Peron and other remnants of the western row of hills became joined to the newly formed plain of beach-ridges in the manner of tombolos.

The level of the sea then dropped sharply in two steps ; first to five feet and then to two feet, during which time the limestone shores of Point Peron and its adjacent islands or headlands became further benched by the marine terraces of the time. Finally, it seems, about 2,000 years ago, the sea-level again became stabilised and this time at about its contemporary level. Since then extensive benching of the limestone shores has taken place, so that there are now wide contemporary reef flats, and considerable erosion of the soft beach-ridge country, where it is unprotected by the limestone hills in front, has resulted in the introduction of broad sweeping sandy bays backed by steep sand hills and the truncated ends of the old beach-ridges.

As a result of this fairly complex geologic and geomorphological history we may see that the character of the shore-line around Point Peron, including the broad sweeps of Mangle's Bay and Warnbro Sound, must be regarded as *compound*, following Douglas Johnson's scheme (1919). As a matter of fact, Johnson's theoretical conclusion that four fundamental shore-line types may exist, *i.e.*, emergent, submergent, neutral and compound, is a somewhat hypothetical one, since, owing to the complex eustatic oscillations which have occurred right up until very Recent times and may even be still in progress today, no shore-line may be regarded as anything but compound, when carefully examined, unless it be a brand-newly exposed volcanic island or a recently accumulated sandbank or an equally recent shore produced in the unstable volcanic belts ; even the rapidly rising isostatic shores of Scandinavia and North America exhibit evidence of eustatic reversals.

We see, therefore, that the Point Peron coastline is in many ways similar to other stable coastlines which have been subject to Quaternary eustatic oscillations. Here we have evidence, first of extensive emergence followed by widespread " drowning," a submergence which took the sea far inland behind the present shore-line, and then a progressive emergence, which occurred step by step, almost up to the present day. The character of this emergence has not been a steady one, however, but rather spasmodic, when long periods of stable sea-level were interrupted by short periods of rapidly changing sea-level. This is shown by the fact that we have horizontal benches separated by short sharp cliffs.

The time occupied by these rapid changes must have been quite remarkably short. There has been much recent research on these matters in Scandanavia which may now provide a more absolute dating by means of levelling, varve analysis, archaeology and palaeontology, all uniting to give accuracy to the Late-Quaternary geologic events. Florin (1944) has demonstrated that one of the early Recent rises of sea-level took place at the rate of about 25 mm. per year, thus much faster than the one millimetre per year rise that may be going on today, according to Gutenberg and others (*see* Fairbridge, 1947 (b)). A change of sea-level at the rate of 25 millimetres (about one inch per year) would enable the change from our 10-foot to five-foot level to be accomplished within a span of only 60 years.

The periods of stability on the other hand, during which broad horizontal limestone platforms could be eroded, must certainly have lasted for many hundreds of years. Judging from the width of the benches (especially on Rottnest, where they are better preserved than on Peron), the 10-foot must have been the longest, requiring perhaps 1,000 years, while the intermediate levels lasted but a few centuries each.

The remarkable stability of the sea during these periods (necessary to produce absolutely horizontal platforms), in contrast to the obvious rapidity of the transitions from one level to the next, raises major questions of geology. We appear to find evidence here against gradual cyclic changes of sea-level, of a type which might be controlled by astronomic-meteorologic causes, and turn to spasmodic " catastrophic " changes of perhaps geotectonic origin.

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APPENDIX I.

MOLLUSCA, ETC.

The following is a brief analysis of the main representatives of mollusca and other shelly marine invertebrates found about Point Peron, either on the contemporary beaches, in off-shore dredgings, or in the 10 to 24 foot raised beach just South of the Point itself (taken to be " early " Recent). For sake of interest, species common also to the late Pleistocene marine horizon at Peppermint Grove are also indicated. The bulk of the Peppermint Grove fauna is not, however, represented at all at Point Peron. The friendly assistance of Mr. B. C. Cotton, of Adelaide, in identifying much of this material is gratefully acknowledged.

