GEOLOGICAL SURVEY OF VICTORIA

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MEMOIR 17

THE MORNINGTON

PENINSULA

By R. A. KEBLE

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FOREWORD

This work was commenced in 1921 but was left incomplete when the author was transferred in 1927 to investigate the possibility of oil occurrences in western Victoria. Shortly afterwards, Mr. Keble was appointed palaeontologist of the National Museum, but less than two years before his retirement he returned to the Mines Department in order to complete this work.

The original maps were prepared from chain and compass traverses, but aerial photographs were utilized in the preparation of the finished work. For this edition the maps have been redrawn on the one mile to one inch standard grid and incorporate more detailed mapping of the Quaternary formations by J. J. Jenkin and other workers in adjacent areas. These Quaternary formations are not fully described in Keble's original text. Bathymetric contours have also been added.

The Memoir describes the geological structure of the Peninsula, the sequence of the Lower Palaeozoic rocks, their faulting and their uplift into blocks in Tertiary times. The economic potentialities, for example, gold, limestone, clays, bauxites, lignites, building stones, and underground water, have also been investigated. The Mornington Peninsula is a key area for determining the sequence of geological events in Tertiary times, and the juxtaposition of marine, terrestrial, and volcanic rocks has enabled this to be deciphered in its broad outlines. The Peninsula is important for its agriculture, orchards and recreational value and this memoir should add to the interest and understanding of all who frequent the area.

D. SPENCER-JONES,
Director of Geological Survey.

I. SOME FACTS CONCERNING THE MORNINGTON PENINSULA

The tower on Arthur's Seat is 1,031 feet above sea level and on the highest point of the Mornington Peninsula. The Geodetic Survey of Victoria, started in 1858, determined a trigonometrical point on this tower as latitude 38 deg. 21 min. 20·4 sec. south, longitude 144 deg. 57 min. 12·2 sec. east, using a base line on Werribee Plains as datum. This point was recovered when a new tower was erected on the site of the old one, and in a letter to the author, Mr. G. W. Brown, engineer for the Shire of Flinders, said " during the excavation of the foundations of the tower, the trigonometrical point was found at a depth of about 2 feet below the surface. It was carefully removed and its exact position fixed by offsets. After a concrete pedestal about 3 ft. 6 in. high had been built the stone was lifted and set into the top of the pedestal. Its position was determined accurately with a theodolite, and I am quite satisfied that the point is in the same vertical plane as originally."

Within the last ten years, Sydney datum has been adopted and the old determinations were recalculated to latitude 38 deg. 21 min. 19·540 sec. south, longitude 144 deg. 57 min. 04.436 sec. east. The trigonometrical point used by the military authorities is on the top of the tower and does not coincide with the old point. It is given as latitude 38 deg. 21 min. 19.581 sec. south and longitude 144 deg. 57 min. 04.432 sec. east.

The climate of the Mornington Peninsula is in one respect unique. The only portion of the Australian mainland in the marine cyclone belt shown on the map by Huntington, Williams, and van Valkenburg (1933) based on climate and human use, is the southern half of Victoria, which includes the Mornington Peninsula. In the map by Huntington (1924) showing the effect of climate on human energy, the high energy belt in Australia closely corresponds with the cyclone belt; it includes besides the southern half of Victoria, Tasmania, and part of New Zealand. Huntington states that climatically

" the ideal condition, or optimum, seems to be mild winters with some frosts, mild summers with temperatures rarely above 75°F., and a constant succession of mild storms and moderate changes in weather from day to day."

He points out that people are most active when the average temperature ranges from 60° to 65°F. The following data obtained from the Commonwealtn Meteorological Bureau indicate that the climate of the Peninsula closely accords with the ideal conditions.
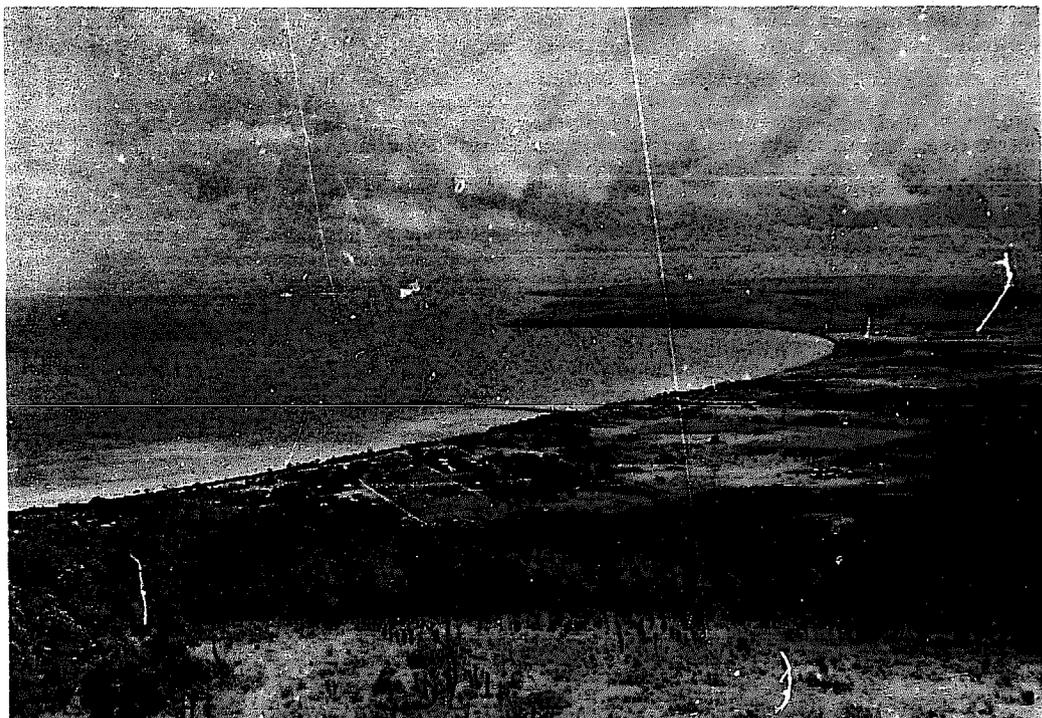
1. View from Arthur's Seat looking north across Dromana Bay. The low ground in the middle distance is the fringe of the Kangerong Basin. On the north side of Dromana Bay is Mount Martha, with Mount Eliza in the distance.

During the year 1947, 33 cyclones and the same number of anticyclones passed over the Peninsula.

The mean temperatures of the town of Mornington and at the Point Nepean Quarantine Station are as follows:

Period (Years)	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Mean.
						Mornington.							
20	65·8	66·5	64·2	58·7	54·7	50·4	48·9	50·3	53·2	56·4	60·0	63·5	57·7
						Point Nepean Quarantine Station.							
14	64·3	64·4	62·1	58·1	54·9	51·1	49·7	50·5	52·0	55·1	58·9	61·6	56·9

The rainfall at Cape Schanck, Mornington, Westerfield (near Frankston), and Shoreham is as follows:

Period (Years)	January.	February.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Mean.
						Cape Schanck.							
58	162	144	217	249	289	330	288	276	269	257	217	207	290
						Mornington.							
54	187	138	202	253	256	302	265	271	282	263	225	206	285
						Westerfield (near Frankston).							
20	196	206	254	330	242	304	274	305	259	258	262	228	311
						Shoreham.							
24	168	173	248	265	355	397	377	372	365	291	270	236	351

Bass, Murray, Flinders, and other early navigators named the main points on the Peninsula, and their names are reminders of the intrepidity of those who ventured into uncharted seas. Western Port figures prominently in the discovery of south-east Australia; it was discovered and named by Bass in 1798. Cape Schanck first appears on an eye-sketch made by Governor King showing the track of the *Lady Nelson*, and was named after Captain John Schanck, Commissioner of the Transport Board and inventor of the centre-board keel of the *Lady Nelson*. Sandy Point appears on Barrallier's map of Western Port made in 1801. Port Phillip was originally named Port King by Murray in 1802, but was renamed Port Phillip by Governor King; he also named Point Nepean after Sir Evan Nepean, Secretary of the Admiralty. Those islets we now call Mud Islands were originally called Swan Islands, but in 1803 Knopwood of Collins' expedition referred to them as Signet Islands. Arthur's Seat was so named by Murray in 1802

" from its resemblance to a mountain of that name a few miles from Edinburgh."

Sullivan Bay near Sorrento was the site of the first white settlement in Victoria, by Collins in 1803; it was named by him after the Permanent Under-Secretary of the Colonial Department.

The Admiralty Charts show what was known up to and about 1836 when Victoria became a political community. Port Phillip was charted by Captain W. Hobson, Lieutenant T. M. C. Symonds, Lieutenant H. R. Henry, and P. F. Shortland of H.M.S. *Rattlesnake* in 1836; and additions were made to this chart by Commander I. C. Wickham and Captain J. Lort Stokes of H.M.S. *Beagle* in 1840, and C. J. Polkinghorne in 1856. Western Port was charted by Stokes in the *Beagle* in 1839, and his chart was issued in 1843. Both of these ships had interesting associations, the *Rattlesnake* with T. H. Huxley, the noted biologist, and the Beagle with Charles Darwin who made his trip round the world in her when he crystallized his ideas for his epoch-making book, the " Origin of Species "; Stokes

accompanied him on this journey. On Hobson's Chart of Port Phillip are shown Point Nepean, King Point, Corsair Rock, Popes Eye, Symonds Channel, Pinnace Channel, South Channel, West Channel, Coles Channel, Leolia Channel, Mud Islands, Middle Ground, Quarantine Ground, Middle Sand, William Sand, Capel Sound, Davy Point, White Cliff, Snapper Point, Observatory Point, Arthur's Seat, Mount Eliza, and Mount Martha. Mount Eliza was named after Mrs. Hobson, not the wife of John Batman as is sometimes stated; Mount Martha was named after Mrs. Lonsdale, Captain Lonsdale's wife. On the copy of Stoke's Chart of Western Port issued in 1843 is shown Cape Schanck, Pulpit Rock, Point Barker, Black Head, Point Bobbanaring, Sandy Point and Low Islet. In the chart of it, issued in 1867 and surveyed by Commander H. L. Cox in 1865, West Head is substituted for Black Head, although the latter name persisted with the older settlers up to the beginning of the century. Low Islet is omitted, Burrabong Creek near Cape Schanck is referred to as Baragundun Creek, and Main Creek is given its native name, spelt Wyrremarong. Fargeet, Stony, and Main Creeks are also shown, while Coolart Creek is shown as Merrick Creek called after the name of the owner of the Coolart pre-emptive right through which it flows. Point Bobbanaring appears as in earlier copies. Bobbanaring or Bobbanary was a noted rain-maker of the Bunurong tribe in whose territory was Point Bobbanaring which was probably his birthplace. Natives were often known by the name of the locality where they were born as, for example, the headman Wonga was born at Wonga or Arthur's Seat.

It becomes a question as to whether native names such as Wonga, Bobbanaring, and Point Nepean's native name Boonatallung, which G. S. Lang states means kangaroo hide, descriptive of its angular shape like a stretched hide, should not be retained. Since, however, such a name as Arthur's Seat (given by Murray) has an historical significance, it has received general acceptance. On the other hand, the substitution of Leo for Bobbanaring as the name of a headland

less than 40 feet high, called Bobbanaring over 100 years ago, and known as such up to the end of last century, is difficult to understand.

Some of the places on the Peninsula retain their native names although we do not know much about them. Such are Tyabb, Moorooduc, Coolart, Warren-quite, Drum Drum Alloc and others. Wallermeryong is the native name for Main Creek, Chechingurk for Balcombe Creek, Biningnaring for Watson Creek, to mention but a few. Balcombe, Baxter, Merricks, and Barker commemorate the names of the first permanent settlers, all of whom were active in the development of the Peninsula.

II. PRELIMINARY DISCUSSION

The Mornington Peninsula, a relatively small area of about 300 square miles, has many of the geological formations found in other parts of Victoria. A preliminary discussion of these, their influence on the topography, and of the several earth movements responsible for their elevation will make their detailed discussion more intelligible.

At the outset, it should be borne in mind that the Mornington Peninsula became a peninsula only after Western Port was formed, and that occurred quite recently. Somewhat earlier, previous to the formation of the Port Phillip Sound (Fig. 39) in the Miocene, the nearest seaboard was somewhere south and west of the Otway area; Tasmania was then part of the mainland, and the region to the north, east, and west of the Otway area was a land-surface.

Formerly all geological formations were simply referred to their known eras, periods, and ages; they are now timed by absolute chronology, calculated from the lead ratios in radioactive minerals found in rocks of like age at many places on the earth's surface. Radioactivity is the process in which the atoms of certain unstable elements such as uranium and thorium, the latter found in the granitic rocks of the Peninsula, break down into atoms of other elements, and finally into the gas helium and the inert mineral lead. The lead ratio indicates approximately the time in years during which the breaking-down process has been in progress. Taken from the time scale given by Holmes (1944), the following are the approximate dates in years of the formations found on the Peninsula:—

Eras.	Periods and Systems.		Approximate Date in Years.
Cainozoic ..	Quaternary	Recent or Holocene	25,000
		Glacial or Pleistocene	1,000,000
	Tertiary	Pliocene	15,000,000
		Miocene ..	35,000,000
		Oligocene ..	50,000,000
		Eocene	70,000,000
Mesozoic ..	Jurassic		150,000,000
Palaeozoic ..	Devonian		320,000,000
	Silurian		350,000,000
	Ordovician		400,000,000

These dates in years are inserted where the periods and systems are discussed here.

The base-rock of the Peninsula is Ordovician (400,000,000 years) and Silurian (350,000,000 years) strata, much of it deposited as mud in the seas of those periods as horizontal beds. These beds were later bent into a corrugated arch known as an anticlinorium. The puckered axis of this anticlinorium is seen in McIlroy's quarry (Photo No. 3) south of Dunn Creek Road, 1·3 miles east of Moat's Corner. Easterly from the quarry along Dunn Creek Road, the beds sloping away from the axis show in the sideling cutting (Figs. 6 and 7). The top of the arch has been planed off by erosion, and successively older beds on the axis have been exposed. Base-rock outcrops over most of the central portion of the Peninsula. The only place where it is found on the shoreline is at Golden Point north-west of Crib Point. Where the Cainozoic has been removed by denudation the base-rock is often exposed.

Arthur's Seat, Mount Martha, and Mount Eliza are granitic stocks. The features of a stock are shown in Fig. 1. It is thought that migrating fluids from below have soaked into the base-rock, resulting in a chemical interchange, the final product being granitic rock. Parts (Photos Nos. 14–16) of the roof of base-rock are found on and in stocks. On the coast road round Mount Martha, about 30 chains south of Martha Cliff, there is an example of this.
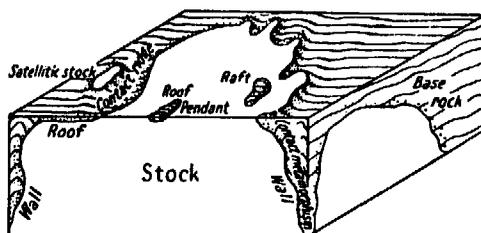

Fig. I. Features of a Stock. [After Holmes.

Jurassic (150,000,000 years) strata, the black coal measures of Victoria, are exposed near Grice Creek; they were also passed through in a bore at Tyabb. They were deposited on a land surface, and although now represented by small exposures, there is little doubt that they were formerly much more extensive. Selwyn (1856) stated that in the Schnapper Point area and on the east shore of Port Phillip

"200 feet of coal strata have been passed through, and that no seam more than 3 inches thick has been discovered. If any available coal deposit exist in this neighbourhood it can only be under the waters of Port Phillip."

One of the features of the Cainozoic rocks found on the Peninsula is the considerable thickness (over 2,000 feet) of basaltic lava that accumulated on its eastern side, and the thickness of over 1,000 feet of marine strata deposited in the Cainozoic sea that accumulated on its western side—the Nepean Peninsula. There was, as elsewhere in Victoria, a considerable lapse of time between the Jurassic and the pouring out of the Middle Eocene (about 60,000,000 years) basaltic lavas known as the Older Basalt. Previous to its extrusion, there was a period of erosion when valleys were cut back and fluviatile deposits accumulated in them referred to here as pre-Older Basalt deposits. The Older Basalt issued from fissures in a very fluid state, flooding the valleys and at some places the watersheds. During the pouring out of the basaltic lavas, the northern portion of the Peninsula remained relatively static, but the southern portion was subsiding. On the southern portion, a bore at Flinders penetrated lava to a depth of

1,300 feet below existing sea-level and did not pass through it (p. 26) but in the northern portion the maximum thickness passed through in a bore at Hastings was under 400 feet (p. 26). The elevation of the pre-Older Basalt land-surface at Hastings is estimated to have been about 1,000 feet above existing sea-level. Underlying the bottom flow there is a lignite seam, the southerly extension of which would, doubtless, be found under the lava at Flinders. Leaves found in deposits under the bottom flow of lava north of the Peninsula indicate that the climate when the lava was poured out was not greatly different to that at present, although elsewhere the climate at that time was warmer. In this region, the temperate climate was due to altitude.

As the lava submerged most of the pre-existing stream system and the drainage had still to find an outlet, it cut out new channels. This was a somewhat slow process on the lava itself, but a relatively rapid one on the less resistant base-rock near its margin. The formation of these new channels was the beginning of what is referred to as the post-Older Basalt Cycle of Erosion. The pattern then set is, with some modification, that of the present stream system. South of what is now Cape Schanck, the trunk-stream of the Port Phillip System was joined by the trunk-stream of the Western Port System flowing from the northeast. Their confluent drainage passed down a trunk-valley parallel with what is now the Otway coast, and emptied into the Southern Ocean somewhere southwest of the Otway area. Operating in the Upper Eocene and throughout the Oligocene (50,000,000 years) and Lower Miocene, the post-Older Basalt Cycle reduced the surface to one of gentle slopes separated by wide valleys. The moist climate during that period, the adequate soil cover, and the stability of the land surface conduced to the luxuriant growth that accumulated as the thick lignite or brown coal deposits at that time. On the Peninsula, the portions of these lignite seams that have not been removed by denudation have been affected by unstable conditions, for there has been an influx into them of earthy material.

The regional subsidence that started after the Older Volcanic activity had so lowered the surface of the Peninsula by the Middle Miocene (about 25,000,000 years) that the high-level Miocene sea encroached on the valleys. It was then that the Middle Miocene limestones, marls, and marine clays were deposited at Sorrento, Flinders, Balcombe Bay, Grice Creek, and Tyabb. At the beginning of the marine period there were short recurrences of the lignitic period, for at Flinders near the jetty, we find a lignite bed resting on the lowest portion of the Flinders limestone. Towards the close of the marine period, in the shallowing waters of the receding Miocene sea, coarser sediments—the Baxter sandstones—were deposited on the floors of the still submerged but emerging post-Older Basalt valleys. Those near Baxter are sandy claystones containing shells and other marine forms, some of which are survivors from the Middle Miocene sea. The sandy claystones are believed to be of Upper Miocene age.

The floor of the Port Phillip Sunkland (Fig. 39) has been unstable over a long period. About the middle of the Miocene, the Sunkland began to subside on Selwyn Fault and the Bellarine Fault. These fault lines converge to the north-east so that the inlet of the Miocene sea that inundated the Sunkland gradually narrowed in that direction. This inlet is referred to as the Port Phillip Sound to distinguish it from Port Phillip Bay formed later by the barring off of the upper portion of the Sound. In the Port Phillip Sound there was deposition of sediment throughout the latter half of the Miocene and during the Pliocene. This fact has been established by the Sorrento Bore which passed through more than a thousand feet of Miocene and Pliocene strata representing deposition over a period of about 10,000,000 years. The strata in the Bore reflect the conditions existing on the land-surface surrounding the Sound. The coarser upper part of the Miocene in the Bore occurs at about the same horizon as the Upper Miocene fossiliferous claystones at Baxter. The falling Miocene sea-level was responsible for increased erosion of the land-surface, and a corresponding increase in the terrigenous material deposited both in the valleys and the adjacent sea.

Early in the Pleistocene, which Penck and others estimate started 600,000 years ago, but for which Holmes fixes 1,000,000 years, the Nepean Bay-Bar formed across the upper part of the Port Phillip Sound. A spit of sediment carried by currents gradually extended from the Bellarine Peninsula toward the high land near Cape Schanck; when it reached the latter it assumed the proportions of a bay-bar. The Nepean Bay-Bar shut off the upper part of the Sound which became the land-locked Port Phillip Bay.

In the Pleistocene or Ice Age, there were alternating glacial and interglacial stages. During the glacial stages, part of the earth's water was held in the ice caps and the sea-level was lowered; during the milder interglacial stages, when the ice caps melted, the water was dispersed and the sea-level rose. It has been estimated that during the last glacial stage, the sea-level was lowered 295 feet. It is apparent that, during low sea-levels of this order, the floor of Port Phillip Bay was uncovered and the Pleistocene Yarra flowed over it (Fig. 43). At the same time, the surface material on the Nepean Bay-Bar was piled up as dunes. Behind the dunes, the river waters collected and found an outlet through them—outlets that, when the sea-level rose, became tideways similar to the channels converging towards The Heads in the southern portion of Port Phillip. Silts and clays were deposited along these tideways, such as the so-called marls on which the peat rests in the Tootgarook Swamp (Fig. 59). The Tootgarook Swamp was formed in an ancient tideway that was blocked by dunes. Shallow marine deposits were passed through at intervals in the Pleistocene of the Sorrento Bore down to a depth of 447 feet (Fig. 40).

The last glacial stage occurred approximately 25,000 years ago. We have passed the peak of the Postglacial, usually referred to as the Postglacial Optimum, and are passing into another glacial stage; the sea-level has already been lowered by from 15 to 20 feet heralding its approach. If it is lowered to the same extent as in the last glacial stage, the outlet of the Yarra will then be well south of the Nepean Peninsula.

The great thickness of Pleistocene dune deposits on the Nepean Bay-Bar is not found across the entrances to Western Port. Since the Miocene sea receded, the Western Port area has been submerged only once, during the Postglacial high sea-level; this was the only time that it was possible for marine currents to bring along sediment that could be built up as a bay-bar. Western Port Bay, in its present form, is geologically very recent; it came into existence within the last 20,000 years. It is the outcome of this high sea-level and the continued subsidence of the Western Port Sunkland on the Tyabb Fault. The scarp of this fault can be seen on the west side of the railway line near Tyabb; between Somerville and Tyabb, the line passes diagonally across the scarp on to the Sunkland. A comprehensive view of the Sunkland may be obtained from the Warrenquite Road between Somerville and the Tyabb-Moorooduc Road.

So far we have been considering sunklands, but extensive areas of the Peninsula have been uplifted. There is the Bald Hill uplifted block, east of Main

Creek extending north beyond Tubbarubba, and the Arthur's Seat uplifted block west of Main Creek and south of the Main Spur, the northern slope of which is the scarp of the Main Spur Fault. These uplifts have had a marked effect on erosion. On the sunklands, hill and dale are subdued into gently sloping rises separated by wide, shallow valleys, as on the Western Port Sunkland, a featureless surface that we know as the Moorooduc Plain. When this subdued surface was uplifted, the wide valleys were deeply entrenched and became narrow, gorge-like valleys such as that of Waterfall Creek and Drum Drum Alloc Creek on the Arthur's Seat block and the upper reaches of Dunn's Creek that has cut back into the Bald Hill block. The Bald Hill block has had, too, a profound effect on the trend of the Western Port Drainage System. The southern portion of that system is now covered by Bass Strait, but a reconstruction of the floor of the Strait enables us to trace the trend of the drainage. Before submergence, the trunk-stream found an outlet to the south-east, impelled in that direction by the Bald Hill block it joined the trunk-stream of the Port Phillip System south of what is now Cape Schanck, and found an outlet in that direction into the Southern Ocean south or west of the Otway area.

Whether we take the Frankston-Hastings Road or the Point Nepean Road when we pass through Frankston on to the Peninsula, we must first climb the blunted scarp of Selwyn Fault. We do so by ascending the long hill on the Frankston-Hastings Road outside Frankston, or Oliver's Hill. Selwyn Fault farther south is a short distance seawards (Fig. 43); the shoreline is actually its scarp that has receded through coastal erosion. Opposite Dromana Bay, it was formerly completely levelled by fluviatile erosion. The sideling cutting at "The Rocks" near Dromana, through which Point Nepean Road passes has been cut in the receding scarp. Turning south from the Point Nepean Road along the Rosebud-Flinders Road, the rising ground on the left for about 4½ miles is the continuation of the blunted scarp leading up to the Arthur's Seat block; there we begin to ascend the scarp, and after a climb of over 400 feet, pass on to the Arthur's Seat block. From the block we can look over the Nepean Bay-Bar, with its consolidated dunes—the Cup Country as it has been called.

The two main highways—Point Nepean Road on the west, and the Frankston-Flinders Road on the east—follow the coastline or are not far inland from the two bays; they were obviously located to afford ready access to the shoreline, but grade has been more or less sacrificed for accessibility. The roads cross the valleys of the streams entering the bays not far from their outlets where they are deepest and their sides steepest. This is so where Point Nepean Road crosses Naringalling Creek and Balcombe Creek, also where the road from Hastings to Flinders crosses East Creek, Stony Creek, and Manton Creek (Fig. 49). It is particularly noticeable in the steep descents and ascents on the Flinders-Rosebud Road before it passes up on to the Arthur's Seat block west of Main Creek. A wide thoroughfare, Three Chain Road, in the middle of the Peninsula where it passes over the Moorooduc Plain, is a road of gentle grades. The easiest grade through the Peninsula is by passing on to it at Pearcedale, skirting the Western Port shore to Bittern, thence proceeding westerly to the drainage divide at the head of Tubbarubba Creek, and following this to the Main Ridge Road.

North of Dromana, the sand of the bathing beaches on the Port Phillip shoreline is derived mostly from the Baxter Sandstones (p. 41) which have been cut into deeply by coastal erosion. South of Dromana the beach sand is mostly from the dune rock, 25 per cent. of which is quartz sand. The sand of the wide, tidal, mangrove flats of the North Arm of Western Port has, too, been derived from the coastal erosion of the Baxter Sandstones, but mixed in with it is a certain amount of silt from the Koo-wee-rup Swamp. The shoreline of the Western Passage of Western Port is mainly rock-bound with occasional pocket beaches such as that at Point Bobbanaring. From Point Sumner to Sandy Point, however—a shoreline of dune deposits and Baxter Sandstones overlying Older Basalt—the beaches are wide and mangroves are absent.

IIIA. SEDIMENTARY BASE-ROCK
LOWER ORDOVICIAN

The base-rock of the Mornington Peninsula is portion of the extensive folded belt of Palaeozoic sediments of south-east Australia, one of the world's major ancient orogenic belts. The thickness of these sediments on the Peninsula probably exceeds 25,000 feet. Those of Ordovician age exposed are more than 15,000 feet thick and were deposited in the wide geosyncline referred to by Schuchert (1916) as the Tasman Geosyncline. Most of the sediments deposited in the central western half of Victoria were deposited in the Tasman Geosyncline. A large part of the eastern half consists of Silurian or Devonian sediments deposited in a later contracted part of the Tasman Geosyncline referred to here as the Gippslandian Basin. That the Silurian and Devonian sediments of eastern Victoria were deposited on the Ordovician strata is apparent from the fact that the latter outcrop as inliers along the major anticlines. On the Peninsula, the Silurian sediments deposited in the Gippslandian Basin are over 10,000 feet thick.

The sediments deposited in the Tasman Geosyncline consisted of muds and sands that were later compacted respectively into mudstones or shales and sandstones.

Much of the sediment was deposited in the Ordovician sea. All these marine deposits are unfossiliferous except the dark graptolite shales which are strongly developed on the Peninsula as elsewhere in Victoria; there is a marked absence of limestone. As in other great geosynclines, the sea no doubt receded at times when terrestrial deposits accumulated.

The fossils found in the graptolite shales suggest their marine environment when the Ordovician sea covered the Peninsula. It is submitted by Lapworth and others that the sediment compacted into graptolite shales could have been deposited in shallow or deep water, but the ecology of the Graptolitoidea calls for the tranquility of the water whether it was shallow or deep. Graptolite shales are usually carbonaceous, which he maintains was not due to the decomposition of the graptolites but to the decomposition of seaweed. The sediments that gave rise to the shales are assumed to have been deposited in

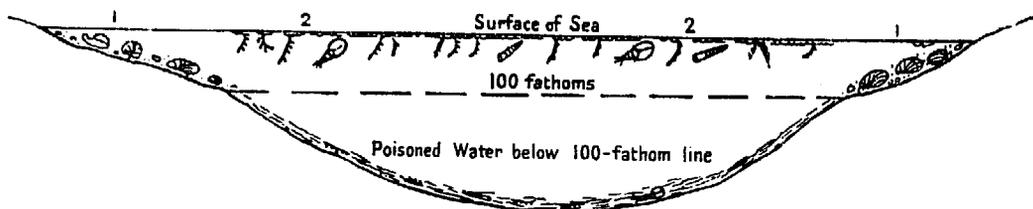" a zone between the agitated bottom where coarser sediments are deposited and the dead water of the deep sea."

Fig. 2. Diagram representing the conditions that prevailed during the deposition of dark graptolite muds.

Notes. 1.— Littoral deposits containing large and abundant benthonic forms.

2.— Algae, with pseudo-planktonic graptolites, also planktonic *Cephalopoda* and *Phyllocarida*.

Below is the lifeless sea bottom with black mud where dead planktonic and pseudo-planktonic organisms which have sunk from the surface waters are entombed. [After Marr and Ruedemann.

Lapworth maintained that graptolites originally had a benthonic mode of existence, then a later pseudo-planktonic one suspended from seaweeds, and latterly a holo-planktonic existence. Ruedemann (1934) observes that the graptolite shales have a characteristic fauna of planktonic and epiplanktonic forms of sponges, brachiopods, crustaceans, &c. Such a fauna is found sparsely represented in the graptolite shales of the Mornington Peninsula and elsewhere in Victoria. Ruedemann significantly points out that this fauna is found on the Sargassum meadows of the central Atlantic and Pacific oceans. Bulman (1938) envisages that

"stagnant, uninhabitable bottom layers with fouling of the mud by vegetable and animal matter accumulating under de-oxygenated conditions which in general imply lack of bottom circulation might occur at abyssal depths but seem in Lower Palaeozoic times to have occurred not uncommonly in shallow, sometimes extremely shallow or lagoon-like embayments of the main ocean where bottom circulation was restricted by submarine barriers."

