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ACCRETIONARY GROWTH STRUCTURES, SOUTHWEST VICTORIAN COAST, AUSTRALIA.

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CONTENTS.

Abstract.

Macro- and micro-accretionary growths of calcareous, phosphatic, pyritic, limonitic, glauconitic and sulphatic composition, are marked features of some of the sediments outcropping along certain parts of the south coast of Western Victoria. Of lesser abundance are siderite, manganese dioxide and halite accretionary growths. Their distribution, mode of occurrence and nature have been studied along some 25 miles of the coastline, extending from Freetrader Point in the southeast, through Princetown and Port Campbell to beyond Peterborough in the west.

The accretionary structures range in form from isolated nodules and concretions to discontinuous layers and sheets developed under different conditions in several horizons of a stratigraphical sequence composed of Lower Cretaceous, Paleocene–Lower Eocene, Lower Miocene–Oligocene, Miocene, Post-Miocene, Pleistocene and Holocene to Recent deposits.

Introduction.

Accretionary bodies of various shapes and sizes composed of different types of secondarily aggregated mineral matter, sometimes markedly different from, often much the same as the principal constituents of their host rocks, occur sporadically in parts and in considerable prominence elsewhere along the southern coastline of southwest Victoria. These structures are in rocks ranging from Lower Cretaceous to Recent in age, exposed in occasional quarries, stream beds, road cuttings, borrow pits and landslip scars, but mainly in bold, commonly vertical sea cliffs.

The area embraced by these studies extends from Freetrader Point (fig. 1) on the south-western flanks of the Otway Ranges, along the seaboard of the Port Campbell coastal plain to a point some 25 miles to the west, beyond Peterborough. Marine and subaerial erosion combined, have exposed the more resistant accretionary growths to the best advantage in steep, high cliffs of relatively soft sediments.

The accretionary growths form sheets, discontinuous layers, irregularly-shaped tuberous forms, individual nodules and concretions, and occasional crystal aggregates. Few of the nodules and concretions reveal concentric structures internally.

Some of the accretions are epigenetic in having formed subsequently to the compaction of the host strata. Others are syngenetic or early diagenetic and were formed concomitantly with the deposition of detrital constituents or shortly afterwards.

Specimens mentioned in this paper are in the collections of the National Museum of Victoria. Reg. Nos. E.2560 to E.2599.

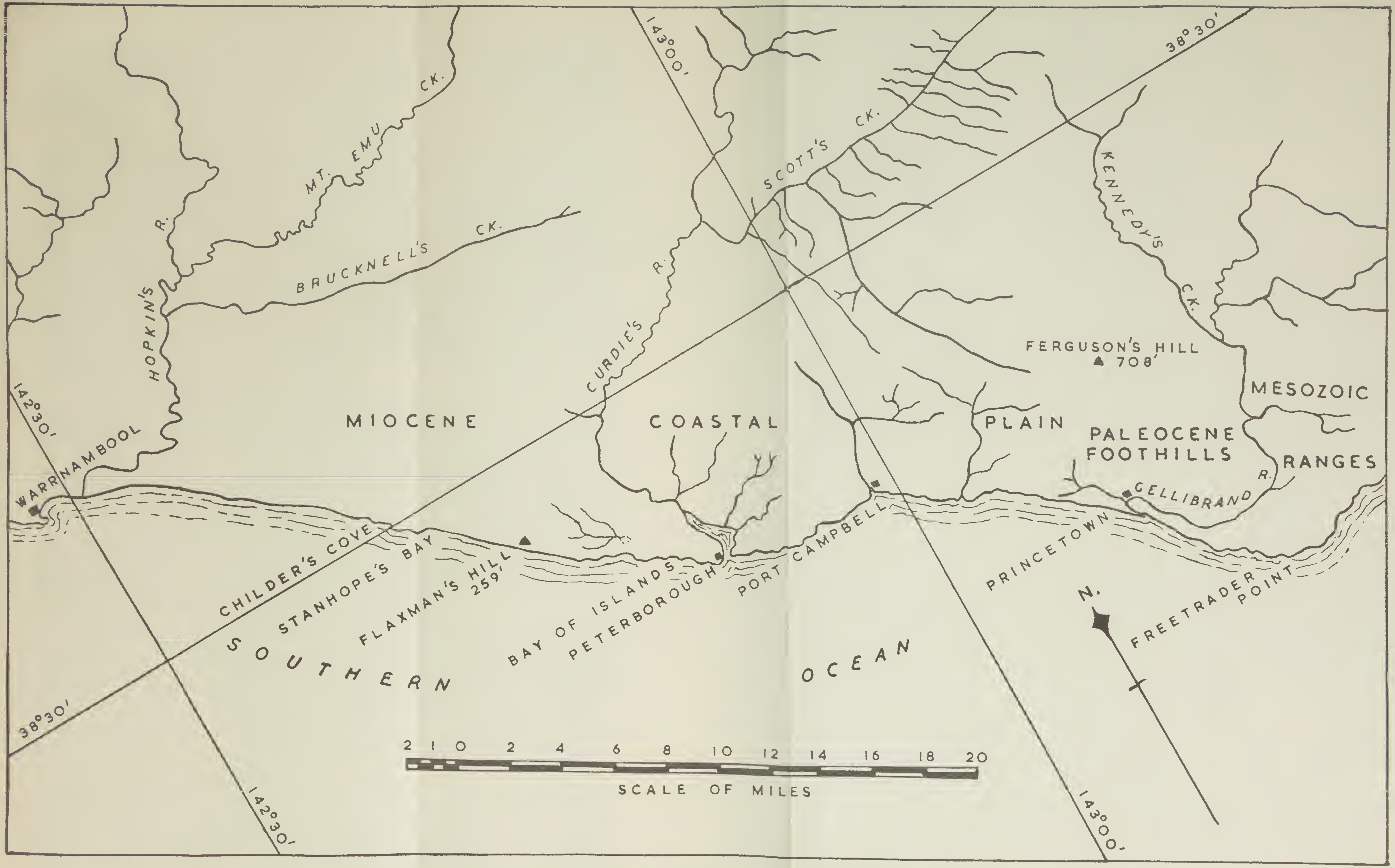

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FIGURE 1.—Locality map of the coastal region between Freetrader Point and Warrnambool, South-western Victoria.

Such accretions are products of the several processes operating when sediments are deposited in environments where they are temporarily out of equilibrium with the prevailing chemical, biochemical and physical conditions.

Factors determining the shapes of the different accretions vary from sediment to sediment and sometimes within the same sediment. Porosity of the sediment and an adequate supply of accretion-building material controlled the development of most of the accretionary bodies. Bedding and joint planes influenced the shape of epigenetic examples in particular. The shapes of some syngenetic to early diagenetic examples were primarily determined by fossil structures which acted as nuclei for precipitation. The shape of derived nodules (e.g. remanié phosphatic examples) was fundamentally controlled by rolling on the sea floor. Agitation was necessary for the development of oolithic grains in some of the sediments, and for the growth of free pisoliths and ooliths in cave pools.

The mineral matter constituting the accretions is most frequently calcareous, sometimes phosphatic and sometimes glauconitic. Less often it is pyrite, limonite, siderite, gypsum or hydrous iron sulphate, and infrequently it is halite or manganese dioxide. Growth has been by external additions and increase by adhesion or inclusion, in places more or less regularly, but not always symmetrically about a central point or line.

Calcareous accretions like those described herein have also been observed in cliffs of Miocene limestone further to the west, where they are prominent at the Bay of Islands, Flaxman's Hill, Stanhope's Bay and Childers Cove (fig. 1).

Although the accretions are minor features of some and wanting from other horizons, calcareous varieties assume importance because of their widespread lateral distribution as lines of nodules and thin sheets in the more richly calcareous horizons of the Miocene strata (Baker, 1943B, p. 360). They form conspicuous, even if small-scale features in the local geomorphology, on weathering of these strata (Baker, 1958).

Some of the accretions have been described previously (Baker, 1942, 1945; Baker and Frostick, 1951); others have received passing mention in studies of the geology and physiography of the Peterborough—Moonlight Head area (Baker, 1943A, 1943B, 1944, 1950, 1953, 1958). This paper (i) brings together the results of studies of all the various types of accretions observed, (ii) provides an overall picture of their occurrence in the stratigraphical sequence, (iii) elaborates upon their distribution, occurrence and nature in the field, (iv) compares their chemical compositions, and (v) discusses their significance in the various host strata.

Distribution.

