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ART. VI.—*The Geology of Warrnambool.*

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Abstract.

A coastal strip of over two miles wide of consolidated Pleistocene calcareous dunes overlies a bedrock of horizontally-bedded Miocene marine limestone. Inland from the dunes is a plain of ?Pliocene olivine basalt overlying siliceous fluviatile sands and gravels, which rest on the bedrock limestone. Holocene shell beds prove a relative land uplift of at least 14 ft. 6 in. Tuff from the extinct Tower Hill volcano overlies a great deal of the area.

Contents.

Introduction.

This paper presents the results of a study of the area comprehended within the boundaries of the city of Warrnambool. A reconnaissance was made of the country within ten miles of the city to establish the general relationships of the formations appearing in the area of detailed study.

The Miocene Limestone.

The bedrock of the Warrnambool District consists of Miocene marine sediments of Barwonian age in thick beds lying horizontally. The strata which outcrop are highly calcareous sediments, sometimes soft and friable, but often considerably indurated with secondary calcite. They form part of the Miocene beds which extend across the south-western part of Victoria into south-eastern South Australia.

The presence of Miocene limestone at Warrnambool has been noted by Wilkinson (1864-5), and in a list of Tertiary fossils Dennant and Kitson (1903) record "*Pecten foulcheri, Magellania insolita, Magasella woodsiana,* and *Lovenia forbesi*" from that city. Murray (1887, p. 104) refers to Miocene marine beds on the Hopkins River.

The writer has found fossils on the northern and south-eastern rim of the Tower Hill crater, also at the outcrops of limestone marked on the map (fig. 2); behind the tennis court at Woodford; in a quarry on the west side of the bridge near the State School at Curdie's River; in the cut for the drainage of Lake Gillear; in a road cutting on the south side of the Cobden-Colac road on the west side of the bridge over the creek which is a branch of the Curdie's River, and in a road cutting on the hill on the Cobden side of Jancourt.

In Western Victoria the Miocene sediments attain a considerable thickness, but at Warrnambool their thickness has not been proved. A bore described by Griffiths (1891) went through dune rock and then Miocene limestone to a depth of 398 feet, where it was still in the latter formation. Many bores have been put down for water in the district, but the deepest other bore of which I have knowledge is one at Wangoom which was sunk to a depth of 170 feet, all of which was marine limestone. At Portland, a bore put down in the Botanic Gardens traversed 2,265 feet of Tertiary rocks without reaching the underlying strata.

The Miocene beds are very fossiliferous, although the preservation is usually very poor. *Lovenia forbesi* and *Ditrupa* appear to be the commonest fossils, the latter often occurring in bands closely crowded with the tests. Brachiopods, pelecypods, and bryozoa are common in the river section on the west bank of the Hopkins River north of the bridge (fig. 1). Dr. F. A. Singleton kindly examined a collection of fossils made by Mr. George Jorgensen and the author. He stated that they indicated a Barwonian age, but on the material collected a closer determination of age could not be made. Mr. Parr kindly examined some material collected from the Miocene limestone at Warrnambool, but the foraminifera were too poorly preserved for determination.

The Pliocene Basalt.

Basalt is seen in the north-east corner of the city of Warrnambool (fig. 1), but this is only the edge of a great lava plain which stretches away to the north (Hills, 1939). It is mostly vesicular and somewhat decomposed, but parts of the flow are dense and comparatively fresh, being of a light bluish colour in hand specimen. A sample collected from the road cutting at the gate of Mr. Wall's property about half a mile north-west of the