The general absence of fossils from the sediments of the Tasman Geosyncline of this area. other than the graptolite shales, makes it impossible to determine whether a bed is of marine or terrestrial origin. Evidence of terrestrial conditions occasionally occurs

on the Peninsula and in the strata of the geosyncline in other parts of Victoria in ripple marks, suncracks, &c. The author found pebbles of shale in a bed belonging to the lower part of the Bendigo Series at Sailor's Fall, near Daylesford. One of these pebbles when split showed a complete graptolite, *Tetragraptus fruticosus* (4-branched), the zone fossil of the lower Bendigonian. The pebbles were either of terrestrial origin or from a strandline implying the close proximity of a land surface existent during Lower Bendigonian times. As Nevin (1942) remarks "although a geosyncline is dominantly an area of deposition, the relation of land and sea is constantly fluctuating. At times the sea is excluded from the trough and erosion takes the place of deposition. It would be strange indeed if, with these many adjustments and uplifts of the sea floor, the sediments were not thrown into gentle folds and warps before the final orogeny. In fact, Willis long ago pointed out the probability that these minor folds would control, in a large measure, the location and attitude of the later more intense folding."

The distribution of *Tetragraptus approximatus* Nicholson gives one an idea of the extent of the Tasman Geosyncline. It reappears from place to place as far west as Inglewood and in the inliers protruding through the Upper Palaeozoic beds in the Gippslandian Basin about as far east as Mansfield, two out-

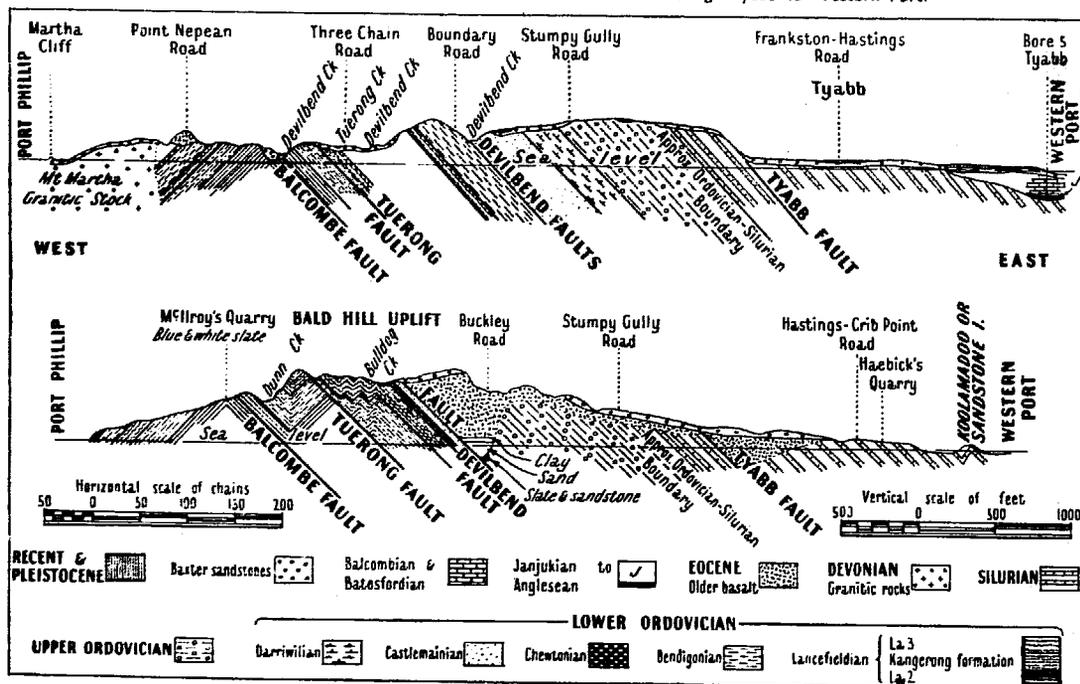Fig. 3. Section of the Peninsula Anticlinorium from Martha Cliff through Tyabb to Western Port.

Fig. 4. Section of Anticlinorium through McIlroy's Quarry and Tubbarubba to Koolamadoo or Sandstone Island.

crops across the strike 140 miles apart. Its northern-most outcrop is also at Inglewood and its southern-most at Bulldog Creek on the Peninsula—localities 100 miles apart. Throughout these distances the bed shows no evidence of lateral variation and is seemingly continuous. It was of course originally deposited virtually as a horizontal bed on the floor of the Geo-syncline. It has since been compressed by folding into a space less than a third of its original width, so that the width of that part of the Geosyncline in which it was deposited was at least three times its folded width or over 400 miles. The width of the European Caledonian Belt is about 300 miles (Holmes 1944, Fig. 200) and the width of the American Appalachian Geosyncline is estimated by Ruedemann (1947), from the distribution of the graptolite shales, to have been about 500 miles.

On the Peninsula the Ordovician strata of the Tasman Geosyncline are exposed in the wide Peninsula anticlinorium; the Silurian strata rests on the eastern limb of the Peninsula anticlinorium.

Since the close of the orogenic revolutions responsible for the folding, the surface of the Peninsula has been subjected to intense denudation. None of the mountain ranges in Victoria is due to crustal folding; they are the outcome of drastic erosion following epeirogenic uplift long after the orogenic revolutions. The crust was formerly pushed up into tectonic mountain ranges but these were long ago levelled out, and the only evidences of their existence are the axes of the succession of anticlinoria occuring at intervals across Victoria, such as the Mornington anticlinorium.

Away from the axis of the Mornington anti-clinorium (Fig. 3 and 4) its eastern limb appears to dip consistently to the east until covered by younger sediments. No wide areas of westerly dip were observed, and where a westerly dip does occur, it usually appears to be the outcome of a roll in the strata. Nevertheless, these observations are based on limited outcrops, for east of the Devilbend Fault much of the surface is covered by superficial deposits, the Older Basalt and the Baxter Sandstones. Figures 3 and 4 are composite sections based for the most part on the succession of the graptolite zones. Graptolites were collected from upwards of 400 localities in detached areas. The sections are across the greatest width of strata exposed but there are intervals of non-exposure where the structure has been inferred from outcrops to the north or south.
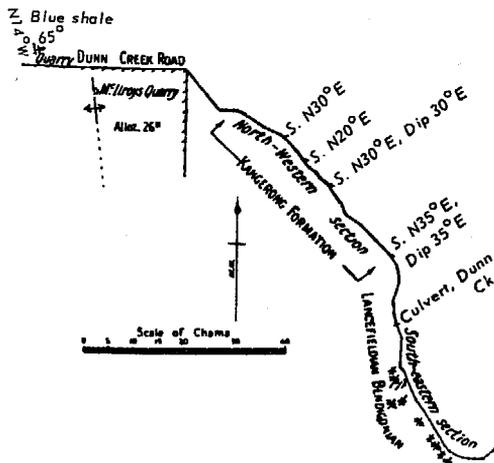
Type sections of the Rangerong Stage are on Dunn Creek Road where good sections are exposed in the sideling cuttings of that road for over a mile from about 18 chains east-south-east of McIlroy's quarry (Fig. 5). This shallow water Stage is exposed in that part of the section north-west of Dunn Creek and shows marked differences in sedimentation and struc-ture from the strata to the south-east on the right bank of that creek. The former is referred to here as the north-west section and the latter as the south-eastern section. The lithology of the former is so different from Lancefieldian beds elsewhere in Vic-toria that the strata merit the distinction of a new stage.

The graptolites from the dark shales in McIlroy's quarry show that the beds there are the oldest on the Peninsula. They are of Lower Ordovician age, low Lancefieldian (La 2) but do not belong to the lowest Lancefieldian beds of Victoria. The anticline through the quarry is the main axis of the Mornington anticlinorium; it trends south 6° west and pitches 20° south. The east limb shows dips of 25° east, approximately the dip of the Kangerong Stage, 18 chains to the east-south-east. The west limb goes away in undulations similar to many of the anticlines in other parts of the Peninsula, particularly that at Koolamadoo or Sandstone Island (Fig. 10). The strata in the quarry consist almost wholly of blue and white shale in bands of variable thickness, the thinner white bands, which are incompetent, being closely corrugated. Baker has pointed out (verb. cit.) that the blue shales in McIlroy's quarry are indurated. It is significant in this respect that they are situated between the Arthur's Seat granitic area and the Balnarring satellitic stock (see Chapter IV.). The joints in the quarry are more or less diagonal to the bedding planes.

The Kangerong Stage comes in below the dark graptolite shale at the point marked in Fig. 6 (3,250 feet) which contains such graptolites as *Tetragraptus acclinans* and *T. decipiens*, which, in the absence of *T. fruticosus*, indicate an upper Lancefieldian horizon. It overlies, however, the low Lancefieldian shales in McIlroy's quarry, although the contact with these is masked. It may be regarded therefore, as of Middle Lancefieldian age (La 2).

Some thousands of feet of it exposed consist of a succession of east dipping sandstones, light coloured shales and mudstones, and occasional thin bands of quarzite; there is a complete absence of the dark graptolite shale. Fine to medium grained sandstones predominate; reddish, yellow, and grey shales make up the rest of the Stage. There are no clastic sediments—nothing coarser than medium grained sandstone. The thin bedded strata show no signs of crushing, structure creep, or flowage. Joint-ing is inconspicuous, there is no evidence of faulting, and there are no dykes in the outcropping portions.

The sandstone bands range up to 30 feet in thick-ness. One bed of shale is 80 feet thick, but the others vary in thickness from a few inches to 30 feet, with the mudstones up to 40 feet. The inclination of the beds has components of both dip and pitch. It is estimated that the pitch of the uppermost beds is about 35° south and their dip about 45° east. As the axis pitches 20° south there is obviously, therefore, a steepening of the pitch to the south. The only deviation from the consistently south pitching and east dipping strata of the Stage is what appears to be a roll at 66 feet from the beginning of the section (Fig. 6). Whether this is only a roll or the crest of a defined anticline is, in the absence of exposure to the north-west, not clear.
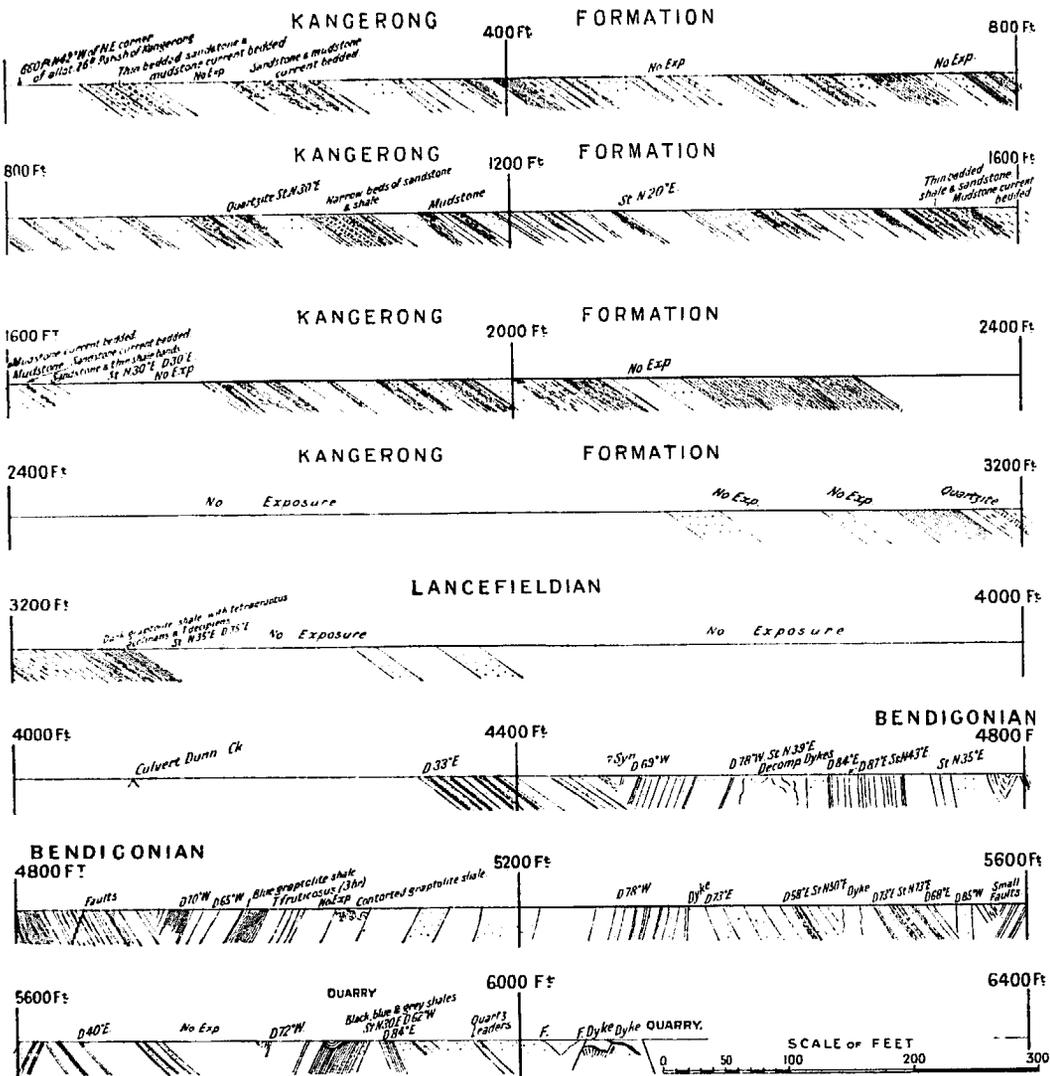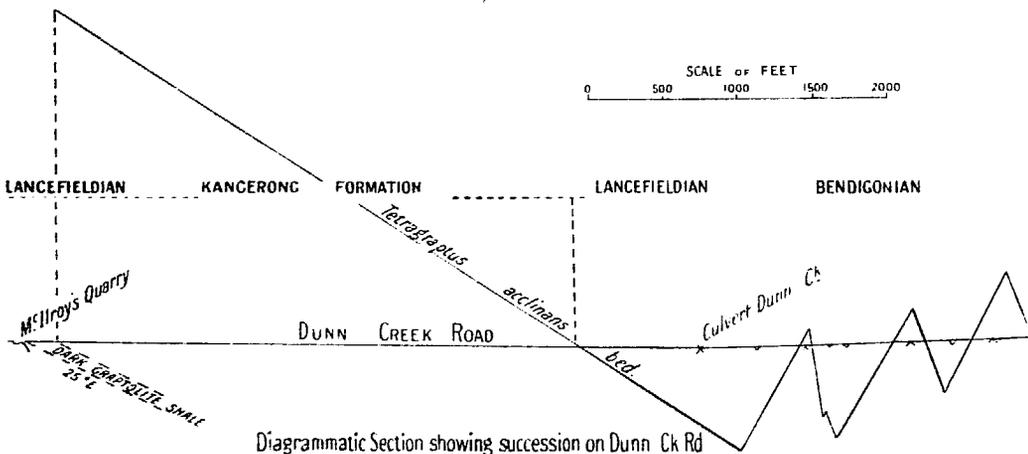

Fig. 5. Traverse of the Dunn Creek Road section.

KANGERONG   400 Ft   FORMATION   800 Ft

680 R N42°W of NE corner of allot 26ª Run of Kangerong   Thin bedded sandstone & mudstone   No Exp   Sandstone & mudstone current bedded   No Exp.   No Exp.

800 Ft   KANGERONG   1200 Ft   FORMATION   1600 Ft

Quartzite St N30°E   Narrow beds of sandstone & shale   Mudstone   St N 20°E   Thin bedded shale & sandstone Mudstone current bedded

1600 FT   KANGERONG   2000 Ft   FORMATION   2400 Ft

Mudstone current bedded   Sandstone current bedded   Mudstone   Sandstone & thin shale bands   St N30°E   D30 E   No Exp   No Exp.

2400 Ft   KANGERONG   3200 Ft   FORMATION

No   Exposure   No Exp.   No Exp.   Quartzite

3200 Ft   LANCEFIELDIAN   4000 Ft

Dark granulite shale with tetragraptus acclinans & T.decipiens St N35°E D 75°E   No   Exposure   No   Exposure

4000 Ft   4400 Ft   BENDIGONIAN   4800 F

Culvert Dunn Ck   D 33°E   ?Syn D 69°W   D 78°W St N 39°E Decomp Dykes   D 84°E D87°E St N43°E   St N.35°E

BENDIGONIAN   4800 FT   5200 Ft   5600 Ft

Faults   D10°W D65°W   Blue graptolite shale T.fruticosus (3hr) No Exp   Contorted graptolite shale   D 78°W   Dyke D23°E   D58°E St N50°E Dyke   D73°E St N33°E   D68°E D85°W   Small Faults

5600 Ft   QUARRY   6000 FT   6400 Ft

D40°E   No Exp   D72°W   Black,blue & grey shales St N30 E D62 W D84°E   Quartz leaders   F.   F Dyke Dyke QUARRY.   SCALE of FEET   0   50   100   200   300

Fig. 6.   Kangerong Stage on the Dunn   Creek Road section.

SCALE of FEET   0   500   1000   1500   2000

LANCEFIELDIAN   KANGERONG   FORMATION   LANCEFIELDIAN   BENDIGONIAN

Tetragraptus   acclinans   bed

McIlroy's Quarry   DUNN   CREEK   ROAD   Culvert Dunn Ck

DARK GRAPTOLITE SHALE 25 E

Diagrammatic Section showing succession on Dunn Ck Rd

Fig. 7.   Stratigraphical position of T. acclinans bed at 3,250 feet in Fig. 6.

All the strata of the Kangerong Stage bear a marked lithological resemblance to the Silurian strata on the east side of the Peninsula. Unlike these, however, there is an absence of ripple marks and suncracks; there is, nevertheless, evidence of current bedding indictative of deposition in shallow, circulating water. All the beds are unfossiliferous and in them there is an absence of vegetable or animal matter. The absence of clastic sediments suggest deposition some distance from a shoreline. It is difficult to visualize the conditions existing during their deposition—whether they were laid down in marine or lacustrine waters.

Incidentally the Stage outcrops in the beds of the creeks east of Mount Martha between the Point Nepean-road and the Three Chain-road, and in the Devilbend Creek upstream from its confluence with Balcombe Creek.

The consistent and prevailing low easterly dip of the Kangerong Stage apparently persists to the syncline at 4,472 feet (Fig. 6) in the south-eastern section, but between that syncline and the Kangerong Stage there are few exposures. South-east of the syncline, the beds are closely folded and, although beds of sandstone predominate, there are several bands of dark graptolite shale; the graptolites from these indicate younger Lower Ordovician beds than that of the Kangerong Stage—Bendigonian and probably transitional Bendigonian–Lancefieldian beds (Figs. 6 and 7).

The strata of the south-east section are acutely folded and there is evidence of crushing, creep, and flowage. Some of the bands are vertical and others highly contorted. The average easterly dip is 62° and
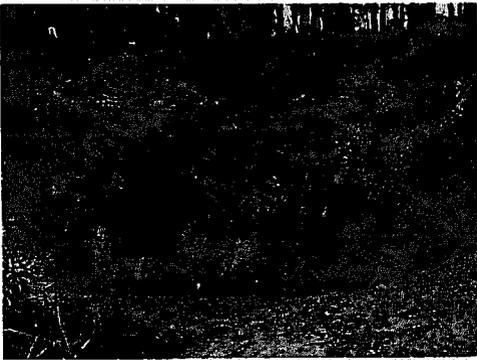
2. Dunn Creek Road section south-east of Dunn Creek. Contorted shale probably of Bendigonian age.

the westerly dip 70°. Few of the anticlines are well defined; their approximate positions can only be located by reversals of dip. A well defined syncline (Fig. 8) showing crushing and flowage shows at 4,798 feet (Fig. 6). The eastern dip near the syncline is 77° and the western dip 52°; the plane of the synclinal axis is inclined 79° west. Some of the crushed anticlines have been freely penetrated by dykes along the axial lines. The anticline at 4,600 feet (Fig. 6) has been intruded by two or more dykes: that at 5,333 feet by a single dyke. At 6,050 feet (Fig. 6) there is a dyke inclined at about 20° east that has thrown out a branch to the east; to the east of this again at 6,100 feet there is another dyke conforming in direction to the branch, and suggesting that it may be a faulted portion of it. At 5,463 feet (Fig. 6), a dyke has intruded the eastern limb of the anticline at 5,333 feet. All these dykes are highly decomposed. The displacements of the many faults cannot be estimated, but in none of them does it appear
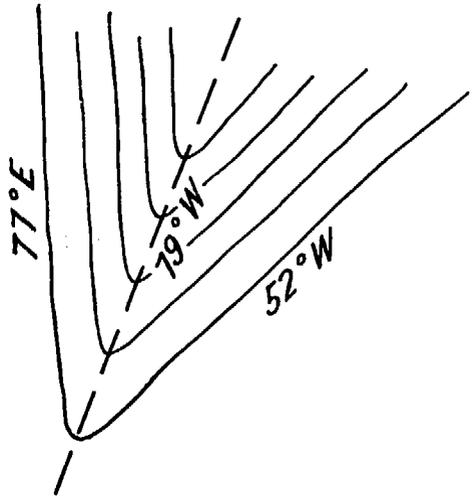
Fig. 8. Syncline on Dunn Creek Road.

to be considerable. The apparent directions of the generally ill-defined anticlines and synclines range between north 30° east and north 43° east; the exposures are too limited in extent to determine their directions with precision. For that reason, they have been shown in parallel lines striking north 37° east, the average of their observed strikes. The direction of the main axis in McIlroy's quarry being north 6° west, there is a divergence of 43° in the axial strikes of the north-western and south-eastern sections. This may be due to the strong southerly pitch of the main axis; it is significant that in the Bald Hill quarry about a mile south-west of the *Tetragraptus acclinans* bed at 3,250 feet (Fig. 6), the beds are approximately of the same age. Apparently they pass from the eastern limb, around the steeply pitching main axis, to the western limb. A detailed survey of the area between Dunn Creek and Bald Hill quarry may solve this question of divergence and incidentally the possibility of the Kangerong Stage resting disconformably on the shales in McIlroy's quarry cannot be excluded.

On the Mornington Peninsula are found many of the graptolite zones occurring in other parts of Victoria. The thickness of the shales representing some of the zones is small while that representing other zones is considerable; the upper half of the oldest formation of the Ordovician, the Upper Lancefieldian, is perhaps more thickly and widely developed than anywhere else in Victoria. The graptolites collected on the Peninsula were from isolated localities as there were few lengthy exposures. For this reason, coupled with the fact that there were many areas of non-exposure, estimates of the thickness of the formations and zones based on structure are unreliable. For the same reason, estimates of the amount of displacement on the major faults are also unreliable. It is known that the movements on the Devilbend shatter belt have been considerable, but because the movements on Balcombe Fault have occurred mostly in the unfossiliferous Kangerong Stage or beneath the Tertiary cover, it is difficult to appreciate their magnitude. There have been, too, recurrent movements on the faults, some probably in pre-Tertiary times. The relative upthrow side of the Devilbend shatter belt has, for instance, been subjected to erosion and some of the strata removed from it. The

measure of the stratigraphical break between the beds on the relative upthrow and downthrow sides represents only the minimum amount of the displacement.

The graptolites were found in bluish-black shales usually somewhat harder than the graptolite shales of other parts of Victoria. On the Peninsula, the Ordovician strata have been more or less silicified; some bands of shale have been changed into black or pale coloured cherty beds and bands of sandstone into quartzite. The less silicified sandstone ranges from medium to fine grained and is often felspathic. No conglomerates were seen. Breccias, other than fault breccias, are rare, but angular pieces of slate are sometimes found in the sandstone. On the sandstones of the Kangerong Stage pebbles of igneous rock projected from the face of the cutting when the Dunn Creek sideling was first cut back, but a recent search for these inclusions was unsuccessful.

The oldest Ordovician strata on the Peninsula are the Lancefieldian beds exposed in McIlroy's quarry (Photo No. 3) on the Dunn Creek-road, and those on the Chechingurk pre-emptive right near the confluence of Devilbend Creek with Balcombe Creek. The latter locality is referred to here as the Chechingurk locality. At both places, the strata consists of bluish-black shales and much of the area between McIlroy's quarry north to the Chechingurk locality is covered by Tertiary sandstone, but the Ordovician strata between these localities appears to pitch north from McIlroy's quarry and south from the Chechingurk locality; there is a reversal of pitch somewhere east of Mount Martha. The strata pitches to the south, south of McIlroy's quarry and to all appearances, north of the Chechingurk locality to the north. It would appear, therefore, that the oldest strata in McIlroy's quarry and at the Chechingurk locality owes its exposure to being on two domes on the main axis of the Mornington anticlinorium. This oldest Lancefieldian strata is covered

3. McIlroy's Quarry. Dunn Creek Road. Crest of main axis of the Peninsula.

on the flanks of the domes by the higher Lancefieldian Kangerong Stage. With a northerly pitch from McIlroy's quarry and a southerly pitch from the Chechingurk locality, it is probable that the main axis of the Mornington Anticlinorium between these two localities is wholly in the Kangerong Stage. As stated, the Stage outcrops in the creeks east of Mount Martha.

An informative study in physical geology presents itself in accounting for the absence of compression and folding in the Kangerong Stage which is stratigraphically intercalated between the closely folded south-eastern section on the right bank of Dunn's Creek and the oldest beds in McIlroy's quarry where only the narrow beds are corrugated. Unfortunately the contact of the Kangerong Stage with the oldest beds in the dome at McIlroy's quarry is not exposed.

Lancefieldian beds are extensively developed on the central portion of the Peninsula, their extent being due to their low dip and the movement of the fault blocks on the several strike faults. East of McIlroy's quarry, Lancefieldian extends as far east as Tubbarubba Creek and west beyond Bald Hill. East of the Chechingurk locality it extends almost to the northerly flowing headwaters of Devilbend Creek and westerly towards Point Nepean-road. In the direction of the strike of the anticlinorium, it extends from a short distance north of Balcombe Creek and the westerly flowing lower reaches of its tributary Devilbend Creek, to the northern boundary of the Older Basalt between Red Hill and the headwaters of Tubbarubba Creek. This extensive area of base-rock is here referred to as the Lancefieldian Basement.

Areas of non-exposure and Tertiary cover make it impossible to work out in detail the structure of the Lancefieldian Basement but the graptolites collected indicate the salient features, and suggest that Upper Lancefieldian strata, in particular the zone of *T. approximatus*, is widely developed.

The exposures at Bald Hill and its vicinity are on the western limb of the anticlinorium as, too, are those on the western portion of the Chechingurk pre-emptive right, at Balcombe and on the lower eastern slopes of Mount Martha. The granitic rocks of Arthur's Seat and Mount Martha were intrusive to the western limb. The raft of Ordovician sediments on the Mount Martha granodiorite near the Port Phillip shoreline and undigested portions of baserock in the Arthur's Seat granite, indicate that the western limb extended much further west and probably underlies the Port Phillip Sunkland.

It is interesting that Bald Hill was the locality in Victoria where W. H. Ferguson of the Geological Survey first found the *T. approximatus* zone in Australia. In a quarry south-west of Bald Hill, near the road leading from Moat's Corner to the Main Ridge Road, J. L. Knight, Mines Department Field Geologist recently found Yapeenian graptolites. Between these two localities superficial deposits possibly cover Bendigonian beds, for such occur between the Lancefieldian and the Yapeenian strata further north.

West of the Lancefieldian Basement on the western portion of the Chechingurk pre-emptive right, Bendigonian beds are exposed in the gully just east of the Point Nepean-road; the shales in the road cutting on that road south of the Balcombe Creek bridge are also of Bendigonian age. On a small quarry on the west side of Point Nepean-road near where the road to the Mount Martha Hotel branches off, the shales are of Yapeenian age. Granodiorite outcrops a short distance west of this small quarry.

As stated the easterly dip of the strata on the east side of the Lancefieldian Basement marks the beginning of what is manifestly the eastern limb of the Mornington anticlinorium (Fig. 3). Travelling easterly over the high ground on the south side of the westerly-flowing lower reaches of Devilbend Creek towards the northerly flowing upper reaches of that creek, one passes from the Basement on to low Bendigonian and then on to high Bendigonian beds before reaching the Devilbend shatter belt. On the same easterly line in a quarry a few chains east of the shatter belt are Castlemainian beds and upstream south of them on the right bank of Devilbend Creek are Darriwilian shales. Further east there is an extensive area of non-exposure reaching to the Silurian area at Tyabb near the corner of the Tyabb and Warrenquite roads.

4. Tuerong Quarry on Buckley's Road, about a mile from Three Chain Road. East-dipping Lancefieldian strata.


5. Tuerong Quarry. Northerly pitching strata.

Travelling easterly over the middle portion of the Basement; i.e., between the westerly flowing lower reaches of Devilbend Creek and the headwaters of Tubbarubba Creek, one passes eastwards from the Basement on to an area of non-exposure and then, near the east side of Buckley Road south of Tuerong quarry, on to Middle Bendigonian beds. The rocks in Tuerong quarry are part of the Basement. East of the Middle Bendigonian beds, there is another area of non-exposure east of which are Yapeenian beds out-cropping near the line of the Devilbend Fault. The last-mentioned Yapeenian beds apparently pitch to the south, for on their strike further to the south are Castlemainian beds. Still further east, on the same easterly line as the right bank of Devilbend Creek are the Middle Ordovician beds exposed in Turner's quarry where the beds are light-blue, cherty shales and quartzitic sandstone. East of Turner's quarry there is an extensive area of non-exposure partly covered by residual base-rock clays and Older Basalt.

At the southern end of the Basement (Fig. 4), east of the McIlroy's quarry, is the unfossiliferous Kangerong Stage from which one passes on to the *T. approximatus* zone near the head of Bulldog Creek. In the hard but fissile blue slate, there are specimens of *T. approximatus* and the allied *T. acclinans* up to 18 inch in length. East of Bulldog Creek there is an area of non-exposure reaching as far as Tubbarubba Creek. Moving upstream in Tubbarubba Creek, one passes from the Basement on to basal Bendigonian beds which extend to the most westerly fault breccia of the shatter belt. The beds on the east side of the breccia are of Yapeenian age—the western part of a small fault block that is faulted against another small fault block of high Castlemainian beds; this in turn is faulted against the Older Basalt (Fig. 27). About 2½ miles east of Tubbarubba Creek on Hunt's Road is Hunt's quarry. The strata there is highly silicified slate interbedded with quartzite; it is unfossiliferous, but its position in respect to the strata in Turner's quarry suggests that it is of Upper Ordovician age.