The distribution of the different types of accretions can be gauged from the areal extents of the various sedimentary formations and members shown in figure 2, used in conjunction with their vertical distribution in the stratigraphical column shown in Table 1.

Table 1.

Vertical distribution of macro- and micro-accretionary growth structures in the stratigraphical sequence of the Moonlight Head—Port Campbell region.

Group and Age.	Host Sediment.	Macro-accretions.	Micro-accretions.
Holocene	Soils	"Buckshot gravel" nodules (ferruginous) Travertine nodules	Micro-forms of the same materials
	Beach, Cave, and Dune Sands	Calcareous sand stalagmites Normal stalactites and stalagmites Calcareous beach sand plasters on cliff bases Calcareous nodules Calcareous tubular and solid cylindrical concretions Calcareous cave pisoliths	Calcareous cave ooliths
Pleistocene	Dune Limestone	Calcareous sheets and nodules	
Post-Miocene	Clay Capping	Limonitic nodules Remanié (Miocene) calcareous concretions	
Heytesbury Group (Miocene)	Port Campbell Limestone (aphanitic)	Calcareous accretions Thin calcareous sheets Pyritic accretions (largely oxidized) Rare phosphatic and pyritic nodules in Rutledge's Creek Member Rare seams of gypsum	Glauconite pellets Foecal pellets
	Glenample Clay (calcareous)	Calcareous accretions Thin calcareous sheets	Glauconite pellets Foecal pellets
	Gellibrand Clay (calcareous)	Occasional calcareous accretions Occasional pyritic nodules (some oxidized) Very rare, small manganese dioxide nodules	Glauconite pellets Foecal pellets

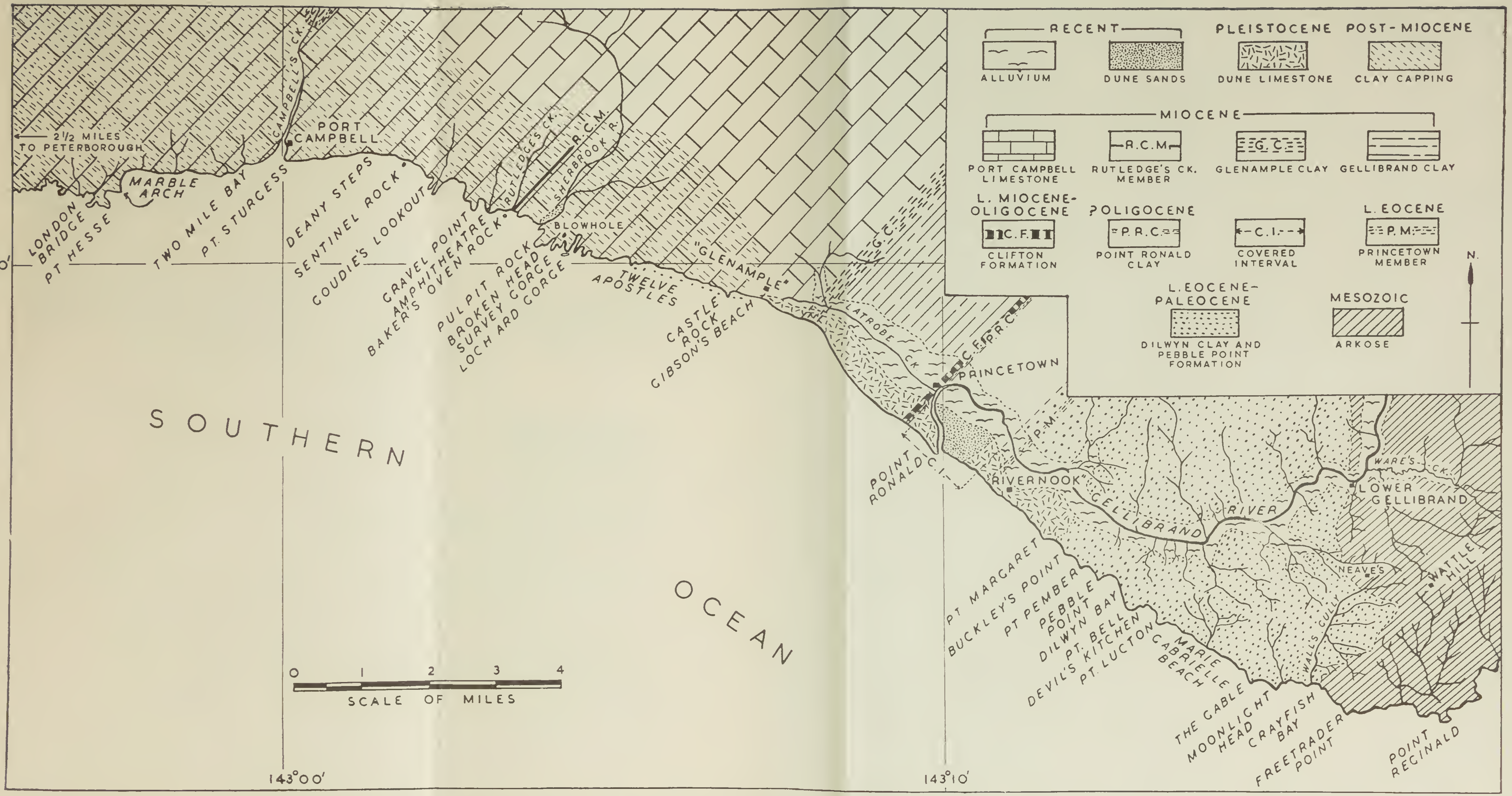

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FIGURE 2.—Geological sketch map of the Moonlight Head–Princetown–Port Campbell coastal region, showing place names.

TABLE 1—*continued.*

Group and Age.	Host Sediment.	Macro-accretions.	Micro-accretions.
Heytesbury Group (Lower Miocene to Oligocene)	Calcareous Clay of the Clifton Formation	Calcareous accretions (some septaria)	Glauconite pellets Foecal pellets
	Bryozoal Limestone of the Clifton Formation	Phosphatic sheets ..	Phosphatized foecal pellets
	Clifton Formation phosphorite	Phosphatic nodules ..	Pellet phosphate
	Gritty Quartz Sandstone (in part calcareous)	.. .. ..	Rare pellet phosphate
(?) Oligocene ..	Point Ronald Sandy Clay		
COVERED INTERVAL.			
Wangerrip Group (Lower Eocene to Paleocene)	Ferruginous Sandstone	Limonitic nodules	
	Princetown Member (carbonaceous silty sandstone) of the Dilwyn Silty Clay	Pyrite nodules Hydrous iron sulphate nodules and thin seams Crystal aggregates of pyrite Crystal aggregates of selenite	Rare, superficial crystal aggregates of halite
	Sandstone bands in Dilwyn Silty Clay	Pyrite nodules Rare phosphatic nodules	Glauconite pellets Minute crystal aggregates of pyrite
	Dilwyn Silty Clay ..	Pyrite nodules Hydrous iron sulphate nodules and thin seams Rare phosphatic nodules	Oolitic grains of collophane Micro-replacements of fossil fragments by pyrite
	Rivernook Member (glauconitic) of the Dilwyn Silty Clay	Calcareous – phosphatic nodules and thin seams Crystal aggregates of gypsum	Glauconite pellets Minute crystal aggregates of pyrite
	Pebble Point Formation (glauconitic sandstones, grits, and conglomerates)	Pyrite nodules Small phosphatic nodules Rare crystal aggregates of selenite Limonitic sheets and nodules Remanié (L. Cretaceous) siderite nodules	Glauconite pellets Foecal pellets Calcite – siderite – glauconite ooliths Calcite rims to detrital grains Collophane ooliths
ANGULAR UNCONFORMITY.			
Otway Group (L. Cretaceous)	Moonlight Head arkose and rare mudstone (Devil's Kitchen Mudstone)	Pyrite nodules Large calcareous accretions ("Cannon Balls") Smaller calcareous nodules Rare siderite nodules Calcareous sheets	Calcareous concentric rim-growths around detrital grains

COMPOSITION.

The chemical compositions of the main types of accretions are shown in Table 2.

TABLE 2.

Chemical Compositions of Accretionary Growths.