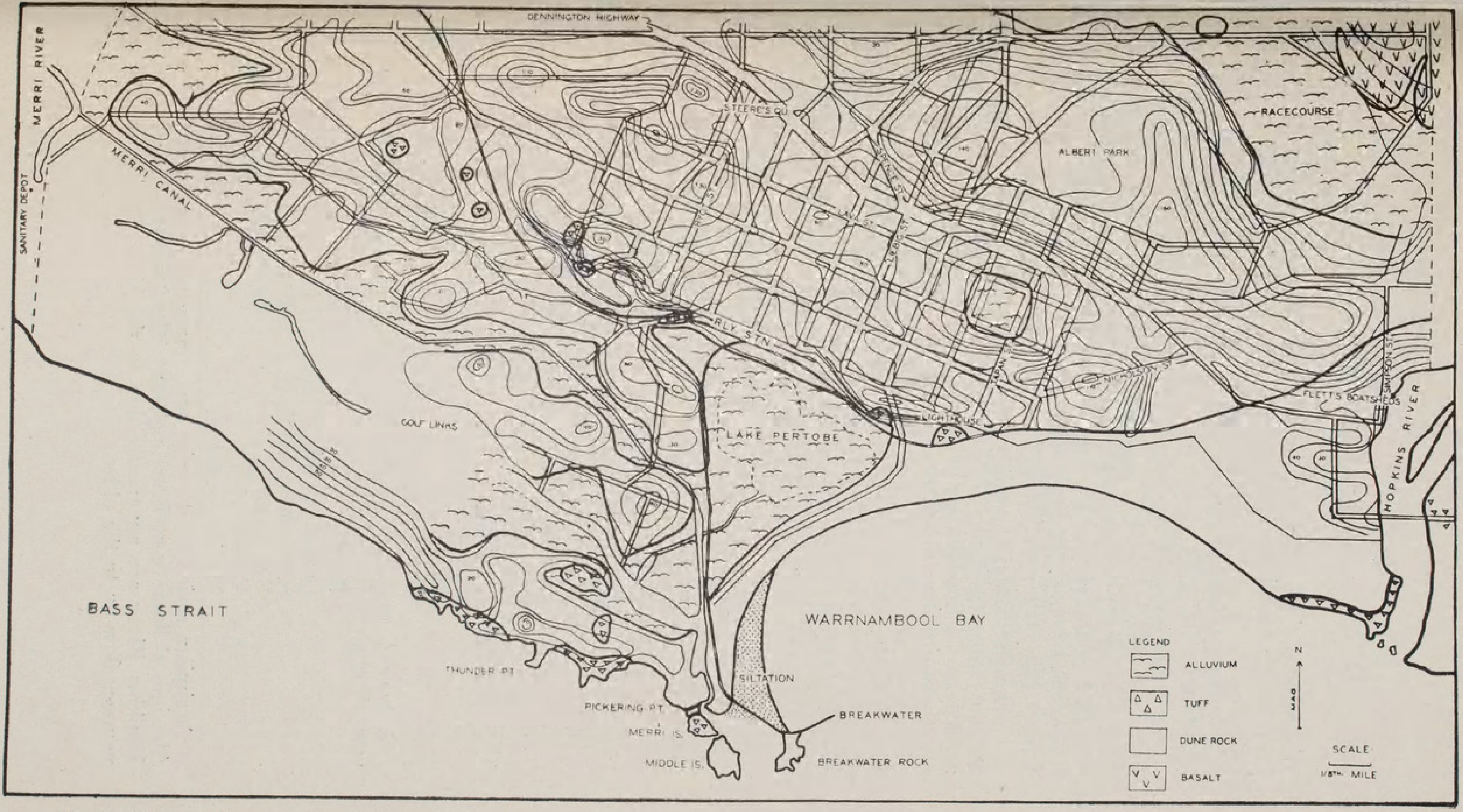

FIG. 1.—Geological Map of the City of Warrnambool, taken from the city map, with 10 feet contours from a sewerage map kindly loaned by the City Engineer, Mr. G. M. Chisholm, B.C.E., C.E.

Wollaston Bridge (fig. 2) has been determined by Dr. A. B. Edwards as an olivine basalt of the Footscray type. The basalt has been used as a building stone in a few instances at Warrnambool, but its chief economic use is for road metal and screenings.

The following evidence has a bearing on the age of the basalt:

1. The flow overlies extensive post-Barwonian fluviatile deposits (fig. 2). Current-bedded sands and gravels have been quarried to a depth of 15 feet on the Wollaston Estate, where basalt superimposes them. Remains of sticks were obtained from a thin clay seam interbedded with the gravels.

2. The pre-basaltic terrain is a diversified one. For instance, sections along the banks of the Merri River at Woodford show a thickness of basalt of about 20 feet, but a boring record $\frac{1}{4}$ mile away near the stone house of Mr. Ben Morgan shows 80 feet of decomposed basalt, 15 feet of clay, and so to the bedrock. A bore at Cudgee Milk Depot proved only 9 feet of basalt, whereas there are basalt quarries nearby. The basalt is seen to occupy small valleys at White's Lane and the Racecourse, but $\frac{3}{4}$ mile behind the Half-Way Hotel towards the Merri River, a bore has shown 60 feet of decomposed basalt to be present.

3. To the north and north-east of Warrnambool the basalt flow which reaches that city (fig. 2) is covered by another flow of more recent date. On Mr. Good's property at Winslow, the following deposits were bored:

Decomposed basalt	..	30 feet
Tuff ..	..	2 ,,
Fresh basalt	..	30 ,,
Yellow clay ..	..	20 ,,
Marine limestone	..	—

A bore on Mrs. McNamara's property near the State School at Cooramook traversed:

Basalt ..	..	80 feet
Gravel ..	..	15–18 ,,
Dense basalt	..	4 ,, (not pierced)

A bore $\frac{1}{4}$ mile off the Ellerslie Road towards Framlingham went through:

Basalt ..	..	124 feet
Coarse gravel	..	15 ,,
Very dense basalt	..	25 ,,
Black clay ..	..	20 ,,
Yellow clay	..	5 ,,
Marine limestone	..	—

A similar series of deposits was traversed by a bore on the Aborigines' Reserve at Framlingham. The Hopkins Falls on the Hopkins River are apparently due to the river flowing off the younger flow on to the older.

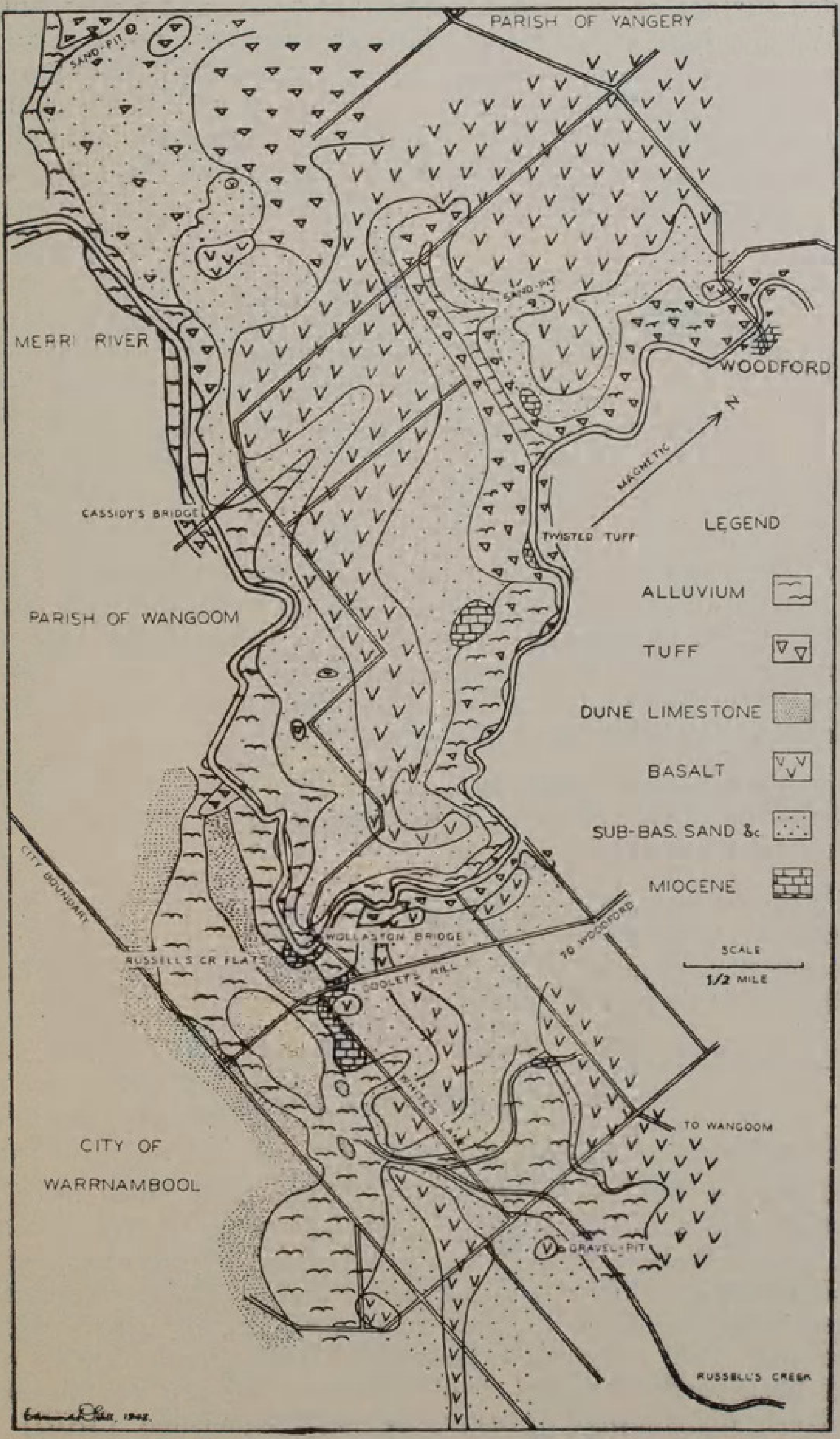

FIG. 2.—Geological Map of an area north of the City of Warrnambool, based on plans of the Parishes of Wangoom and Yangery.