IIIB. MIDDLE AND UPPER ORDOVICIAN, SILURIAN

There are isolated outcrops south of the Lancefieldian Basement—small areas of Palaeozoic sediments protruding through the Eocene Older Basalt. One near Merricks North is in the valley of the tributary of East Creek flowing from near Red Hill railway station towards Merricks. Graptolites obtained there indicate that the shales are Middle Ordovician, but close to the Middle-Upper Ordovician boundary. Bayne's quarry on the small area of base-rock on the Shoreham–Red Hill Road on the north side of Stony Creek is in easterly-dipping shale of Upper Ordovician age, probably part of the east limb of the anticlinorium. An outcrop of base-rock a few acres in extent about 2 miles south of Stony Creek near the west side of the Punty Road and on the left bank of a tributary of Manton Creek consists of unfossiliferous mudstone suggestive of Silurian mudstone. Silurian strata here would imply that the Upper Ordovician strata in Bayne's quarry has passed over the axis of the anticlinorium and the supposedly Silurian mud-stone is resting on it.

The Punty Road inlier is highly significant as limiting the thickness of the Older Basalt through which it protrudes to a few hundred feet, compared to over 1,300 feet proved by the Flinders Bore some 2 miles to the south-east and a probable thickness there of over 2.000 feet.
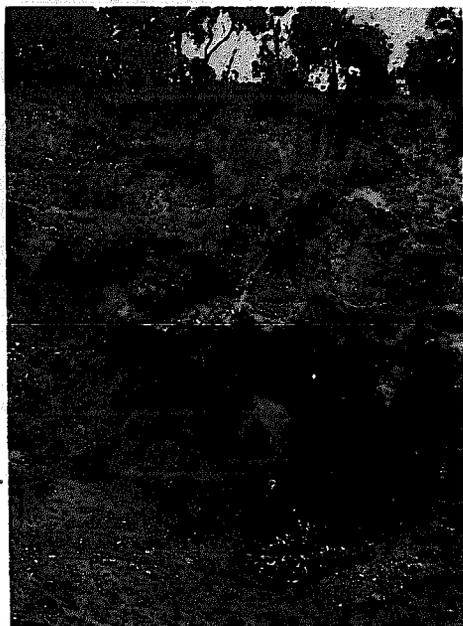
6. Bayne's Quarry, 2·5 miles W.N.W. of Shoreham. East-dipping Upper Ordovician shale and sandstone.

In the northern portion of the Peninsula on the Moorooduc Scarp near Moorooduc railway station and the high ground to the north behind it, Middle Ordovician base-rock and granodiorite outcrop. This merges near the Frankston–Somerville Road into Upper Ordovician; the graptolites in a quarry on the side of that road near Baxter railway station are of basal Upper Ordovician age. Silurian strata is

7. Frankston–Hastings Road near Baxter cutting showing strong east dip.

exposed in the railway cutting and near the railway between Langwarrin and Baxter railway stations, but the area between the Frankston–Somerville Road and the railway is covered with dune sand which marks the Upper Ordovician–Silurian contact.

On the Peninsula, the strata in the Gippslandian Basin consist of shale, mudstone, and medium to coarse-grained sandstones. A conglomerate occurs near the northern boundary. There is a complete absence in the Silurian strata of the dark graptolite shales so characteristic of the Ordovician strata. Limestone does not occur at the surface, but was penetrated by a bore near the Flinders Naval Base. Fossils were found at a few localities; they consisted of brachiopods, crinoids, bryozoa, graptolites, &c., indicative of different conditions to those existing in the Ordovician sea. Evidence of strandline conditions and the proximity of a land surface is found in ripple marks, suncracks, &c. The conglomerate shows in the water channel a mile east of the railway line between Langwarrin and Baxter or about $1\frac{1}{2}$ miles east of the hypothetical Ordovician–Silurian boundary. The author obtained from the conglomerate a pebble of compacted blue shale which

when split disclosed a restricted Upper Ordovician graptolite of Bolindian age, specifically *Climacograptus scalaris*. Bolindian strata has not been found on the Peninsula; it may be there, covered by superficial deposits, as is most of the Peninsula Upper Ordovician, but it has been most probably removed by denudation. The Ordovician–Silurian boundary is not exposed as it, too, is masked. Its position in respect to Silurian deposits exposed in the railway cutting between Langwarrin and Baxter is somewhere in the mile west of the cutting. On the Frankston–Hastings road a mile west of the railway cutting are dark graptolite shales of basal Upper Ordovician age.

From the foregoing facts it is inferred:

(a) the Bolindian series, or the greater part of it on the foreland of the Gippslandian Basin, has been removed by denudation to form part of the Silurian sediments in that Basin, in particular the conglomerate;

(b) some thickness of Silurian sediments had been deposited in the Basin before the conglomerate was laid down;

(c) the Bolindian strata was compacted and presumably deformed before it was removed by denudation. The conglomerate was laid down during the downwarping of the Basin;

(d) the conglomerate was deposited as a horizontal bed near the shoreline. By downwarping and compression, it has been folded in with the younger sediments of the Basin;

(e) the edge of the Basin was still further to the west.

To what extent the strata of the Tasman geosyncline were folded before the deposition of the Silurian is problematical. It would seem that the strata had at least been thrown into the gentle folds typical of these geosynclines suggested by Willis (see p. 10); possibly compression had advanced well beyond this stage. The overfolds in some of the Ordovician strata in the Moorooduc quarry are some distance east of the axis of the anticlinorium. This overfolding on the east limb some distance from the axis is inconsistent with the folding observed elsewhere on the Peninsula, as the folds on that limb are usually merely rolls in the strata. Compression of the strata undoubtedly increased the deformation of the earlier deposits of the Tasman geosyncline.

8. Moorooduc Quarry, near Moorooduc railway station. Steeply-pitching anticline in Middle Ordovician strata.
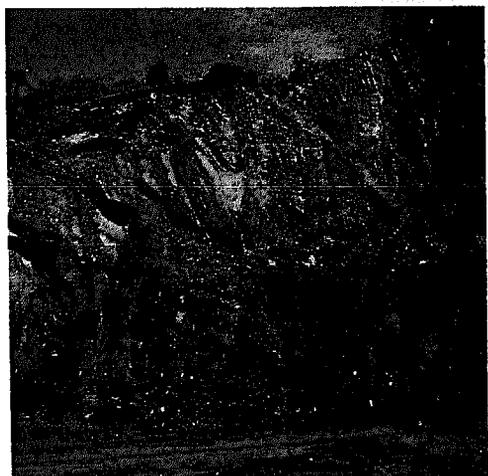
9. Moorooduc Quarry. Overfolded syncline and anticline.

There are no long exposures of Silurian strata. That in the railway cutting half a mile north of Somerville railway station shows signs of metamorphism. On the eastern side of the railway reserve, south of Robinson Road and south of Langwarrin railway station (Fig. 9), the soil has been removed for about
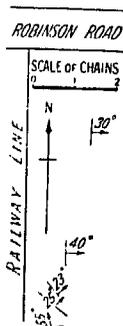
Fig. 9. Dips of sinuous strata near Robinson Road, Langwarrin.

7 chains exposing generally normal shales and mudstones, mostly red but of a variety of colours, and some bands of sandstone. The strata is seamed with veins of laminated quartz. The strike varies considerably, but the prevailing dip is to the east. Exposed in the railway cutting, about 30 chains to the south, are highly coloured shales and mudstones and a few narrow bands of sandstone, a southerly extension of the strata near Robinson Road. The strike here is north 20° west and the dip 45° east. From a fine-grained sandy shale, some fragmentary graptolites and polyzoa were obtained—a uniserial graptolite probably *Monograptus*, a doubtful biserial form probably belonging to the *Diplograptidae*, and an indeterminate species of *Fistulipora*. The association indicates a low Silurian, Keilorian age.

The most extensive outcrop of Silurian strata is that at Koolamadoo or Sandstone Island, about half way between Hastings and Crib Point (Photos Nos 10-13). There Selwyn, in 1854, obtained crinoids from his Locality B7. Apparently these are the only fossils to be obtained, for the author, after a lengthy search, failed to find any belonging to another class. Selwyn (1854) concisely described the strata as consisting mainly of from fine to medium grained sandstone, usually grey, some felspathic and highly micaceous shales of several hues, and occasional narrow bands of quartzite. (Photo No. 10.) There is a certain amount of alteration but not as much as in Haebick's quarry on the mainland 1·3 miles to the west. Most of the strata are exposed on a platform encircling the island between high and low water marks. There are a few outcrops above high water mark on the

east side of the island; on the west side there is a solid face—a bedding plane, rising to a height of 12 feet (Photo No. 11).
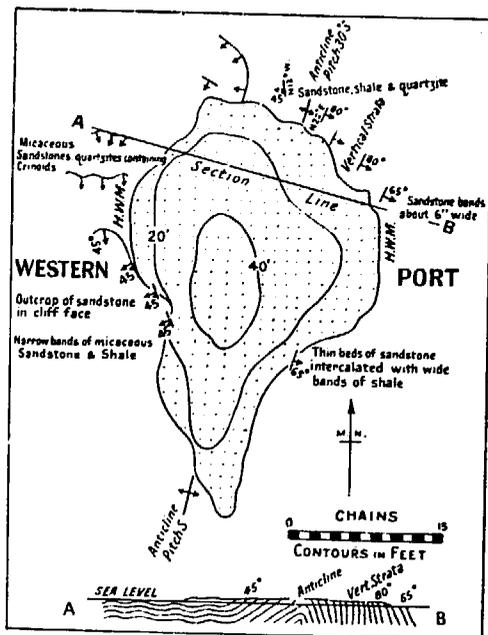
Fig. 10. Map and section of Koolamadoo Island.

Structurally, the island is an anticline (Fig. 10), the axis of which bears north 18° east, its axial plane inclined to the west, and at the north end pitching 30° south. The strata on the western limb dip at an angle of about 45° for about 5 chains from the axis and makes into shallow undulations some of which pitch as much as 45° south. The strata on the eastern limb dip steeply near the axis, at places are almost vertical, but further east are inclined at about 65°.

At Golden Point on the mainland opposite Koolamadoo Island, the strata are similar to that on the island, but there is a wide band of sandstone exposed that was not seen on the island. Selwyn (1854) described the outcrop as " siliceous sandstone grey and mottled thin bedded." The wide band of sandstone has been quarried for building purposes. The beds have been thrown into undulating folds which account for the divergent dips and strikes recorded by Selwyn; the dips shown by him have components of both dip and pitch.

Views of Koolamadoo or Sandstone Island.
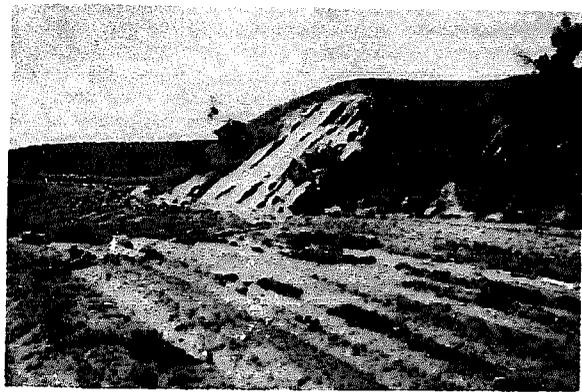
10. Regular, thin-bedded Silurian strata.   11. Face of Silurian strata 12 feet high, on west side of island.
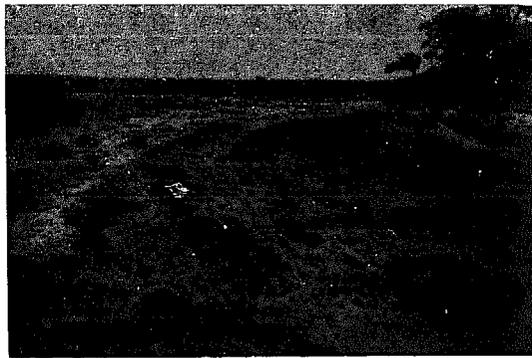
At Haebick's quarry, the strike of the Silurian quartzite and massive sandstone is north 80° east and the dip is 24° south. In the so-called gravel pit on Hunt's Road 3·4 miles west-north-west of Bittern railway station, actually a quarry in quartzite and hard altered slate, there is an anticline the axis of which strikes north 30° west and pitches north at a low angle. The strata on both limbs of the anticline dip at 20°. On the Tyabb-Moorooduc Road 4 or 5 chains west of the Warrenquite Road there is a shallow cutting exposing Silurian shales, sandstone, and occasional bands of coarse micaceous grit and quartzite striking north 25° east and dipping from 70° east to almost vertical. One of the coarse micaceous sandstone beds contains casts of brachiopods and crinoids. At the tennis court on the north side of the road, 4½ chains west of the Warrenquite road, the strata consists of mudstone and shale striking north 25° east and dipping 63° east. On the Warrenquite Road north of where that road crosses the creek a few chains north of its intersection with the Tyabb–Moorooduc Road, mudstone and shales are exposed striking north 45° east and dipping 60° west.

The base-rock of the eastern side of the Peninsula is of Silurian age. The silicification so characteristic of the Ordovician beds is much less evident, and in most cases is usually associated with igneous intrusions. The Silurian base-rock has been described elsewhere in this Memoir.

Further views of Koolamadoo Island.
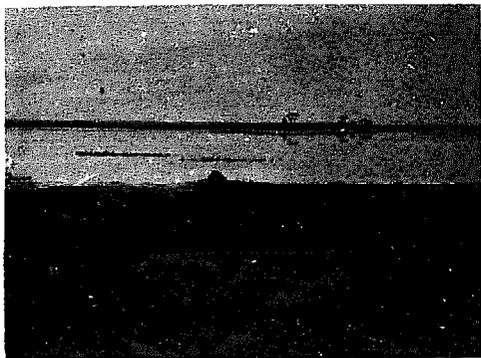
12. Island as seen from Golden Point, near Crib Point. 13. Contorted strata.

IV. GRANITIC AREAS

There are four granitic areas on the Mornington Peninsula—the Arthur's Seat locality often referred to as the Dromana granite, the Mount Martha area, the Mount Eliza area, and the Oliver's Hill area. As the extent of each, exposed as a land surface, does not exceed 40 square miles, they may be regarded as stocks (Daly 1914).

A satellitic stock possibly exists (Fig. 11) near the south-west corner of the Parish of Balnarring immediately south of the drainage divide. There, a small inlier of base-rock, decomposed to a thick residual soil, is covered with rounded, sub-angular, and angular quartz sand. Some of the angular sand is a translucent, vitreous quartz that still retains its crystalline form and is suggestive of the close proximity of a granitic rock. This may be the source of the numerous gem-stones found in Tubbarubba and Bulldog Creeks both of which head on the area. If there is a stock hidden by superficial deposits, there is no doubt that it is distinct from the Arthur's Seat area, for its confines to the north and west are Ordovician base-rock. There are also inliers of Ordovician base-rock to the south and Silurian shales and sandstones are exposed at Crib Point; Silurian limestone is known to occur under the Older Basalt at the Flinders Naval Base.

The eastern extension of the Arthur's Seat area shows on the floors of Main Creek and Stony Creek. The Mount Martha area extends north under the Tertiary deposits at Balcombe Bay where it was penetrated by bores. The Oliver's Hill and Mount Eliza granodiorite is exposed on the north-west drainage fall to Port Phillip in the deeply dissected valleys as well as in some coast sections.

There is little doubt that all these stocks are injections from the same magma chamber, and there is evidence that they were formerly covered by a roof of Palaeozoic strata.

The following are micrographic analyses of :—1—granite from Dromana or the Arthur's Seat area, 2—granodiorite from Mount Martha, 3—granodiorite from Mount Eliza, and 4—granodiorite from Oliver's Hill, all made by Mr. George Baker, MSc. (1938). He has made a detailed examination of the granitic rocks of the Mornington Peninsula and the particulars given here are mainly from his observations.

—	1.	2.	3.	4.
Quartz	34·8	27·4	29·37	35·88
Orthoclase	33·9	27·5	17·59	21·71
Plagioclase	24·9	..	39·87	28·57
Oligoclase	..	34·7	..	..
Biotite	4·3	7·8	12·23	11·40
Hornblende	1·5	1·5	0·59	0·08
Accessories	0·6	1·1	0·30	2·36
Specific Gravity	2·63	..	2·70	2·64
Silica Percentage	75·0	..	69·5	72·0

Fig. II. Granitic Stocks of the Mornington Peninsula.

Comparing the Dromana granite with the Mount Martha granodiorite, the former has 7 per cent. more quartz and 3·5 per cent. less biotite than the latter. In the Dromana granite the ratio of orthoclase to plagioclase is 1·4 : 1, while in the Mount Martha granodiorite the ratio of orthoclase to oligoclase is 1 : 1·3. Although the quartz and biotite are present in the same ratio at Mount Martha and Oliver's Hill, the former contains 8·5 per cent. more quartz and 4 per cent. less biotite. The Dromana granite has 2 per cent. less quartz and 5 per cent. less biotite than the Mount Eliza granodiorite (Baker 1938). The Mount Martha granodiorite has 10 per cent. more orthoclase and 5 per cent. less oligoclase than that at Mount Eliza, but the ratio of these two felspars in the latter is 1 : 2·3. The Mount Martha, Mount Eliza, and Oliver's Hill granitic types are thus more closely allied to the granodiorite than the granitic clan.

Baker points out that although the Dromana granite was intruded into dacite and Ordovician rocks, its heavy mineral assemblage and index number indicate that few contamination minerals, either as xenocrysts or as a result of the processes of contamination, were generated from the invaded rocks, or that if contamination products were added to the magma in the early stages of intrusion, such products have sunk from view. The Mount Martha granodiorite was intruded into more extensively developed argillaceous rocks, from which a considerable amount of biotite was generated and added to the magma, in which, too, there was less sinking of newly formed basic minerals. At Mount Eliza, conditions were likewise favourable for the generation of biotite, but either in greater quantity than at Mount Martha, or else with considerably less sinking of assimilation products. At Mount Eliza, andalusite and garnet were also added to the magma as xenocrysts. He adds that although the Dromana granite and Mount Martha and Mount Eliza granodiorites may have all been derived from a common magma chamber, differentiation and sinking of assimilation products continued further at Dromana. In support of his inference that the Mount Martha and Mount Eliza granodiorites were intruded into argillaceous rocks, it is evident (Figs. 3 and 4) that they were intruded through the thick highly argillaceous Kangerong stage (p. 11) on the western limb of the Peninsula anticlinorium. Whether or not this stage existed over the Dromana granite is problematical.

Examples of apatite crystals with colourless pleochroic cores occur, states Baker (1941), in the Dromana granite, in the hornblende diorite schlieren at The Rocks, and in the Mount Martha, Mt. Eliza, and Oliver's Hill granodiorites.

The apatite crystals with coloured cores are subordinate in amount to those with colourless and pale green cores. The coloured cores consist of four types in the granitic rocks of the Peninsula.

(a)—those that are pleochroic from purple or azure blue to brown. These cannot be assigned conclusively to being inclusions of any particular mineral species, but are probably referable to partially resorbed ferromagnesian mineral matter.

(b)—those that are pleochroic from darker to lighter greenish-brown and from bluish-green to greenish-brown. These are referable to inclusions of hornblendic material.

(c)—those that are pleochroic from black or dark brown to lighter brown and are inclusions of biotite.

(d)—greenish coloured, non-pleochroic cores that are probably chloritic.

In the table of heavy minerals given by Baker (1938) from Dromana 1, Mount Martha 2, Mount Eliza 3, and Oliver's Hill 4, the symbol A signifies very abundant, a abundant, C common, O occasional, R rare, and V very rare.

—	1.	2.	3	4.
Index Number	3·4	7·1	12·4	8·3
Specific Gravity	2·62	2·58	2·70	2·64
Anatase, blue	V	..	..	..
Andalusite, pale green	..	..	V	..
Apatite, colourless	O	C	C	C
Apatite, with pleochroic cores	R	V	V	V
Biotite, greenish-brown	a	..	..	..
Biotite, brown	O	A	A	A
Chlorite	O	V	O	O
Epidote	R	..	..	V
Garnet	..	V	O	..
Gold	V	..	..	..
Hornblende, greenish-brown	C	O	a	R
Ilmenite	..	R	R	C
Magnetite	C	R	V	..
Orthite	..	..	V	..
Pyrite	O	R	O	..
Rutile	..	V	..	..
Sphene	O	V	O	..
Tourmaline, blue	..	..	V	..
Zircon, colourless	C	C	C	C
Zircon, pale yellow	..	V	..	..
Zoisite	V	..	..	..

Apatite crystals with coloured cores are closely associated with contaminated portions of the granitic intrusions of the Peninsula; they seem to be a consequence of contamination processes upon assimilation by the magmas of the intruded base-rock.
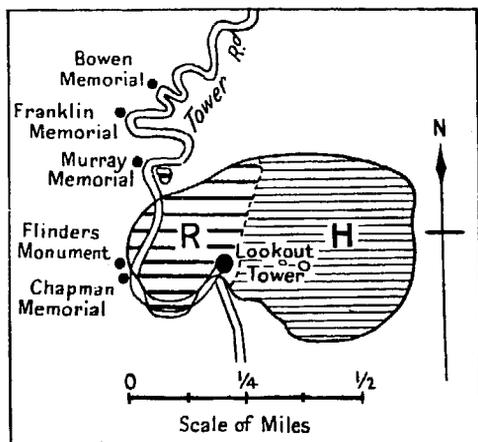

Fig. 12. Sketch map showing locations along Tower Road, and the outcrop of dacite. Hornblende-dacite (H). Rhyodacite (R). [After Baker.

ARTHUR'S SEAT GRANITIC AREA.

On or near the summit of Arthur's Seat, Baker describes areas of hornblende-dacite and rhyodacite (Fig. 12). A small outcrop of rhyodacite also occurs north of the main mass. His micrometric analyses of the dacites are as follows:—

—	1.	2.	3.	4.
Quartz..	2·97	30·5	29·8	27·4
Plagioclase	21·66	38·5	33·6	23·4
Orthoclase		21·2	25·6	35·3
Hornblende	8·30	0·3	5·2	8·1
Biotite..	3·86	6·8	4·0	1·6
Accessories	1·78	2·7	1·8	4·2
Groundmass	61·42			

1. Hornblende-dacite, Dromana, 2. Biotite-rhyodacite, Dromana. 3. Hornblende-biotite-rhyodacite, Dromana. 4. Hornblende-rhyodacite, Dromana.

The absence of orthoclase from the hornblende-dacite and its relative abundance in the rhyodacite is noteworthy. Another difference between the two rocks is the considerable amount of microcrystalline groundmass in the the hornblende-dacite, while constituents of the rhyodacite are large enough to be identified and measured micrometrically. The heavy mineral assemblages in the rhyodacite consist of hornblende, biotite, apatite, zircon, magnetite and ilmenite. Rare garnet and epidote occur in contact types, also occasional pleochroic cores in apatite crystals. The index figures are:

	Index No.	Sp. Gr.
Hornblende-dacite	5·6	2·68
Biotite-rhyodacite	1·5	2·61

Baker found that in these rocks a certain amount of recrystallization had taken place as a result of thermal metamorphism.

" Phenocrysts of orthoclase-perthite and oligoclase sometimes possess lacineal borders, associated with myrmekite and separated patches of quartz, often in optical continuity. Large areas of ilmenite are surrounded by clusters of small biotite flakes, whilst the accessory minerals are apatite, zircon, and rare crystals of sphene and pyrite. The hornblende is pale green in colour, possesses crenulate boundaries, sieve structure, and abundant small inclusions of ironoxide, factors which indicate that the hornblende is a thermal metamorphic product of the rhyodacites.

The hornblende-dacite is a porphyritic rock with embayed phenocrysts of quartz, brownish green primary hornblende, occasional brown biotite developed as a reaction product between the acid groundmass and ilmenite, and corroded and zoned phenocrysts of oligoclase. Crisscross fibres of pale green hornblende, which is probably secondary in origin, are partially altered to biotite. Specks of sulphide minerals are visible in the hand specimens. The microcrystalline groundmass consists of quartz, oligoclase, ilmenite, biotite, and pale green hornblende. Chlorite is occasionally associated with small crystals of sphene, and the accessory minerals are zircon and apatite. The felspar phenocrysts are sometimes zoned with inclusions of sphene and green chloritic material and often possess pale greenish cores due to the presence of hosts of dust-like inclusions and chloritic decomposition products. Where certain of the oligoclase phenocrysts possess blocky structure, this has been produced by intergrowth with small amounts of orthoclase introduced from the intrusive granite."

The contact of the hornblende-dacite and granite can be seen at some places and no clearly marked metamorphic changes are visible.

The dacites are older than the granite for contact specimens provide clear evidence of the metamorphism of the former. Veins of granite containing small xenoliths of rhyodacite have invaded the dacite. Since these igneous bodies contain inclusions of Silurian sedimentary rock, the youngest Palaeozoic sediments of the Peninsula anticlinorium, they must be of post-Silurian age. In Baker's words

" by analogy with occurrences of dacite in other parts of Victoria, they may be regarded as having been extruded in Upper Devonian times, while the granite is a later stage in the Palaeozoic igneous history, probably late Upper Devonian to early Carboniferous."

A dyke of felspar-hornblende-porphyrite (Fig. 13) exposed in a quarry on the coast road about 27 chains east-north-east of the Eastern Lighthouse, and a similar dyke nearby are probably genetically related to the dacites.
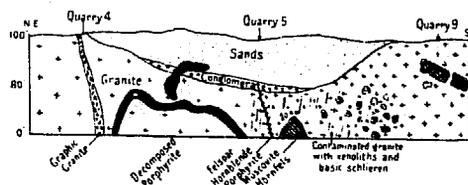

Fig. 13. Diagrammatic section at The Rocks, Dromana. [From Baker.

Baker confined his study of the granite to exposures in the quarries numbered on the map (Fig. 14) and to road cuttings. Quarries 2, 3, 4 and 8 are in normal granite, 5 and 9 in contaminated granite, 6 and 7 in granite-porphyry and 1 in aplite. The Dromana granite he describes as a medium even-grained rock with abundant greenish orthoclase.

"In thin section, it consists of quartz, orthoclase-perthite, oligoclase and biotite. The oligoclase is often blotchy due to the intergrowth with orthoclase, and sometimes possesses saussuritised cores. Muscovite is secondary after plagioclase, epidote occasional, and myrmekite rare. Hornblende is generally confined to areas where assimilation of hornblende diorite has occurred, and is therefore a contamination mineral in the granite. The accessory minerals consist of sphene, zircon, ilmenite, and apatite. The sphene is usually associated with the hornblende and may likewise be a contamination mineral. The felspars are often cloudy from abundant sericite, chloritic material and kaolin. Optically continuous patches of quartz fill the interspaces between some of the felspar crystals, and where such quartz patches occur myrmekite and micrographic intergrowths are abundant."

The following is a chemical analysis of the green granite from Shirref's quarry, Dromana, by F. F. Field, Chief Chemist and Assayer of the Mines Department Laboratory:—

SiO_2 ..	..	..	73·42
Al_2O_3	..	..	13·50
Fe_2O_3	..	..	0·89
FeO ..	..	..	1·27
MgO ..	..	..	0·25
CaO ..	..	..	1·84
Na_2O	..	..	3·06
K_2O ..	..	..	4·44
H_2O+	..	..	0·55
H_2O-	..	..	0·16
TiO_2 ..	..	..	0·34
MnO ..	..	..	0·15
BaO ..	..	..	0·05
CO_2, P_2O_5	..	..	tr.
Li_2O, Cl.	..	..	tr.
ZrO_3, SO_3	..	..	nil
Cr_2O_3, NiO	..	..	nil
CoO, FeS_2.	..	..	nil

Sp. Gr. 2·65

99·92

Although ZrO_3 was not present in the sample analyzed, zircon occurs in the microscope slides.

McInerny (1929) states that the joints in the building stone quarry examined by her are approximately east and west and north and south. Much of the Arthur's Seat granitic area is, however, closely jointed, one set bearing west-north-west and another east-north-east.

Baker (1938) states:

"The xenoliths in the Dromana granite have been derived from two sources from sedimentary rocks and from igneous rocks. Argillaceous Ordovician rocks which became enclosed in the granite magma, have been converted into muscovite hornfels consisting of an interlocking aggregate of quartz grains, laths of muscovite, and abundant scattered grains of iron ores. Brown tourmaline of pneumatolytic origin occasionally wraps around some of the quartz crystals, whilst prisms of foxy-red and yellow rutile have recrystallised from the original titaniferous minerals in the sedimentary inclusions. Small laths of biotite are occasionally developed, and well rounded crystals of zircon are present.

Coarser grained portions of these sedimentary inclusions are sometimes inshot with granitic material. Smaller xenoliths consist of a mosaic of quartz and pale green micaceous material Biotite plates contain sagenitic webs of sphene, and minute pyritohedra of pyrite are included in the quartz grains.

The heavy mineral assemblage of these xenoliths is made up of abundant prisms of yellow-green to dark brown tourmaline, with ilmenite, rutile, apatite, rounded zircon, biotite, andalusite, muscovite, and rare staurolite."

Dykes of granite-porphyry, granophyre, felspar-porphyry, microgranite, graphic granite, aplite, and quartz are associated with the later phases of the intrusion of the granite. Granite-porphyry occurs in quarries 6 and 7 and at The Rocks; a granophyre
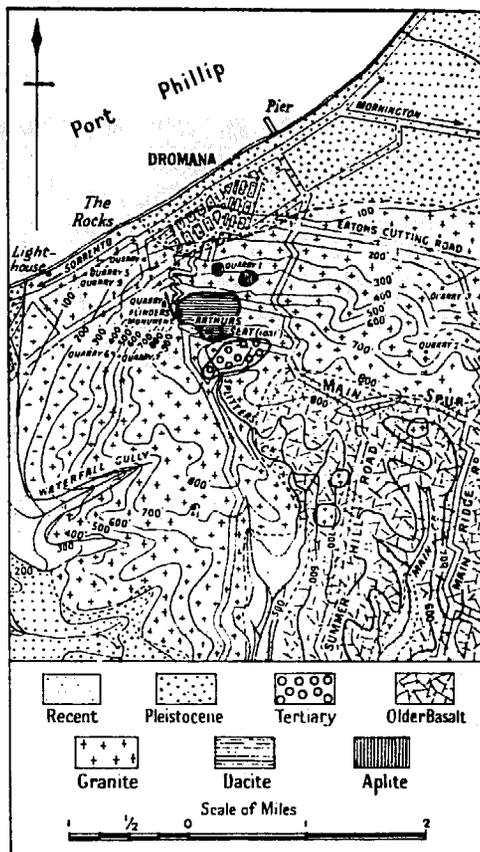
Fig. 14. Geological sketch map of Arthur's Seat.
[After Baker.

dyke 4 feet wide separates the granite from the rhyodacite in the road cutting above the Murray Memorial; felspar-porphyry dykes about 6 inches wide intrude the granite at the Chapman Memorial and a similar and slightly wider dyke containing veins of pink orthoclase cuts the granite just below the Murray Memorial. A microgranite dyke 30 feet wide, cut by veins of aplite, occurs at the Flinders Monument. Graphic granite shows (Fig. 13) in the road cutting between quarries 4 and 5 and a narrow vein traverses the contaminated granite in quarry 5 (Fig. 13). Aplite dykes are common throughout the Arthur's Seat granitic area.