—	1.	2.	3.	4.	5.	6.	7.	8.
	%	%	%	%	%	%	%	%
R_2O_3	0·58	1·74	1·08	0·33	33·38	41·68	0·94	3·48
$CaCO_3$	96·28	69·66	92·50	96·17	30·32	41·18	88·06	93·06
$MgCO_3$	1·72	19·83	1·62	0·87	0·67	0·77	0·83	2·54
H_2O (+)	tr.	3·06	0·31	0·12	3·11	0·22	1·11	tr.
H_2O (−)	tr.	1·16	0·11	0·11	1·61	0·17	0·80	tr.
P_2O_5	..	..	..	..	18·97	12·96	..	..
Insoluble residue ..	1·54	3·66	4·42	2·45	10·85	3·08	7·76	1·46
Total ..	100·12	99·11	100·04	100·05	98·91	100·06	100·10	100·54
Sp. Gr. of Powder* ..	2·73	2·67	2·70	2·73	2·88	2·92	2·67	2·73

(anal. G. C. Carlos.)

(* The specific gravity values of the powdered accretionary growths were determined in distilled water at 20° C. on an air-damped balance.)

KEY TO TABLE 2.

1. Dense calcareous accretion with *Ditrupa wormbetiensis*, from Port Campbell Limestone. Quarry, Spark's Gully, 2½ miles east of Port Campbell.

2. Port Campbell Limestone (aphanitic) adjacent to and enclosing specimen No. 1 (Table 2). Quarry, Spark's Gully, 2½ miles east of Port Campbell.

3. Nodular calcareous accretion from Port Campbell Limestone. Marble Arch, 2¾ miles west-southwest of Port Campbell.

4. White to buff-coloured calcareous accretion from calcareous clay immediately above limestone in the Clifton Formation. Three quarter mile southwest of Princetown.

5. Phosphatic cylindrical accretion from Gellibrand Clay, 1½ mile west of Princetown.

6. Phosphatic cylindrical accretion with shelly fragments, from coquina band, Rutledge's Creek Member. Mouth of Rutledge's Creek, 3½ miles east-southeast of Port Campbell.

7. Round, nodular calcareous accretion from Gellibrand Clay. One and half mile west of Princetown.

8. Calcareous cylindrical accretion from Port Campbell Limestone. Pulpit Rock, 4 miles east-southeast of Port Campbell.

A chemical analysis of the Port Campbell Limestone is included in Table 2 (column 2) for comparison with that of an accretion from the same locality; this reveals that the enveloping limestone, contains approximately 11·5 times as much magnesium carbonate as the lime-rich accretion (column 1, Table 2).

Ratios of the principal constituents of the analysed accretions are listed in Table 3. These show a wide range in the relationships of $CaCO_3$ and $MgCO_3$ in nodules from different beds, and significant variations in the relationships between total carbonate contents and insoluble residues.

TABLE 3.

Ratios of principal constituents of analysed accretionary growths.

Sample Number (as in Table 2).	$CaCO_3 : MgCO_3$.	Total $CO_3 : P_2O_5$.	Total CO_3 : Insoluble Residue.
1	56·0	..	63·6
2	3·5	..	24·4
3	57·0	..	21·3
4	110·5	..	39·6
5	45·0	1·6	2·9
6	53·5	3·2	13·6
7	106·8	..	11·5
8	36·6	..	65·5

Specific Gravity.

Specific gravity values of hand specimens of different shapes of accretions of similar and different chemical compositions, determined in distilled water at 20°C. on a Walker's Steelyard, are shown in Table 4.

Specific gravity variations among accretions of the same composition (Table 4) reflect the presence of impurities such as alteration products or included alien mineral matter. Thus the specific gravity of pyritic accretions in the Gellibrand Clay (2·33—3·82) varies according to degrees of alteration to gypsum and hydrous iron sulphates (copiapite, &c.), and in older formations (2·98—4·00) according to the amounts of quartz and carbonaceous matter entrapped from the host sediment. Examinations of polished surfaces confirm these observations, and reveal that the pyrite acts as a cement to detrital quartz grains, thus contrasting with well-developed pyrite crystals in Tertiary marine clays at Torquay, Victoria (Edwards and Baker, 1951, pp. 40-44), where little host rock material has been incorporated in the pyrite.

TABLE 4.

Specific Gravity Values of various types of Accretionary Growths.

Type.	Shape.	Sediment.	Specific Gravity.
Calcareous	Sub-spherical, nodulose ..	Port Campbell Limestone ..	2·50
,, ...	Irregular	,, ,, ,, ..	2·24
,, ...	Ellipsoidal to sub-spherical, flat and nodulose	,, ,, ,, ..	2·26–2·32
,, ...	Elongated, nodulose ..	,, ,, ,, ..	2·45 2·48
,, ...	Cylindrical to sub-spherical	Gellibrand Clay	2·21–2·60
,, ...	Irregular, nodulose ..	Calcareous Clay of the Clifton Formation	2·56–2·61
Calcareous septaria ..	Sub-spherical	,, ,, ,, ,,	2·47–2·49
Pyritic, partially oxidized	Elongated, cylindrical ..	Port Campbell Limestone ..	3·67
Pyritic, altered to gypsum and copiapite, &c.	Irregular, nodulose to cylindrical	Gellibrand Clay	2·33–3·82
Pyritic, with some included carbonaceous matter	Sub-spherical to tuberous and ellipsoidal	Princetown Member (carbonaceous silty sandstone)	2·98–3·43
,, ,, ,,	Irregular	Dilwyn Clay (carbonaceous silty clay)	3·10
Pyritic	Sub-spherical to ovoidal ..	Pebble Point Formation (sandy grits, &c.)	3·90–4·00
,, ...	,, ,, ,, ..	Otway Group (arkose) ..	3·43–3·46
Phosphatic	Cylindrical	Coquina band, Rutledge's Creek Member	2·45
,, ...	Irregular, sub-spherical, ellipsoidal, cylindrical	Clifton Formation Phosphorite	2·74–3·27
Phosphatic with Glauconite	Sub-spherical to ellipsoidal	Dilwyn Silty Clay ..	2·93
,, ,, ,,	,, ,, ,, ,,	Pebble Point Formation (sandy grits, &c.)	2·69–2·73
Limonitic	Layers	Pebble Point Formation (gritty ironstone)	2·82–2·93
Limonitic (oxidized pyritic accretions)	Elongated, cylindrical ..	Port Campbell Limestone ..	2·86–3·32
Limonitic (brown) ..	Sub-spherical	Holocene "buckshot gravel" horizon	2·70–2·83
Limonitic (black) ..	,, ...	,, ,, ,, ,,	3·13–3·53

Specific gravity variations of limonitic layer accretionary structures from the Pebble Point Formation (Table 4), arise from different contents of fine to medium sand size, and sometimes coarser, quartz grains. Variations among the cylindrical limonitic accretions in the Port Campbell Limestone, result from different degrees in the alteration of pyrite to limonite. Among the "buckshot gravel" nodules and granules, the variations in specific gravity (2·70—3·53) are due primarily to differences in the nature and amount of the iron oxide composing them, some being earthy and limonitic, others being more compact and containing magnetic iron oxide (? maghemite).

Phosphatic accretionary growths vary in specific gravity because of different contents of (*a*) shell debris and micro-fossils, (*b*) superficial alteration to limonite, (*c*)detrital quartz grains of varying size, (*d*) glauconite pellets, and (*e*) calcite ooliths.

Specific gravity differences (2·21—2·61) among calcareous accretions are due largely to varying degrees of compaction and cementation, and partly to different contents of adventitious mineral matter, shell debris, and/or small fossils.

Types of Accretionary Growth Structures.

Calcareous Accretionary Growths

The wide vertical distribution of calcareous accretions is shown in Table 1, where the range is indicated as extending from Lower Cretaceous to Recent and occurrences are listed from most of the formations.

Lower Cretaceous

Examples of late diagenetic calcareous accretions from the Lower Cretaceous arkose are two inches up to a foot or so across, mainly spherical to sub-spherical in shape, sometimes ovoidal, and on weathering, they protrude conspicuously from cliff faces and shore platforms as " cannon-balls " (cf. Edwards and Baker, 1943; Baker, 1950, p. 19). They contain from 45 per cent. to 50 per cent. acid soluble (1 : 1 HCl) carbonate, and detrital quartz, felspar, chlorite and occasional hornblende, biotite, zircon, tourmaline, &c. The carbonate is largely calcite which acts as a cement and forms coatings around most detrital grains, besides infilling many interspaces. Because of this, the " cannon-balls " seldom reveal concentric internal structures, while bedding planes, whether horizontal or dipping, sometimes appear to pass uninterruptedly through them. In places, they reveal small flange-like protuberances resulting from extended growth along the bedding planes.

In addition, flat-lying lenticular nodules and sheets occur along bedding planes, while occasional precipitation along joints, especially on the northwest side of Point Lucton, has resulted in the development of steep to almost vertical veins of epigenetic calcite.