4. Consolidated dune limestone (Pleistocene) rests on the eroded surface of the basalt. This can be seen in a road cutting in White's Lane (fig. 3) which is the furthest point inland at which the dune rock is found, and so presumably a remnant of the oldest line of dunes. As it is believed that the dune-building began with the Ice-Age (= Pleistocene), it may be inferred that because the dune rock overlies the eroded basalt, that the basalt is not younger than Upper Pliocene.

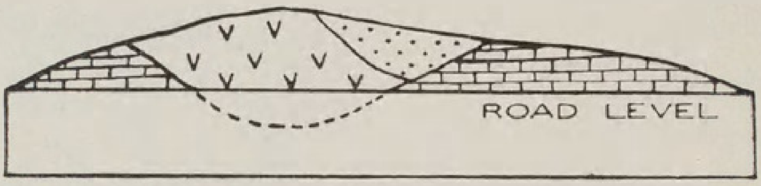

FIG. 3.—Road Section at White's Lane, north of Warrnambool, showing consolidated dune rock resting on the eroded surface of the basalt.

5. The basalt has been widely dissected by streams (fig. 2), and the records of the very numerous borings made for water in the district show the flow to be mostly in a state of decomposition. Buckshot gravel is plentifully developed over the basalt, tens of thousands of tons of this material having been used for road-making in the Warrnambool shire.

Thus the decomposition of the basalt, its dissection by streams, and the big development of buckshot gravel all indicate an older rather than a younger age for it.

From the evidence for the age of the basalt outlined in this section of the paper it will be seen that this lava flow is post-Miocene in age and pre-Pleistocene, and may therefore be referred to the Pliocene period.

The Pleistocene Dunes.

1. EXTENT AND CHARACTER.

Murray (1887, p. 131) writes, "The sand rocks of Post-Tertiary age along portions of the coastline, as at Warrnambool and Cape Otway, are aerial deposits formed by the action of the wind blowing sand into dunes and hillocks which subsequently consolidated owing to the presence of calcareous matter derived from the shell fragments associated with them. These rocks have been partly denuded, and their materials are now in course of fresh distribution by every wind." Etheridge (1876) and Pritchard (1895) have also given a general account of these dunes. Rawlinson (1878) and Mahony (1917) made observations on the Warrnambool dunes, the latter giving a chemical analysis of the dune material.

The dunes are a conspicuous feature of the coast from some distance east of the Hopkins River as far as Port Fairy which is 16 miles west from Warrnambool. The city of Warrnambool is built on the dune rock. In this paper the consolidated dune sandstone (if one thinks of its texture) or limestone (if one thinks of its chemical composition) is treated separately from the loose sand of the present mobile dunes. The former are considered to be Pleistocene in age, while the latter are of Holocene age.

The consolidated dune rock is extensively developed at Warrnambool where it is very thick and stretches inland for $2\frac{3}{4}$ miles At this distance inland the Merri River runs for over 3 miles parallel to the coast, flanked on one side by basalt and on the other by dune rock. At Albert Park the dune limestone reaches a height of over 160 feet above sea level. Mr. Keith McCrabb informs me that bores put down at his own place (46 Spence-street) and at the Paragon Cafe in Liebig-street, traversed 96 feet and 65 feet respectively of dune rock. Mr. Bruce informs me that a bore put down at the premises of Bruce and McClure, Lava-street, proved a depth of 80 feet of dune rock. All these places are about 70 feet above sea level. A bore put down at the Sanitary Depot near Levi's Point penetrated 110 feet of dune sandstone before reaching the marine limestone which was bored a further 10 feet. The location of the bore is 43 feet above sea level, so the sandstone occurs to a depth of 67 feet below sea level at this point which is about $\frac{1}{3}$ mile from the coast.

The Admiralty Chart of the coast shows that the shore platforms, which are formed of consolidated dune sandstone and shallow waters, extend seawards for about a quarter of a mile. Seven hundred yards out from the mouth of the Hopkins is the "Hopkins Reef" which is of the same rock. A line of section taken east from Pickering Point through Breakwater Rock traverses half a mile of island and platforms before entering moderately deep water. Taking into account the shore platforms (Plate II., fig. 4), there is a width north and south of 3 miles of dune rock at Warrnambool. The presence of rock stacks and the fact that the pebbles washed up on the beach are all dune rock shows that it stretches out to sea for some distance. In some rock stacks aeolian bedding can be clearly seen running down as far as visibility extends below the low water level. Thus, stretching round the coast for some 20 miles there are these dune deposits extending inland from one to three miles, and on the evidence of bores and coastal features occurring to a depth well below the present sea level.

The material of the dunes is predominantly calcareous, consisting of comminuted shells, echinoid tests and polyzoa, and of foraminifera. Three published analyses give the percentage of carbonate of lime as 92·43 (Officer, 1891), 86·25 (plus 6·64 of magnesium carbonate—Mahony, 1917), and 92·85 (Coulson, 1940, p. 330). In a cutting on the road to Cassidy's Bridge, 200 yards north of the Warrnambool-Dennington highway, a quartzose sandy soil can be seen under 18 inches of tuff. This quartzose layer is probably due to leaching of the limestone in which there is a small percentage of quartz. Crocker (1941) so explains similar horizons in the South Australian dunes.

The dune rock is sometimes comparatively soft, and friable. The rock, when even and compact, is used for building purposes, being sawn into blocks with ordinary steel saws. The consolidated dune limestone is mostly traversed by calcitic seams sometimes 3 inches wide. In places the sandstone is so indurated that it is glassy and splintery when broken, as, for example, at the east end of Albert Park where it is crushed for road-making purposes.