It should be noted that the contemporary suite from Point Peron was collected from *both* sides of the headland, that is to say from two extremely different habitats . that on the West, being one of reefs and rocky shores (mainly gastropods and echinoids) : that on the East being one of sandy beaches or muddy flats (mainly pelecypods). The absence of pelecypoda, save for the single form *Barbatia pistachia*, from the Peron raised beach clearly indicates its limited environment, while the discovery of *Katelysia scalarina*, etc., in what appear to be raised beach deposits of similar age near Lake Richmond, suggests that here, in contrast, there was a protected bay. The raised beaches on the East side of Garden Island are likewise rich in bivalves. The late Pleistocene Peppermint Grove beds appear to be somewhat mixed in character.

As regards the taxonomy, it may be seen that since the last general check-list of West Australian mollusca was published by Hedley (1916) there have been numerous generic or subgeneric changes, and some of these have been indicated. The specific names, however, have only changed in a few instances.

A.—Living : Point Peron, Garden Island and vicinity.
B.—10 to 24 foot Raised beach, Point Peron.
C.—Late Pleistocene, Peppermint Grove.

	A.	B.	C.
PELECYPODA.			
Family—Amphidesmatidae			
Amphidesma cuneata (Lamarck, 1818). (= *Crassatella*)	x		
Family—Anomiidae			
Monia ione Gray, 1849	x		
Family—Arcidae			
Acar laminata Angas, 1865. (= *Arca*)	x		
Barbatia pistachia (Lamarck, 1819). (= *Arca radula* ; *A. fasciata*)	x	x	
Family—Cardiidae			
Cardium racketti Donovan, 1826	x		
Cardium cyngorum Deshayes, 1855	x		
Cardium imbricatum Sowerby, 1841	x		
Cardium foveolatum Sowerby, 1841	x		
Family—Carditidae			
Cardita crassicosta Lamarck, 1819	x		
Cardita incrassata Sowerby, 1825	x		
Family—Chamidae			
Chama ruderalis Lamarck, 1819	x		
Family—Cleidothaeridae			
Cleidothaerus albidus (Lamarck, 1819) (= *Chama*)	x		
Family—Crassatellitidae			
Eucrassatella pulchra (Reeve, 1842)	x	....	x
Family—Donacidae			
Deltachion chapmani Gatliff and Gabriel, 1923	x		
Family—Glycymeridae			
Glycymeris (*Veletuceta*) *striatularis* (Lamarck, 1819) (= *Pectunculus*)	x		
Family—Hiatellidae			
Hiatella australis Lamarck, 1822	x		
Family—Leptonidae			
Ephippodonta macdougalli Tate, 1888	x		
Myllita deshayesi d'Orbigny and Recluz, 1850	x		
Family—Limidae			
Austrolima gemina Iredale, 1929	x		
Limatula strangei Sowerby, 1872	x		
Family—Lucindae			
Divalucina occidua Cotton and Godfrey, 1938	x		
Cavatidens perplexa Cotton and Godfrey, 1938	x		
Family—Mactridae			
Austromactra cumingi (Reeve, 1854) (=*M. cuvieri*)	x		
Austromactra australis (Lamarck, 1818)	x		
Electromactra flindersi Cotton and Godfrey, 1938	x		
Lutraria rhynchaena Jonas, 1844	x		
Family—Mytilidae			
Brachyodontes erosus (Lamarck, 1819) (= *Mytilus*)	x	....	x
Modiolus albicostus Lamarck, 1819	x		
Mytilus planulatus Lamarck, 1819	x		
Family—Ostreidae			
Ostrea sinuata Lamarck, 1819 (= *O. angasi* Sowerby, 1871)	x		
Saxostrea gradiva Iredale, 1939	x		