"A prominent, closely jointed dyke of aplite, 50 feet wide, strikes north-north-west near the Flinders Monument, and small offshoots from it sometimes have very dense, dark, fine-grained borders. Dykes and veins of aplite intrude the hornblende-dacite about half a mile east of the Lookout Tower, whilst a larger intrusion occupies a considerable area around quarry 1. Two fine-grained dykes of aplite cut through the granite porphyry of quarry 6, and numerous veins and dykes are exposed along the Tower Road cuttings, especially near the Bowen Memorial. They ramify through portions of the granite in a sinuous manner, but are straight and parallel where confined to joint planes."

Quartz veins occur in many places both in granite and in rhyodacite.

Regarding the order of appearance of the Palaeozoic igneous rocks in the Dromana petrographic province, Baker concludes that

"the oldest rock, the hornblende-dacite, is the most basic and it most probably represents the chilled edges of a dioritic magma, which occupied the magma chamber early in the stages of the process of magmatic differentiation

which ultimately produced a granite. The hornblende-dacite is the volcanic equivalent of hornblende diorite, so that by roof fissuring, portion of the hornblende diorite magma escaped to the surface as a lava flow. The vents through which this portion of the magma reached the surface would eventually become sealed, and differentiation processes continued in the magma chamber until the composition was analogous to that of granodiorite. At this stage, further roof fissuring occurred and rhyodacite was poured out at the surface, the rhyodacite being the volcanic equivalent to granodiorite. After this second outpouring of magma, the vents were sealed up, and remained sealed whilst the magma, gradually becoming more granitic in composition, stoped its way upwards, and differentiation and sinking of assimilation products continued, until the magma finally crystallised as a potash-granite. The remaining acidic liquors of the intrusion were then injected through the older rocks, probably in the order of granite-porphyry, granophyre, felspar-porphyry, microgranite, graphic granite, aplite, and finally quartz veins, thus closing the magmatic activity of the Dromana province.

The absence of a floor of Ordovician rocks for the extruded dacites may be attributed to assimilation and removal during the intrusion of the granite magma, rather than to wholesale roof foundering. The dacites are thus thought to have reached the surface through numerous small fissures, which did not give rise to any widespread or great thickness of lavas, as in Central Victoria, and which would, on account of their small size, be more readily sealed up after extrusive activity had occurred."

MOUNT MARTHA GRANODIORITE AREA.

The following observations on the Mount Martha granodiorite have been condensed from notes supplied by Mr. George Baker. He has made a detailed examination of the raft of Palaeozoic sediments on the coast road 30 chains south of Martha Cliff and of the granodiorite itself.

The greater part of the Mount Martha granodiorite is medium grained, consisting of quartz, zoned poikilitic oligoclase, interstitial orthoclase, orthoclase microperthite, and abundant biotite with numerous pleochroic haloes. A pale-green to darker green hornblende is associated with biotite in dark coloured clots, and has been largely altered to biotite. Accessory minerals are apatite, zircon, and iron ore minerals. Secondary minerals are represented by chlorite and a little epidote. Myrmekitic intergrowths appear in the more contaminated portions of the granodiorite, particularly below the raft, where orthoclase microperthite locally becomes prominent. They are more marked in nearby basic schlieren.

Micrometric analyses bring out the variations in the volume percentages of the minerals between normal and contaminated granodiorite and basic schlieren:—

—	Normal Granodiorite.	Contaminated Granodiorite.	Basic Schlieren Below Raft.
Quartz	27·4	33·4	18·2
Orthoclase	27·5	15·9	16·1
Oligoclase	34·7	37·5	42·2
Biotite	7·8	12·5	13·1
Hornblende	1·5	..	8·6
Accessories	1·1	0·7	1·8
Ratio of orthoclase	1 : 1·3	1 : 2·4	1 : 2·7

The Mt. Martha granodiorite is relatively uniform in character. Minor variations are principally due to colour changes resultant upon increased biotite content in parts where assimilation is evident near the raft. There, it is somewhat fine grained, usually grey in colour, but varies from pale-green in some parts to pink in others. The green and pink colourations are weathering effects combined with variations of the chloritic and orthoclase microperthite contents. These parts become very dark in colour where contaminated by reconstituted, partly dispersed zenolithic material.
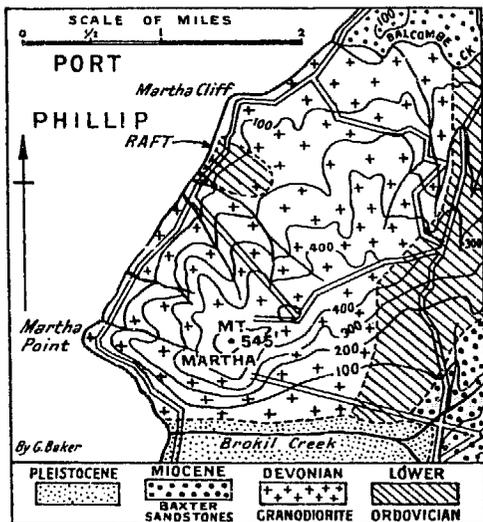
Fig. 15. Geological map of the Mount Martha granodiorite and raft.

Of considerable interest is the raft (Fig. 15), a small area of Palaeozoic sediments surrounded by granodiorite. The original shales and mudstones have been altered to micaceous, bluish-grey and lighter grey hornfels, the sandstone to arenaceous hornfels, more rarely to quartzite. The form of the occurrence of this small area suggests that it is a raft rather than a roof pendant. Some of the lighter coloured types of spotted hornfels in its south-west portion dip 78° south-east, so that their strike is north-east. The dip of the planes of micaceous minerals a little further to the south-west is 58° south-west, indicating a north-west strike. The strike of the Peninsula anticlinorium is a few degrees east of north. These divergent strikes in the small area are suggestive of a raft, a portion of the base-rock that has drifted away from its original position.

The raft is intruded by granodiorite and is capped as well as underlain by it. It is from a half to three-quarters of a mile across, and about 65 feet thick.
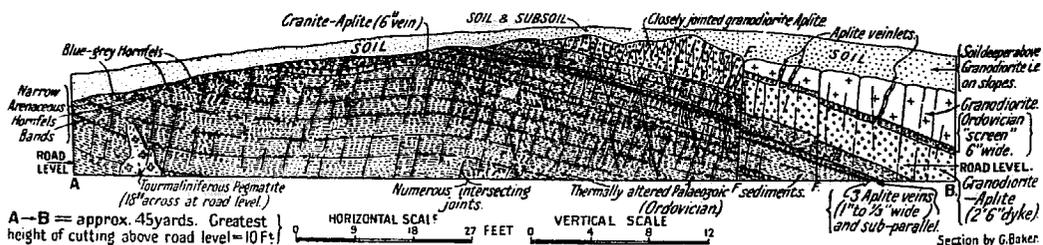
Fig. 16. Sketch section of Raft.
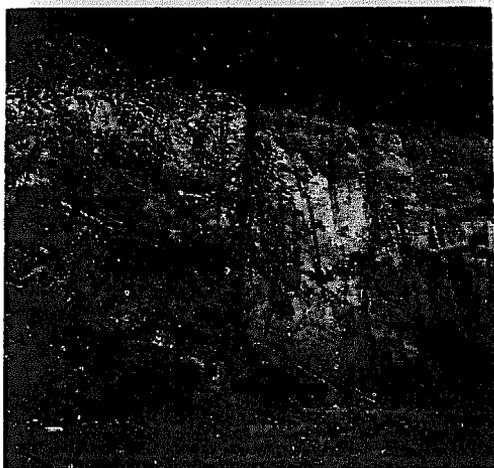
14. Above : Mount Martha raft exposed in a sideling cutting, Beach-road, Mount Martha.
15. Left : Mount Martha raft. Faulted aplite intrusion ; high-angled fault with down throw to south-west.
16. Below : Mount Martha raft. Portion of Palaeozoic sediments north-east end of raft, showing jointing and " fold " structure.

It is not a continuous exposure; it shows at the north-east end of the sideling cutting for some 45 yards (Photos Nos. 14-16) and is separated from the south-west exposure by 300 yards of granodiorite. The south-west exposure shows discontinuously over 75 yards of sidelong cutting; over this distance there are exposed a number of parallel intrusions of the granodiorite varying in width from a foot to 18 feet. Two of the narrower of these, occurring between more extensive bands of altered sediments, are more highly contaminated than the others.

The roots of the raft are seen in the cliff slope below the sideling cutting about 20 feet above sea-level. Small xenoliths are common in the underlying granodiorite; large portions stoped from the roots of the raft are less altered and have sunk only 15 feet. The granodiorite around the roots, like the Palaeozoic rocks forming them, is closely jointed. The altered sediments in the north-west sideling cutting have been invaded by a dyke and numerous veins of aplite (Photo No. 15). Subsequent faulting, with development of slickensides and polishing of joint faces in all these rocks is largely associated with movements along the Selwyn Fault zone.

Features of the raft are its fold-like structure where it is exposed in the north-eastern sideling cutting (Fig. 17) and the almost vertical disposition of the altered sediments in the south-western exposure (Fig. 17). The principal rock type is typically a fine-grained, bluish-grey, muscovite hornfels that has been partly tourmalinised. It resembles in most respects the muscovite hornfels of The Rocks, Dromana (Baker 1938):—

"The typical hornfels consists of interlocking quartz grains, sheaves of muscovite, and abundant, minute grains of iron ore minerals. Biotite is rare. Small crystals of red and yellow rutile, blue anatase, and zircon occur sporadically. Tourmaline has been introduced between the quartz grains partly replacing muscovite."

Portions of the hornfels have taken, especially in the south-west portion of the raft, a fine banded appearance, the fine bands being due to the occurrence
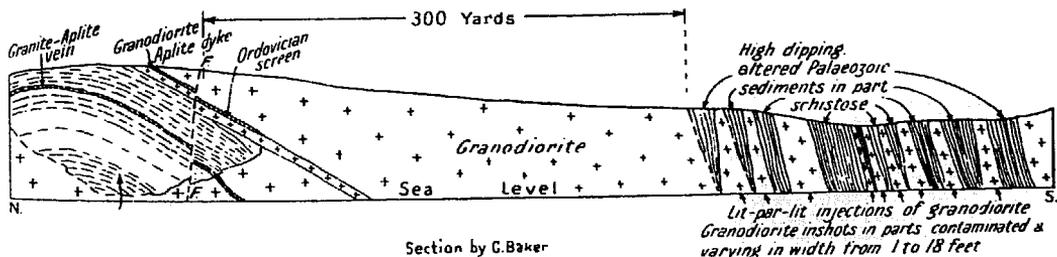
Fig. 17. Raft of altered Palaeozoic sediments showing fold structure.
Generalized section showing separated portions.

17. Mount Martha raft—North end. Sub-parallel aplite veins along low angle joint planes in granodiorite.
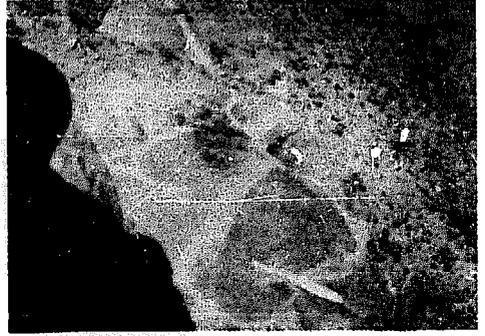
18. Aplite veins following small faults that have displaced lighter bands of Palaeozoic sediments altered by alkali metasomatism.

of more frequent reddish-brown biotite in more or less parallel alignment and separated by narrow quartzite bands. In this portion, too, other parts of the hornfels have a distinct banded character due to occasional narrow, small scale *lit-par-lit* injections of contaminated granodiorite veinlets along original bedding structures.

The effects of other processes of thermal metamorphism led to further alteration, especially felspathisation which was followed by injections, mainly of an aplitic nature but in part pegmatitic, between original structures of the base rock. Intercalated with the dark coloured types of the hornfels are fine, even grained, light coloured rocks of saccharoidal texture, formed by the alteration of the sandstones. Parts of the altered sediments in contact with inshots of contaminated granodiorite are distinctly schistose for short distances from the contact.
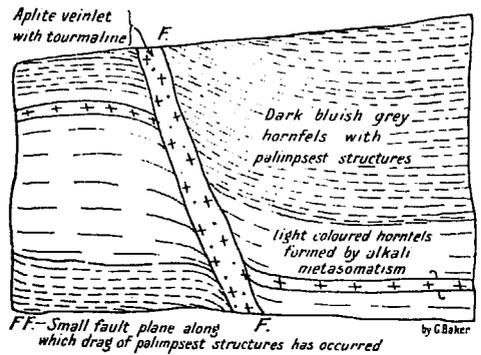
Fig. 18. A sketch of a hand specimen showing an aplite veinlet with tourmaline filling a small fault plane along the broken ends of the palimpsest structures of the hornfels and the lighter coloured bands ; these have been subjected to drag.
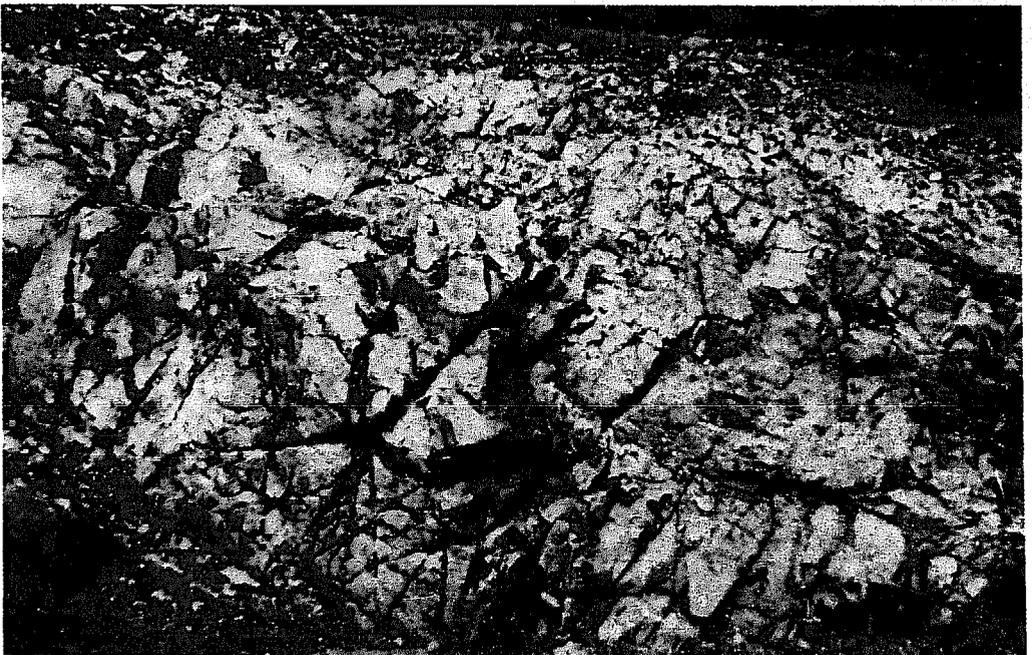
19. Mount Martha raft. Close-up view of contact between altered Ordovician strata and aplite dyke showing the character of the joint systems.

Basic schlieren occur near sea-level and a little to the north of the roots of the raft. They form patches of dark coloured, roughly banded rocks in the granodiorite, trending 25° east of north and having a general easterly dip.

Xenoliths occur sporadically in the granodiorite. They are more abundant and less altered round the roots of the raft, varying there from a fraction of an inch across to 10 feet. There is a progressive change in them as one leaves the raft; they finally grade into ghost-like remnants dispersed through the granodiorite to form xenolithic strew.

A dyke of aplite, 2 ft. 6 in. wide, injected between the screen of altered sediments and the granodiorite, is one of the numerous dykes and veins (Photos Nos. 17-19) cutting through the granodiorite and the raft. Their injection and that of the pegmatite represent the last phase of igneous activity associated with the intrusion of the Mount Martha granodiorite.

Some of the joints and faults are probably due to stresses released when the cooling intrusive body contracted; others have been caused by continued application of forces similar to those that led to the rise of the magma through the crust, while others still are definitely due to deformation by entirely unrelated forces developed at a much later date than the formation of the intrusive body.

Among the pebbles in the conglomerate at The Rocks at the foot of Arthur's Seat are some of augite-dacite. Baker (1938) remarks that

"since all of the pebbles . . . . were obviously derived from an adjacent coastline, augite-dacite must also be present in the district."

The author has reason to believe that it occurs off Martha Point.

MOUNT ELIZA GRANITIC AREA.

Skeats (1907) investigated the characters of the granitic stock at Mount Eliza and the acid veins proceeding from it, also the nature of the metamorphism of the Palaeozoic sediments affected by its intrusion. Much of the area is covered with granitic detritus and the granodiorite is best exposed in a shallow quarry near the summit of Mount Eliza.

Skeats gives its ultimate chemical composition estimated from its percentage mineral composition determined by micrometric analysis:

Percentage Mineral Composition.	Orthoclase.	Anorthite.	Albite.	Quartz.	Biotite.	Hornblende.	Apatite.	Percentage Chemical Composition.
	17·50.	14·24.	25·63.	29·37.	12·23.	0·59.	0·30.	
SiO₂ ..	11·38	6·15	17·62	29·37	4·70	0·24	..	69·46
Al₂O₃ ..	3·24	5·24	5·00	..	1·76	0·09	..	15·33
Fe₂O₃..	..	..	..	..	0·66	0·01	..	0·67
FeO ..	..	..	..	..	1·80	..	..	1·80
MgO ..	..	..	..	..	2·00	0·07	..	2·07
CaO ..	..	2·86	..	..	..	0·08	0·20	3·14
K₂O ..	2·96	..	..	..	1·00	..	..	3·96
Na₂O ..	..	..	3·00	..	0·07	..	..	3·07
P₂O₅ ..	..	..	..	..	..	..	0·10	0·10
H₂O ..	..	..	..	..	0·13	..	..	0·12
							Total ..	99·72

His description is as follows:—

The rock is grey, fairly even grained, and felspar, quartz, black biotite and a little hornblende are visible in the hand specimen. Its specific gravity is 2·69. Under the microscope . . . . it is noticed that both plagioclase and orthoclase are present, that some of the biotite has been altered to chlorite, abundant needles of apatite are included in the generally ragged crystals of biotite, and a little rutile is probably present. The symmetrical extinction angles of the plagioclase lamellae range from about 11 deg. to 17 deg. The crystals are frequently zoned, the margins being invariably more acid, and sometimes untwinned. The central parts of the crystals correspond to andesine of composition Ab₃An₂, the margins to oligoclase of composition Ab₄An₁, the average composition of the plagioclase as a whole is probably near Ab₄An₁. The plagioclase is generally somewhat kaolinised, and usually idiomorphic. The orthoclase, containing some minute irregular intergrowths with albite, is, however, fresh and moulded on the plagioclase. The structure of the rock, as a whole, is hypidiomorphic, and the average grain-size is 1 mm.

The metamorphic rocks in the Moorooduc quarry, ¾ mile north of Moorooduc railway station, may be taken as typical of those of the Moorooduc Scarp (p. 62). Skeats's description of them is as follows:—

The rocks consist of sandstones and slates. The sandstones, some of which occur in fairly thick beds, show little visible alteration except that in places they are changed to quartzite. The slates are, however, highly altered. Among the slates are some with alternate dark and light laminae. On splitting a specimen of laminated slate along a bedding plane, elongated colourless prismatic crystals up to an inch in length were seen. A fragment of one of these crystals examined under the microscope shows the refractive index, polarization colours, and pink to colourless pleochroism characteristic of andalusite.

Thin sections of the slates show the occurrence of two types, the one more, the other less altered. The less altered type is a spotted slate . . . . Under the microscope crypto-crystalline to micro-crystalline aggregates of a white micaceous mineral are seen to form abundant lighter areas with subrectangular boundaries, while the finer-grained groundmass consists of biotite, quartz, uniaxial white mica, hematite, limonite, and some dark red-brown rutile crystals.

The white uniaxial mica is possibly bleached biotite, since some of the larger crystals have apparently unaltered brown areas parallel to the cleavage traces sic while hematite and limonite surround the white mica in such a way as to suggest that the iron has been leached from biotite and deposited as oxide round the bleached crystals.

The more altered type of slate . . . . shows complete recrystallization of the clastic materials. The rock consists mainly of a number of interlocking quartz granules and micaceous minerals. The latter include biotite, muscovite and bleached biotite (?). No trace of spotted structure is seen, but the original bedding planes are defined by lines along which there is a greater concentration of biotite and hematite, and larger crystals of the micas occur along these laminae. Among the minor constituents minute rutiles occur, and a few pleochroic granules of tourmaline, which have been included in the bleached micas. Andalusite is not represented in this rock.

Skeats states that the apophyses in the metamorphosed slates and sandstones in the Moorooduc quarry consist of somewhat decomposed acid extrusions from the plutonic mass. They vary from fine grained aplitic rocks to fairly coarse pegmatites, the largest vein seen measuring about 3 feet in width. In places quartz and felspar alone are present, and at other places biotite and muscovite and occasionally black tourmaline. The micas are usually in large flakes up to 0·75 inches in length. Kitson (1900) has drawn attention to the general concentration of the mica along the walls of the veins the central parts being relatively free from that mineral.

Baker (1937) illustrates a crystal of orthite (allanite) from the Mount Eliza granodiorite. It is a suboval crystal with a fresh core of orthite enclosed largely by hornblende against which has formed a pleochroic halo. He remarks that the development of such a halo is of rare occurrence and indicates that the orthite carries one or more radioactive elements, the width of the halo suggesting the presence of thorium.

V. OLDER BASALTIC LAVAS

In 1911, the Geological Survey of Victoria put down two bores on the Flinders lava field. One, the Flinders Bore, was on the foreshore near the mouth of Dodd's Creek a quarter of a mile north of the Flinders jetty, and the other, the Cape Schanck Bore, was on the Flinders–Rosebud road where that road crosses Main Creek 2¼ miles north-east of Cape Schanck. In 1922 the Mines Department, under the author's supervision, put down the Hastings Bore, on the Warrenquite Creek near Hastings, about 100 yards from where the Hastings Flinders road crosses that creek. The purpose of the Flinders and Cape Schanck Bores was to locate the South Gippsland coal-measures. Neither bore reached them, but the bores contributed a wealth of information concerning a phase of Victorian geology—the great extravasation of basaltic lava known as the Older Basalt. This is found at many places in the Western Port and Port Phillip basins. It covers the southern portion of the Mornington Peninsula; there the Flinders and Cape Schanck Bores are wholly in basaltic lava to depths of 1,300 and 860 feet respectively. The Hastings Bore entered lava at a depth of 47 feet and in 418 feet passed through six lava flows with alternating bands of brown coal, clay, &c. In respect to the Flinders and Cape Schanck Bores, Table A gives the drill foreman's record of the strata passed through, checked in 1911 by the late D. J. Mahony and the author. The author himself checked the record of the Hastings Bore as the core was brought to the surface.

intercalated with it below 1,300 feet as well as the 250 feet of lava exposed on the hill slope to the north that has been removed by denudation from the site of the bore. The seams of brown coal and beds of clay which would undoubtedly exhibit lateral variation, together with the thickness of lava that has been denuded suggest a thickness of over 2,000 feet.

Such a thickness has its parallels in other parts of the world in what are known as plateau flows, the word plateau being used here in its etymological sense of horizontal. The lava flows of the Deccan Traps in India, the basalts of Oregon in the United States, the Thulean basalts of northern Ireland, western Scotland, Iceland, Greenland, Spitzbergen, those of Siberia, Patagonia, and other places are plateau lavas. Vulcanologists believe these extensive, horizontal flows issued quietly from fissures as very fluid lava. Some of the flows and ash, however came from volcanic cones rendered inconspicuous by the fluidity of the lava. The lava flows at Flinders appear to have issued in the same way as those of the Deccan Traps. In this connection, trap is used in its Swedish meaning as " steps " or " stairs ", suggestive of the step-like topography of the Deccan. The Deccan lava welled out over a land surface through linear fissures as a highly liquid magma and spread out as wide horizontal or nearly horizontal sheets. There, the common petrological type is a normal augite-basalt of a prevalent greyish-green colour but in places black or lighter shades. In texture, it grades from homogeneous crypto-crystalline to coarsely crystalline.

TABLE A.

Flinders Bore.		Cape Schanck.		Hastings Bore.	
Bore 1. Flinders, 12 Feet above L.W.M.		Bore 1, Fingal, about 100 Feet Above L.W.M.		Bore 6, Tyabb, 20 Feet Above L.W.M.	
	Thickness.	—	Thickness.	—	Thickness.
	Ft. In.		Ft. In.		Ft. In.
Surface soil, dark	1 0	Surface sand ..	8 0	Surface sands, clays, and ironstone	47 0
Clay, yellow	20 6	Clay, sandy ..	1 6	Basalt	5 0
Basalt, decomposed	112 0	Boulders, basalt rubble	6 0	Clay, yellow ..	123 0
Basalt, hard, jointy	843 0	Basalt, concretionary, hard	18 0	Basalt, hard ..	96 0
Clay, basaltic ..	176 0	Basalt, decomposed	63 6	Clay, ligneous	4 0
Basalt, hard broken	20 6	Basalt, dense, and decomposed		Basalt, soft ..	10 0
Basalt, decomposed, and basaltic		portions	271 9	Clay and sand	20 0
clays	127 0	Basalt, gravel, and conglomerate	8 9	Wood, fossil ..	1 0
		Clay, basaltic, red and grey	187 0	Basalt, hard ..	81 0
		Basalt, crushed and broken in		Coal, brown ..	3 0
		places	178 6	Clay, ligneous	6 0
		Clay and decomposed basalt,		Coal, brown ..	4 0
		slickensided in places	69 0	Basalt, hard ..	43 0
		Basalt	48 0	Coal, brown ..	9 0
				Basalt, hard ..	3 0
				Coal, brown, and clay bands	20 0
				Clay and fine sand	44 0
				Clay, ligneous	1 0
				Clay, fine sandy bands	10 0
				Clay, light brown	34 0
				Slate and sandstone, Silurian	34 0
Total depth bored	1,300 0	Total depth bored	860 0	Total depth bored	558 0

In correlating these bore records, it is highly probable that the 176-ft. clay band in the Flinders Bore is the 187-ft. band in the Cape Schanck Bore and both are the southern extension of the 123-ft. band in the Hastings Bore. If so, the strata below 47 feet in the Hastings Bore is that through which the Flinders and Cape Schanck Bores would have passed had they been pushed to a depth of approximately 2000 feet. To arrive at an estimate of the total thickness of the lava at Flinders, one must take into consideration the seams of brown coal, clays, &c.

The lava flows are often separated by thinner partings of ashes, tuff, and scoria, as are the Flinders flows. The ash and tuff indicate some explosive intensity, but the extrusion of the main mass was quiet. It was extruded in the late Cretaceous or lower Eocene and may be older than the Flinders lava.

The periphery of the Deccan has been intruded by numerous dykes, but the fissures from which the Flinders lava issued have not been located. The so-called craters—the Punch Bowl 1·7 miles west-south-west of Flinders, and the depression at " Whistle

wood," a mile west of Shoreham—have seemingly been formed by streams cutting back and sapping an easily removed flow below a more resistant one The fact that the depressions are on the surface of the lava field that has been lowered by erosion some hundreds of feet excludes the possibility of their being due to volcanism.

Only the great thickness of lava revealed by the Flinders and Cape Schanck Bores is referred to here as the Flinders plateau lava. It covers an area of about 25 square miles (Fig. 19) south of a line bearing west-north-west from the outlet of Manton Creek to Western Port. The lava north of this line, its thickness measured in hundreds of feet, occurs as flows confined to valleys referred to as confined lava flows (Keble 1918). In the Western Port and Port Phillip basins north and north-east of the Mornington Peninsula there are many lava residuals covering fluviatile clays, sands, and coarser material, also lignite or brown coal. These residuals are remnants of the lava flows that poured down the valleys of the drainage systems covering the surfaces of the flood plains, but obviously confined to the valleys until they reached the subsiding Flinders area, there taking on the character of plateau flows. The main characteristic of plateau flows are their extent and horizontality. In his comments on the Oregonian basalts, Washington (1922) states—

"The great extension and substantial horizontality of the Oregonian basalts and the striking way in which, water-like, they flowed over and submerged the topographic features indicating a high degree of fluidity, are the chief physical characters of the region, in which it is one with that of the Deccan."

Horizontality is not limited, however, to the plateau flows, it is a feature, too, of the confined flows.

The main physiographical divides separating the Western Port drainage system from the adjoining systems converge to the south-west, that on the east and south towards Cape Woolamai, and that on the west towards Arthur's Seat. The main volume of lava appears to have come from the north-east (Fig. 19), receiving tributary flows from the north and possibly the north-west; near Sandy Point it was joined by a large tributary flow from the north. North of Cape Woolamai, the main lava stream turned westwards past the granitic Pyramid Rock on the south side of Phillip Island. So far, it preserved its character as a confined lava flow. The following are the logs of bores on Phillip Island and the mainland east and north of Western Port:—

PHILLIP ISLAND.

	ft.	in.		ft.	in.		ft.	in.
Soil ..	4	9	Soil ..	2	0	Sands and	12	0
Older basalt	195	3	Older basalt	213	0	clays		
Clay	94	0	Quartz gravel	1	6	Older basalt	174	0
Base-rock at	294	0	Base-rock at	216	6	Base-rock at	186	6

MAINLAND.