The "cannon-balls" occur in localized positions, e.g., as at the head of Crayfish Bay and in cliff faces and shore platforms at The Gable and Point Lucton; their size and concentration are evidently due largely to variations in porosity of the host arkose. The principal cement away from these structures, is likewise calcite, but in much smaller concentrations (occasionally as low as 3 per cent. of the matrix); it was derived from connate waters (Edwards and Baker, 1943, p. 207). Layered calcite along joint and bedding planes is partly secondary to the calcite cement of the host rock, and a few examples have been observed in which they cut through the accretions.

Lower Miocene to Oligocene

Calcareous accretions in marine calcareous clays overlying the Clifton Formation limestone, average 2" x 2" x 1" in size, and are sub-spherical to irregular, rarely nodulose. Some have the typical cracks of septaria (Plate II., fig. P) which are not infilled with mineral matter and which crudely radiate and widen towards the centres of hand specimens. These are sometimes crossed by finer cracks concentric with the margins of the accretions, but the whole pattern of cracks is largely polygonal.

Most specimens have pure white, soft chalky crusts (Plate II., fig. Q) and more compact cores of cheese-like consistency and pale buff colour. They are principally calcium carbonate (Table 3, column 4), with a small amount of buff-coloured clay, minute quartz particles, rare zircon and rare dark brown, sausage-like pellets 1 mm. long (probably faecal pellets).

The growth of these accretions in calcareous clays involves initial development of a calcareous gel mass containing a little aluminium and magnesium carbonate. Case hardening, followed by dehydration of interior portions, resulted in a pattern of surface cracks from shrinkage on irreversible chemical desiccation. Subsequent exposure to atmospheric agents and wetting by sea spray, produced the white, soft chalky crusts, in a manner comparable with the production of patination in flint.

Miocene

Miocene calcareous accretions occur as occasional nodules in the marine calcareous Gellibrand Clay and Glenample Clay, and as numerous nodules, sheets and cylindrical structures, &c. in the more favourable horizons of the marine aphanitic Port Campbell Limestone.

Gellibrand Clay

Sub-spherical, cylindrical and tuberous accretions in the Gellibrand Clay are ½″ to 4″ across (Plate II., figs. L to N). They consist largely of $CaCO_3$, but contain a little magnesium carbonate, alumina, and significant proportions of insoluble residue (Table 2, column 7) composed of pale pinkish-buff clay with abundant small, angular quartz grains and rare zoisite, zircon and garnet.

In thin sections, the analysed accretion (Table 2, column 7) reveals a matrix of fine-grained, interlocking aggregates of calcite crystals 0·02 mm. across. Complete skeletons of foraminifera, minute gasteropods and ostracods like those in the host sediment, are embedded in the minutely granular calcite matrix; their interiors are usually infilled with coarser calcite crystals up to 0·15 mm. across. The matrix also contains fragments of bryozoa, broken spines and spicules, and rare fragments of larger shelly fossils. Occasional small, vugh-like structures lined with calcite crystals 0·05 mm. in size, could represent replaced portions of fragmented fossils. Rare minute pellets of glauconite are little larger than the granular calcite, while glauconite also infills a few tests of foraminifera. As there is no evidence to show that fragmentation of the fossils resulted directly from accretionary-generating processes, it is apparent that some submarine erosion, by current action, occurred prior to sedimentation, and less stable skeletal elements were thereby fractured.

The accretions are regarded as being syngenetic to early diagenetic, in a sediment accumulated partly by current action. Components were carried in to a region where a rather more stagnant environment prevailed than for the greater part of the depositional period of the younger Port Campbell Limestone. The acid soluble (1 : 1 HCl) fraction of the host calcareous clay is sometimes as low as 36 per cent., which is approximately 2·5 times less than the calcareous accretions.

The area of deposition was largely one in which fine detrital terrigenous mineral matter, accompanied by fossil fragments, micro-fossils and shells of larger forms living in the muddy calcareous environment, were accumulated under quiescent conditions. The growth of accretions in this sediment was thus comparable to that outlined by Weeks (1953). Removal of CO_2 that had accumulated under the somewhat stagnant environment was inhibited. Rapid using up of available oxygen resulted in lime being retained in solution as bicarbonate. The calcium carbonate was subsequently deposited as accretions in favourable positions, such as around congregated fossil shelly matter, where the soft parts of the organisms, decomposing under anaerobic conditions, locally yielded centres with an alkaline environment of ammonia or amines. Conditions were thus created where the pH value was approximately 7·5 and hence favourable for $CaCO_3$ precipitation. Nuclei for initial precipitation were provided by foraminifera, ostracods, small gasteropods, small fragments of larger shells and bryozoa, and to some extent by foecal pellets, glauconite pellets and detrital mineral grains.

Somewhat stagnant environments such as this are normally low positive (only slightly oxidising) in the oxidation-reduction potential, ranging to negative (reducing); the existence of stagnant conditions rather than the low oxidising-reduction potential, initially retained the lime in solution.

Glenample Clay

Calcareous accretions in the Glenample Clay are generally similar in appearance and origin but less frequent than in the Gellibrand Clay, the sediment containing fewer fossils. Towards the top of the formation, which heralds in the more richly calcareous sedimentation of the Port Campbell Limestone formation, layered accretionary growths formed prominently along some of the bedding planes.

Port Campbell Limestone

The most abundant calcareous accretions exposed in the area studied, occur in the limestone facies characterising the Port Campbell Limestone. This formation, some 250 to 300 feet thick, occurs at the top of the not particularly thick Tertiary series of sediments (some 2,500 to 3,000 feet thick) of the Moonlight Head—Port Campbell—Peterborough region. It is of wide lateral extent, however, and exposed in many places. The best array of accretions occurs on stripped zones (Baker, 1958) produced at cliff edges in positions where sea spray and rain-water run-off combine effectively to remove vegetation, soils and veneers of Post-Miocene Clay. Such stripped zones vary in width along certain of the cliff tops from a few feet at the edges of cliffs up to 200 feet high, to 60 or 70 yards on cliff tops up to 40 or 50 feet high.

Along most parts of the limestone sections of the coastline, extending from Gibson's Beach through Port Campbell to Peterborough and beyond (figs. 1 and 2), the calcareous accretions stand out from bold, vertical cliffs as more or less horizontal lines of small isolated knobs or as narrow, thin ledges where united into more or less continuous layers. Such growths appear in cliff faces more frequently towards the upper portions, where the several thin layers are so spaced as to extend over a zone up to 6 feet or so thick, as at Point Hesse, Broken Head and environs (Baker, 1958), the Amphitheatre, &c.

Nodular varieties of the accretions are mainly irregular in shape, sometimes tuberous (Plate I., figs. A and B), cylindrical (Plate II., fig. D), or ring-like (Baker, 1958, Plate XXVIII.). Others are sub-spheroidal to ovoidal and wrinkled (Plate I., figs. F, N, R, S and T). The more irregular of the isolated accretions commonly possess wart-like excrescences (Plate I., figs. C and U). Where a number of smaller accretions partially coalesce, filigree patterns (Plate I., fig. O) sometimes result.

None of these accretions show concentric structures. Some contain such macro-fossils as *Ditrupa wormbetiensis, Seripecten yahlensis,* echinoids, brachiopods and bryozoa, others contain micro-fossils such as foraminifera, ostracods and spicular fragments. The genera and species of these fossils are the same as in the host sediment. Less stable fossil structures were generally taken into solution, and the ingredients subsequently reprecipitated in the accretions. Thin sections reveal both a similar bio-facies and a similar litho-facies for accretions and host limestone. Cross sections of typical cylindrical and nodular accretions (analyses 3 and 8, Table 2) show rare, small angular grains of quartz, rare felspar, a little glauconite, occasional complete foraminifera and fragments of small shells and bryozoa, set in a matrix of fine-grained calcite. Much of the calcite cement is murky and forms crystals 0·005 mm. to 0·600 mm. in size; rarer clear calcite crystals average 0·040 mm. across. Apart from non-filled bryozoal structures, pore spaces are common and range in size from 0·1 mm. to cavities of irregular shape approximately 5 mm. by 2 mm.

The Port Campbell Limestone was formed on a shallow, well-aerated sea bottom subject to only small influx of clastic terrigenous material, so that relatively pure limestone accumulated. Horizons rather richer in calcareous materials than others, are up to 98 per cent. acid soluble (1 : 1 HCl.).