APPENDIX I.—*continued.*

	A.	B.	C.
PELECYPODA—*continued.*			
Family—Pectinidae			
Mimachlamys asperrimus (Lamarck, 1819) (= *Pecten*)	x	....	x
Mimachlamys australis (Sowerby, 1847) (= *Pecten*)	x		
Notochlamys anguineus (Finlay, 1926) (= *Chlamys*)	x		
Notovola alba (Tate, 1887) (= *Pecten*)	x		
Family—Pholadidae			
Pholas australasiae Sowerby, 1814	x		
Family—Pinnidae			
Pinna dolabrata Lamarck, 1819	x		
Family—Psammobiidae			
Flavomala biradiata (Wood, 1815) (= *Solen ; Gari ; Soletellina*)	x	....	x
Family—Solemyidae			
Solemya australis Lamarck, 1818	x		
Family—Spondylidae			
Spondylus tenellus Reeve, 1856	x		
Family—Tellinidae			
Macoma deltoidalis Lamarck, 1818	x		
Pseudarcopagia victoriae Gatliff and Gabriel, 1914	x		
Salmacoma inequivalvis (Sowerby, 1867) (= *S. beryllina*)	x		
Tellina perna Spengler, 1798	x	....	x
Family—Veneridae			
Chioneryx cardioides (Lamarck, 1818)	x		
Dosinia victoriae Gatliff and Gabriel, 1914	x		
Gomphina undulosa (Lamarck, 1818) (= *Venus*)	x		
Katelysia peroni (Lamarck, 1818) (= *Venus*)	x		
Katelysia scalarina (Lamarck, 1818) (= *Venus*)	....	x	x
Macrocallista bardwelli Clench and McLean, 1936 (= *Paradione*)	x		
Placamen flindersi Cotton and Godfrey, 1938	x		
Proxichione laqueata (Sowerby, 1853) (= *Venus ; Antigona*)	x	....	x
Sunemeroe vaginalis (Menke, 1843) (= *Cytheria ; Sunetta*)	x		
Tawera lagopus (Lamarck, 1818)	x		
Venerupis crenata Lamarck, 1818	x		
Venerupis exotica Lamarck, 1818	x	....	x
Family—Vulsellidae			
Malleus meridianus Cotton, 1930	x		
GASTROPODA.			
Family—Acmaeidae			
Notoacmea septiformis (Angas, 1865) (= *Acmaea, Patelloida*)	x		
Patelloida alticostata (Angas, 1865) (= *Patella*)	x	x	x
Patelloida nigrosulcata (Reeve, 1855)	x		
Family—Buccinidae			
Cominella eburnea (Reeve, 1846) (= *Buccinum*)	x		
Josepha tasmanica (Tenison-Woods, 1879)(= *Cominella suturalis ; C. tasmanica*)	x	x	x
Niotha pyrrhus Menke, 1843	x		
Family—Bullidae			
Bullaria tenuissima (Sowerby, 1868) (= *Bulla*)	x	....	x
Family—Calyptraeidae			
Sigapatella hedleyi Smith, 1915	x		
Zeacrypta immersa (Angas, 1865) (= *Crepidula*)	x		
Family—Cancellariidae			
Nevia spirata (Lamarck, 1822) (= *Cancellaria*)	x		
Family—Cerithiidae			
Ataxocerithium serotinum (Adams, 1855) (= *Cerithium*)	x		
Cacozeliana granarium (Kiener, 1842) (= *Cerithium*)	x	x	x
Campanile laeve (Quoy and Gaimard, 1834) (= *Cerithium ; Ceratoptilus*)	x	x	
Pseudovertagus aspera Linne, 1758	x		
Family—Conidae			
Floraconus anemone (Lamarck, 1810) (= *Conus*)	x	x	x
Family—Cymatiidae			
Charonia rubicunda (Perry, 1811) (= *Cymatium lampas*)	x		
Mayena australasia (Perry, 1811) (= *Cymatium australasia*)	x	x	
Negyrina subdistorta Lamarck, 1822	x		
Family—Cypraeidae			
Ornamentaria annulus (Linné, 1758) (= *Cypraea*)	x		
Ravitrona caputserpentis (Linné, 1758) (= *Cypraea*)	x	x	x
Zoila friendii (Gray, 1831) (= *Cypraea*)	x		
Family—Fissurellidae			
Austroglyphis lincolnensis (Cotton, 1930) (= *Diodora*)	x		
Entomella candida (Adams, 1852) (= *Emarginula*)	x		
Scutus anatinus (Donovan, 1820) (= *Patella; Parmophorus*)	x		
Sophismalepas nigrita (Sowerby, 1835) (= *Lucapinella; Fissurella*)	x		
Family—Gadiniidae			
Gadinia albida Angas, 1867	x		
Family—Haliotidae			
Marinauris roei (Gray, 1826) (= *Haliotis*)	x		
Marinauris scalaris (Leach, 1814) (= *Haliotis*)	x		
Sanhaliotis elegans (Koch, 1844)	x		
Family—Hipponicidae			
Antisabia erma Cotton and Godfrey, 1938	x	x	
Sabia conica (Schumacher, 1817) (= *Amalthea ; Hipponix*)	x	x	
Family—Ianthinidae			
Ianthina violacea Linné, 1758	x		