Corinella.			Lang Lang.		
	ft.	in.		ft.	in.
Clays and sands	330	6	Clay, sand ..	346	0
Older basalt ..	47	6	Older basalt..	76	9
Clays and sands	68	0	Ligneous sands and clay	17	7
			Older basalt..	47	6
			Ligneous clays, &c. ..	166	10
Base-rock at ..	446	0	Base-rock at	744	8
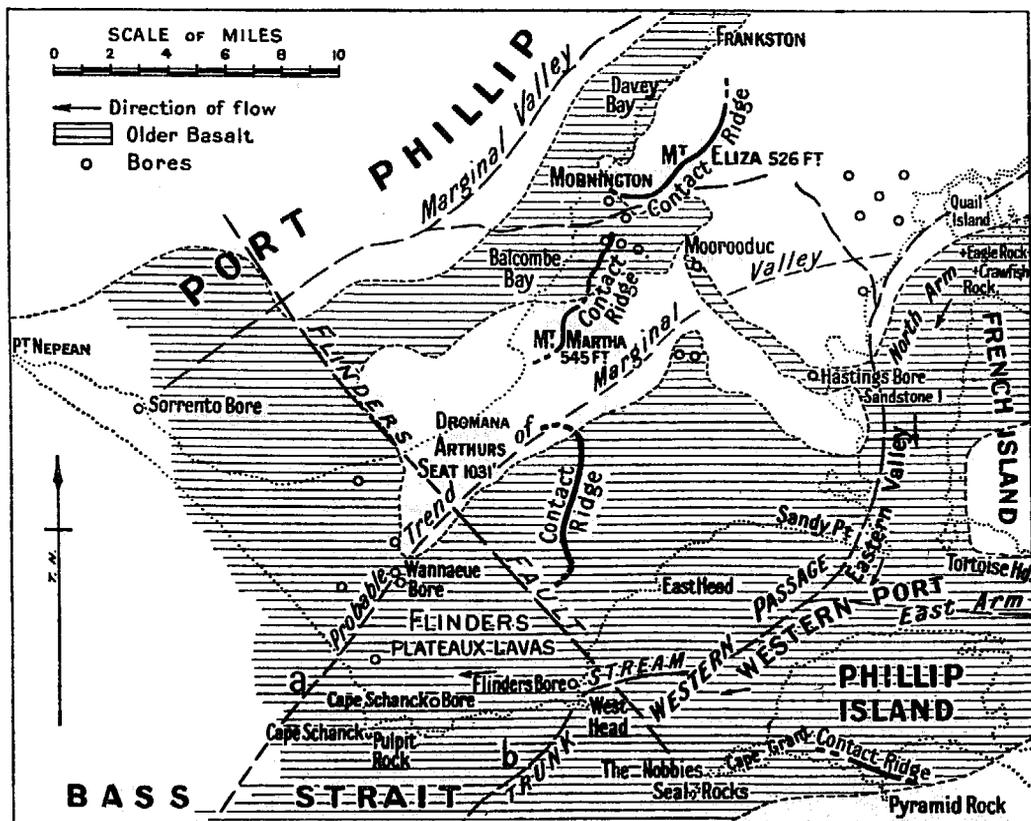
Fig. 19. Map showing surface and probable sub-surface extent on Peninsula of the thick Flinders Plateau lava which extends south-west from Flinders Fault. North-east from fault the lava is relatively thin and mainly confined to lava-flooded valleys.
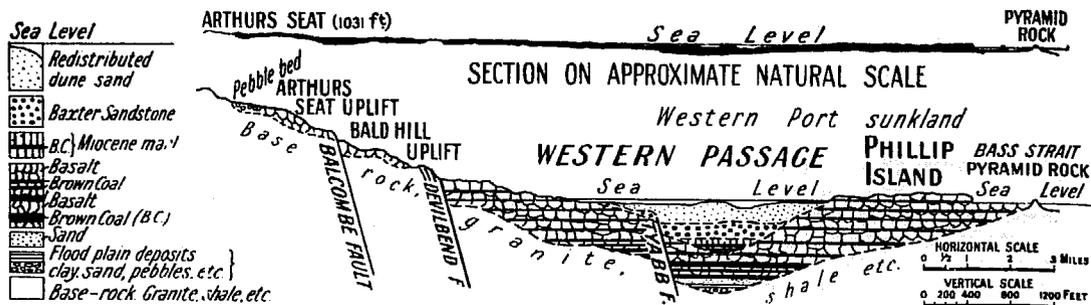
Fig. 20. Partly hypothetical section from Arthur's Seat to Pyramid Rock, Phillip Island.

These logs represent an average thickness of Older Basalt of less than 150 feet; this may not be the true average but it is evident that we are concerned with lava flows of a combined thickness of a few hundreds of feet. The total thickness of lava in the Hastings Bore is 238 feet. Comparing the strata passed through it will be noticed that in some of the bores, those at Hastings (p. 26) and Lang Lang, lignite or brown coal alternates with or underlies the lava flows, while in others the flows rest directly on an antecedent flow or bedrock without a parting of lignite. It is inferred that the presence of the lignite indicates the proximity of flood plain deposits and the middle of the valley (p. 32). There is little doubt that the basal brown coal seam in the Hastings Bore, deposited on a flood-plain of a tributary valley now 440 feet below existing sea-level, passes under the plateau flows near Flinders. There, however, it is at least 1,600 feet from the surface or approximately 1,000 feet lower than its level at Hastings. This implies a slope from place to place of 50 feet to the mile, which is not that of a mature valley such as is suggested by the fluviatile and lignite deposits under the confined flows. The only explanation is that the Flinders area subsided. From the foregoing facts, it appears that there has been both a local subsidence of the Flinders area—local from the standpoint of the present distribution of land and sea—and regional subsidence. The land surface in the vicinity of Hastings was, when the extrusion of the Older Basalt commenced, probably well over 1,000 feet higher than it is now and it has been lowered by regional subsidence, not by some local movement.

The local movement, it is believed, occurred along a hidden fault (Fig. 19), bearing south-east from the northernmost point of the Bellarine Peninsula to about 2 miles north of Flinders and thence somewhere south of Pyramid Point. This fault is one of the lines of weakness on which the subsequent movements of Bass Strait occurred. The author (1946) in his contribution on the Port Phillip Sunkland stated that his

" inference that there has been movement along this line is based on the fact that south of it there is a big suite of beds in the Sorrento and other bores, typified by a class of sedimentation not found to the north of it."

The suite he was referring to comprises the Upper Miocene and Pliocene sediments in the Sorrento Bore. Balcombian sediments of the same age and deposited under the same conditions as those at or below a depth of 1,310 feet in the Sorrento Bore, are found at the surface north of the hidden line of movement implying a subsidence of at least that amount. It is apparent that here we are dealing with a line of weakness—a major fault—along which there has been considerable movement. At the surface it is masked by the waters of Port Phillip, Western Port, or Bass Strait, by Quaternary or

Tertiary deposits, and significantly by the Older Basalt. Because it cannot be seen and its existence is assumed it is referred to here simply as the Flinders Fault (Fig. 19). The first movement on it was at the start of the Older Volcanic activity when the cumulative outpourings of the confined lava flows from the east, north-east, and north, flooded the subsiding fault-block on its southern down-throw side. Viewed from this standpoint, the great thickness of plateau lavas at Flinders and Cape Schanck is an accumulation on a sunkland of lava from all parts of the Western Port basin. The overall period during which the accumulation took place is contemporaneous with that of the confined flows at all places behind the Flinders plateau lavas, but the lava from a specific area to the east, north-east, or north is represented only by certain of the plateau flows.

Macroscopically, the basaltic lava of the Mornington Peninsula is from coarse to fine grained; the Older Basalt generally consists of all gradations from coarse dolerite to glassy tachylite (Skeats 1910). Edwards (1938) remarks that the types of Older Basalt or the lava of the Older Volcanic series of the Mornington Peninsula and Victoria generally form an association closely comparable with the Tertiary plateau magma suite of Scotland, corresponding to Kennedy's (1933) olivine-basalt magma type. He records, mainly from bores but also from outcrops on the Peninsula, titanaugite, iddingsite, and olivine basalts. These resolve themselves into six types—the crinanites and crinanite basalts, the Mooroduc type, the Mirboo type, the Keilor type, the Buckland type, and the Flinders type. His description of these types is condensed in Appendix A (pp. 75 and 76).

The best surface section of a series of flows in both the Western Port and Port Phillip basins is in the cliff face overlooking Bass Strait from West Head near Flinders to Cape Schanck. Most of these flows are higher in the series than those passed through in the Flinders and Cape Schanck bores. The cliff face consists, in the main, of successive flows spread out on the residual soils formed by the decomposition of the surfaces of the underlying flows and possibly the ash and tuff on them. The thicknesses of the flows vary; on the west side of Point Barker along Main Creek, there are six flows in a height of about 100 feet, but in the cliff face overlooking Bass Strait there are about ten in 300 feet. At sea-level, the thicker portions of the flows have resisted coastal erosion and remain as stacks detached from the main mass of basalt, such as Pulpit Rock and Elephant Rock. The decomposed surfaces of the flows overlain by other flows consist of partially baked, reddish clay; that exposed to existing sub-aerial weathering is of a red to black, unctuous clay. In shallow hollows in the residual soils are pockets rich in ilmenite and magnetite. Between the flows in the cliff face there are no intercalated sediments or accumulations of lignite; the decomposition of the

flows was evidently rapid and the lapses of time between the successive outpourings short. This is true only in regard to the upper plateau flows; the thicknesses of brown coal and clays between the flows in the Hastings Bore and, inferentially, between the bottom plateau flows in the Flinders and Cape Schanck Bores, indicate longer time intervals.

In the cliff face, the flows are horizontal or slightly undulating. Their near approach to horizontality over a distance of 8 miles is evidence of the non-existence of a deformative period since they were extruded. The flows are not closely faulted like the Jurassic strata on the east side of Westernport. About 3½ miles east of Barker Point, the continuity of the successive lava flows in the cliff face is interrupted by a deep, narrow, compact flow; the horizontal flows rest against what is seemingly a newer flow, but whether the latter belongs to a later period of the Older Volcanic or is still younger, cannot be determined. That there has been more recent activity is evident from the fact that along the Bass Strait shore between West Head and Cape Schanck

the rocks along the Bass Strait shore a number of zeolites—analcite, natrolite, phillipsite, gmelinite, stilbite, sphaerostilbite, and chabazite; he also records aragonite, calcite, halloysite, and magnetite. On the saddle of the isthmus connecting the small peninsula terminated by Pulpit Rock, there are scattered fragments of a vein of magnetite, and aragonite containing traces of strontium. Pisoliths and ooliths are found in the Angel Cave near the Reading Desk.

The basaltic lava of the Port Phillip basin probably came from points of fissuring not yet known in that basin north-west or west of Frankston. Its distribution and thickness suggest that it everywhere occurs as a confined lava field. The Mornington lava field (Fig. 19) extends along the western shore of the Peninsula from Frankston, its eastern edge being at different distances in from the shore of Port Phillip and its western edge submerged by the waters of that bay. It is exposed at many places between Frankston and Grice (Gunyong) Creek. It is absent from the mainland between Grice Creek and Mornington but has probably been submerged inshore. Between

20. West Head, near Flinders. Dyke intrusive to the Older Basalt.

21. The Reading Desk below the Cape Schanck lighthouse. The seat of the Reading Desk is a basaltic dyke.

there are dykes, at some places in vertical section in the cliff face, at other places cutting across the flows on the wave platform or at levels between tides. Near West Head, a sinuous wall of dyke rock from a foot to 8 feet in height and 2 feet in thickness strikes generally to the south-west, and there is also another dyke about 3 feet thick striking south-easterly. The dyke walls have a limonitic casing and the dykes themselves contain such minerals as hornblende, oligoclase, biotite, apatite, secondary calcite, and gmelinite. A dyke at Simmons Bay shows on the surface of the wave platform as well as in the cliff face; its composition approximates closely to that of the dykes at West Head. At Cape Schanck, another dyke may be traced at low-water across the shallow bay between the small peninsula terminated by Pulpit Rock and the cliff immediately under the lighthouse. It appears in section half way up the cliff face and its projecting upper end forms the seat of what is known as the Reading Desk.

The residual soils merge into a light to dark-grey, soft decomposed rock with developments of calcite, steatite, wacke, limonite and other secondary minerals. At Point Bobbanaring there is a pavement showing the cross-sections of decomposed columnar basalt; the hexagonal columns are cased with limonite along the joint planes. Mitchell (1930) records from

Mornington and Mount Martha, it extends further inland where it has been located by bores. It is well developed east of Mornington; there the log of the Tanti Bore was as follows:—

Bore 9 Moorooduc.

		Feet.	Inches.
Soil	..	1	0
Sandy clay, mottled	..	12	0
Sand and clay	..	9	0
Sand, fine and coarse	..	28	0
Gravel and clay ..	..	2	0
Clay, blue and grey	..	12	0
Clay, basaltic	..	6	0
Basalt, hard	..	113	0
Brown coal	..	0	6
Base-rock struck at	..	183	6

The basaltic lava in this bore is thicker than that passed through in any other bore put down in the Port Phillip basin; it suggests that the lava is of inconsiderable thickness.

South of Mornington, it outcrops at a point immediately south of the old cement works at Balcombe Bay, as columnar basalt on a small headland about ¾ mile south of the cement works, and on

Shag Island between those places. Still further south it outcrops on the northern slope of Mount Martha and may be seen in the road cutting on the Point Nepean road on the south side of Balcombe Creek. From there, the lava field apparently turned to the west-south-west, skirting the granitic areas of Mount Martha and Arthur's Seat; Kitson (1900) shows an outcrop of Older Basalt on the shore 25 chains north-east of the mouth of Balcombe Creek. Its extension west of Mount Martha is, however, covered by the waters of Port Phillip.

The question of the age of the Older Basalt is a vexed one. The Tertiary palaeogeography of the Peninsula and the presence there of marine Tertiaries of ages that have been ascertained with some precision justify the following statement of facts.

Nowhere on the Peninsula is a marine bed intercalated with the flows of the Older Basalt. It is evident from the fact that the Middle Miocene limestone at Flinders rests on the eroded surface of the basalt, a surface resulting from the post-Older Basalt cycle of erosion, that that cycle reached an advanced stage before it was submerged by the Middle Miocene

sea when the limestone accumulated. Moreover, at Flinders, a thickness of some hundreds of feet of basalt had been removed by erosion before the Middle Miocene submergence occurred. The Oligocene (Anglesean) *Cyclammina* marine sands at Anglesea were deposited in the submerged trunk-valley of the post-Older Basalt cycle. The original base level of the trunk-stream was the shoreline of the Eocene sea that existed south of the Otway Peninsula (Baker 1943). That being so, the trunk-stream was functioning in the Eocene and since it cut back over the Older Basalt, the age of the basalt is assuredly Eocene. It hinges, however, on how long the post-Older Basalt cycle was in operation before the marine transgression commenced. The author believes it started before the Upper Eocene, and the age of the Older Basalt is, at least, Middle Eocene. It may have been functioning over a much longer period than he ascribes to it, for there are no criteria for estimating the duration of a cycle of erosion. It may be found that the Older Basalt is older than Middle Eocene, and is possibly contemporaneous with the Deccan Traps.

VI.   EOCENE PRE-OLDER BASALT DEPOSITS

Eocene beds older than the Older Basalts are exposed on the Mornington Peninsula in the coast section between Frankston and Mornington or a short distance inland. All these beds are sparingly fossiliferous. A number of plant fossils have, however, been identified from leaf impressions found at Berwick, 14 miles north-north-east of the Mornington Peninsula in flood-plain deposits immediately below the Berwick lava-residual—flood-plain deposits that there overlie brown coal a few feet in thickness. The lava at Berwick is really a northern extension of that on the Peninsula. Determinations from leaf impressions are suspect, but if those of the genera are at all reliable, they possess an ecological significance. The genera determined for the leaf impressions include *Aristotelia, Commerconia, Nephelites, Tristanites, Eucalyptus, Apocynophyllum, Atherosperma, Mollinedia, Hedycarya, Daphnandra, Lomatia, Fagus, Carpolithes,* and *Phyllites.* Deane[3] (1902) who identified the genera, concluded that at the time the Berwick flood-plain was laid down

" the flora of the district from which the leaves were derived was as typically Australian as that of any district at the present day."

Fagus (Nothofagus), the beech, is perhaps the most significant of these identifications; it is now confined in Victoria to the south and east parts of the State, usually in moist sheltered localities, but ascending to 3,000 or 4,000 feet and there becoming merely a shrub (Ewart 1930). *Atherosperma,* Sassafras, is found only in the southern, north-eastern, and eastern parts of Victoria. *Lomatia* is now similarly confined and the Victorian species of *Hedycarya* is usually found on mountains or river banks. As to the climate implied by these genera, the only generalization that seems justified is that it was as cool as, or cooler than, the present climate, a feature due to altitude.

Hills (1938) discussed the contention of Sussmilch (1937) that the fruit and leaves at Berwick and other places in Victoria, New South Wales, and Queensland belonged to a single floral association called by the

latter the Cinnamomum Flora. Hills pointed out that this flora has been shown to have a probable range in Victoria from Oligocene to Lower Pliocene, that it is essentially an Australian flora (Deane 1902[1]), and that it includes not only genera (e.g. *Cinnamomum*) restricted to-day to warmer and moister parts of Australia but also genera such as *Casuarina* and *Eucalyptus* that still live in Victoria. It is clear, he adds, that climate or topographic changes have caused the dying out of the subtropical types in Victoria, while other genera have lived on in spite of such changes.

If, as suggested, the flora implies a climate as cool as or cooler than that prevailing now, such is consistent with the former elevation of the deposit in which the leaves are found—an elevation of probably 1,000 feet above existing sea-level. That *Cinnamomum,* genus *sensu stricto* could exist in such a climate is improbable. Deane (1902[1]) commenting on the floras of Pitfield, Mornington, Sentinel Rock (Otway Coast), Berwick, and Won Wron, in some of which the leaf recorded as *Cinnamomum* is present states:

"As to the likeness of other leaves to those of eucalyptus there cannot be the slightest doubt; they are a feature of this series, and when one bears in mind the Bacchus Marsh beds [which contain *Cinnamomum*]—also Eocene, and therefore probably not very far removed from the Berwick deposits in point of age, geologically speaking —contain no similar leaves, one must recognize the fact as one of great significance. It shows at that geological period, as at the present time, two classes of vegetation were growing alongside one another, namely a 'brush' type, characterized by the absence of *Eucalypti* and *Proteaceae,* and an open forest type, in which those groups or their ancestral prototypes flourished."

Incidentally, although he assigned some plant beds to the Eocene, which is correct, this was based on a misconception as to their stratigraphical position.

The pre-Older Basalt deposits on the Peninsula outcrop only in the northern part of it. At Grice Creek, grey and brown sandy and gravelly sandstones with angular and subangular fragments of quartz underlie

the basalt which has hardened and discoloured the upper layers of the sandstones. At another place, the sandstones or gravels rest on a conglomerate which in turn rests on granodiorite. The conglomerate includes pieces of quartz, sandstone, and angular and rounded slate.

On the slope of Oliver's Hill, near Frankston, where sub-basalt beds are exposed, the sections are partly covered with slipped material. The beds consist of conglomerates, sandstones, mudstones, grits, gravels, &c. resting on the denuded surface of the granodiorite and underlying Older Basalt, some of it *in situ.* Kitson (1900) records the section (Fig. 21A) in the old clay pit near the mouth of Tangenong
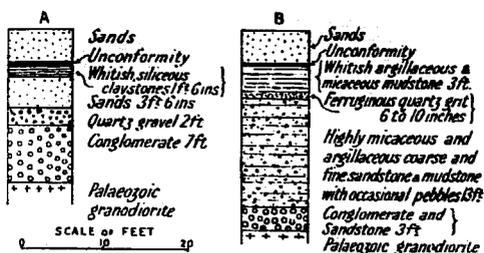
Fig. 21. A. Section in clay pit near the mouth of Tangenong Creek.

B. Section compiled from Kitson's section from Landslip Point to Davy Bay.

(Naringalling of Kitson) Creek. The conglomerate consists of Lower Palaeozoic slate, shale, and sandstone pebbles, some containing graptolites, together with others of granitic origin; the pebbles are intermixed with gravelly clay and sand. This merges upwards into gravel, sand, and finally into white, siliceous claystone with obscure organic impressions and partly indurated with the appearance of porcellanite. Resting on these is Older Basalt or sand. Very much the same stratigraphical sequence is seen in Fig. 21B, a section compiled from Kitson's section of the coast from Landslip Point to Davy Bay. The north-east end of this section is shown in Fig. 22.

Kitson observed that the upper portion of the whitish, argillaceous and micaceous mudstone (Fig. 21B) is altered for a depth of from 2 to 8 inches at the contact of the basalt to what has been described as a porcelain-jasper. The succession at Landslip Point (Fig. 22) appears to be one of strata that has been little disturbed. The section shows the conglomerate resting on the denuded surface of the granodiorite, and overlying the conglomerate, apparently conformably, 35 feet of strata; this strata underlies the fossiliferous Landslip Point ironstone believed to be of Middle Miocene (Balcombian) age (see p. 40), the bottom of which marks an unconformity. The southern end of the section from

Landslip Point to Davy Bay consists largely of slipped and resorted material. If here the eastern edge of the lava-field was 70 feet above existing sea-level as at Grice Creek (Fig. 33), much of it has since been lowered by landslips, indicated by floaters in Kitson's sections. Some of the lower blocks may be *in situ,* for example the block at sea-level in Fig. 22; others have been pinched in with the granodiorite while parts of it were slipping. There seems to be little doubt that the Older Basalt formerly rested on the undulating surface of the white, argillaceous and micaceous mudstone (Fig. 21B).

The stratigraphical position of the conglomerate exposed near Osborne, south of Mornington, is obscure.
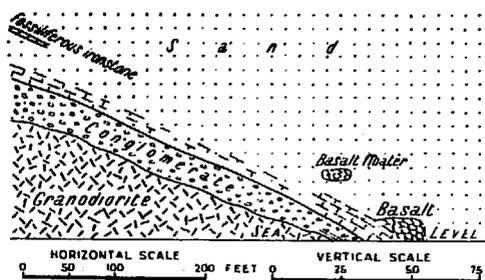
Fig. 22. North-east end of Kitson's section from Landslip Point to Davy Bay.

Deposits underlying the Older Basalt have been penetrated by bores at many places. Bore 2, Moorooduc, passed into them at a depth of 77 feet; there they consisted of a bed of gravel and sand 19 feet thick, overlying yellow and grey clay 3 feet thick which rests on Palaeozoic sandstone. In Bore 5, Moorooduc, the sub-basalt bed is 4 feet of ligneous clay resting on granodiorite; in Bore 7, Moorooduc, the Older Basalt rests directly on the granodiorite. Near the centre of the Peninsula, Bore 1, Bittern, passed through the Older Basalt at 192 feet into 26 feet of white, sandy clay resting on Palaeozoic sandstone and slate. Bore 2, Bittern (sic) (Fig. 27) passed through the Older Basalt at 264 feet into 22 feet of stiff sandy clay, 2 feet of gravel and sand, 16 feet of ligneous sand, a foot of grey slate (sic), 107 feet of ligneous clay, and bottomed on Palaeozoic sandstone. The beds underlying the Older Basalt in the Hastings Bore have been discussed (p. 26).

All the beds below the Older Basalt are terrestrial. If the land surface on which they were laid down was, as suggested, 1,000 feet above the Eocene shoreline which did not greatly differ in height from the present shoreline, the former must have been a considerable distance south of the Peninsula region.

VII. LIGNITIC PHASES OF THE MORNINGTON PENINSULA

Twenhofel (1932) states that—

" stratigraphic and depositional evidence on the important coal fields of the world shows that the coals were laid down in swamps on broad coastal or inland plains—lacustrine or fluviatile—during stages of relative or approximate base-level; that the regions were undergoing intermittently slow subsidence or, in the case of inland deposits, filling of the basins."

Two conditions are specified—a swamp-covered surface with little or no fall, and regional subsidence. In the Peninsula region, the first condition existed on or near the flood-plains. In the Hastings Bore, the basal flow of basalt 3 feet thick rests on a seam of brown coal 20 feet thick which accumulated on a flood-plain, which was the surface of the fluviatile deposits 85 feet thick, consisting of clay and fine sandy bands. These rest on a Silurian basement. A seam of brown coal 9 feet thick then accumulated on the basal flow and this seam was covered by another lava flow; the alternation of lava flow and brown coal seam recurred at least four times during the period represented by the bore core. We have in the Hastings Bore upwards of 40 feet of Eocene brown coal or lignite. The surface of each flow decomposed into a residual clay, similar to the soil partings in the Bass Strait cliffs; this supported the vegetation that accumulated as brown coal. The flood plain deposits in the Hastings Bore were those that accumulated in a tributary valley of the pre-older Basalt trunk stream (Fig. 19). A cross-section (Fig. 20) of the valley of the trunk stream suggests that it was a mature valley.

That there had been regional subsidence is indicated by the fact that the basal flow of the Hastings Bore, and incidentally the flood plain on which the underlying brown coal seam rests, is about 440 feet below existing sea-level and the bottom of the valley on which the flood-plain was deposited is about 500 feet below sea-level. If uplift had occurred to any extent the erosion arising from it would have removed the residual soil cover on the lava flows and the vegetation. There was, nevertheless, some oscillation or periods of increased rainfall as suggested by the earthly impurities in the coal. The accumulation of lignitic material started as soon as there was sufficient residual soil to promote growth. The annual rings in the tree trunk passed through in the Bore at 305 feet indicate seasonal changes.

There was a cessation of lignitic accumulation during the early vertical erosion stage of the post-Older Basalt cycle. When, however, the surface was levelled to one of late maturity, giving wide valleys between low hills with graded slopes, conditions were set for the great Oligocene-Miocene lignitic accumulation. The surface of late maturity is referred to here as the Moorooduc Plain, for it is typically developed on the Peninsula at Moorooduc (Photo No. 22), 5 miles east-south-east of Mornington. The Moorooduc Plain extended in every direction well beyond the Moorooduc region; the only elevated points on its mature surface were the contact ridges and the monadnock-like granitic areas. Towards the end of the mature stage the valleys were flooded by the Tertiary sea, but the lignitic period still persisted and brown coal continued to accumulate during periods of emergence. At Flinders lignite rests on Batesfordian limestone and at Parwan, near Bacchus Marsh, Balcombian marine clay is intercalated with the lignites.

22. Moorooduc plain near Moorooduc, in the centre of the Peninsula. Arthur's Seat in distance, to right.

The lignitic period came to an end with the regression of the Tertiary sea in the Upper Miocene during the Cheltenhamian. This was followed by a complete change of conditions. The new land surface was covered with medium to coarse grained fluviatile deposits—the Baxter Sandstones (p. 41) in place of the preceding generally fine deposition. The Baxter Sandstones heralded the beginning of the Pliocene cycle of erosion which continued with interruptions through the Quaternary to the present.

The deposits that accumulated in the valleys during the post-Older Basalt cycle consist of pebble beds representing the stage of vertical erosion, and sands, clays, &c. passing up into lignite or brown coal representing the lignitic period. The pebble beds are preserved as remnants of a formerly more extensive deposit on the Arthur's Seat and Bald Hill uplifted blocks (p. 43); they consist of pebbles, gravel, and boulders of many types of rock, slate, sandstone, quartzite, grit, hornfels, jasper, and igneous rocks including basalt. Some of the slate pebbles containing graptolites are from the base-rock to the immediate north. The basalt pebbles are obviously from the Older Volcanic lavas. The age of the pebble beds is, then, post-Older Basalt; they are considered to range from the Eocene into the Oligocene.

At Grice Creek, the 4-ft. basal bed of " basalt concretions and pebbles " (Kitson 1900) resting on the Older Basalt is, no doubt, an outcrop of the Arthur's Seat pebble beds, but deposited by the Port Phillip Stream System. Kitson has detailed this section:

	Thickness ft in.	
[Balcombian] marine, calcareous clays—		
Light bluish-grey, fine, micaceous sand-stone	2	6
Similar coarser sandstone with subangular and rounded quartz grains ..	7	0
Light-grey clay with quartz grains ..	7	0
Dark, bluish, micaceous sandstone with interlaced joints of calcite and basalt concretions or pebbles	4	0

Upstream the Balcombian clays overlie spheroidal Older Basalt; near their junction, secondary calcite has formed in the once covered intersecting joints.

The sediments underlying the Balcombian clays show no evidence of the existence of conditions favouring lignitic accumulation; their stratigraphical position and texture suggest that they were laid down in the earlier part of the post-Older Basalt cycle.

The conglomerate resting on the Older Basalt at Landslip Point nearer Frankston is probably a northerly extension of the Grice's Creek conglomerate.

The lignites were penetrated by bores at Balcombe Bay and Tyabb; Table B gives the boring records. In Bore 6 the 17 feet of sandy clay and the 24 feet of sand beneath the Balcombian marl at 35 feet and resting on the lignitic phase appear to be transgressive sediments formed usually on the strandline of a marine transgression (cf. Davies 1934) and the 29 feet of sandy clay and ironstone together with the 35 feet of sand in Bore 3, Moorooduc are also probably such. In the Tyabb area, the Balcombian marls rest directly on the lignites: there are no transgressive sediments. The marls were deposited in a valley cut in the lignites (Fig. 23), formerly about 140 feet but now only 20 feet thick; 120 feet of lignite has been removed by erosion to form the valley in which the marls rest.

The log of Bore 8 Parwan in another part of the Port Phillip Basin is given for comparison. The correlation of the strata passed through shows how the lignitic period merges with that of the marine transgression.

TABLE B.

Bore 3, Moorooduc.	Thick-ness.			Bore 6, Moorooduc.	Thick-ness.			Bore 4, Tyabb.	Thick-ness.	
	Feet.				Feet.				Feet.	
Clay and gravel	8	Upper Miocene	Marl.. ..	35	Middle Miocene (Balcombian)	Sand ..	9	Pleistocene
Sandy clay and ironstone	29 ⎫	Transgressive sediments	Sandy clay ..	17 ⎫	Transgressive sediments	Sandy clay ..	48	? Upper Miocene
Sand ..	35 ⎬		Sand ..	24 ⎰		Marl ..	123	Middle Miocene (Balcombian)
Brown coal ..	1 ⎰ Lignitic phase	Ligneous clay..	2 ⎫		Brown coal ..	4 ⎫	
Gravel and sand	48		Coarse sand ..	4 ⎬ Lignitic phase	Ligneous clay..	12	
White, sandy clay	7		Ligneous clay..	33 ⎰	Brown coal or ligneous clay	9 ⎬ Lignitic phase	
Gravel and sand	7				Ligneous, sandy clay	7	
Sandy clay ..	40				Brown coal or ligneous clay	3 ⎰	
					Sandy clay ..	47	
Palaeozoic sandstone.			Eocene basalt.			Palaeozoic sandstone.		
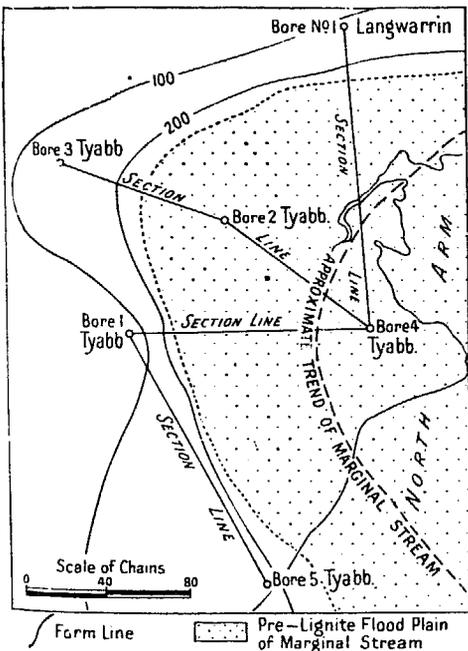
Fig. 23. Map of the lignites and marls in the Tyabb area.
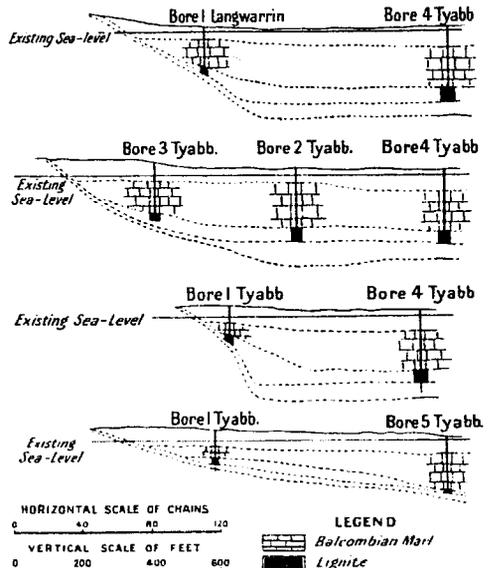
Fig. 24. Sections of the lignites and marls in the Tyabb area.