Much of the limestone was originally a calcareous slime into which dropped small complete organisms, fragments of organisms, and a little fine detrital mineral matter. During diagenesis, crystallization within the bounds of the growing accretions yielded small calcite crystals in places uncleared of minute inclusions; some of the larger pore spaces became lined with clearer calcite. The rock thus seems to have been partly detrital and partly a gelatinous chemical precipitate which, during diagenesis, crystallized as fine-grained aggregates to form the numerous accretions.

Comparison of accretions and host limestone shows that the accretions contain 98 per cent. acid soluble carbonates and little fine-grained (-100 mesh B.S.S.) mineral matter, while the adjacent limestone contains rather less soluble carbonates and a little more insoluble residue (Table 2, columns 1, 2, 3 and 8). Among the insoluble residues are buff-coloured isotropic clay substances, rare angular quartz and garnet, occasional chitinous matter, a few plates of muscovite, rare prismatic tourmaline (possibly anthigenic), microcline, orthoclase, zircon, a few opaque minerals and partially oxidised glauconite.

Although there was no significant change in total carbonates on accretionary growth, there are nevertheless marked differences in the relative amounts of $CaCO_3$ and $MgCO_3$ between accretion and host rock (Table 2, columns 1 and 2). Ratios of $CaCO_3$: $MgCO_3$ are similar for different accretions from localities five miles apart (Table 3, Nos. 1 and 3), but these are considerably in excess of the ratios for the host limestone (Table 3, No. 2). The greater lime carbonate content of the accretions is apparently due to calcareous shelly matter being dissolved and reprecipitated soon after deposition, under conditions of local increases of pH value favouring lime carbonate precipitation, at a time when the enveloping calcium-magnesium carbonate was unlithified and possibly gel-like.

No bedding planes have been observed passing through the accretions (cf. Tarr, 1921), and the indications are that the accretions are syngenetic to early diagenetic in origin. Whereas the magnesium-bearing host became compacted to form a soft, friable, aphanitic, pale buff-coloured limestone with an earthy appearance, the accretions were cemented into more compact bodies enclosing generally fewer but nevertheless similar fossil remains. The different physical characteristics of the accretions rendered them less prone to attack by erosion.

Post-Miocene Clay

Calcareous accretions in the Post-Miocene Clay which caps the Miocene limestone (Baker, 1944, p. 95) are identical with those in the Port Campbell Limestone formation, where they were formed originally. They were more resistant to processes of dissolution that affected the upper horizons of the friable limestone from which the Clay capping is a residual deposit, and hence they constitute remanié accretions.

Pleistocene

The Pleistocene dune limestone contains calcareous accretions of epigenetic origin. Consisting largely of $CaCO_3$ with a little $MgCO_3$, they form secondary discontinuous layers of dense travertinous material, one to three inches thick, along some major stratification and minor cross-bedding planes. They formed from solution of comminuted shell waste that comprises a considerable proportion of the dune limestone, followed by precipitation along bedding structures. A few nodular growths arose from partial cementation by material similarly derived, but precipitated in interstices of the highly porous dune rock.

Holocene

Calcareous accretions in Recent to Holocene beach, cave and dune sands vary in shape, position of formation and mode of origin. Different forms acquired different shapes and sizes according to the prevalent conditions in their places of formation. Thus normal stalactites, stalagmites and stalagmitic encrustations were accreted in several caves in the Port Campbell Limestone along various parts of the coastline (Baker and Frostick, 1951), sand stalagmites were developed in the upper layers of the sandy floors of certain caves in the limestone (Baker, 1942, p. 662), while pisoliths and calcareous " spats " were generated in cave pools (Baker and Frostick, 1951). Beach plasters grew where higher-level beach sands averaging 75 per cent. acid soluble (1 : 1 HCl) constituents became cemented to cliff bases in places of more concentrated cliff face seepage of carbonate-rich waters (Baker, 1943, fig. 23, p. 372); their positions, up to six and eight feet above normal beach level, indicate former beach heights at the cliff bases.

In addition, tubular and solid cylindrical concretions and sub-spheroidal to ellipsoidal nodules of secondary $CaCO_3$, lying loosely in more recent (unconsolidated) dune sands, have been accumulated around roots and fallen twigs, &c.

The cave pisoliths in particular, the calcareous stalactites, stalagmites and stalagmitic encrustations generally, and some of the cylindrical concretions from the aeolian sediments, are the only ones with true concentric structures.

The soils of the district contain occasional calcareous nodules and thin sheets of calcareous "hardpan", formed epigenetically from carbonate-rich waters circulating through the Port Campbell Limestone. These are usually denser and less porous than calcareous accretions in the Port Campbell Limestone.

Calcareous micro-accretions of syngenetic to early diagenetic origin, are represented in various parts of the stratigraphical succession by such features as (i) concentric rims around detrital grains in Lower Cretaceous arkose, (ii) concentric bands and cores in calcite-siderite-glauconite ooliths in the Pebble Point Formation, and (iii) calcite coatings around detrital grains in a thin bed of sandstone interbedded with the lower part of the Dilwyn Silty Clay, where calcite also occurs in ooliths.

Of recent origin are the calcareous cave ooliths (upper size limit = 2 mm. in diameter), found with cave pisoliths in small pools of carbonated waters on the floors of caves in Loch Ard Gorge (Baker and Frostick, 1951).

Siderite Accretionary Growths

Rare nodule-like accretionary growths of siderite up to 6″ and 12″ across, occur in the Paleocene conglomerate of the Pebble Point Formation, Devil's Kitchen area. Derived by weathering from Lower Cretaceous arkose and mudstone, they are rounded, well-polished, often buff-coloured to darker brown, and sometimes reveal numerous fine, superficial cracks. Thin coatings of limonite on several of the siderite accretions are likewise cracked.

Phosphatic Accretionary Growths

Accretions of phosphate occur sporadically in the Paleocene and Lower Eocene strata of the Moonlight Head—Princetown district. A phosphorite bed 3 to 4 feet thick in the Lower Miocene-Oligocene Clifton Formation, is composed largely of phosphatic nodules. Isolated examples containing nearly 19 per cent. P_2O_5 appear in a few horizons of the Miocene, e.g. Gellibrand Clay and Rutledge's Creek Member.

Paleocene-Lower Eocene

Phosphatic accretions in the Paleocene Pebble Point Formation are seldom sharply defined against the matrix of the host glauconitic coarse sandstones and grits, and only become evident on weathering. They are sub-spherical to irregular in shape (Plate II., figs. Y and Z), up to 5″ across, syngenetic in origin, and were evidently precipitated as a colloidal gel incorporating extraneous matter. On testing, they yield little evidence of carbonates and an estimated few per cent. of P_2O_5. A few contain shelly fragments, others consist of pellets of glauconite, rounded quartz grains up to 4 mm. across, and some argillaceous material with the phosphate.

In the younger Rivernook Member which is interbedded with the Dilwyn Silty Clay, occasional phosphatic accretions contain rather more calcite and a little siderite. Qualitative tests indicate an estimated amount of not over 3 or 4 per cent. P_2O_5. They are more sharply defined against the host sediment (glauconitic silty clay), and sub-spherical to spherical in shape; a few are more calcareous still, with only traces of phosphate (Baker, 1950, p. 24).

Some 250 feet stratigraphically higher in the Dilwyn Silty Clay, a few phosphatic accretions exposed in dark grey silty claystone west of Rivernook House (fig. 2), are 3″ across, light grey in colour, and almost spherical in shape. They contain *Nuculana,* small globose gasteropods, fragments of wood and an occasional propodus of *Callianassa,* all of which, among others, are represented in the Paleocene Pebble Point Formation. Along with pellets of glauconite, these fossils are enclosed in a compact cement of collophane; residues from acid digestion contain plant debris, foecal pellets and detrital quartz, bleached biotite, magnetite, epidote, zircon, flint, ilmenite and leucoxene, of average grain size 0·2 mm. Most grains are rounded to sub-angular, the smallest are quite angular.

Thin sections reveal a matrix of calcareous material and brown collophane with embedded detrital grains. Original wood fragments have been replaced by calcite, leaving isolated remnants of brown to black carbonaceous matter enclosing a few small grains of pyrite. Fragments of bryozoa have been partially replaced by collophane and some chambers of foraminifera partly infilled with pyrite and collophane.

These accretions evidently formed syngenetically on the sea floor, in the presence of organic matter and a little detritus of a non-organic character, as a result of chemical reaction and precipitation.

Lower Miocene-Oligocene

Abundant phosphatic accretions in the Clifton Formation are ½″ to 12″ long (Baker, 1945, p. 89), light to dark brown in colour, have relatively smooth surfaces, and are mostly ovoidal to irregular, sometimes cylindrical in shape (Plate II., figs. R to V).