APPENDIX I.—*continued.*

GASTROPODA—*continued.*	A.	B.	C.
Family—Littorinidae			
Melarhaphe unifasciata (Gray, 1826) (= *Littorina*)	x		
Family—Marginellidae			
Marginella ovulum (Sowerby, 1846)	x	x	x
Family—Mitridae			
Mitra glabra (Swainson, 1821)	x	....	x
Vicimitra rhodia (Reeve, 1845) (= *Mitra*)	....	x	
Vicimitra rosetti (Angas, 1865)	x		
Family—Muricidae			
Bedeva assisi (Tenison-Woods, 1877) (= *Trophon*)	x		
Emozamia flindersi (Adams and Angas, 1863)	x		
Rapana mira (Cotton and Godfrey, 1932)	x		
Family—Nassariidae			
Nassarius particeps (Hedley, 1915)	x		
Parcanassa Pauperata (Lamarck, 1822) (= *Buccinum*)	x		
Family—Naticidae			
Friginatica beddomei (Johnston, 1884) (= *Natica*)	x		
Notochlis sagittata (Menke, 1843) (= *Natica*)	x		
Propesinum pictum (Recluz, 1843) (= *Sinum*)	x		
Uber conicum (Lamarck, 1822) (= *Natica ; Polinices*)	x	x	x
Uber plumbeum (Lamarck, 1822)	x		
Family—Neritidae			
Melanerita melanotragus (Smith, 1884) (= *Nerita*)	x	x	
Nerita lineata (Gmelin, 1791)	x	x	
Family—Olividae			
Oliva australis Duclos, 1835	x	....	x
Family—Patellidae			
Cellana limbata (Phillipi, 1849) (= *Patella*)	....	x	
Cheilea occidua (Cotton, 1935)	x	x	
Patellanax squamifera (Reeve, 1855) (= *Patella*)	x		
Family—Philinidae			
Philine angasi (Crosse and Fischer, 1865)	x		
Family—Pyrenidae			
Euplica bidentata (Menke, 1843) (= *Columbella, Pyrene*)	x		
Family—Scalidae			
Clathrus jukesiana (Forbes, 1852) (= *Scalaria, Epitonium*)	x		
Scala imperialis (Sowerby, 1844) (= *Scalaria*, = *Epitonium*, = *Clathrus*)	x		
Family—Siphonariidae			
Siphonaria baconi Reeve, 1856	x		
Family—Stomatiidae			
Stomatella imbricata Lamarck, 1816	x		
Family—Strombidae			
Doxander campbelli (Griffiths and Pidgeon, 1834) (= *Strombus*)	x		
Family—Thaidae			
Dicathais aegrota (Reeve, 1846) (= *Purpura textilosa ; P. aegrota ; Thais textilosa*)	x	x	x
Family—Tonnidae			
Tonna variegata (Lamarck, 1822) (= *Dolium*)	x	....	x
Family—Trochidae			
Angaria tyria (Reeve, 1842) (= *Delphinula*)	x		
Austrocochlea rudis (Gray, 1847) (= *Monodonta*)	x		
Cantharidus lehmanni (Menke, 1843) (= *Trochus*)	x		
Euriclanculus personatus (Phillipi, 1847)	x	x	
Gibbula lehmanni (Menke, 1843) (= *Turbo ; Prothalotia*)	x		
Herpetopoma aspersa (Phillipi, 1846) (= *Trochus*)	x		
Isoclanculus yatesi (Crosse, 1863) var. *ringens* (Menke, 1843)	x		
Mesoclanculus consobrinus (Tate, 1893) (= *Clanculus*)	x		
Mesoclanculus denticulatus (Gray, 1826) (= *Monodonta*)	x		
Phasianotrochus eximius (Perry, 1811)	x		
Phasianotrochus irisodontes (Quoy and Gaimard, 1834) (= *Trochus ; Cantharidus*)	x		
Tallopia callifera (Lamarck, 1822)	x		
Thalotia conica (Gray, 1847) (= *Monodonta ; Thalotia woodsiana ; Cantharidus*)	x	x	x
Family—Turbinidae			
Bellastrea squamifera (Koch, 1844) (= *Astraea fimbriata ; Trochus*)	x		
Mimelenchus ventricosa (Swainson, 1822) (= *Phasianella ventricosa ; P. perdix*)	x		
Ninella torquatus (Gmelin, 1791) (= *Turbo stamineus* Martyn, 1784)	x		
Phasianella australis (Gmelin, 1788) (= *Buccinum*)	x		
Senectus intercostalis (Menke, 1843) (= *Turbo pulcher*)	x	x	x
Family—Turridae			
Zemitrella lincolnensis (Reeve, 1859) (= *Lachesis ; Fusinus*)	x		
Zemitrella austrina (Gaskoin,1852)	x		
Family—Vermetidae			
Siliquaria australis Quoy and Gaimard, 1834	x		
Vermicularia sipho (Lamarck, 1818) (= *Serpula*)	x	x	
Family—Volutidae			
Amoria pallida (Gray, 1834)(= *Voluta volva ; Scaphella*)	x		
Melo miltonis Gray, 1834 (= *Amoria, Scaphella*)	x		