Bore 8 Parwan.

	ft.	in.	
Basalt	320	0	Pleistocene
Clay, white, stiff	12	0	
Clay, brown, with grey, hard limestone boulders	38	0	
Clay, white	12	0	Middle Miocene
Clay, blue, fossiliferous ..	4	0	(Balcombian)
Clay, white, sandy, with limestone boulders	28	0	
Clay, blue, fossiliferous ..	9	0	
Clay, black, ligneous	2	0	Lignitic Phase
Coal, brown	9	0	
Clay, blue, fossiliferous ..	34	0	Balcombian
Sand, hard, with little pyrites ..	13	0	Transgressive Sediments
Coal, brown	24	0	
Sand, cemented, with pyrites ..	0	6	Lignitic Phase
Coal, brown	8	6	

Lignite outcrops in the coastal cliffs south of the old cement works at Balcombe Bay. About ¾ mile south of the cement works is a seam of lignite in ferruginous sandstone near high water mark. Above it is a bed containing plant fossils (Kitson 1900); this bed underlies 20 feet of grey, white, and yellow sands which pass upwards into 12 feet of drab and yellow gravelly clay with crystals of selenite and which underlies 12 feet of red and yellow clay. Some of the plant fossils were determined by Deane (1902[2]) as *Eucalyptus praecoriacea* Deane, *Daphnandra,* and cf. *Podocarpus* (a conifer). He considered that the eucalypt approached closely the living *E. coriacea*. If the identifications are reliable, they throw some light on the flora that contributed to the lignites.

A lignite containing fruits outcropping in the small bay a few chains south of the cement works may be the reappearance of the *E. praecoriacea* bed, but, as far as the author knows, none of the fruits found in this bed have been identified.

23. Fossil plant. *Eucalyptus praecoriacea*, figured by Deane.

Vill.   FAULTS

24. Selwyn fault where it crosses the Bass Strait shoreline 1·5 miles north of Cape Schanck. On the right the cliff face is the fault scarp that has receded by coastal erosion. In the foreground is the clay debris in the fault channel.

The pattern of the major fault lines conforms to the main trend lines of the folding of the Palaeozoic sedimentary base-rock (Fig. 50). As already stated, the base-rock consists of Ordovician and Silurian sediments. The main axes of the folds in these trend north-north-east which is that of the major strike faults. Balcombe Fault (Fig. 35 & 49) is approximately parallel to and near the main axis of the anticlinorium; Selwyn Fault is on its western limb, and Devilbend Fault on its eastern limb. Tyabb Fault is also probably a strike fault. These are the more obvious fault lines, but the stream pattern indicates subsidiary later movements along these faults.

The channels of the several faults are masked by superficial deposits and it is difficult to determine whether they are actually fractures or flexures. There is, however, no doubt about the movements on them; the displacement of the fault blocks is shown in the interrupted succession of the graptolite beds, the displacement of the overlying Tertiary beds, and the stream pattern.

Selwyn Fault (Figs. 35 & 49) was recognized as a line of movement by A. R. C. Selwyn, the first Director of the Geological Survey of Victoria nearly 100 years ago. Its flexure is seen only at one place, in the cliff overlooking Bass Strait, 1·5 miles north of Cape Schanck (Photo No. 24) but the cliff south of where the fault crosses the coastline to Cape Schanck is actually its fault scarp that has receded easterly and been blunted by coastal erosion. North of this, on the Peninsula, it has been covered by superficial

deposits or by the waters of Port Phillip. Its continuation under Bass Strait as far south as King Island (Fig. 39) shows in the bathymetrical contours of the Strait. It is described by Hills (1940) as a "hinge fault, the displacement dying out to the north but increasing towards the south."

The author (1946) describes it from its appearance in the cliff face as "a warp with incipient fractures, the warp tilting the beds on its north-west side downwards at a small angle."

That it is a fractured warp is true, but the fractures penetrate to some depth; they have been channels for circulating underground water which has decomposed the basalt into a red clay. This clay merges into hard basalt flows, those on the east tilted at a small angle to the south, those on the west at a greater angle to the north-west, and in a few chains disappearing underfoot. The Nepean Peninsula has been lowered on Selwyn Fault. The marine sediments in the Sorrento Bore rest on this tilted surface; they were penetrated to a depth of 1,680 feet, but the bore did not pass through them to the underlying terrestrial beds which are possibly lignites. The difference in the levels of the Balcombian on the relative upthrow side at Mornington and the relative downthrow at Sorrento is over 1,300 feet.

Confined to a narrow shatter belt, there are three, or probably four, definite lines of fracture (Fig. 25), concerned in what is styled the Devilbend Fault. The probable fourth line of fracture is covered by superficial deposits. On the lines of fracture have moved narrow blocks of strata apparently on normal faults, the block on the east side consisting of strata younger than that on the relative upthrow western side. The
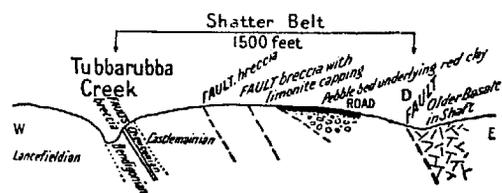
Fig. 25. Section across shatter belt of the Devilbend fault at Tubbarubba.

thickness of the graptolite beds on the Peninsula cannot be estimated with any degree of precision, but the total displacement at Tubbarubba is not less than 1,000 feet. About 4 miles north of Tubbarubba, the shatter belt is seen (Fig. 26) in the valley of Devilbend Creek which has cut its channel along it.

Fig. 26. Section across Devilbend Creek, 4 miles north of Tubbarubba.

There have been repeated movements on the fracture lines. The first movements were probably pre-Tertiary but there have been movements since the

extrusion of the Older Basalt such as that at "D" in Fig. 25. This is the edge of the Bald Hill uplift and there is no evidence of it north of Bore 2 Bittern (sic). This bore was put down on the downthrow side of "D" on the 292-ft. contour, and at 264 feet, 28 feet above existing sea-level, passed through the bottom flow of the Older Basalt (Fig. 27). About a mile south of Bore 2, the basalt can be seen in a shallow shaft 4 or 5 chains east of the road to Merricks on the east side of the Tubbarubba diggings. The Older Basalt has been denuded from the
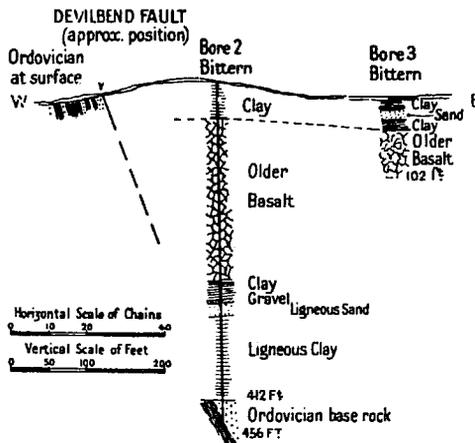
Fig. 27. Diagram showing position of Bore 2 in relation to fault line and the Older Basalt.

upthrow side of the fault, but the bottom flow outcrops 1½ miles south-south-west of Bore 2 at the 450-ft. contour. It is estimated that before it was denuded, the basalt flow opposite the bore rested on a surface about 600 feet above existing sea-level. On these figures, the displacement on the fault elevated the Bald Hill block about 400 feet above the surface of the Moorooduc Plain (p. 32).

There is evidence of the Devilbend Fault as far south as Musk Creek (Fig. 49) where the Flinders Fault crosses the Peninsula. There is no evidence of it south of Musk Creek.

Evidence for the Balcombe Fault is mainly physiographical but the fault line marks a distinct break in the stratigraphical sequence of the base-rock. It is a line of recurrent movements, one of which is discussed later in connection with the Bald Hill and Arthur's Seat uplifts. A post-Miocene movement is suggested by the fact that Balcombe Creek in its middle reaches has cut its valley on the Upper Miocene Baxter Sandstones in the direction of the strike of the underlying base-rock. The Tuerong Fault (Fig. 58) is from 40 to 60 chains east of the Balcombe Fault. Tuerong Creek has likewise cut its valley on the Baxter Sandstones in the direction of the strike of the underlying base-rock and it, too, follows a post-Miocene movement on the Tuerong Fault. Both the Balcombe Fault and the Tuerong Fault are masked by superficial deposits.

From its appearance near Tyabb, Tyabb Fault is a single fracture with the downthrow—the Western Port Sunkland—on its east side. The displacement is about 200 feet (p. 57).

The Flinders Fault has already been discussed in connection with the Older Basalt lavas.

Evidence of faulting across the strike of the base-rock (cross faults) is mainly to be had in the geomorphology; the author has not seen the channel of a cross-fault; yet there is no doubt about their existence. Displacement on them is more apparent on the edge of an uplift block, such as the scarp of the Arthur's Seat uplift, the bold northern face of the Main Spur trending easterly from the Rocks near Dromana. The Main Spur Fault (Fig. 50) is coincident with a line of weakness that probably extends across the Peninsula; the east-south-east trend of the shoreline of Western Port from Point Sumner towards Sandy Point is along this line. There is also physiographical evidence of cross-faulting coincident with the lower reaches of Balcombe Creek upstream from its outlet into Port

Phillip to the confluence of Devilbend Creek. This is referred to (p. 60) as the Chechingurk Fault (Fig. 58), as it is roughly coincident with Chechingurk or Balcombe Creek.

There are examples of a few faults diagonal to the strike of the base-rock. There is evidence of one (Fig. 32) at the south end of the Middle Miocene marls at Balcombe Bay. Its trend is approximately north-east, its displacement about 50 feet, with the down-throw on the south-west side. A diagonal fault reef (Fig. 63) extending for over half a mile and bearing north 31° west occurs near the head of Bulldog Creek. The displacement on this fault has been very small.

IX. THE TERTIARY SEA

The Middle Miocene marine sediments at Flinders, Balcombe Bay, and Grice Creek outcrop approximately at existing sea-level and are seemingly identical with the contemporaneous sediments below 1,310 feet in the Sorrento Bore. The type of sedimentation both in the outcrops and in the Bore is one deposited at a depth of about 200 feet in the neritic zone (low-tide to 600 feet) in an epicontinental

sea, and its homogeneity indicates that it accumulated on a bottom that had attained base-level of deposition in a neritic environment where mud accumulates. It is obvious, then, that the present level of the Middle Miocene beds in the Sorrento Bore is about 1,000 feet lower than the sea-bottom on which they were originally deposited and there has been tectonic subsidence below existing sea-level to that amount.
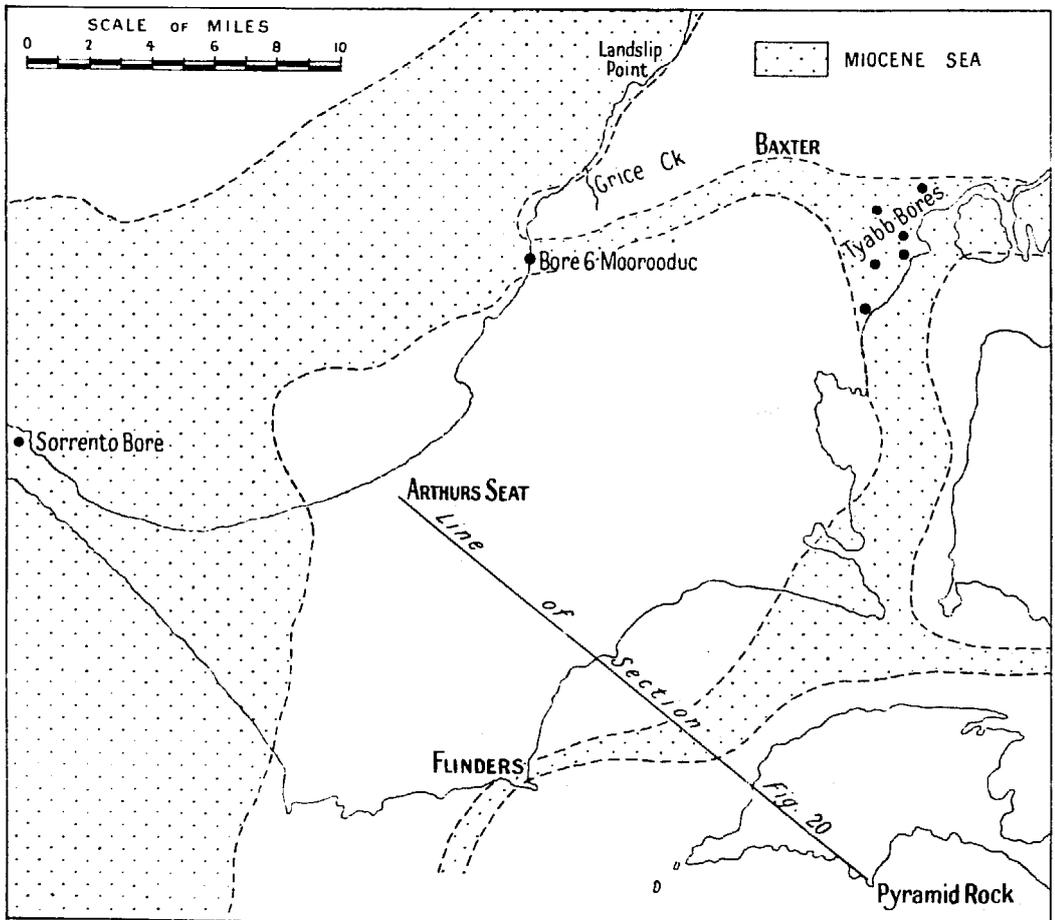
Fig. 28. Probable extent of the Miocene sea.

It is evident, too, that as the outcropping marine sediments together with those near the surface at Tyabb were deposited in the same depth of water as the Balcombian sediments in the Bore, the Port Phillip Sunkland did not start to subside until after the Balcombian sediments had been deposited. Sedimentation during the Miocene was controlled by tectonic movements of the land-surface and oscillations of sea-level. The lowering of sea-level caused increased erosion on the land-surface on the relative upthrow side of Selwyn Fault and the Sunkland was loaded with the denuded material. The influx of denuded material is noticed in the Bore at 902 feet in the upper part of the Cheltenhamian and throughout the rest of the Tertiary.

Brooks (1926) states that, generally speaking, the climatic zones in Europe during the Tertiary lay 10 to 15° north of their present positions. This implies a world-wide high sea-level (Daly 1934) during that period of the order of the high Quaternary sea-levels such as the Sicilian high sea-level, which was 330 feet above existing sea-level (cf. Zeuner 1945). The coarser sedimentation of the upper part of the Cheltenhamian and the Kalimnan suggests a shallowing of the Tertiary sea, presumably the lowering of sea-level mentioned by Suess (1904) as occurring during the Upper Miocene. The sea-level then sank so far that the contemporaneous marine deposits could nowhere be found above present sea-level (Davies 1934). In the Sorrento Bore, this regressive phase appears to have ended before the deposition of the unfossiliferous Werrikooian strata at 490 and 503 feet, which probably represents its culminating lagunar stage.

The drainage of the Western Port system emptied into the Port Phillip system about 20 miles south of what is now Cape Schanck. South-west of the confluence, the trunk-valley, parallel to what is now the Bass Strait shore, passed through the Otway-King Island Gate, emptying probably into the Eocene sea that we know existed (Baker 1943) south or west of Cape Otway. It was through the Gate, passing north-east up the trunk-valley, that the high level sea of the Tertiary encroached to form what is referred to here as the Port Phillip Sound (Fig. 39)—the neritic environment of the Anglesean, Janjukian, Batesfordian, Balcombian, and lower Cheltenhamian faunas.

The Balcombian marls at Balcombe Bay, Grice's Creek, and Tyabb were deposited when the high level Miocene sea encroached on the land-surface on the south-west side of the Sunkland. Twenhofel (1932) states that

" during the times of the geologic past when lands were reduced to low peneplains, slight rises of sea-level extended the neritic environment far into the hearts of the continents and added thousands of square miles to this area."

On the Peninsula, the Miocene transgression submerged the lignites that had accumulated on the floodplains. It is a significant fact that the Tertiary marine beds are not found on the old drainage divides. Apparently the divides were never covered by the Tertiary sea which only submerged the low-lying areas between them. The texture of the shell marls and calcareous clays suggest deposition below wave-base in the embayments; vertical erosion of the graded land surfaces surrounding the embayments was practically non-existent until the Tertiary sea began to recede in the Cheltenhamian.

X. MIOCENE MARINE DEPOSITS

On the Mornington Peninsula, the Tertiary marine transgression was responsible for the deposition of strata, some outcropping, but much of it masked by superficial deposits and revealed by boring. Tertiary strata in Victoria are usually horizontal; there is little deformation, and if a bore has been pushed to some depth, the microzoa in the core may supply reliable evidence as to the succession. The percentage of lime varies in the strata generally referred to by palaeontologists as marls at Balcombe Bay and Grice Creek. The following percentages were determined at the Mines Department Laboratory (Keble 1917):—

	I.	II.	III.
Lime	0·36	20·77	5·33
Lime carbonate	0·64	36·97	9·48

I. Clay from Balcombe Bay. II. Shelly marl containing septaria from Balcombe Bay. III. Shelly clay containing septaria from Grice Creek.

All the deposits owe their lime contents to the shelly material from the Miocene sea in which they accumulated. The deposits were, for the most part, transported from the residual soils arising from the decomposition of the Palaeozoic base-rock shales, mudstone, sandstone, &c.; the soils on the Older Basalt and the granitic rocks also contributed, and possibly to a limited extent those on the Jurassic rocks. The amount of calcareous matter in these residual soils was small.

The Sorrento Bore, put down in the Port Phillip Basin at Sorrento (Fig. 19) on the Nepean Peninsula, passed through Pleistocene deposits into Tertiary strata at a depth of 490 feet and continued in it to a depth

of 1,693 feet. The 1,203 feet of Tertiary passed through consisted almost exclusively of marine beds deposited in the Port Phillip Sound. Singleton (1941) correlated these beds in his tentative table of Tertiary strata, but did not specify depths. His subdivisions are given in the following excerpt from his table. Their probable limits in the bore and the correlation of outcrops further north have been added by the author.

	STAGES		SORRENTO BORE. feet	Outcrops, MORNINGTON PEN.
PLIOCENE	UPPER	WERRIKOOIAN	490–520	
	MIDDLE	ADELAIDEAN	521–584 (provisional)	
	LOWER	KALIMNAN	585–730	
			hiatus(no core)	BAXTER LANDSLIP POINT BALCOMBE BAY GRICE CREEK TYABB FLINDERS
MIOCENE	UPPER	CHELTENHAMIAN	758–1309	
	MIDDLE	BALCOMBIAN	1310–1667	
	LOWER	BATESFORDIAN		
		JANJUKIAN		
OLIGOCENE	UPPER	ANGLESEAN		

Fig. 29. Excerpt from Singleton's Correlation Table of the Tertiary Rocks of Australia to which is added the specific limits of the horizons in the Sorrento Bore and the stratigraphical positions of outcrops on the Mornington Peninsula.
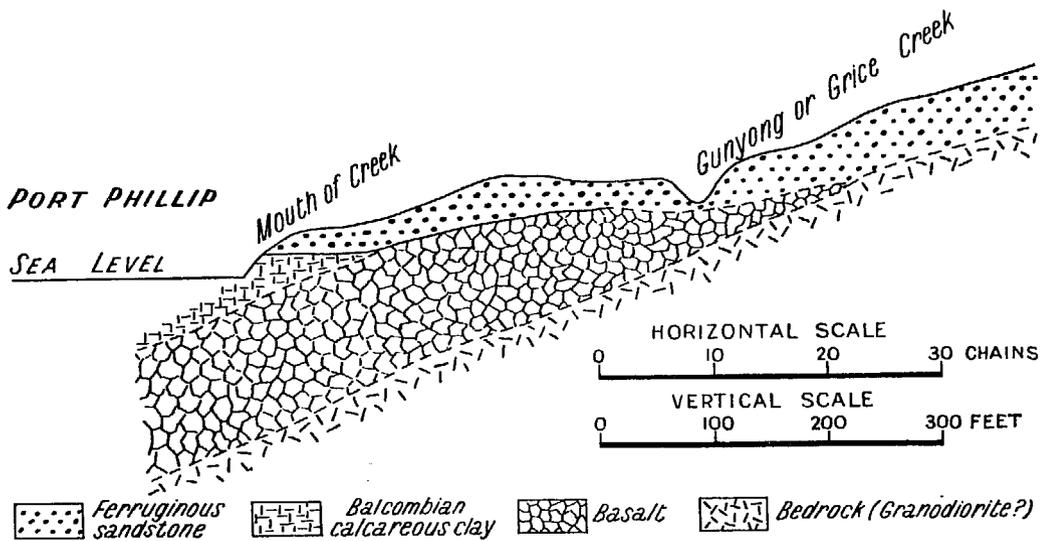
Fig. 33. Section along south side of Grice Creek.

The age of the two shallow water facies—the Landslip Point fossiliferous ironstone and the Baxter sandy claystone—is uncertain. Chapman (1921) endeavoured to show that the age of the Landslip Point ironstone is Janjukian in conformity with his conception of the Tertiary succession. He pointed out that *Ditrupa cornea* var. *wormbetiensis* McCoy, *Terebratula* (?) *aldingae* Tate, *Chlamys* (*Pecten*) *praecursor* Chapman, and *P.* [cf.] *flindersi* Tate are restricted and typical Janjukian forms. In the Sorrento Bore, *Ditrupa cornea* var. *wormbetiensis* ranges from Pliocene into the Miocene, through the Kalimnan sand-rock into the lower part of the Cheltenhamian marl, but not into the Balcombian marl. It is known, however, that its range is from basal Balcombian to Kalimnan. *Terebratula aldingae* is a typical Janjukian form. *Chlamys* (*Pecten*) *praecursor* is not recorded from the Sorrento Bore. Hall and Pritchard (1901) record from Landslip Point *Chlamys* (*Pecten*) *dichotomalis* Tate, which Singleton considers to be a less common but apparently restricted fossil of the Balcombian, also *Bathytoma rhomboidalis* (T. Woods) and *Vaginella eligmostoma* Tate, regarded by him as characteristic of the Balcombian. The evidence seems to favour a Balcombian age for the Landslip Point ironstone.

From the Watson Creek sandy claystone Chapman recorded *Chlamys* (*Pecten*) *praecursor* and a number of indeterminate fragments of polyzoa. He concluded that

"these polyzoa are in such abundance as to lead one to infer that the ironstone is largely a replacement of a limestone comparable to the polyzoal rock at Batesford and Grange Burn . . . ."

His inference regarding replacement is open to question, but Miss Irene Crespin, B.Sc., Commonwealth Palaeontologist, who examined the claystone confirms his identification of *Chlamys* (*Pecten*) *praecursor*; she also found *Lepidocyclina howchini* Chapman and Crespin, which definitely establishes, in her opinion, the age of the claystone as upper Middle Miocene.

25. Low cliff of Miocene marl, Balcombe Bay.

XI.   BAXTER   SANDSTONES

The Tertiary fluviatile ferruginous sandstones spread widely over the Peninsula are referred to here as the Baxter Sandstones. They are found more particularly over the middle and northern portions and overlie the Older Basalt where its surface has been reduced to one of low relief. They are not, however, found on any parts of the Bald Hills and Arthur's Seat uplift blocks.

When the Miocene sea receded, vertical erosion of the emergent land surface commenced and extended to those surfaces that surrounded the Middle Miocene embayments. In the initial stage of this cycle sediment was removed from one place and deposited at a lower level. Denudation continued for a longer period on the more elevated portions while the lower portions were being covered. Thus we find the overlying sandstones at Balcombe Bay, Grice Creek, and probably those at Tyabb, separated by a sharp line of demarcation from the underlying marls, for the surface of the marls had been denuded before the fluviatile Baxter Sandstones were deposited on it. The sandy claystone at Watson Creek was deposited in a low-lying part of the valley. At the same time, headward erosion to the west by both Watson Creek and Balcombe Creek formed the saddle known as Baxter Gap. At Watson Creek, where the deposition of the Baxter Sandstones quickly succeeded the deposition of the shallow penultimate phase of the Upper Middle Miocene deposition and there was little erosion, one would expect a less defined line of contact. Unfortunately, this is not exposed, but the narrow width of the valley suggested by the proximity of the base rock implies this. As the marls are not

GENERALIZED SECTION
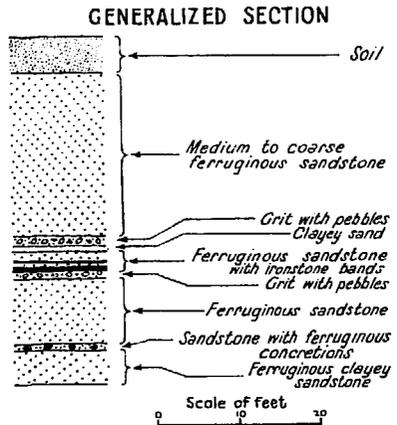
Fig. 34. Section of Baxter Sandstones in road cutting on the Moorooduc-Mornington Road.

present at Landslip Point, the relationship to the fossiliferous ironstones is uncertain. The slipped nature of the section adds to this uncertainly (cf. Kitson 1900). We do not know the age of the beds underlying the ironstones, but those overlying them are apparently freshwater beds that may be portions of the Baxter Sandstones.

Thus, the junction between the marine sediments and the Baxter Sandstones represents a period that varies in length; its duration at a particular locality depends on when the erosion of the underlying marine

26. Mornington. Cliff of Baxter Sandstones and the beach resulting from its disintegration.

sediments ceased and the accumulation of the fluviatile sandstones began, which varies from place to place.

In the Tyabb Bores, the sandstones are 42 feet thick (Fig. 30). In the cliff section at Balcombe Bay they are 36 feet thick, which is the thickness of the edge of a land-slipped area; inland behind the slip they are 50 feet thick (Fig. 32). Near Davy Bay they are about 100 feet thick.

The fluviatile character of the sandstones is well shown in a section in a cutting on the Moorooduc-Mornington road, 3 miles south-east of Mornington Jetty, on the east side of Balcombe Creek. There a cross-section of a valley is defined by a seam of grit and small pebbles. The texture of the sediment below the floor of the valley is finer than that deposited in it. Its profile suggests that the covered land surface was one of low relief which was levelled out by the accumulation of fluviatile sediments; this levelled surface was again dissected and the same cycle passed through to be again and again repeated. The

sandstones are many-times-resorted fluviatile deposits. The sedimentation was comparable to that in the formation of a delta. Their major part was derived from the denudation of the Palaeozoic base-rock and granitic rocks, and the uncovered sub-basalt beds and Older Basalt itself also contributed their quota. Their thickness represents denudation over a considerable period—denudation that may have extended through the Upper Miocene, possibly into the Pliocene. Since, on the Peninsula, the sandstones rest disconformably on Upper Middle Miocene sediments and some time lapse must be ascribed to the disconformity, they are placed in Singleton's Upper Miocene, Cheltenhamian. Crespin (1943) in her subdivision of the Gippsland Tertiaries regards the Cheltenhamian as a facies of the Kalimnan (Pliocene) and erects a new stage, the Mitchellian, which she states overlies the Balcombian and underlies the Kalimnan. Stratigraphically, the Baxter Sandstones seem to fall into the Mitchellian. Their general coarseness is suggestive of deposition in a climate of ample rainfall consistent with that implied in connection with the Upper Miocene.

XII.   PLIOCENE CLAYS AND SANDS

Overlying the Palaeozoic base-rock and Older Basalt at many places on the Peninsula there is a succession of terrestrial, unfossiliferous clays, sandy clays, sandy loam, and sands. It is best developed east of the Devilbend Fault where it reaches a total thickness of 50 feet.

Since the sand in the strata is presumed to have been derived from the Baxter Sandstones and the surface layers of the strata have been dissected by streams that had their beginnings in the Pleistocene, its age is considered to be Pliocene. In the Sorrento Bore, attention has been called to the coarsening of the sedimentation of the marine Miocene Cheltenhamian (746 to 902 feet) and the Pliocene Kalimnan (585 to 741 feet). These coarser marine phases had their terrestrial equivalents. The terrestrial phase contemporaneous with the Cheltenhamian is taken to be the Baxter Sandstones; the above-mentioned clays, sandy clays, sandy loams, and sands are contemporaneous with the Kalimnan.

The following are some records of it from bores:—

Bore 2, Bittern.		Bore 3, Bittern.		Hastings Bore, Bore 6, Tyabb.	
	Thickness.		Thickness.		Thickness.
	ft. in.		ft. in.		ft. in.
Surface soil ..	2 0	Surface soil..	1 0	Surface sands,	47 0
Red and white clay	26 0	Red clay with ironstone	11 0	clays, and ironstone	
Blue clay with ironstone bands	7 0	gravel		Older basalt..	5 0
		White sandy clay	3 0		
Variegated clay	15 0	Red and yellow sand	13 0		
Basaltic clay..	6 0	Ligneous clay	6 0		
Older basalt..194	0	Basaltic clay	23 0		
		Older basalt	43 6		

XIII.   BALD HILL AND ARTHUR'S SEAT UPLIFTED BLOCKS

The Bald Hill and the Arthur's Seat uplifted blocks (Fig. 35) are raised portions of the Palaeozoic base-rock and granite together with their cover of Older Basalt, and in regard to the Arthur's Seat block its cover of Lower Pleistocene dune-rock. Before they were raised, the surfaces of the uplifts were southerly extensions of the Moorooduc Plain.