They are principally collophane with varying amounts of shelly and detrital mineral matter; the P_2O_5 content ranges from nearly 1 per cent. to 15 per cent. Examples with dark coloured outer crusts are lighter brown inside, the outer crusts consisting of limonite up to 1 mm. thick, developed by recent weathering.

Thin sections show a cement largely constituted of isotropic, amorphous collophane, which also occurs in places as pellet phosphate. The cement includes angular quartz 0·2 mm. across and well-rounded quartz grains up to 2 mm. across; grains of fresh felspar and flakes of white mica appear in a few of the accretions. Narrow rims of manganese dioxide envelope some of the quartz grains, while layers of lepidocrocite 0·8 mm. thick, calcite 0·2 mm. thick and further lepidocrocite 0·1 mm. to 1·0 mm. thick, form the outer crust of the dark coloured nodules. The cores of such accretions are brown collophane with occasional detrital grains, foraminifera, fragments of bryozoa, small brachiopods, gasteropods and spines of echinoids. *Globigerina*, the more commonly represented genus among the foraminifera, frequently shows exceptionally well-preserved ornamentation, while some of the Lagenids and a few others are also relatively well-preserved; some are infilled with collophane, others with calcite. Zooaria of bryozoa encrusting some of the accretions, are usually phosphatized, sometimes replaced by iron hydroxide, according to whether they were exposed to recent weathering or protected in unexposed parts of the nodule bed.

These nodules were originally regarded as rolled pebbles (Wilkinson, 1865), but their phosphatic nature was not recognized until more recently (Baker, 1945). Their smooth surfaces and rounded character suggest growth while rolling on the sea bed, for even irregularly shaped and somewhat branching varieties reveal some rounding. Because of conflicting evidence, there is some doubt regarding the origin of all of these accretions. The presence among them of the derived Paleocene nautiloid *Deltoidonautilus bakeri* Teichert (cf. *Aturia clarkei* according to M. F. Glaessner), in a phosphatic matrix like that of the nodules generally, points to the possibility of some of the accretions being allochthonous. Enclosed foraminifera, &c., in other accretions from the same deposit, however, are autochthonous, being the same as genera and species in the matrix of the host sediment, which is mainly a similar matrix to that of the Clifton limestone. Also, quartz grains of similar size and similar degree of rounding as quartz grains in the underlying deposit (gritty sandstone with shell fragments), indicate that such nodules were formed more or less *in situ*, and not transported in as products weathered from older formations. The encrusting bryozoa, which are autochthonous, do not help to solve the problem, for they could have become attached to either a newly formed or a derived nodule. Being non-weathered themselves, however, there is no doubt that such bryozoa belong to the host sediment, and hence bryozoal-encrusted phosphatic nodules were not transported in as such.

An explanation of the above evidence requires the co-existence in the same nodule bed of phosphatic accretions derived in different zones—some were chemically precipitated on a sea floor of unconsolidated gritty sandstone in Lower Miocene-Oligocene times, and are autochthonous, a smaller number was derived by erosion of nearby Lower Eocene-Paleocene sediments and transported into the Lower Miocene-Oligocene theatre of sedimentation, and are allochthonous.

The presence of such phosphatic accretions in stratigraphical sequences, usually indicates an unconformity. The Clifton phosphorite is at the base of the Clifton Formation, and apparently conformable with the underlying gritty sandstone. Its nodules are set in a mixed matrix constituted partly of Clifton limestone ingredients, partly of gritty sandstone constituents. The fossils in this matrix are the same as those in the Clifton limestone, which is rich in well-preserved bryozoa, pelecypoda, single corals, echinoids, sharks' teeth, &c. It would thus appear that the Clifton phosphorite and limestone mark the onset of late Oligocene to early Miocene sedimentation in these parts of Victoria, while the gritty sandstone forming the sea floor at that time, evidently represents the termination of Eocene sedimentation.

A few feet above the phosphorite bed, two bands up to a foot thick each, in the Clifton limestone, are also partially phosphatized. They are possibly late diagenetic or even epigenetic in origin, the phosphate coming from enclosed bryozoa, brachiopods, &c. Deposition from connate waters locally enriched in phosphate, was largely confined to two bedding planes, but also formed a few accretions within the body of the limestone.

Radioactivity of the phosphatic accretions

Autoradiographic examination of phosphatic accretions from the Clifton Formation revealed an even, though sparsely scattered distribution of alpha-particle activity, after 21 days exposure to an Ilford C2 (50 microns) nuclear research emulsion plate. Rare relatively weak concentrations of alpha-particle tracks due to point sources, indicate somewhat higher, local activity, evidently arising from small spots of radiocolloids.

Analysed phosphorites (Davidson and Atkin, 1953) show 0·001 per cent. to 0·150 per cent. U_3O_8, with thorium negligible and potash insignificant in all phosphorites.

Since no discrete uranium minerals have been detected in the Clifton phosphorite, its weak radioactivity can only be attributed to the collophane phase being uranium-bearing. The uranium evidently possesses a greater geochemical affinity with the apatite (collophane) structure than with other phases encountered, the uranium substituting for calcium in the lattice. On the other hand, the concentration of uranium in rich phosphate beds of the Phosphoria Formation, Western U.S.A. (Thompson, 1953), is not wholly due to the phosphate, and may partly depend on the organic matter or other components present. Hence, in the Clifton phosphorite, point sources of activity may represent uranium associated with organic matter containing radiocolloids, or with rare local concentration independent of such fossil organisms. The general nature of the autoradiograph, however, with its wide scatter of alpha-particle tracks, points to the wider spread collophane as the source of much of the less concentrated radioactivity.

Davidson and Atkin (1953) have shown that there is normally a fixed $U_3O_8 : P_2O_5$ ratio throughout any single sample, but that throughout any sequence of phosphatic sediments, the uranium content may so vary that the richest phosphate beds are not always the more radioactive. Since there is an antipathetic relationship between uranium and carbon dioxide, calcium-rich phosphorites are always low in uranium. On this basis, the Clifton phosphorite, with its phosphatic accretions embedded in a strongly calcareous environment, must be expected to possess only a low uranium content.

Miocene

Phosphatic accretions are sparse in the Miocene sediments. Only a few isolated examples occur in the Gellibrand Clay and in the Rutledge's Creek Member, where they are evidently syngenetic in origin.

One from the Gellibrand Clay (portion shown in Plate II., fig. O), measuring 18″ by 1″ in size, is cylindrical in shape. Its dip was the same in amount and direction as the poorly marked bedding planes of the host sediment. It is of brownish colour and contains approximately 19 per cent. P_2O_5 (Table 2, column 5). Small complete fossils and fragments of fossils in the accretion, match those in the host calcareous clay.

One in the calcareous clay at Rutledge's Creek (Plate II., fig. E), contains less P_2O_5 (Table 2, column 6) and more calcareous material. It was collected from a biostrome in the calcareous clay. The $CO_3 : P_2O_5$ ratios (Table 3, Nos. 5 and 6) are variable, being twice as great for the Rutledge's Creek specimen. This accretion is also cylindrical in shape, and measures 5″ by 1″. It likewise lay with its longer axis parallel with bedding planes which are stressed at Rutledge's Creek by laminae of shelly material in places. This accretion contains comminuted shelly matter, set in a calcareous-phosphatic-argillaceous matrix. Two biostromes in the Rutledge's Creek Member, provide records of two periods of wholesale destruction of marine Miocene organisms, the destroyed portions of which yielded small, local concentrations of phosphate, and these, with calcareous material, produced the isolated accretions.

Insoluble residues from the Miocene phosphatic accretions are small in amount, but three times as great from the Gellibrand Clay as from the Rutledge's Creek Member (Table 2, columns 5 and 6). The residues include pinkish-buff coloured clay, small angular quartz grains, and rare zircon, garnet and white mica.

Each of the accretions contains similar amounts of $MgCO_3$ (Table 2) and comparable ratios of $CaCO_3 : MgCO_3$ (Table 3).

Syngenetic to early diagenetic phosphatic micro-accretions occur as pellets in the Pebble Point Formation, and in both the limestone and the phosphorite in the Clifton Formation. Occasional oolitic collophane grains in the Dilwyn Silty Clay, and in its thin stratum of interbedded sandstone containing *Trochocyathus* and *Odontaspis*, are sometimes rimmed with pyrite, sometimes almost completely replaced by pyrite (Baker, 1943a, p. 248).