Caves are common in the dune limestone as they are in the Miocene marine limestone. In the excavations for the sewerage system several more of these caves were located. Belvedere Cave, which is a few hundred yards upstream from Flett's boatshed on the Hopkins River is in Miocene limestone and possesses the remains of stalagmites and stalactites. Many other caves are known in the district (*vide* Bonwick 1858, and Osburne 1887).

The aeolian bedding in the dune rock at Warrnambool shows that at the time of their formation the prevailing winds were south-west as they are now (Rawlinson, 1878). This is shown also by the disposition of the tuff deposits. The windward slopes of the dunes are 10 to 15 degrees, and the leeward slopes 30 to 33 degrees.

Another conspicuous feature of the dune sandstone is the presence of buried soil horizons such as noted previously at Warrnambool by Murray (1887, fig. 45) and Archibald (1894), and at Portland by Coulson (1940). The soil layers vary in thickness from 2 feet to a few inches, and can best be seen in the cliff sections along the coast, especially in the vicinity of Thunder Point where five layers can be seen counting the one under the tuff. The lowest (Pl. II., fig. 2) is 3 feet thick and can be followed for ½ mile round the cliffs, where it ultimately fades out in an "unconformity" which is only a cross-bedding. Such unconformities are due to the planation of an older dune which had been consolidated, and the building of a later one on the eroded surface. An unconformity (Pl. II., fig. 5) thus represents a break in the process of dune-building as does a soil horizon. Three other soil horizons can be seen close together at Thunder Point (Pl. II., fig. 3), and a fifth under the Holocene tuff which caps the cliff (Pl. II., fig. 7). Soil horizons can again be seen at Pickering Point, Ryot-street road cutting, Simpson-street road cutting, Nicholson-street Quarry, and Albert Park Quarry. That at Pickering Point as well as some noted in sewerage excavations have been indurated by the deposition of calcareous matter in them. Further, the soil layers are fossiliferous containing numerous land shells, and sometimes carbonized plant fragments. The dune rock itself contains occasional Helicid land shells. The discovery of alleged human impressions in the dune sandstone has occasioned much discussion (Officer, 1892; McDowell, 1899; Pritchard, 1895; Gregory, 1904; MacDonald, 1904; Chapman, 1914) but they are generally regarded as very doubtful. Footprints of birds and animals have been found (Chapman, 1914).

2. Origin.

Present conditions are not adequate to account for the Warrnambool dunes because:

1. Although of aeolian origin, the dunes descend to a considerable distance and depth beneath the sea, in spite of a Recent uplift of about 15 feet above sea level (p. 143).

2. The presence of soil layers and of unconformities in the dune rock indicates some alternation of conditions.

3. The present quantity of shells and other calcareous tests available for fragmentation into sand cannot account for the accumulation of so immense an amount of dune-rock.

4. The dune-rock cliffs are at present being rapidly broken down by wave action, i.e., the existing forces of denudation markedly exceed those of construction.

5. Offshore there is a submarine valley, partly at least in the dune rock.

As the wind-bedded rock extends below the present sea level, the dunes must have been built when the sea was relatively much lower than it is now. In recent times the sea has been about 15 feet higher than now (p. 143), but in Pleistocene times there was a big eustatic drop in sea level. Hills (1939) has drawn attention to the work of Sayles (1931) on the ancient dunes of Bermuda, and suggested an analogy between them and Australian formations. Sayles states that the soil horizons in Bermuda represent the less adverse conditions of the interglacial periods. Daly (1935) states that the last eustatic drop in sea level was of the order of 75 metres which would join Tasmania and Victoria, and this fits in very well with the essential identity of the faunas and floras on both sides of Bass Strait. An Ice Age origin for the dunes also explains the third point set out above, concerning the quantity of material involved in the construction of the dunes. Of this Daly (1935, p. 197) writes, " When, with each major glaciation, the strand-line moved outward over the gently sloping shelves surrounding continents and islands, wide areas of loose marine sands and muds were exposed to the winds. The dried sands were lifted and carried inland by the onshore winds." Furthermore, since the deposition of the dune sandstone, marine and estuarine shell beds have been laid down (probably by post-glacial high-level seas) along the lower reaches of the Hopkins River, in Lake Pertobe, at Dennington, at a locality near Tower Hill, and at Port Fairy. Also since the deposition of these shell beds the Tower Hill volcano has been active and then become extinct. The consolidated dune sandstone is therefore older than Holocene and is to be referred to the Pleistocene period. If the soil horizons represent interglacials, then the formation covers most, if not all, of the Pleistocene period.

Mr. W. J. Parr has kindly examined material collected from the beach on the west side of the mouth of the River Hopkins, and from the Pleistocene dune sandstone at Steer's Quarry, Warrnambool. From the former locality he has determined *Discorbis dimidiatus* (Jones and Parker), *D. australis* Parr, *Elphidium macellum* (Fichtel and Moll), *E.* sp. indet., and *Quinqueloculina lamarckiana* d'Orbigny. From the latter locality the same species of *Discorbis* and *Elphidium* were found, in addition to *Quinqueloculina* sp. indet., and *Triloculina trigonula* (Lamarck). Mr. Parr has noted that the species of foraminifera are all common in Victorian shore sands, but that in the above samples they were commoner in the Hopkins beach sand than in the Warrnambool dune rock.

In discussing the dunes of the adjacent Portland District (which has a similar structure to that of Warrnambool), Coulson (1940) claims that "The widespread formations at 400 to 500 feet altitude, which cover the basaltic Portland promontory and its westward extension to Swan Lake and Mt. Kincaid, indicate uplift of the order of 400 feet, after allowing 100 feet as the height to which dune formations can be built and levelled off in this district." Thus Coulson holds that ordinary dune-building forces in this part of Victoria could not have elevated the sand above 100 feet. However, it should be noted that—

1. Similar sea-line dunes occur at Warrnambool (60 miles from Portland) to over 160 feet, and these may be compared with those on King Island to 250 feet (Debenham, 1910), at Sorrento to 225 feet (Gregory, 1901), at Anderson's Inlet to 250 feet, in the Glenelg area to 300 feet, and in West Australia to 300 feet (Etheridge, 1876).

2. Coulson postulates uplift to explain dunes at 400-500 feet, yet explains dunes from 500-740 feet as due to migration up slopes. May not the dunes at 400-500 feet be due to similar migration?