Appendix I.—*continued.*

CEPHALOPODA.	A.	B.	C.
Sepia (*Amplisepia*) *apama* Gray, 1849	x	x	
Sepia (*Arctosepia*) *braggi* Verco, 1907	x		
Sepia (*Mesembrisepia*) *chirotrema* Berry, 1918	x		
Sepia (*Decorisepia*) *cottesloensis* Cotton, 1929	x		
Sepia (*Solitosepia*) *glauerti* Cotton, 1929	x		
Sepia (*Glyptosepia*) *hedleyi* Berry, 1918	x		
Sepia (*Solitosepia*) *hendryae* Cotton, 1929	x		
Sepia (*Mesembrisepia* ?) *irvingi* Meyer, 1909	x		
Sepia (*Mesembrisepia*) *novaehollandiae* Hoyle, 1909	x		
Sepia (*Solitosepia*) *occidua* Cotton, 1929	x		
Spirula spirula Linné, 1758	x	x	
ECHINODERMATA. —ECHINOIDEA.			
Amblypneustes formosus Valenciennes, 1846	x		
Amblypneustes leucoglobus Döderlein, 1914	x		
Amblypneustes ovum (Lamarck, 1816)	x		
Amblypneustes pallidus (Lamarck, 1816)	x		
Breynia australasiae (Leach, 1815)	x		
Echinocardium cordatum (Pennant, 1777)	x		
Goniocidaris tubaria (Lamarck, 1816)	x		
Heliocidaris erythrogramma (Valenciennes, 1846) var. *parvispina* Clark, 1938	x		
var. *armigera* (Agassiz, 1872)	x		
Holopneustes inflatus Agassiz, 1872	x		
Holopneustes porosissimus Agassiz and Desor, 1846	x		
Peronella lesueuri (Agassiz, 1841)	x		
Phyllacanthus irregularis Mortensen, 1928	x		
Protenaster australis (Gray, 1851)	x		

Note.—Asteroidea, Crinoidea, etc., have not yet been studied.

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APPENDIX II.

FORAMINIFERA.

by W. J. PARR.

At the request of Dr. Rhodes W. Fairbridge, I have identified the foraminifera picked out by him and his students at the University of Western Australia, and have combined the results in the following table to show the distribution of the species in the different samples.

The foraminifera are from :—

Sample No. 1 .... Point Peron, modern beach sand.
,, No. 2 .... Naval Base P.O., modern beach sand.
,, No. 3 .... Trigg Island, modern beach sand.
,, No. 4 .... Rottnest (Geordie Bay), modern beach sand.
,, No. 5 .... Garden Island, modern beach sand.
,, No. 6 .... Geraldton Harbour, modern dredging.
,, No. 7 .... Point Peron, 10 to 24 foot raised beach.
,, No. 8 .... Point Peron, late Pleistocene eolianite.
,, No. 9 .... Trigg Island, late Pleistocene beach rock.
,, No. 10 .... Minim Cove Quarry, late Pleistocene marine band.
,, No. 11 .... Peppermint Grove, late Pleistocene " *Arca* " horizon.
,, No. 12 .... Peppermint Grove, late Pleistocene, current bedded marine band (10 feet below " *Arca* " band).