Pyritic Accretionary Growths

Accretions of pyrite are essentially small, fine-grained crystal aggregates, and are typical of less calcareous to non-calcareous carbonaceous sediments which appear low down in the Tertiary succession, although they have also been noted in the earlier lacustrine Lower Cretaceous arkose and in the much later marine Port Campbell Limestone (Miocene).

The crystal aggregates tend to be irregular in arrangement; more regular radial structures of spherulitic types (Plate II. fig. V) are infrequent. Some contain pyritized fossils as nuclei (Plate II., figs. F and G).

Polished surfaces of the pyritic accretions from several horizons in the Tertiary sediments, and also from the Lower Cretaceous arkose, reveal that marcasite is absent (cf. Edwards and Baker, 1951, pp. 40-45; Baker, 1953, p. 128).

Lower Cretaceous

Pyritic accretionary growths have been noted in the Lower Cretaceous arkose forming the shore platform on the Devil's Kitchen side of Point Lucton, and are only accessible at low tides. They possess thin, dark brown limonitic exteriors, and occur as single nodules and small groups of nodular forms ranging up to 3″ by 2″ by ½″ in size. Like the calcareous accretions in this rock, some of the pyritic accretions when freed from the host sediment, reveal small flange-like structures developed by slightly extended growth along a prominent bedding plane. They were evidently formed in much the same way and apparently about the same time in the late diagenetic history of the sediments, as were the calcareous and sideritic accretionary growths.

Polished surfaces reveal that the pyrite encloses translucent minerals (quartz and felspar) and the following opaque minerals: magnetite, limonite with occasional remnants of magnetite, ilmenite and rutile. Locally, the pyrite has largely replaced the calcareous and/or argillaceous cement of the arkose host. The pyrite tends to be rather more concentrated in the outer zones of the nodules, forming more heavily pyritized rims approximately 1 mm. thick. In such areas, threads of pyrite are more frequent along cracks in the quartz and along cleavage planes in the felspars, than they are towards central portions of the nodules. Parts of the pyrite nodules are crowded with minute residual particles of unreplaced gangue; such areas are more common towards central portions of the nodules.

Paleocene-Lower Eocene

A few pyrite accretions in the Pebble Point Formation are sub-spherical to ovoidal nodules up to 1″ across (Plate II., figs. V to X). Several reveal internal radial growths, in places interrupted by included detrital quartz grains up to 0·5 mm. in size. Minute euhedra of pyrite are occasionally exposed on outer surfaces of some of the accretions. A few elongated accretions consist of pyrite replacing fossil wood, others are partially replaced shelly fossils.

Pyrite accretions occur sporadically in the Dilwyn Silty Clay, where they are sometimes flat and elongated, measuring 1½″ by ½″ by one sixth of an inch. In the thin interbedded sandstone bed containing *Trochocyathus* and *Odontaspis,* pyrite nodules are up to 4 mm. in size, while adjacent parts of the same bed reveal pyrite partially replacing the argillaceous matrix. They are larger and more numerous in the Princetown Member (P.M. on fig. 2), where they form nodular growths with variable amounts of interstitial pyrite cement, rather than crystal aggregates. Their shapes vary from sub-spherical (1½″ across) and ellipsoidal (1″ by ¾″ by ½″) to irregularly tuberous (3½″ by 1½″ by 1″). Many are dense, compact nodules of pyrite, but some possess papillate protuberances with well-formed pyrite crystals a fraction of a millimetre in size, studded over the outer portions. Many contain detrital sub-angular to sub-rounded quartz grains, some carbonaceous matter, and occasional small areas of unreplaced carbonaceous silty clay. Others form pseudomorphous replacements and impressions of coalified wood fragments and of the corallum and septa of species of *Trochocyathus* (Baker, 1953, p. 128).

Miocene

Pyrite accretions are few in number, sporadically distributed and up to 3″ long in the Gellibrand Clay (Baker, 1944, p. 101) and in the Port Campbell Limestone and its interbedded Rutledge's Creek Member. Irregularly shaped forms (Plate II., fig. G) represent pyritic replacements of branching bryozoans, others partially replaced shelly fossils (Plate II., fig. F) with only slight disruption of the shells.

Pyrite accretions in the Port Campbell Limestone have been principally altered to limonite, more especially where exposed in cliff faces and on the stripped zones (Baker, 1958) near the edges of cliff tops. These accretions generally have the form of long, slender, cylindrical rods with usually more or less parallel, straight sides (sometimes broadly curving), rather roughened surfaces and dark brown colour where strongly oxidised. Several reveal remnants of pyrite occupying the cores of the long cylindrical rods.

They are usually distributed as sporadic, widely separated individual structures, but in places, as at the northwestern end of Gravel Point, they are rather more concentrated, some two dozen or so occurring over an area of approximately 50 square yards. They range in size up to 8 or 9 inches in length and just under ½″ in diameter. Most examples lie parallel with the bedding planes, but a few are oblique to and a small number normal to the bedding; those parallel with the bedding show random orientation within any particular bedding plane. A few broken, weathered specimens possess hollows up to 3 or 4 mm. deep at each end, where either the pyrite core or its more altered and porous decomposition products (limonite, and rarely basic iron sulphates) have been removed; such hollows are not apparently allied to any fossil structures, and no such structures have been observed directly associated with these cylindrical accretions. They are, however, evidently a result of the activity of sulphur bacteria, and thus indirectly connected with the decomposition of the original organic matter incorporated in the Port Campbell Limestone.

Micro-accretions of pyrite are principally replacements of other micro-structures, often those of minute fossil organisms and occasionally of pellets of phosphate and of glauconite.

In polished surfaces of pyrite in the Dilwyn Silty Clay, small fragments of bryozoa have been detected in the pyrite. In phosphatic portions of the interbedded sandstone containing *Trochocyathus* and *Odontaspis,* microscopic spherical aggregates of pyrite are embedded in a matrix of collophane, from which they are sometimes separated by thin rims of calcite. Micro-accretions in the Gellibrand Clay (Miocene) result from the pyritic replacement of foecal pellets and the infilling of the chambers of foraminifera.

Significance of the authigenic pyrite

The significance of the authigenic pyrite developed in these sediments, lies in the fact that it usually forms where marine waters have become more or less stagnant on deoxygenation, as a result of the breakdown of organic matter on bacterial attack. During the process, H_2S was liberated and reacted with available $FeCO_3$ to form pyrite.

The organic matter was virtually all marine in the Gellibrand Clay, the Port Campbell Limestone and the Rutledge's Creek Member. In the Older Tertiary rocks, however, significant quantities of terrestrial organic matter (mainly plant debris) were swept into the seas of the period, more especially during deposition of the carbonaceous Princetown Member and occasionally during deposition of parts of the Dilwyn Silty Clay and the Pebble Point Formation. In these sediments, syngenetic or early diagenetic pyritic accretions were more abundantly developed under conditions of more widespread stagnation. Shelly fossils no longer remain in the Princetown Member, because of the prevailing acidic conditions. In the lacustrine Lower Cretaceous sediments, the organic matter was evidently all of terrestrial origin, and pyritic accretions associated with its decomposition are very limited in distribution.

Manganese Dioxide Accretionary Growths

Accretions of manganese dioxide are scarce in the Tertiary sequence (Table 1), and have only been noted in the Gellibrand Clay (Miocene), where they are up to 0·5″ by 0·4″ by 0·4″ in size. They are evidently of syngenetic origin and are mainly composed of manganese dioxide with some iron hydroxide and a few detrital grains.

Limonitic Accretionary Growths

The limonitic accretions are epigenetic and result principally from the alteration of pyrite and glauconite in various horizons of the Tertiary sediments, in which they appear as layers and nodules.

Paleocene-Lower Eocene

Oxidation of the glauconite in gritty sandstones of the Pebble Point Formation in the Moonlight Head—Point Margaret district (fig. 2), has given rise to abundant nodules of limonite and relatively extensive layers of limonite up to 5 feet thick. Their content of quartz grains varies up to 50 per cent. of the rock. Fossil structures have been completely obliterated from parts of the sediments so affected.

Oxidation of pyritic nodules in ferruginous sandstones above the Princetown Member, has produced a few limonitic nodules.

Lower Miocene-Oligocene

A few of the smaller phosphatic nodules and some phosphatized fossils in the Clifton Formation phosphorite, have been completely replaced by limonite, while larger nodules possess enveloping crusts of limonite. Such accretions of limonite result from relatively recent weathering of phosphatic nodules exposed to sub-aerial agents, but examples with thin crusts of limonite enveloping a layer of carbonate which is underlain by a zone of lepidocrocite concentric with outer zones, are evidently indicative of the earlier onset of limonitization.