3. The factors limiting the height of such dunes (as described, e.g., by Cornish, 1896-7, and Olsson-Seffer, 1907) apply only to sands in open country, and not to sands migrating up slopes. Worcester (1939, p. 229) refers to the piling up of dune sands to over 1,000 feet in the San Luis Valley, Colorado.

The present writer is of the opinion that there has been no post-Pliocene uplift of the order of 400 feet in the Portland-Warrnambool area.

The Holocene Shell Beds.

In 1917 Chapman and Gabriel listed shells collected from a small patch of rock about 100 yards upstream from Flett's boatsheds on the west bank of the River Hopkins. Deposits extending for about a mile have now been traced on the east bank of the river, overlain by tuff (Pl. II., fig. 8). In the section shown in the photograph there are the following thicknesses of deposits :—

9 inches soil.

3 ft. 3 in. tuff.

3 inches to 1 foot agglomerate composed of sand and angular fragments of dune rock.

14 ft. 6 in. limestone composed of numerous Holocene shells in cemented calcareous sand.

The rock is often crowded with shells, many of the bivalves having the two shells still together, showing that they were deposited in quiet waters and not thrown up on to a storm beach by waves. The shells are generally whole. The highest placed fossil observed was collected from 11½ feet above high-water mark (the river is tidal as far up as Allansford). Flat smooth pebbles of dune sandstone are common in this Holocene deposit, a layer of 9-inch thick being developed in one locality. Chapman and Gabriel thought that the Hopkins shell-rock was part of the Pleistocene dune formation (pp. 4, 13). However, the examination of further outcrops on the opposite bank of the river shows that the deposit is resting on dune rock, and is largely composed of materials derived from the dunes, and therefore is to be regarded as post-dune. The fossils are all of recent character. The same authors attributed the height of the shell bed to "local uplifts due to volcanic activity in the western district" (p. 5). An explanation based on the world-wide drop in sea level in recent times advocated by Daly (1935), is also feasible.

Similar Holocene shell beds occur on the flats at the northern end of which is Lake Pertobe, where boring has proved a thickness of 20 feet of sediments over the dune-rock. Chapman and Gabriel (1917) also reported on shells collected from this locality but considered that "this deposit probably belongs to a later episode than the shell-beds underlying the tuffs." The Merri Canal has exposed these beds, some of which are still loose and some consolidated. The beds are packed with shells, most of which are whole, and many of the bivalves have the two shells still in place. At the upstream end of the flats, near the Warrnambool Woollen Mill, oyster shells are common. On the Merri Canal 4½ inches to 5 feet of these Holocene shell beds are exposed above river level on the west bank.

Shell beds are also known at Dennington (Chapman and Gabriel, 1917, p. 4), where a fauna was obtained 8 feet from the surface, and underneath volcanic tuff. Records of bores show that underneath this shell bed there is a boulder bed of at least 15 feet thickness. Behind the ocean foredunes there is a swampy area which leads right up to Dennington (fig. 4). In very rough weather the sea washes over into this swamp. On the road from Warrnambool to Dennington about 200 yards east from the turn off to Cassidy's Bridge, an excavation for a large electric power line pole brought up numerous flat pebbles and sea shells, some of the latter being water-worn.

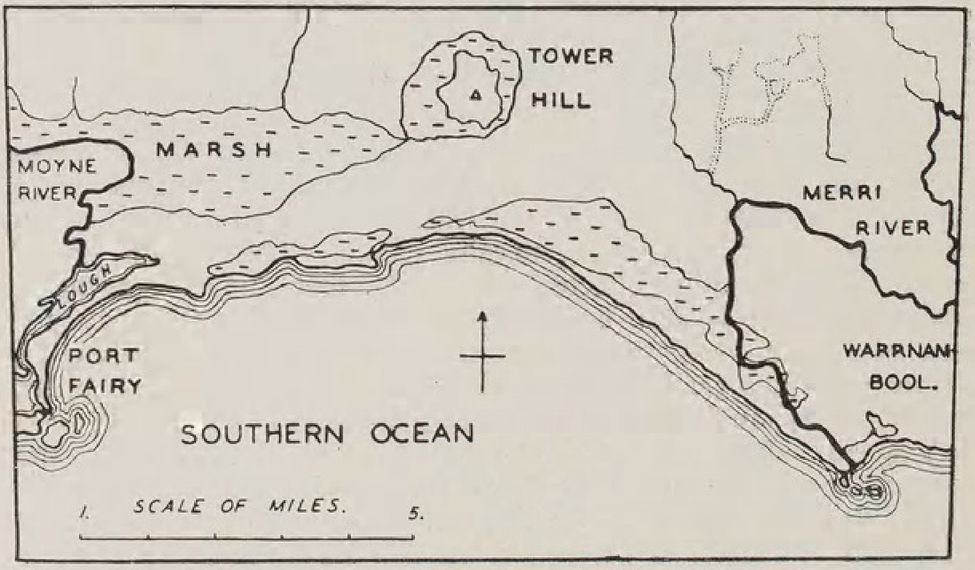

Fig. 4.—Map (after Archibald, 1891) showing stream-pattern in Warrnambool District.

The shell beds at Dennington, Lake Pertobe, and Hopkins River, rising to a maximum height of 14½ feet above sea level, indicate a relative uplift of the land of at least that amount. This is referred to in the present paper as the 15 feet uplift.

Shell beds not unlike those at Warrnambool are known also at Port Fairy (Rawlinson, 1878, p. 31), Gellibrand (Murray, 1877, p. 127), and in the Port Philip area (Hills, 1939, p. 90). Coulson (1940) has brought forward evidence of a 10-ft. relative rise of the land in the Portland district. David (1914) remarks, "The so-called raised beach of about 15 feet is so general around Australia, that it is probably due to a eustatic negative movement of the sea surface" (p. 289).

That the relative fall in sea level at Warrnambool was a recent one is corroborated by some physiographic features. On the north boundary of Lake Pertobe is the precipitous scarp of Cannon Hill (Pl. II., fig. 6). This is an old sea cliff, while the gentler slope in the foreground is due to the piling of volcanic tuff against this cliff. When a trench for a water main was dug at the railway crossing just west of the Warrnambool railway station, a sea shell (*Trochus undulatus*) was found in dune rock under tuff. This shell was complete and is the only sea shell which has been found in the dune rock. It is significant that it is at the foot of this cliff. The scarp passes in one direction round to the Woollen Mill, and in the other past the lighthouse towards the Hopkins River.