The Bald Hill block moved on the Devilbend Fault on the east, the Balcombe Fault on the west, and a diagonal fault or warp on the north; southwards it extends to the Bass Strait coastline. The amount of uplift was about 400 feet; its highest point, a short distance east of Arthur's Seat, is 800 feet above existing sea-level. It was uplifted in the early part

of the Pleistocene or more likely in the Pliocene, for resting against its western side is calcareous dune-rock believed to be of Lower Pleistocene age.

The Arthur's Seat block moved on Selwyn Fault on the west, Balcombe Fault on the east, Main Spur Fault on the north; southwards it extends like the Bald Hill block to the Bass Strait coastline. Its highest point is Arthur's Seat (1,031 feet). Granitic rocks outcrop at its northern end. Further south these are covered with Older Basalt which, however, has been dissected by streams deeply enough at some places to expose the underlying granite. Still further south, for a distance of 5 miles, the basalt is covered by freshwater sands piled up in places into dunes.
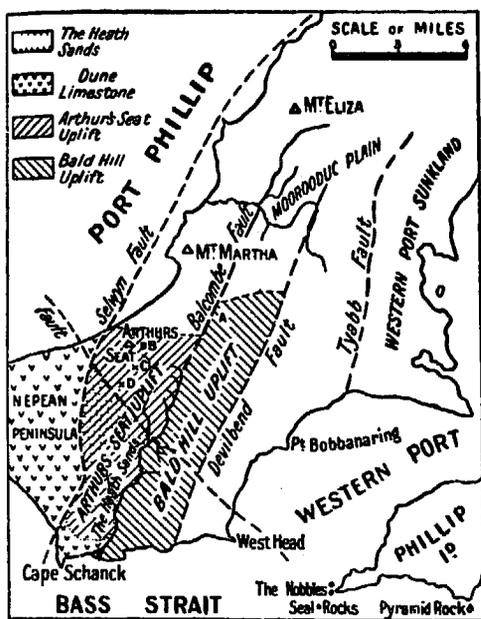
Fig. 35. Map showing extent of the Bald Hill and Arthur's Seat Uplifts. A, B, C and D, Pebble Bed deposits.

varying elevations of the Pebble Beds (Fig. 37). Taking as a datum the surface of the Moorooduc Plain assumed to have been about 200 feet above existing sea-level, there have been uplift movements of the Arthur's Seat block, a first movement, one *en bloc*, of about 300 feet above the datum, a second of the portion north of Drum Drum Alloc Creek of about 200 feet, and a third movement, the most recent uplift of it, *en bloc* of 100 feet. As these estimates are based on an assumed datum, and tilting has to be allowed for, they are only approximations.

The marginal valley in which the Pebble Beds were deposited was across the line of Selwyn Fault (Fig. 51) about half-way between where the fault passes on to the Peninsula near Rosebud and leaves it 1·5 miles north of Cape Schanck; the fault line is, throughout this distance, masked by superficial deposits. The blunted scarp of the Devilbend Fault can be seen in the distance on the west side of the road between Shoreham and Flinders, and has been breached by the deep valleys of the tributaries of Manton Creek. The high ground on the upthrow side is locally known as the Bracken.

The bathymetrical contours south of the Bald Hill and Arthur's Seat uplifted blocks show the Quaternary trunk-stream flowed to the south and east (Fig. 36). The Tertiary trunk-stream flowed to

This tract is locally known as the Heath and the sands are referred to here as the Heath Sands. Outcropping at some places through the Heath Sands are inliers of Older Basalt. About two miles from the Bass Strait shore, the uplifted block is covered by the calcareous dune-rock referred to. In the coast sections this is seen directly to overlie the Older Basalt and it is inferred from its position that it is an easterly extension of Lower Pleistocene (Mindel or Malanna) dune-rock from 428 to 398 feet in the Sorrento Bore that has been raised on the uplift. This being so, the Arthur's Seat block was raised towards the close of the Lower Pleistocene or the beginning of the Middle Pleistocene, somewhat later than the Bald Hill block. This contention is supported by the distribution of the Heath Sands which had their origin mainly in the disintegration of the calcareous dune-rock. The sands together with the dune-rock are restricted to the Arthur's Seat block and are not found on the Bald Hill block. It will be noticed in Fig. 35 that the line separating the two blocks is the channel of Main Creek; the fault line is not actually the creek channel, but its direction approximates to it.

Cross-faults have subdivided the Arthur's Seat block into one or more minor fault-blocks, the displacement of which is accompanied by tilting. The tilting shows plainly in sections of the Older Basalt lava flows—those in the cliff sections north of Cape Schanck and on the east side of Main Creek north of its outlet to Bass Strait. The lines of these cross-faults are generally masked by superficial deposits, but the movements on them are evident from the
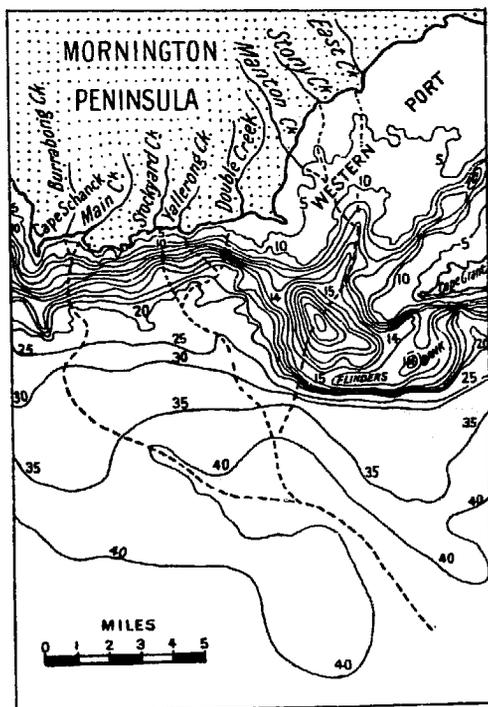
Fig. 36. Bathymetrical chart south of Arthur's Seat and Bald Hill Uplifts.
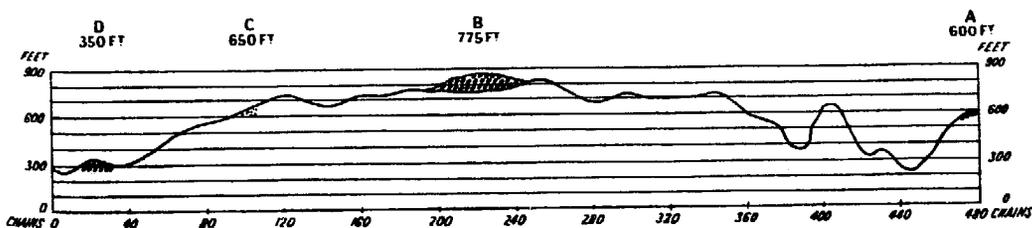
Fig. 37. Section showing altitudes of Pebble Bed deposits.
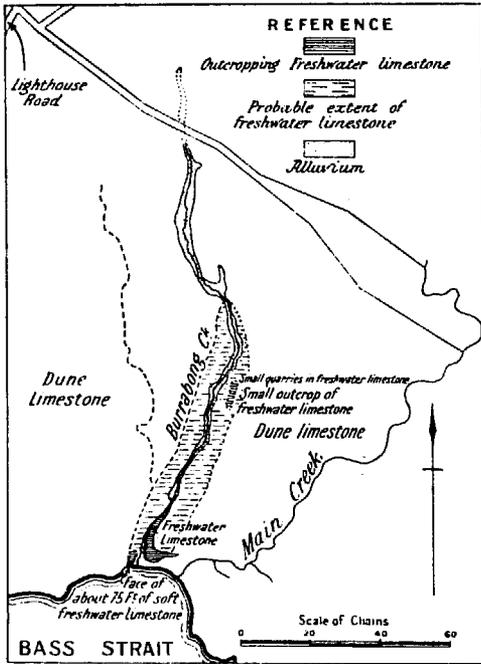
Fig. 38. Freshwater limestone in the valley of Burrabong Creek.

the south-west; the change in direction is doubtless closely connected with the raising of the blocks. The Tertiary valley of the Burrabong Creek was formed before the lignitic period, for resting on its initial flood-plain is lignite underlying freshwater limestone (Fig. 38). Burrabong Creek rises about ¾ mile east of what is known as the Black s Camp at the junction of the Cape Schanck Lighthouse road with the Rosebud-Flinders road. By some obstruction, now covered by the waters of Bass Strait, its valley was dammed and a lake formed behind the barrier; in this lake the freshwater limestone accumulated. This limestone was later covered by the Lower Pleistocene dune-rock previously referred to, and through this the present valley has been cut to a depth of 300 feet. It is one of the few examples of a stream being cut out in dune-rock and this was made possible by the shallow depth of the impervious freshwater limestone.

The conglomerate up to 3 feet thick (Fig. 13) exposed in the road cutting on the coast road at The Rocks is, according to Baker (1938), 40 feet above sea-level at its eastern end, and from 15 to 20 feet above it 100 yards to the west. Resting on it are sands up to 50 feet thick containing sporadic pebbles. The conglomerate apparently rests on a wave-platform obviously cut after the Arthur's Seat uplift; its age is late Pleistocene.

XIV. PORT PHILLIP SUNKLAND

The Port Phillip Sunkland is a fault-block tapering from a width of more than 50 miles where it opened on to the Southern Ocean through the Otway-King Island Gate, to about 10 miles north-west of the Mornington Peninsula (Fig. 39). It has been lowered on two lines of movement trending south-south-west, Selwyn Fault and the Bellarine Fault, and also, within itself in regard to its southern portion, on a third and old line of movement at right angles to the other two faults, the so-called Flinders Fault. The southern portion has been lowered 1,600 feet.

Before the submergence of the Port Phillip Sunkland in the latter half of the Miocene, the area was drained by the trunk-stream of the post-Older Basalt Cycle. Towards the close of the Eocene, the valley of the trunk-stream was invaded slowly by the Tertiary sea and partly submerged. The subsidence of the Sunkland brought about its complete and deep submergence by the Miocene and Pliocene sea, and Port Phillip Sound in its late Tertiary form came into existence. Towards the close of the Tertiary, the Pliocene sea receded and the Werrikooian emergence occurred. This was followed by the alternating periods of submergence and emergence of the Pleistocene or Ice Age. Geologists time the various stages of the Ice Age in years by absolute chronology, but owing to the fact that its lowest limit has not been definitely fixed, their estimates differ. Accepting the Gunz, an early glaciation, as the first stage, a total duration of 600,000 years for it was fixed by Penck (1909), and this agrees closely with the astronomical scale (Zeuner 1945). In the time scale published by Holmes (1944) its duration is given as 1,000,000 years.
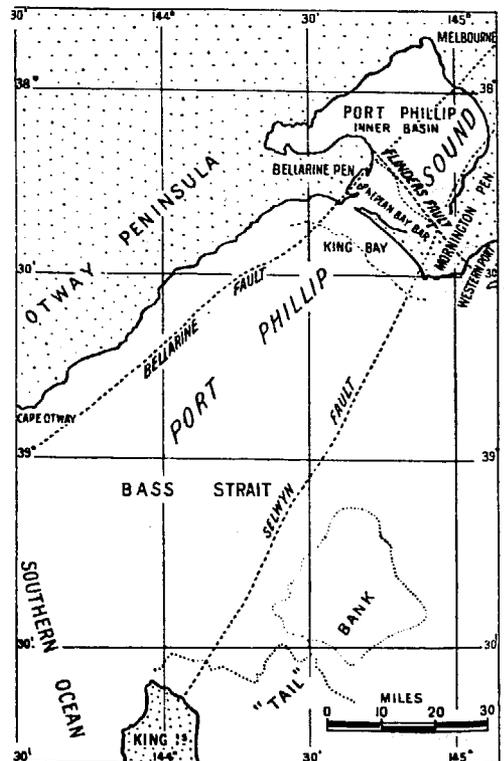
Fig. 39. Map showing Port Phillip Sound and Sunkland and the fault lines on which the latter moved.

In the Northern Hemisphere, the subdivisions and the time-intervals since they occurred, based on the astronomical scale, are as follows:—

Glacial and Interglacial Stages.	Symbol.	Years.	—
Würm or last glaciation. Three cold phases	W3 W2 W1	25,000 72,000 115,000	Upper Pleistocene
Last interglacial	R/W	..	
Riss or penultimate glaciation. Two cold phases	R2 R1	187,000 230,000	Middle Pleistocene
Great interglacial or penultimate interglaciation	M/R	..	
Mindel or antepenultimate glaciation Two cold phases	M2 M1	435,000 476,000	Lower Pleistocene
Antepenultimate interglacial ..	G/M	..	
Gunz or early glaciation. Two cold phases	G2 G1	550,000 590,000	

Contemporaneous with the Würm, Riss, and Mindel, it is thought, are the Tasmanian glaciations (Lewis 1945), and those of Mount Kosciusko (David 1923); these have not been subdivided into their cold phases. A broad correlation is as follows:—

Tasmania (Lewis, 1945).			Kosciusko (David, 1923).
Würm ..	Margaret ..	Small moraines and cirques	Mountain tarn stage
Riss ..	Yolande ..	Moraines and cirques	
Mindel ..	Malanna ..	Moraines ..	Kosciusko–Snowy River moraines

There are apparently no traces of the Gunz in Tasmania or Kosciusko, and significantly, there is no terrestrial deposit in the Sorrento Bore that could be correlated with it. Nevertheless, according to Tindale (1933) its existence is implied by the Cave Range, a coastal terrace in south-east South Australia.

Port Phillip came into existence as a bay when, at the beginning of the Ice Age, the Nepean Bay Bar formed across the Port Phillip Sound from the Bellarine Peninsula to the Mornington Peninsula. It appears from the record of the Sorrento Bore (479-435 feet) that after the Werrikooian emergence much of the Port Phillip Sunkland was covered by sea which encroached on the valley of the Pleistocene Yarra to form the open bay in which was deposited the products of denudation from the Werrikooian land-surface and that transported by currents. The transported material carried by currents from the south-west accumulated to form a spit that projected from the western portal, Point Lonsdale in its Pleistocene position, across the Port Phillip Sound towards the higher ground near Cape Schanck, the eastern portal. Parr (1946) examined the microzoa from the core of Bore 5 Wannaeue, 10 chains south of Bore 4, referred to here as the Wannaeue Bore (Fig. 59), which penetrated the strata of the Bay Bar to a depth of 282 feet. The core examined was

from the Pleistocene marine deposits laid down on the 210-ft. platform (Fig. 42), and in it he found Miocene forms that he inferred were carried thither along a tidal channel, presumably forms derived by coastal erosion from the Balcombian, Janjukian, and Angelsean deposits on the Bass Strait shore of the Bellarine or Otway Peninsulas.

Since the Nepean Bay Bar had its beginning in the early part of the Ice Age, the column of strata comprising it should reveal the changing conditions of that age. During the glacial stages, part of the earth's hydrosphere was held in the ice caps and there were regressions of the sea, the area of the land surface was increased, and on the emergent parts of the Bay Bar dune deposits accumulated. During the relatively warm interglacial stages, the ice caps more or less melted, the water was returned to the oceans and sea-level rose; the areas that had been uncovered during the glacial stages were again flooded and on them accumulated marine and estuarine deposits.

The Sorrento Bore, although it passed through the whole column of glacial and interglacial strata, gives us a very incomplete record of the 489 feet of Pleistocene strata bored (Chapman 1928); the samples were taken, on the average, 22 feet apart, with some as much as 40 feet. For the upper part of this thickness, we have a check section in the core of the Wannaeue Bore (Keble 1946) which penetrated the Pleistocene to a depth of 262 feet. Every part of the core was examined by the author as it came to the surface. In a general way, it corroborates the record of the Sorrento Bore as to the extent and alternation of terrestrial and marine phases. The marine deposits from both bores contain marine organisms indicative of estuarine or shallow water conditions; these consist of sands, sandstone, grits, clays, shallow water limestones, and drift, the drill foreman's term for material drifted in from outside the Bay Bar. These marine deposits overlie a platform of dune-rock and are overlain by dune rock. It is probable that the marine deposits were somewhat thicker, and portions of them have been incorporated in the overlying dune-rock.

The lowering of sea-level during the Mindel glaciation uncovered the spit that was to be the foundation of the Bay Bar and it was piled up into dunes (428-398 feet). When the sea-level began to rise again in the succeeding interglacial stage (387 feet), the dune surface was levelled by wave action and submergence, forming a platform on which the marine clay at 387 feet was laid down. In the core of the Sorrento Bore there is a record of seven such cycles and in the Wannaeue Bore four. Fig. 40 is a synoptic record of both the Wannaeue and the Sorrento Bores correlated with what are thought to be the glacial and interglacial stages. The depths given in each bore log are those below existing sea-level.

NOTE.—A synoptic record of the Wannaeue and Sorrento Bores is shown on the following page.

WANNAEUE BORE	SORRENTO BORE	EUROPEAN STAGES	TASMANIAN STAGES

Dune-sand and rock

32'
41'
43'

Dune-sand and rock

85'
91'
98'
102'
112'
Drift
117'
122'
Dune-rock

153'
Clay
170'
Drift
Dune-rock
186'
Drift
204'
Clay
210'

236'
Dune-sand and rock
246'
Dune-rock
256'
Heavy drift
262'

SORRENTO BORE:
57' Dune-rock
102' Dune-rock
120' Dune-rock
157' Dune-rock
168' Dune-rock
197' Marine shallow water limestone
216' Dune-rock
259' Marine shallow water limestone
265' Clay
288' Dune-rock
314' Marine calcareous quartzose sand & grit
333'
378' Dune-rock
387' Marine clay
398' Dune-rock
406' Dune-rock
420' Dune-rock
428' Dune-rock
435' Shelly beach sand
450' Marine clay
466' Marine calcareous sandstone
479' Estuarine clay

EUROPEAN STAGES:
Wurm 3
Interglacial
Wurm 2
Interglacial
Wurm I
Interglacial
Riss 2
Interglacial
Riss I
Great Interglacial
Mindel 2
Interglacial
Mindel I

TASMANIAN STAGES:
Margaret
Yolande
Malanna

Fig. 40. Synoptic record of Bore 4, Wannaeue and Sorrento Bore.

XV. LATER STAGES IN THE DEVELOPMENT OF PORT PHILLIP

On the mainland, the Pleistocene land surfaces are completely buried by overlying deposits, but the bathymetrical contours of Bass Strait and Port Phillip show portions of them. To a depth of 35 fathoms the contours of Bass Strait show (Fig. 41) by their transverse direction the outer face of the upper part of the Nepean Bay Bar resting on a surface with contours typical of fluviatile dissection. Indicated by loops in the transverse contours are the outlets of the old tideways.

Fig. 41. Bathymetrical chart of Bass Strait showing the outer face of the Nepean Bay Bar.

From time to time, tideways change their direction and also their outlet, but they do not lose level like a river channel; the floor of their channel is level, as, too, is the platform on which they have been scoured out. That being so, the footage below low-water mark of the platforms on the outer face of the Nepean Bay Bar should correspond with that of the platforms in the Wannaeue Bore. In the section (Fig. 42) of the profile of Bass Strait, south-south-west from The Heads, the 120, 210, and 264-ft. platforms are undoubtedly the southern extensions of the 122, 210, and 262-ft. platforms on which the high sea-level estuarine deposits of the Wannaeue Bore rest. Above

10 fathoms the section of the floor, masked by shore debris, does not show the platform representing the 41-ft. clay band in the Wannaeue Bore.

It has been suggested (Keble 1946) that in Port Phillip, the interglacial high sea-levels are probably indicated by the submerged tilted terraces (Fig. 43) on the sides of the Inner Basin of that bay. These terraces are considered to be of eustatic not fluviatile origin.

What has occurred repeatedly during the formation of the Nepean Bay Bar, is now happening in the shoal-waters at the south end of Port Phillip. We must consider it in the knowledge that the present, the Postglacial, is actually an interglacial stage that has passed its Optimum. Sea-level was at its highest some thousands of years ago, and, with the approach of the prospective glacial stage, is now falling. Evidence of its maximum height in the Postglacial is in the 15 to 20 feet raised beach found at many places on the shores of Port Phillip Bay (cf. Hills 1940) and Bass Strait.

The floor of Port Phillip in the shoal water area consists of shoals—the Great Sand, South Sand, Middle Sand, and others, separated by such tideways as the West Channel, Symonds Channel and South Channel (Fig. 45). The tideways were scoured out by the rising sea after the second last cold phase (W2) by the ingoing and outgoing tidal streams. The rivers and streams emptying into the Inner Basin (Fig. 39) added to its water content and increased the scour of the outgoing tidal stream. Although the scour has been of some intensity, it has not inhibited the deposition of fine sediment in the tideways; the author was informed by one who was engaged in dredging the main channels that the type of material removed was a black silt. The present ingoing tidal stream sets east-north-east across the Middle Ground and through Pinnace Channel, one of the lesser channels, but the outgoing stream passes obliquely through the various channels. The deposition of fine sediment has not however, been restricted to the tideways. Mud Island was covered by the Postglacial sea to a depth of from 10 to 15 feet. The surface of the islands was the bottom of that sea and consists of a sandy mud deposited in probably its shallowest part and well away from a tideway.

The surface of the Nepean Peninsula remains as it was when it formed during the last glacial stage (W2); very little of it has been submerged by subsequent high sea-levels. There was an oscillation of the Port Phillip Sunkland in the late Pleistocene that raised

Fig. 42. Profile of Bass Strait along line S. 18° W. from the middle of the Fairway through The Heads.

Fig. 43. Bathymetrical chart of Port Phillip and section of floor.

Fig. 44. Shoal-water of Port Phillip.

a large part of the Peninsula beyond the reach of sea-level. As evidence of the terrestrial origin of the surface deposits, there is the record of the extinct kangaroo described by Gregory (1901).

There was a tideway—the Tootgarook Tideway, the former channel of which can be clearly discerned from a point of vantage on Arthur's Seat and which is now partly occupied by the Tootgarook Swamp (Fig. 59); it had an outlet to Bass Strait about 3 miles north-west of Cape Schanck. A tideway in this position could be accounted for either by subsidence or the possibility that the dune series of the second cold phase did not reach the eastern portal of the Nepean Bay Bar. Chapman (1919) identified a number of fossils from a shell-marl in the swamp. He listed both marine and fresh water species and suggested that the marine shells indicated some antiquity, a Pleistocene age. The level of the Swamp is under 20 feet above sea-level and the presence of the marine shells could possibly be due to the transgression of the Post-glacial high sea-level.

Hills (1940) draws attention to the gradual fall in elevation of the Recent raised beaches from near Sorrento towards The Rocks near Dromana and infers that the emergence was caused, at least in part, by tectonic movements. He says that at the site of the First Settlement overlooking Sullivan Bay near Sorrento, the raised beach is 5 or 6 feet above high water-level and rests on the flanks of the Pleistocene consolidated dunes, but in a short distance it passes into horizontal shell beds about 3 feet above high water mark, and at Rye into well stratified beach sands. Overlying these beach sands at places are loosely cemented dunes which are, too, therefore of Recent age. Between Rye and The Rocks, he states, at all localities where exposures are visible, there are stratified beach deposits ranging from fine sand to coarse broken shells underlying the kitchen middens and superficial sand drifts along the coast. The elevation of these beach deposits ranges up to 4 feet above high water level. They are in places overlain by low sand ridges with intervening swales. He states:

"The above beach deposits and shell beds appear to have been originally laid down below high water mark to judge by similar formations along the existing beaches. This is indicated by the arrangement of the shells in well-defined layers, the majority lying with their convex surfaces uppermost. The common occurrence of paired valves and

of unworn shells, even of fragile types, further points to the deposition below swash mark, possibly between low and high water level, or even lower. In the beach sands the stratification is well defined by coarse and fine layers or by black bands rich in magnetite, ilmenite, and other heavy minerals such as zircon."

Selwyn Fault and also the Flinders Fault cross the coast between Rye and The Rocks (Fig. 43) and had there been any appreciable Recent movements on them, such would certainly show in the section. The uplift that placed a large part of the Nepean Peninsula beyond the reach of the recent high sea-level occurred in the late Pleistocene. One could ascribe it to the movement responsible for the tilting of the eustatic terraces of the Inner Basin and it is suggestive that The Fairway through The Heads is near the lowest part of the tilted area, near the Bellarine Fault (Fig. 41).

The main tideways of the southern portion of Port Phillip were scoured out in the interglacial (W2/3) between the second and last cold periods. Their average depth (7 or 8 fathoms) corresponds with the depth (41 feet) of the interglacial clays in the Wannaeue Bore. The whole area covered by the shoal-waters appears to have been covered by the dune-sand of the last glacial period; it not only covered the area between the tideways, but filled in the channels. Most of it has been removed from the channels by the scour of the Postglacial high sea-level, but parts of it still clog those portions of the channels near the Inner Basin.

In Capel Sound (Fig. 44) there is a scour-hole near its western end. A scour-hole is evidence of the former existence of a tideway (Keble 1946). This tideway in the vicinity of Sorrento connected Port Phillip with Bass Strait about the same time as the Tootgarook Tideway and, like it, was clogged with sand. Its outlet is indistinctly visible at the 10 fathom contour of Bass Strait, obscured to some extent by inshore debris. Its channel could not have been deeper than the average depth of Capel Sound—41 to 48 feet.

The waters of Bass Strait are encroaching rapidly on the Nepean Peninsula. At one place on the Bass Strait shore, the author saw a kitchen midden that was covered by the rising tide; it was formerly well above high water level, but foreshore erosion had lowered en bloc the dune-rock on which it rests.

The Mud Islands group in Port Phillip, 4½ miles north of Sorrento, consists of four islets of a total area of over 250 acres built up on an outcrop of Pleistocene consolidated dune-rock protruding through the shallows known as the Great Sand. The group has an atoll-like configuration—a circle of elongate islands enclosing a relatively large tidal lagoon. Except along their outer fringes, where dunes are being piled up, the surface is flat, about 5 feet above low-water mark. On the islands are petrel rookeries from which guano was obtained during the middle decades of last century. A section exposed at the main guano deposit is as follows:

(a) dune sand still accumulating and probably contemporaneous with the loosely compacted dunes resting on the raised beach between Sorrento and Dromana.

(b) guano.

(c) sandy mud, the sand of which is being sorted out and built up into dunes.

(d) shelly limestone consisting of Recent shells loosely cemented. The limestone layers dip to the southwards.

(e) Pleistocene dune-rock comparable with the Pleistocene dune-rock on the Nepean Peninsula.
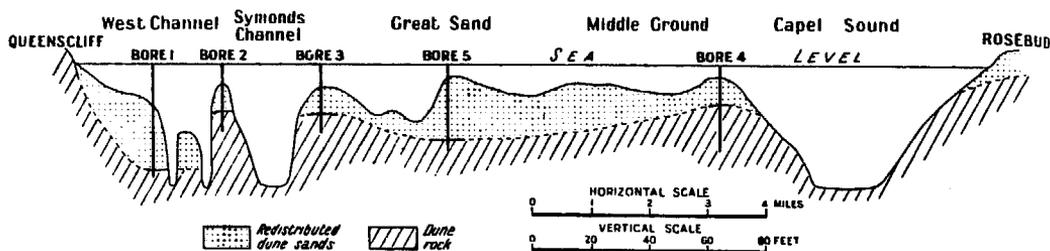
Fig. 45. Sketch section through shoal-water area.

If the early charts are reliable, the configuration of Mud Island has been considerably modified in the last 80 years by progradation at some places and coastal erosion at others. It has been pointed out that the group was covered by the high sea-level of the Post-glacial optimum; assuming a progressive fall of sea-level, the islets were uncovered 3,000 or 4,000 years ago.

From what has been stated regarding the development of Port Phillip Bay, it has been in existence during periods of high sea-level for about 500,000 years; it assumed its present configuration about 10,000 years ago and has departed from it very little since. During periods of low sea-level, it ceased to exist as a bay but possibly as an inland lake or probably as a large swamp.

XVI.   DUNE   DEPOSITS

Dune deposits have been discussed in the preceding pages more particularly in connection with the fluctuations of sea-level, but the origin of the wind-blown sand, as well as its distribution, is important both from a scientific and an economic standpoint.

The dune sands of the Mornington Peninsula fall into two classes—a calcareous type containing about 25 per cent of quartz sand and a high percentage of calcareous matter, and a siliceous type consisting almost wholly of quartz sand. The dune accumulations of the calcareous type are restricted to the Nepean Peninsula and the southern portion of the Arthur's Seat uplift block. The siliceous type covers most of the northern portion of the Peninsula, extending from Port Phillip to Western Port. Much of the Western Port Sunkland north of Hastings is covered with it, and it extends some distance inland from the shoreline between Mornington and Mount Martha. There are deposits on the shoreline of Western Port. In the interior of the Peninsula, small deposits are found at a number of places—at the Jaen Jaen Swamp at Moorooduc, in the valley of the Devilbend Creek near Moorooduc, at Somerville on the relative upthrow side of the Tyabb Fault, and elsewhere.

The dune areas had an important bearing on the settlement of the Peninsula; the soil of a dune tract is invariably poor and for that reason sparsely settled. The soil on the calcareous dunes is grassed during the winter months and the early settlers transferred their stock there at that time to spell their richer paddocks on the volcanic soils.

The main source of the siliceous sand was the Baxter Sandstones when they were disintegrated by the removal of the clay which bonded the sand in them; some of it came however, from the disintegration of the calcareous dune-rock. It is apparent that the age of the dunes is later than the disintegration of the parent rock. If this was the Upper Miocene Baxter Sandstones, it could be Pliocene or younger; if the Lower Pleistocene dune-rock, Middle Pleistocene or

younger. The Baxter Sandstones are not found on the Bald Hill or Arthur's Seat blocks, nor is dune-rock found on the former, except along its western edge. There are no dune sands on the Bald Hill block. The Heath sands were derived, for the most part, from the Lower Pleistocene dune-rock on the southern part of the Arthur's Seat block. Some of these sands have been redeposited, for they reach to the bottom of the valleys of Drum Drum Alloc Creek and Main Creek. Both these creeks were rejuvenated after the Arthur's Seat uplift.

The dune sands on West Head, resting on sands and clays up to 20 feet thick, are remnants of the bar across the Western Passage; they are redeposited siliceous sands derived from the Baxter Sandstones; there has not been an accession of calcareous material as on the Nepean Bay Bar.