(In the following table, the frequencies of the occurrences are shown thus : c = common ; f = frequent; x = less than five specimens. (Except in columns 3, 9, 11 and 12, the frequency is not recorded.)

Species.	Sample No.											
	1	2	3	4	5	6	7	8	9	10	11	12
TEXTULARIIDAE—												
Textularia agglutinans d'Orbigny	....	....	f	x	....	....	....	....	....	x		
Textularia sp. aff. *conica* d'Orbigny	x	....	x	x	....	....	....	....	....	....	....	c
Textularia sp. aff. *pseudogramen* Chapman and Parr	x	....	x	....	x	....	....	....	c			
Textularia pseudotrochus Cushman	....	....	....	....	....	....	....	....	c			
VERNEUILINIDAE—												
Clavulina multicamerata Chapman	x	x	....	x	....	x						
Clavulina pacifica Cushman	....	....	x	....	....	x	....	x				
Cribrobulimina polystoma (Parker and Jones)	x	....	....	....	....	x						
Gaudryina (*Pseudogaudryina*) *hastata* Parr	x	....	x	....	....	....	....	....	x			
Gaudryina (*Siphogaudryina rugulosa* Cushman	....	....	....	....	....	x						
MILIOLIDAE—												
Hauerina fragilissima Brady	....	....	....	....	....	....	....	....	....	x	x	
Pseudomassilina agglutinans (Keijzer)	....	....	....	....	....	x						
Pyrgo sp.	....	....	x									
Pyrgo sp. (broad form)	....	....	....	....	x	....	....	....	x			
Pyrgo denticulata (Brady)	....	....	....	....	....	....	....	....	x	....	....	x
Pyrgo striolata (Brady)	....	....	....	x	....	x						
Quinqueloculina australis Parr	....	....	c	x	x	....	....	x				
Quinqueloculina baragwanathi Parr	....	....	....	....	....	x	....	....	....	....	....	x
Quinqueloculina bosciana d'Orbigny	....	....	c	....	....	....	....	x				
Quinqueloculina sp. aff. *bradyana* Cushman	x	x	f	x	x							
Quinqueloculina sp. aff. *costata* d'Orb	....	....	c	....	x	x	....	x	....	x	....	x
Quinqueloculina laevigata d'Orbigny	....	....	....	....	....	x						
Quinqueloculina lata Terquem	....	....	c	....	x	....	....	x				
Quinqueloculina lamarckiana d'Orbigny	....	....	....	....	x	x						
Quinqueloculina cf. *seminulum* (Linné)	....	....	x	....	x	....	....	....	....	....	....	x
Quinqueloculina subpolygona Parr	x	....	f	....	....	x	x	....	....	....	....	x
Quinqueloculina sp. aff. *vulgaris* d'Orbigny	x	x	c	x	x	....	x	x	x	x		
Spiroloculina sp.	....	....	....	....	....	....	....	....	....	x		
Spiroloculina antillarum d'Orbigny	x	x	x	x	x	x	x					
Spiroloculina milletti Wiesner	....	....	....	....	....	x	....	....	....	x		
Triloculina sp. nov.	....	....	c	....	....	....	....	....	....	....	....	f
Triloculina bassensis Parr	....	....	x	....	x	....	x					
Triloculina oblonga (Montagu)	x	x	x	x	x							
Triloculina rotunda d'Orbigny	....	....	....	....	....	x						
Triloculina striatotrigonula Parker and Jones	....	....	c	....	x	x	....	....	x	....	....	x
Triloculina subrotunda (Montagu)	x	x	....	x	....	x	....	x	....	....	....	x
Triloculina tricarinata d'Orbigny	x	....	c	....	x	x	....	....	....	....	....	f
Triloculina cf. *trigonula* (Lamarck)	x	x	x	x	x	....	....	....	c	x		