The Holocene Tuff.

Nine miles west of Warrnambool is the extinct volcano of Tower Hill, which was of the explosive type, and tuff and fine lapilli ejected from it extend eastwards a little beyond Warrnambool. Apart from accumulations in depressions such as the valley of the Merri River, the capping of tuff does not exceed 3 feet in the vicinity of Warrnambool. Greater thicknesses are found to the north-east of the volcano, showing that the prevailing winds during the eruption were south-west as they were in the Pleistocene (deduced from the orientation of the dunes), and are now. Errey (1894, p. 24) thought that the tuff had been laid down under water. There is no evidence for this apart from the tuff in the river beds. Similar stratification of the tuff (Pl. II., fig. 7) is seen on the top of the cliffs at Thunder Point, on the sides of the hills, and in the hollows. Tuff is prominent all along the banks of the River Merri, so much so that locally the rock is known as "Merri stone". It is also an important constituent of the river flats where sometimes it is bedded and sometimes mixed with alluvium. An interesting structure observed in the banks of the Merri River (Pl. II., fig. 1) is a sub-circular arrangement of the "stratification". The weathering of the variant textures in the tuff shows that apparently the volcanic dust mixed with the water of the river until a viscous consistency was attained, whereupon it was turned over so as to appear somewhat like a stiff cake mixture which has just been stirred.

In addition to the tuff shown on the maps, there are many little patches too small to be so recorded. Former small hollows in the terrain have been filled up and levelled off with deposits of tuff. Also some soils show by their colour and texture that they have been admixed with tuff. An interesting profile is to be seen in a quarry between Nicholson-street and the railway line (Pl. II., fig. 9). From the bottom up the layers are:—

Consolidated dune limestone.

18 inches black "fossil" soil horizon.

6 inches buff coloured calcareous sand.

6 inches tuffaceous sand layer.

2 inches present black soil layer with grass.

The Merri River runs for a considerable distance on a bed of tuff, which can be seen outcropping on its banks to a depth of 10 or 15 feet, and in places there are small islands of tuff. For some distance upstream from the Wollaston bridge, the tuff is piled high against the eastern side of the valley.

The tuff is fossiliferous in places. Carroll (1898) found the skeleton of a dingo at Tower Hill 60 feet from the surface. Walcott (1920, p. 69) refers to "large and deep footprints, measuring about 9 inches in length, in volcanic tuff, which were exposed in the floor of a cutting made to connect Nestle's Milk Factory with the railway line at Dennington, near Warrnambool". Chapman (1926) records a leaf, *Eucalyptus* sp., from the tuff.

The stratification of the tuff (Pl. II., fig. 1) as seen at Warrnambool and to even more marked degree at Tower Hill itself, shows that the volcanic activity was intermittent. Bonwick (1858, p. 61) records a layer of black soil and remains of vegetation at a depth of 120 feet interbedded with tuff. On the west bank of the Merri River, $\frac{1}{4}$ mile upstream from the Wollaston bridge, the following section can be seen (the lowest outcropping stratum being named first:—

15 inches dark-grey ash with fine lapilli.

5 inches light-grey ash, graded thick to fine upwards.

2 inches clay.

3 inches ash with fine lapilli.

8 inches laminated clay in layers of about $\frac{1}{2}$ inch.

6 inches dark ash with fine lapilli.

9 inches clay and ash mixed, merging upwards into light-grey ash.

The alternation of beds of fine clay with beds of tuff indicates a discontinuity at least at this point in the deposition of the volcanic material. However, such alternation of bedding is rare.

The volcanic ejectamenta are of very recent age because—

1. They rest on the Holocene shell-beds described above (Pl. II., fig. 8). This means that the tuff is later than at least the beginning of the post-glacial recession of the sea (if the 15-foot relative rise of the land at Warrnambool is due to this cause).

2. At Cannon Hill, Warrnambool, the tuff rests against the base of an old sea cliff which is only a few feet above sea level. The town clerk of Warrnambool (Mr. H. J. Worland) has a photograph showing high seas washing over the foredunes into the lake at the bottom of this cliff. The preservation of this bank of tuff without apparent erosion, and of a similar bank a little further east near the lighthouse (fig. 1) is evidence that the tuff has been deposited since the completion of the post-glacial recession of the sea.

3. Where tuff rests on hillsides in the areas mapped, it has been noted that it always follows the present contours of the countryside.

4. The Merri River has not yet cut through the tuff in its bed.

5. Mulder (1909) claims that the meaning of aboriginal names " shows that they saw the volcanoes in action, but at a period so remote that even tradition had died out, the names only surviving."

However, Mr. A. S. Kenyon (personal communication) informs me that the meanings given by Mulder are incorrect, and are to be ascribed to " wishful thinking and blackfellows' courteous replies ".

The Holocene Alluvium.

Along the Merri River from Cassidy's Bridge upstream, there are river flats situated generally about 15 feet above river level. Tuff outcrops along the banks of the river for most of the way, and it is commonly met with in excavations on the flats. The alluvium is itself sometimes seen clearly to contain tuffaceous material. The deposition of tuff in the valley is considerable as so much was washed off the sides of the valley into the river course. The result was a building up of the river bed by more than 15 feet, thus slightly rejuvenating the stream which has cut through this new bed to an average depth of 15 feet. Below Cassidy's Bridge are many swamps and flats covered with reeds. These are covered in flood-time, whereas the high level alluvium just referred to is not now reached by flood waters. Many of these low-level flats are in the nature of dune swales which have been extended by fluviatile and marine action.

Russell's Creek, a tributary of the Merri River, has two levels of alluvium in the upper and lower parts of its course respectively, and these will be described in the physiography section.

The map of Warrnambool constituting fig. 1 shows a patch of alluvium in the vicinity of Japan-street. This is a swale hollow which used to become a lake in winter until a tunnel 27 chains long was cut through a dune ridge to the sea.

Lake Pertobe is bounded on the east, west, and south by alluvial deposits which have been superimposed on the Holocene marine shell-beds already described. In the winter the lake extends considerably, and the alluvium is thus partly lacustrine and partly due to wash from the higher ground surrounding the flats. The alluvium near the lake abounds with the shells of small freshwater mollusca. Alluvium with similar shells occurs on the south bank of the Merri River near the outcrop of Miocene limestone 2½ miles upstream from Wollaston Bridge (*vide* fig. 2).