Miocene

Most of the exposed pyrite nodules and cylindrical accretionary growths in the Gellibrand Clay, Port Campbell Limestone and Rutledge's Creek Member, have been oxidized to limonite pseudomorphs. A few exposed by quarrying of the Port Campbell Limestone are rather less altered. Occasional shells originally infilled with, but not replaced by pyrite in the Gellibrand Clay and the Rutledge's Creek Member, have become disrupted by volume increases attendant upon alteration of the pyrite.

Holocene

Limonitic accretions (" buckshot gravel ") in an old lateritic soil horizon some 18″ below the present soils, are mainly sub-spherical to irregular nodules up to ¾″ across. Pale to deeper brownish-yellow, earthy examples are partly calcareous and limonitic. Dark brown to black, more compact varieties are strongly magnetic maghemite. Most of these are structureless, but some show concentric accretionary growth structures. Variations in composition are reflected in the specific gravity values (Table 4).

Associated with dissected Post-Miocene Clays near the edges of cliff tops, occasional mounds up to 6 feet high, composed of irregularly shaped blocks of limonite (up to a foot across), are comparable in origin with the " buckshot gravel ". They represent more extensive deposition of limonite in near-surface positions (Baker, 1958, p. 178).

A few other limonitic accretions of somewhat different origin, have been generated in one or two pools in a sea cave in Loch Ard Gorge, where they are partly calcareous and were formed from iron hydroxide slime in calcium carbonate-bearing cave waters (Baker and Frostick, 1951).

Micro-accretions of limonite with sub-spherical shape and oolitic dimensions (2 mm. and under), are relatively numerous among the " buckshot gravel " components.

Glauconitic Accretionary Growths

Glauconite occurs almost entirely as micro-accretions, usually small pellets. These are most abundant in the lower part of the

Tertiary succession (cf. Table 1), especially in the Pebble Point Formation and the Rivernook Member, and at the base of the Dilwyn Silty Clay; they are rather less abundant in the sandstone bands interbedded with the Dilwyn Silty Clay.

In the younger Tertiary formations, occasional glauconite pellet accretions are dotted through the matrix materials of the Clifton phosphorite. In certain horizons of the Port Campbell Limestone, they are of sufficient abundance in some narrow bands to impart a pale greenish colour to the limestone, as at the Amphitheatre and the environs of Rutledge's Creek.

Where freshly uncovered, the glauconite pellets are green, but oxidation in many exposures has converted a large number of the pellets to a ferruginous clay-like substance. The pellets are mainly ovoidal in shape, and measure 0·5 mm. by 1·0 mm. In places, the glauconite alternates with calcite in ooliths; elsewhere, it forms rims 0·02 mm. thick on quartz grains. Some of the glauconite is weakly pleochroic and biaxial negative, and seems to have been recrystallized, probably as a result of the reconstitution of mica-type clay minerals under shallow water marine conditions, in the presence of organic agents and under reducing conditions. Some of the pellets contain admixed detrital quartz, and were apparently subjected to considerable rolling about on the sea floor.

Glauconite pellet accretions in the Port Campbell Limestone and its interbedded Rutledge's Creek Member, are principally ovoidal to sub-spherical in shape, and range up to 1 mm. in size. Several, however, are replaced micro-fossils, more often foraminifera, less frequently ostracods.

Siliceous Accretionary Growths

Nodules of flint with typical protuberances and irregularities where unbroken, occur among worn calcareous accretions forming the bulk of the infrequent and limited pebbly and cobbly beaches at the base of the steep limestone cliffs, e.g., as at Deany Steps near Port Campbell township. Similar nodular flints among the beach components near Pebble Point, are rare among a host of well-rounded pebbles of rocks alien to known outcrops in these parts of Victoria. Fractured nodules of flint also occur on cliff tops 300 feet above sea level, near Rivernook House, Princetown district; these were evidently collected from the beaches by the aborigines, and utilized by them for various purposes.

The flint nodules are dense, more or less homogeneous microcrystalline to cryptocrystalline aggregates of chalcedonic silica and quartz, and structureless except for the occasional fossils present. All are patinated, with grey to white crusts surrounding dark grey to almost black cores of varying diameter compared with the widths of the patinated crusts. A few are light grey to buff-coloured throughout, indicating extensive patination.

These flint nodules have not been observed *in situ* in any rocks of the district, and although their content of sponge spicules, echinoid spines, bryozoal fragments and occasional foraminifera seems to be generally like that of the Port Campbell Limestone, it cannot be proved at present that the nodules were syngenetically developed therein. It seems more likely that they originated elsewhere (e.g., from the Gambier Limestone in South Australia), and were carried into the area by recent ocean currents.

Sulphatic Accretionary Growths

Accretions composed of hydrous sulphates of lime (selenite) and of iron (copiapite, &c.), are epigenetic and restricted to those horizons in the Tertiary sediments which are richest in pyrite nodules.

Selenite, the least common type, occurs in the Princetown Member and in other parts of the Dilwyn Silty Clay, as isolated crystals up to an inch long, and as a few aggregates of blade-like crystals up to 3 mm. long, often cloudy from inclusion of silt and clay from the host rock. Rare, flat-lying seams consist of the more fibrous variety of gypsum.

In sediments such as the Gellibrand Clay and the Rutledge's Creek Member, small crystals of selenite are usually confined to encrustations on partially oxidized pyritic replacements of fossil gasteropods and bryozoa.

More common, especially in the carbonaceous sediments in the lower portions of the Tertiary sequence, are pale sulphur yellow and sometimes deeper yellow to pale orange coloured, earthy nodules of irregular shape, and narrow seams and films along poorly defined bedding and joint planes. These consist of basic iron sulphates derived from alteration of the pyritic accretionary growths, and in places they have migrated considerable distances through the host sediments, picking out structure planes that are otherwise difficult to trace.

Halite

Microscopic crystals of halite up to 1 mm. in size at the most, and aggregate growths of halite in parts of the Princetown Member and the Rutledge's Creek Member, are locally abundant and epigenetic in origin. They are derived largely from present day cyclic salts, and as a result of wetting by salt spray followed by drying, the crystallization of halite (i) in the pore spaces of the rock, (ii) along contacts between host rock and fossils, and (iii) within the structural elements of some of the fossils, plays an important part in causing swelling and disintegration of the sediments.

Descriptions of Plates.

Plate I.

A to U—calcareous accretions from the Port Campbell Limestone at Marble Arch, 3 miles west of Port Campbell, Victoria. (all x 0·9).

Plate II.

(A to Z—all x 0·9).

A to D—calcareous accretions from the Port Campbell Limestone at Broken Head (A), at Deany Steps (B) and at Pulpit Rock (C and D).

E—portion of phosphatic accretion with included shell fragments, from coquina band in Rutledge's Creek Member, Rutledge's Creek, $3\frac{1}{2}$ miles east-southeast of Port Campbell.

F to K—partially oxidized pyritic replacements and nodules from the Gellibrand Clay, $1\frac{1}{2}$ mile west of Princetown, Victoria. In F, pyrite has partially disrupted a gasteropod; in G, pyrite has replaced a fragment of a bryozoan.

L to N—calcareous accretions from the Gellibrand Clay, $1\frac{1}{4}$ mile west of Princetown, Victoria.

O—portion of 18″ long phosphatic accretion from the Gellibrand Clay, $1\frac{1}{4}$ mile west of Princetown, Victoria.

P—septarian nodule (calcareous) from calcareous clay immediately above the Clifton limestone, nearly 1 mile southwest of Princetown, Victoria.

Q—calcareous nodule with white, chalky crust (enclosing buff-coloured, more compact core), from same locality and horizon as P.

R to U—superficially oxidized phosphatic replacements and nodules from the Clifton Formation phosphorite, nearly 1 mile southwest of Princetown, Victoria. R = tuberous form; S = half of a cylindrical form, with depression at the top; T = replaced bryozoan; U = sub-spherical nodule polished by exposure to recent wave action.

V to X—unaltered pyritic nodules from the Pebble Point Formation, Pebble Point, $3\frac{3}{4}$ miles southeast of Princetown, Victoria.

V—broken in half to expose internal radial growth structure.

Y to Z—sub-spherical to irregularly shaped phosphatic—calcareous—glauconitic accretions from the Pebble Point Formation, Pebble Point and environs, $3\frac{3}{4}$ miles southeast of Princetown, Victoria.

Z—reveals occasional quartz grains 3 mm. across.

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Plate I.

Plate II.