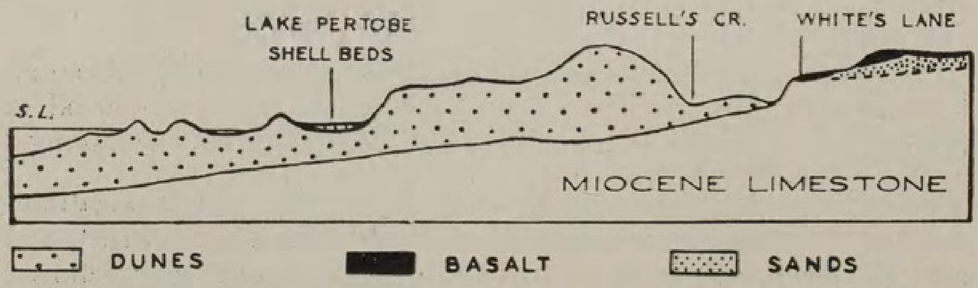

FIG. 5.—Geological Section along Liebig-street, Warrnambool, projected to the Wangoom Road in the north, and to a short distance seawards from Pickering Point in the south.

The Holocene Dunes.

Fringing the ocean for the whole area mapped (fig. 1) there are mobile dunes which are Holocene in age, although composed of the same calcareous sand as the Pleistocene consolidated dunes. For most of the distance they cap the consolidated dune cliffs, but east of Lake Pertobe they occur at sea level. Originally these dunes were closely covered with ti-tree (Osburne, 1887) as is indicated by the presence of numerous root incrustations (cf. Hall, 1901).

The former Government botanist, Baron von Mueller, introduced marram grass as a means of re-anchoring the sand of the mobile dunes, and where developed this treatment has proved successful (cf. Matthews, 1934, p. 90). However, as the grass grows higher so the dunes mount, with the result that they are now much higher than formerly. For instance, the dunes at the Warrnambool Beach (east of Lake Pertobe) used to be so low that during the winter storms the sea water would drive over them and run into Lake Pertobe towards Cannon Hill, but now they have built up to about 20 feet high.

At the mouth of the Hopkins River (west side), at Thunder Point, and at a few other points, the mobile dunes can be seen to be resting on a bed of tuff from 2 to 3 feet thick.

Palaeogeography and Physiography.

North of the city of Warrnambool there runs a clearly defined scarp from 15 to 20 feet high, which is probably the Pliocene shoreline. This scarp consists chiefly of basalt, which is to be expected since it is so resistant a rock, but it is not simply due to differential erosion because the basalt occurs in some places at a lower level in front of this scarp, e.g., at the north-east corner of the Warrnambool racecourse and at White's-lane. The Pleistocene dunes were piled against this barrier, and the Merri River has 3½ miles of its course marginal to it. From the scarp the underlying Miocene limestone shelves away southwards towards the sea, as the following figures indicate:—

At White's-lane, about 70 feet above sea level.

Albert Park, about 26 ft. 6 in. above sea level.

Spence-street, about 20 feet below sea level.

Lava-street, about 10 feet below sea level.

Sanitary Depot, about 67 feet below sea level.

On this slope, which would be left dry by the retreating Pleistocene sea, the sand dunes were built up, and in time consolidated by the secondary deposition from percolating waters of calcium carbonate. The advancing sea began the demolition of these dunes, the sea being then some 15 feet higher than it is now. Parts of the post-Pleistocene shore line can still be seen as described in the section on the Holocene shell beds. Borings have shown that the dune rock floor below the Lake Pertobe shell beds slopes from the foot of Cannon Hill to a depth of 26 feet below ground level when the beach is reached.

Lady Bay (or Warrnambool Bay as it is called on some maps) is an inundated swale, the line of islands and shore platforms on its seaward side being a continuation of the line of dunes which constitute the coastal cliffs. A former course of the Merri River was along the swale behind this first row of dunes. However, sand from the mobile dunes kept blowing into the stream tending to block it and in any case washing into the harbour, so a canal was cut to divert the river. This canal followed the swale behind the second row of dunes. Fig. 1 shows how the alluvium of Lake Pertobe extends up behind the third row of dunes, and Bonwick (1858) suggested that the Merri once flowed out at this point too. The seaward sloping floor beneath Lake Pertobe is consonant with this idea. The present course of the Merri River after leaving the basalt is along the hindermost of the swales which is marginal to the basalt. It is clear too that the Merri River at one time flowed into the sea west of Dennington (fig. 4), and it is probable that it was then that the estuarine beds were deposited there. The Admiralty chart shows a submarine valley south of Tower Hill. The exit to the sea south of Dennington was ultimately blocked by the shifting sand of the mobile dunes, and the impounded waters then found an outlet along the first swale to Lady Bay. A similar thing has happened at Port Fairy to the Moyne River forming the Belfast Lough as it used to be called (Belfast is an earlier name for Port Fairy). *Vide* fig. 4.

The valley of Russell's Creek, a tributary of the Merri River, is characterized by two areas of alluvial flats differing 20 to 30 feet in height, and caused by two bottlenecks in the course. The first constriction is near the mouth of the stream where a line of strongly consolidated dunes is the obstacle. A local base level of erosion has been developed called the " Russell's Creek Flats ". The second constriction is in the basalt north of the racecourse.

Bands of hard travertine retard the weathering of the dune rock. Sometimes a whole slope of a hillside can be seen to be determined by the presence of such a band. It is marked along the shoreline where travertine bands form cliff tops which are sometimes undercut by erosion. The erosion of the cliffs is often rapid, due to the washing out of soil layers, which causes the cliff above to collapse. There are wide shore platforms with many solution cups, and in places there are rock stacks and islands rising above the level of the platforms. Caves have also developed in the cliffs. The rapidity of the erosion of the cliffs is indicated by the disappearance of aboriginal kitchen middens which are common along the cliff-tops. In the eleven years the author has had this part of the coast under observation, one of these middens has completely disappeared. No middens have been found under the volcanic tuff and since this deposit is geologically so recent the length of time of human occupation of the area must be very brief.

The River Hopkins (on the eastern border of the city) is tidal as far as Allansford, where it leaves the basalt. At the mouth there is a bar and a little offshore there is a reef. Mobile dunes cap consolidated dune sandstone on both sides of the mouth, and formerly sand often blew across the mouth blocking the river until the next storm swept it clear. In the interests of fishermen a channel has been blasted through the dune rock bar. North of Flett's boatsheds (west bank) there are high Miocene limestone cliffs, while on the east bank are the Holocene shell-beds. A regular layer of tuff can be seen surmounting the east bank, while on the west bank the tuff occurs only at intervals—generally in hollows. In the lower reaches of the river the stream follows the boundary between the Pleistocene dune rock and the Miocene bedrock. A low island once existed upstream from the bridge (fig. 1), but the erection of a causeway forming the approach to the bridge from the east bank produced new river currents which eroded away the island to a wide mudflat which is bare at low tide and covered by about a foot of water at high tide. South of Lady Bay there is only one submarine valley, which suggests that the Hopkins and Merri Rivers may have entered the sea by a common stream when the sea level was lower than it is now.

In the map (fig. 4) it is seen that the direction of flow of streams is dominantly in two directions—the one, north to south, and the other, west-north-west to east-south-east. Although the streams flow on Miocene limestone, Pliocene basalt and sub-basaltic fluviatile deposits, Pleistocene dune limestone, and Holocene tuff, they all conform to this same stream pattern. The reason is that the physiography is dominated by the basalt, because where streams flow on the Miocene limestone or sub-basaltic deposits they are superimposed, where they flow on dune rock, the dunes are aligned to the basalt, and where they flow on tuff, they flow in courses previously determined.

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Description of Plate.

PLATE II.

FIG. 1.—Subcircular "stratification" in tuff on bank of Merri River south of Woodford. *Vide* text p. 145.

FIG. 2.—The lowest and largest soil horizon seen in the cliffs at Thunder Point.

FIG. 3.—Cliff near Thunder Point showing three soil horizons close together and a fourth under the tuff at the top of the cliff. The horizons are numbered on the photograph 1-4.

FIG. 4.—Shore platforms in dune rock near Breakwater Rock.

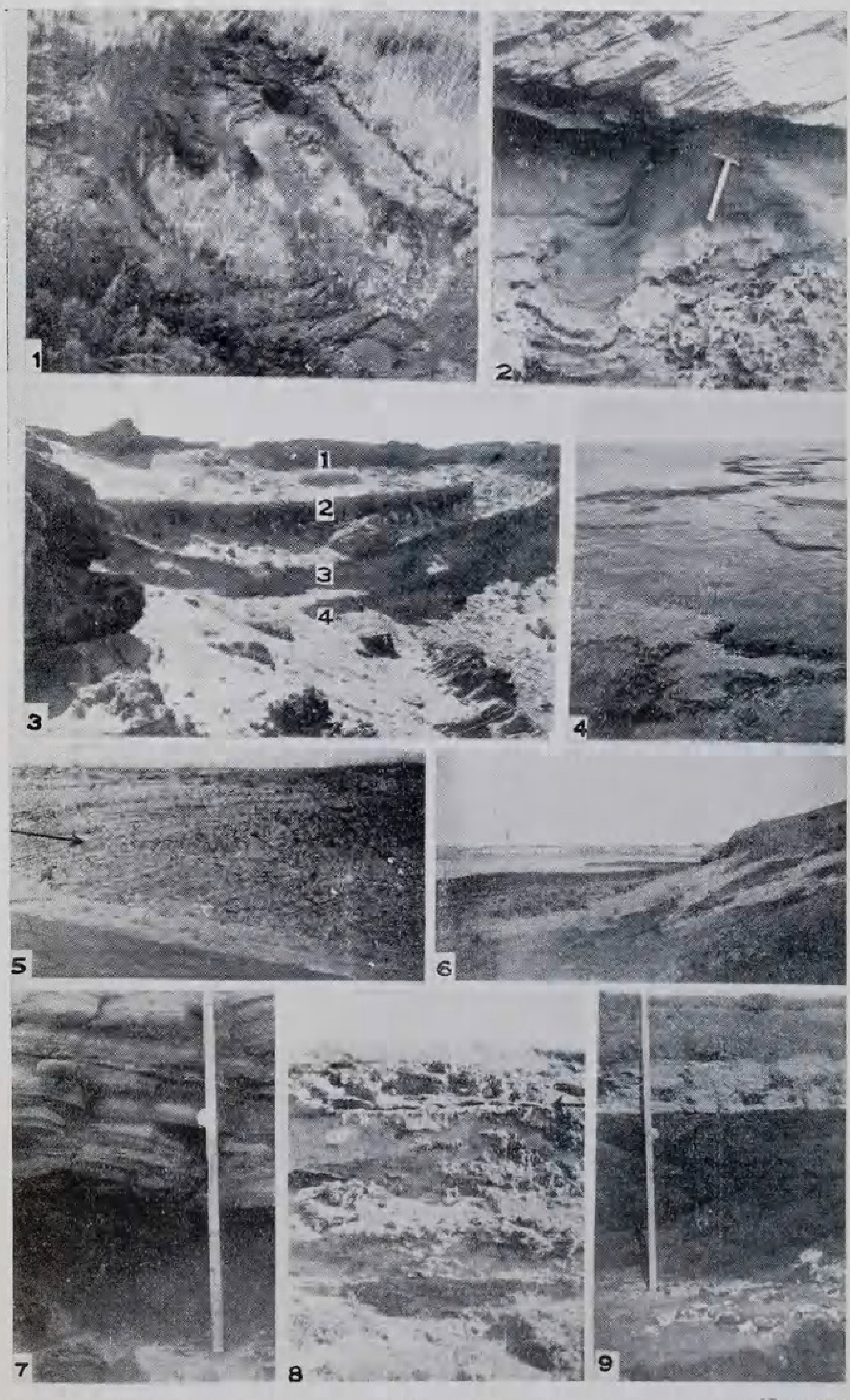
FIG. 5.—Road section, Nicholson-street, Warrnambool. On the planated surface of an older dune, a newer one has been constructed. The arrow on the left of the photograph indicates the break between the two formations.

FIG. 6.—Cannon Hill, Warrnambool, with Lake Pertobe in the background. In the foreground, the slope is composed of tuff piled up against the old sea cliff, which is represented by the precipitous rocks seen beyond the slope.

FIG. 7.—Banded tuff on soil layer, which in turn rests on consolidated dune rock at Thunder Point, Warrnambool. The lower end of the ruler is resting on the dune rock.

FIG. 8.—Holocene shell beds on the Hopkins River, surmounted by a layer of tuff. The arrow on the right of the photograph indicates the upper limit of the shell beds and the beginning of the tuff.

FIG. 9.—Profile in quarry near Nicholson-street. For details *vide* text, p. 146.



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