Cross-bedding in the Pleistocene dune-rock of the Nepean Peninsula is evident in the cliff sections of Bass Strait and Port Phillip. The dune-rock has been consolidated by the downward passage of meteoric waters which dissolved the calcareous matter and redeposited it; the dune-rock is too porous to hold surface water. The layers, inclined in many directions, imply winds from all quarters. In the cliffs of Bass Strait a short distance north-west of Selwyn Fault, on its downthrow side, the sandfall-slope is to the east. The sand was evidently impelled by a west or south-west wind, driven against the scarp or flexure of the fault, and carried upwards towards the surface of the Arthur's Seat block.

There is a belt of moving dunes on the shore of Bass Strait of an average width of a quarter of a mile. An early settler informed the author that these moving dunes have formed since the shoreline was denuded of its timber and scrub; exposed to the wind and weather, the dune-rock commenced to disintegrate, the calcareous matter was removed, and the siliceous sand residue was piled up into dunes. In the same way the

dune-rock on the higher ridges and knolls, where it is exposed to the prevailing wind, is being rapidly disintegrated. One can visualize the whole of the Nepean Peninsula relapsing into its former state as an area of unconsolidated and shifting dune sand—a veritable desert. The sand of the shoreline belt shifts from time to time and exposes trees that were enveloped where they grew, the leaves coated with lime being still preserved; at one place a post-and-rail fence was uncovered.

Spread over the surface of the basaltic soil and probably other soils is a thin cover of fine siliceous sand, obviously wind-borne. It is never more than a few inches thick and is of sporadic occurrence. It could be classed as loess.

XVII. WESTERN PORT SUNKLAND

After the regression of the Tertiary sea from the trunk-valley and tributary valleys of the Western Port Stream System, the Miocene sediments deposited in those valleys offered, after emergence, little resistance to the superposition and re-establishment of the new drainage system. This developed much along the same lines as the older one, and its submergence by the Postglacial sea gave rise to the Western Passage, the North Arm, and the East Arm of Western Port. The Middle Miocene sediments were covered after emergence by the Upper Miocene Baxter Sandstones (Fig. 30). These outcrop at many places inland from the shoreline of the North Arm and the northern portion of the Western Passage; they are exposed on the shoreline at Crib Point, Stony Point, Golden Point, Barrilliar Island (Fig. 46) and south of Point Sumner. The sand resulting from their disintegration was piled up into dunes which were submerged by the Postglacial sea to form Western Port and levelled by wave action to form much of its floor. The inundation that caused Western Port was geologically quite recent, certainly within the last 20,000 years.

The valleys after inundation by the sea were deepened and widened by tidal scour to function as tideways known as the Western Passage or Entrance, North Arm, and East Arm. Incidentally, the tidal streams were responsible for the banks at the edges of the tideways. The tideways broadly outline the trends of the old river channels, but tidal scour has removed from them every vestige of the old fluviatile deposits. If any portions of these remain, they are covered by the resorted dune sand of the banks and tidal flats. Tidal flats are confined to the North and East Arms of inner Western Port; there are no tidal flats in the Western Passage.

The North Arm has actually two channels, the North Arm itself, and a narrow channel inshore and parallel to the western shoreline of French Island (Fig. 46). In the North Arm, the minimum depth of water is as charted, 40 feet, and the maximum 96 feet; where it junctions with the East Arm, it is 1·3 miles wide and over 40 feet deep, but it narrows opposite the north end of the Middle Spit (Fig. 46) to half a mile, and opposite the north end of the North Spit, west of Scrub Point (Fig. 46), to about 12 chains with the same depth of water. There it opens into Bagge Harbor which is half-a-mile wide and over 3 miles long. Bagge Harbor has a minimum depth of 54 feet and an average depth of 67 feet. The narrow channel inshore towards French Island has an average width of half-a-mile and is nowhere less than 25 chains wide; its maximum depth is 64 feet, but there are shoals in it with less than 6 feet of water covering them. There are no estuaries to the streams entering it from French Island. The North Spit (Fig. 46) between the North Arm and the narrow channel is 4 miles long and has a maximum width of ¾ mile; it converges to a point at both its north and south ends; it is covered at high tide with from 4 to 9 feet of water. The Middle Spit to the south of it is also widest across the middle and pointed at the ends; it is 2 miles long, less than half-a-mile wide, and is covered at high tide with 2 feet of water. The building of the North Spit and indirectly the Middle Spit is closely connected with Eagle Rock and Crawfish Rock (Fig. 46), respectively about 1·3 miles northwest and a mile north-north-east of Scrub Point. The tidal current passing through the deep and narrow tideway between these rocks swung to the west-south-west and then curved round to the south; North Spit was formed in the slack-water on the inner side of the curve.

The Tidal Bank (Fig. 47) of the north-east corner of French Island has been formed from the sediment dropped where the incoming tidal stream flowing up the North Arm meets that coming up the East Arm. Measuring along the line of deepest water in both arms from where the tidal streams divide at the head of the Western Passage, to where they meet, the tidal current passing up the North Arm has to flow approximately 24 miles and that up the East Arm 21½ miles (Fig. 47). Many of the channels on the Tidal Bank have been formed wholly by tidal scour and are the inlets and outlets of this scour. Those emptying into the North Arm head opposite those emptying into the East Arm, and between their respective sources the two incoming tidal streams meet, as indicated by Fig. 47. Other channels lead to creek outlets and have been formed by the combined action of the outflowing creek water and tidal scour.

All the streams entering the North Arm have been entrenched by the Recent lowering of sea-level. Most of them enter small bays or inlets. Estuaries are formed in and adjacent to the outlets of streams where, states Twenhofel (1932),

"the stream current is periodically barred from flowing into the sea by rise of tides, the water level of the stream being raised so that portions of the banks exposed at low tide are inundated at high."

The Postglacial rise of sea-level was accompanied by estuarine conditions that lasted until the depth of the sea exceeded the tidal range. In Hastings Bay the tidal range is about 10 feet. Where the outflowing fluviatile waters met the tidal stream near the edge of the main tideways, the former dropped its sediment and a bank
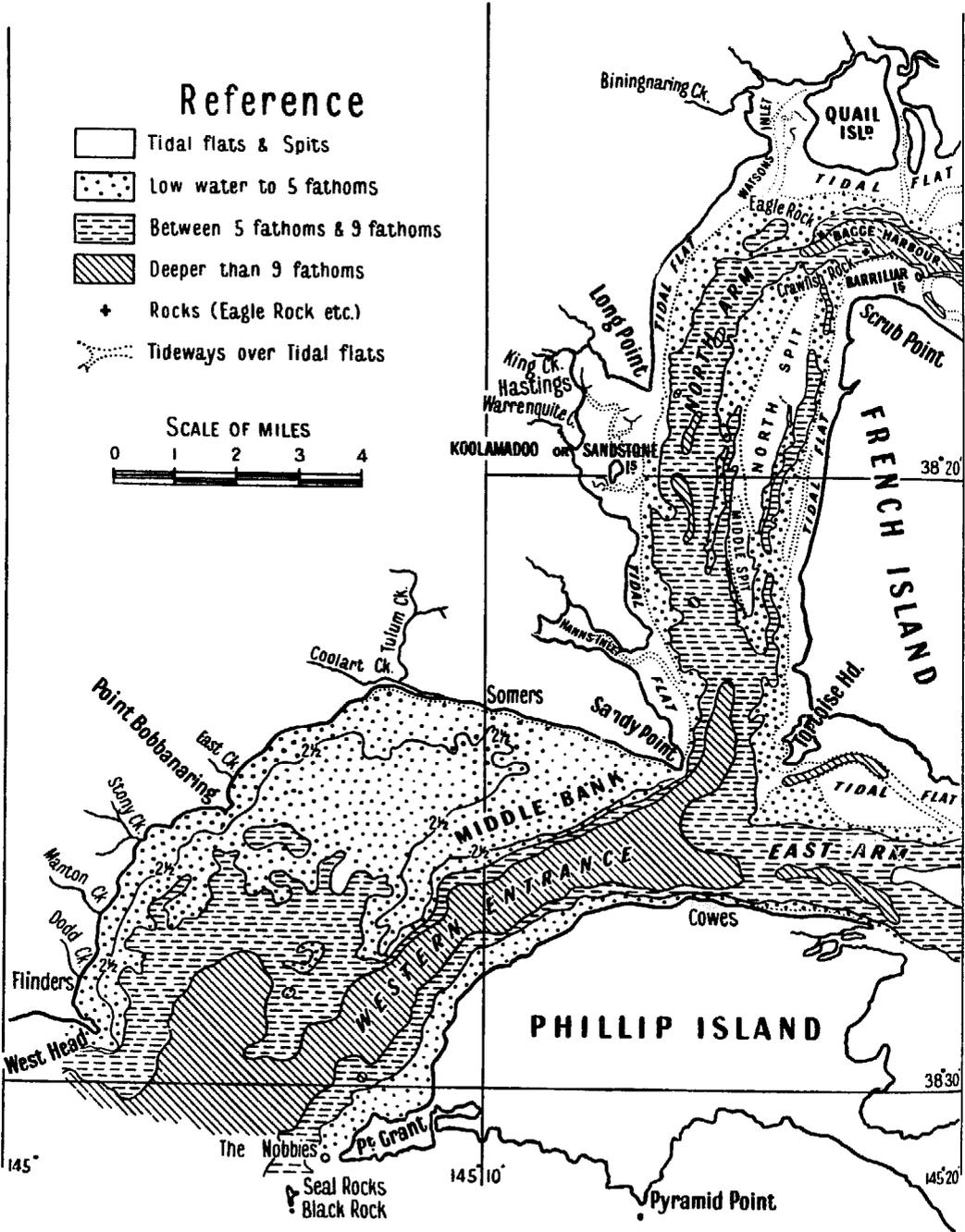
Fig. 46.   Scoured-out valleys of Western Port stream system.

started to form (Fig. 48). The bank in Hastings Bay is built on a platform near the edge of the main tideway about 18 feet below existing sea-level; the bank reaches to within 6 feet of sea-level. The bank in Watson Inlet near the edge of the tideway has been built on a platform 32 feet below sea-level and reaches to within 4 feet of it. A bank marks a former outlet of a stream; submergence was due either to a tectonic subsidence of the floors of the bays or inlets, or, most probably, to eustatic adjustment. It would seem that the banks started to form when the Postglacial sea first covered the platforms, and have been forming ever since. Since the Postglacial Optimum, sea-level has been lowered to within a few feet of the top of the banks, and the time is rapidly approaching when they will emerge as land surfaces. Hills (1942) suggests that the stretch of coastline in the neighbourhood of Quail Island, which is on the east side of Watson Inlet, originated as a result of the submergence of the edge of the Cranbourne Plain, which adjoins the Koo-wee-rup Basin on the west, and that the long tidal inlets extending round Quail Island are drowned valleys.
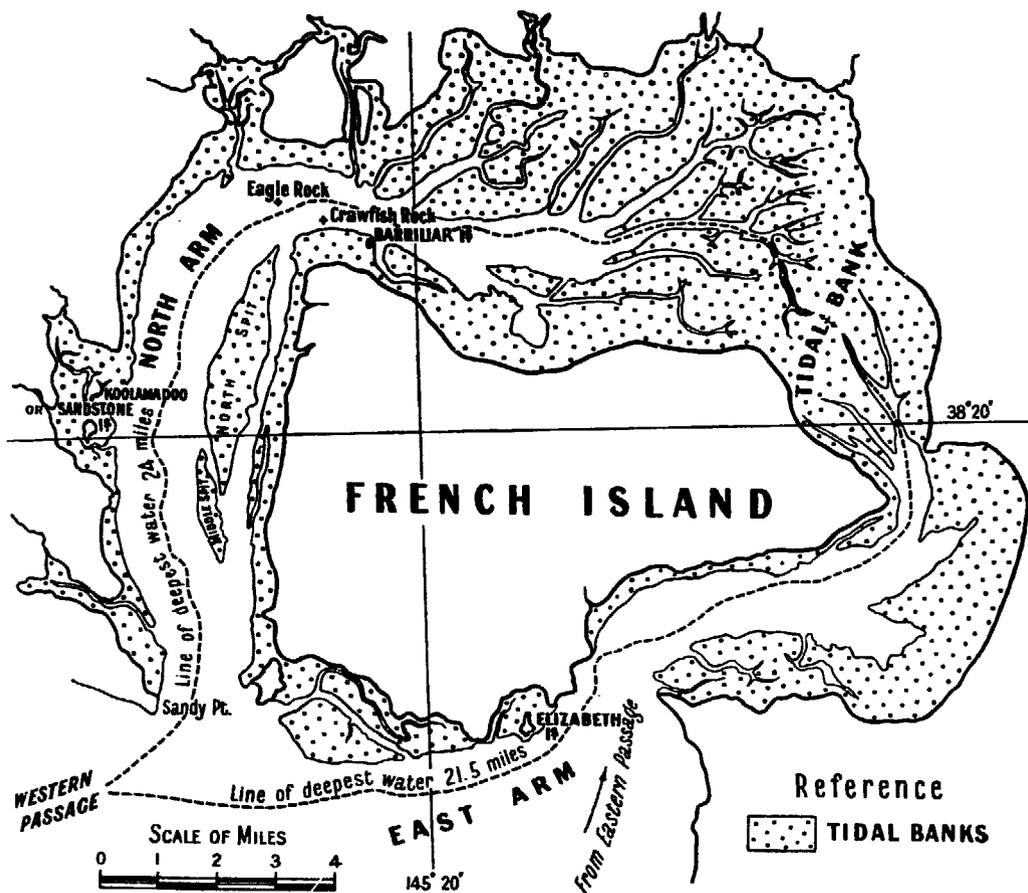
Fig. 47. Bathymetrical chart showing the tidal bank and its relation to the tidal streams.
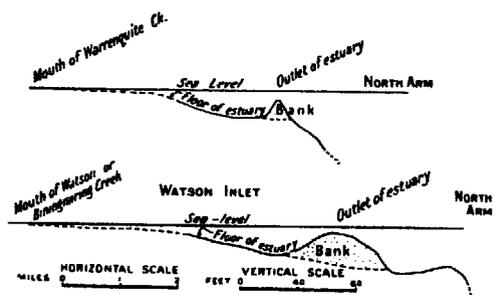
Fig. 48. Sections of the drowned estuaries of Watson Inlet
and that near Koolamadoo Island.

XVIII.   GEOMORPHOLOGY

The geomorphology of the Mornington Peninsula has had an important bearing on deposition and there have been frequent references to it.

The Peninsula, excluding the Nepean Peninsula (its western extremity), which has no streams and consists of dune deposits, is drained by the Bass Strait, Western Port, and Port Phillip stream systems (Fig. 49), the streams being grouped according to the waters into which they empty. These stream systems were developed from the post-Older Basalt stream system channels to drain the area after the Eocene topography had become flooded by the lavas of the Older Basalt. After this basaltic flooding, the south-sloping plain was extensively covered by lava. To the

north of the extensive land plain, lava fields were restricted to the main valleys and their tributaries. The topographical relief, after the lava flooding, consisted of the uncovered interfluves of the pre-Older Basalt stream system, and of the higher level granitic areas that had been partly protected from erosion by contact ridges.

A contact ridge (Fig. 50) is defined here as the ridge surrounding the granitic intrusions due to the resistance to erosion of the metamorphic aureole. Contact ridges are a conspicuous feature of the topography in many parts of Victoria. As the granitic rocks were intruded in the latter half of the Palaeozoic, they have been permanent divides over
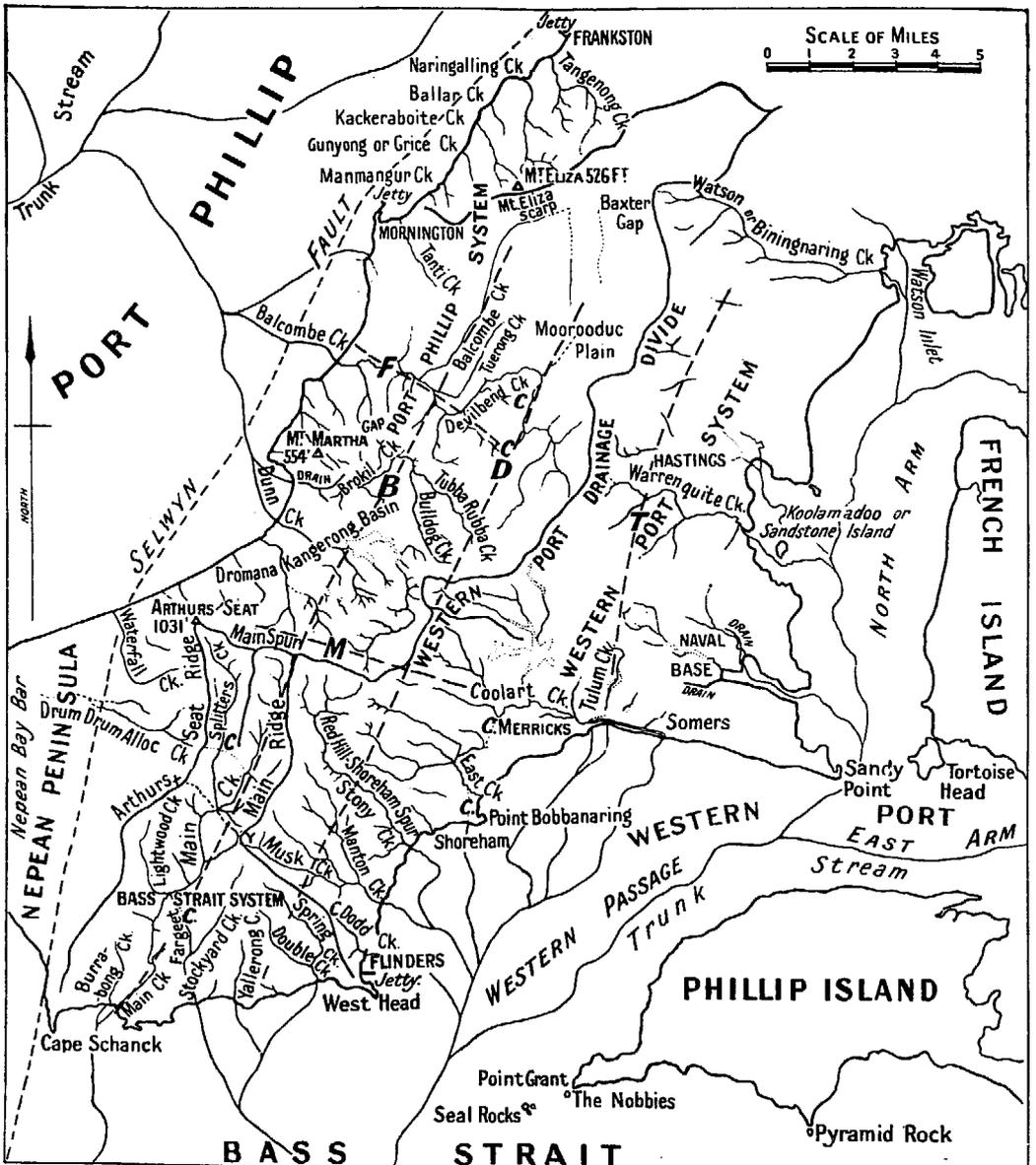
B.-Balcombe Fault. D.-Devilbend Fault. T.-Tyabb Fault. M.-Main Spur Fault. F.-Tuerong Fault. C.-Capture

Fig. 49.   Stream systems of the Peninsula.

SCALE OF MILES
0 1 2 3 4 5 6 7 8
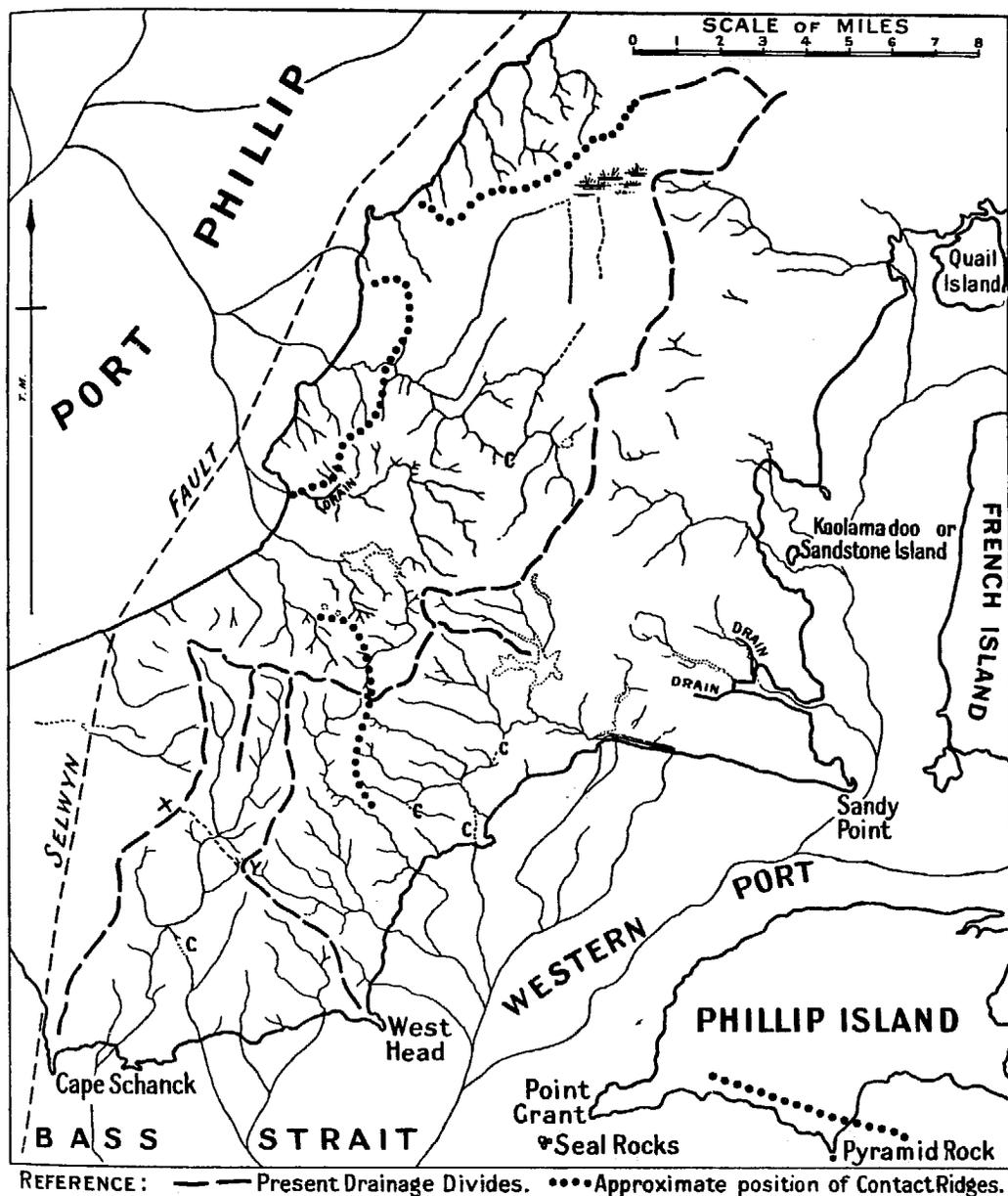
Fig. 50. Map showing the present drainage divides of the Peninsula.

REFERENCE: —— Present Drainage Divides. •••• Approximate position of Contact Ridges.

a very long period, and the oldest geomorphic feature preserved. The relatively high relief of the granitic areas—Arthur's Seat (1,031 feet), Mount Martha (544 feet), and Mount Eliza (530 feet)—owe their elevation to the fact that the contact ridges largely prevented the cutting back of streams into the areas and their reduction by fluviatile erosion. That Arthur's Seat is some 500 feet higher than Mount Martha or Mount Eliza is because Arthur's Seat has been raised by the Arthur's Seat uplift; before the uplift, the high points were approximately at the same elevation—about 500 feet above existing sea-level. Contact ridges regulated in some particular areas the spacing of the valleys before the extrusion of the Older Basalt. Those on the east sides of the Arthur's Seat and Mount Martha granitic areas, and

also the south-east side of the Mount Eliza area determined the direction of the pre-Older Basalt drainage as they do the present drainage.

It has been pointed out earlier that the lava flows in the cliff sections of the Bass Strait coastline are gently undulating. These undulations were caused by the uneven extrusion of the lava and not by deformation; it was in these depressions on the lava plain that the channels of the subsequent streams first formed. The trunk-stream (Fig. 19) and its tributaries (Fig. 49) cut back on the Flinders lava field. Some of these tributaries never reached the limits of the lava plain; others reached the less resistant rocks at the edge of it and became marginal streams. It was then that the pattern of the existing stream system was formed. The history of the geomorphic

development of the Peninsula is largely that of the competition, during the Tertiary and since, of two streams, tributaries of the post-Older Basalt trunk-stream. The Western Port stream (Fig. 19) cut its way back from the trunk-stream to form the eastern valley and became a marginal stream to the infilled tributary valley (north of Hastings) of the pre-Older Basalt trunk-stream. It became the master stream of the Western Port System from early in the post-Older Basalt cycle until its valley was recently inundated to form the Western Entrance and North Arm of Western Port. The other, the western marginal stream (Figs. 19 and 51), cut its way back from the south-west of the Peninsula. Its former trend is indicated by the remnants of the pebble beds (Fig. 35), the coarser part of its flood-plain, on the Arthur's Seat and Bald Hill Uplifts.

This western marginal stream was soon dominated by the Western Port stream. North-east of the pebble beds on Bald Hill (Fig. 35A), evidence of its extension in that direction has been removed by denudation, except, perhaps, near Tubbarubba Creek where a pebble bed near the margin of the Older Basalt was penetrated by prospecting shafts. The western marginal valley (Fig. 19) apparently extended north-easterly towards the channel of Western Port on the north side of French Island, which may be a portion of it, scoured out by tidal action. If so, it had been captured by the Western Port stream.

(A) BASS STRAIT STREAM SYSTEM.

The tributaries cutting back easterly from the western marginal stream headed formerly on the Main Ridge, but those north of the line x—y in Fig. 51 have since been captured by Main Creek of the Bass Strait System. Main Ridge is now the drainage divide between the Bass Strait and Western Port Systems, and Main Creek is the master stream of the Bass Strait System. That it is a capturing stream is shown by the fact that it has cut across and captured the headwaters of Fargeet Creek of the Bass Strait System and Drum Drum Alloc Creek of the Port Phillip System, adding the latter to the Bass Strait System.

Lightwood Creek (A, Fig. 51) rises on the Arthur's Seat uplift block, flows first south-south-west, then circles round to the south-east where it junctions (B, Fig. 51) with Main Creek near what is locally known as Long Point (Fig. 51). Before Main Creek cut back and captured it, it continued on its south-easterly course (C and D, Fig. 51) passing through the notch (E, Fig. 51) in the drainage divide between Main Creek and Stockyard Creek and down the valley of Fargeet Creek (F, Fig. 51), a tributary of Stockyard Creek, and Stockyard Creek itself (G, Fig. 51). Fargeet Creek has been beheaded and its upper reaches (A and B, Fig. 51), now Lightwood Creek, have been diverted into Main Creek. The capture took place when Fargeet Creek was uplifted by the Bald Hill uplift block. Both the existing and former portions of the through stream have been deeply entrenched. The original elbow has been removed by the entrenchment, but its lowered course still retains the conformation of the elbow. It is interesting that upwards of 100 years ago the pointed tongue of land on the south side of the elbow of capture was called Long Point.

The Lightwood Creek capture furnishes information for determining the age of the upper portions of the flood-plains in the streams of the Bass Strait Stream System. Lower Pleistocene (Mindel or Malanna) dune-rock (Chapter XIII.) occurs on both sides of the valley of Main Creek near its outlet to
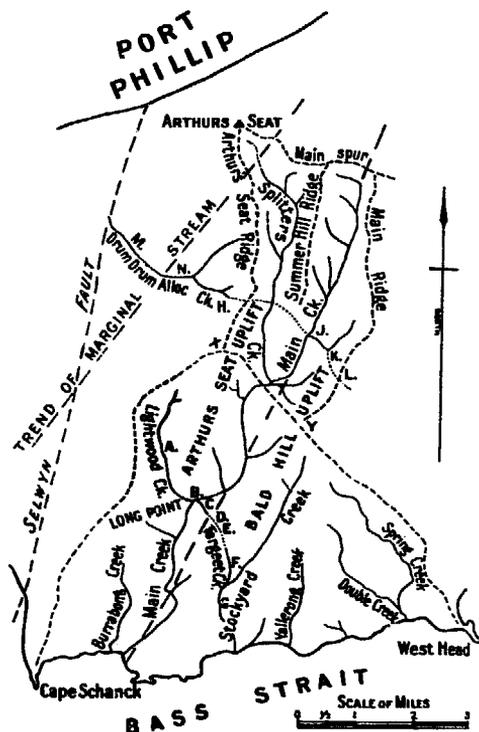
Fig. 51. Map of Bass Strait stream system showing the captures.

Bass Strait. Main Creek obviously found its way through the dune material before it was consolidated to form the dune-rock. On the left bank of the creek the Lower Pleistocene dune-rock rests against the blunted scarp of the Bald Hill block so that this was uplifted either earlier in the Lower Pleistocene or the Pliocene. The following succession is suggested by the sections in Main Creek and its former tributary Burrabong Creek:—

Pliocene.—Surface of mature erosion, presumably contemporaneous with that of the Mooroodu Plain.

Pliocene or Lower Pleistocene.—Bald Hill uplift block.
    Beginning of the erosion of Main Creek valley along the scarp of the uplift.
    Fargeet Creek capture.

Lower Pleistocene.—Freshwater limestone of Burrabong Creek Valley.
    Drum Drum Alloc Creek capture.
    Arthur's Seat uplift block.

Middle Pleistocene to Recent.—Period of lateral erosion when flood-plain, represented by fragments of it on the sides of the valley, was deposited.
    Rejuvenation.
    Accumulation of existing flood-plain.

Recent.—15 to 20-ft. entrenchment since Post-glacial Optimum.

Main Creek started to cut back about 300 feet above existing sea-level. It cut its channel to a depth of about 150 feet, when there was a period of lateral erosion represented by the remnants of flood plain on the sides of its valley. The present flood plain and its entrenchment were due to eustatic adjustments, but the previous stages to tectonic

movements. During the greater part of the Pleistocene, the drainage of Main Creek found an outlet to the south-east (Fig. 36) and not on to the Port Phillip Sunkland. The fluctuations of sea-level indicated by the Sorrento and Wannaeue bores have had little effect on the Main Creek valley.

The remnant of the flood-plain on Main Ridge (E, Fig. 51) is part of the old flood-plain of Fargeet Creek before its headwaters, now Lightwood Creek, were captured by Main Creek in the early Pleistocene or Pliocene. The age of the remnant is therefore early Pleistocene or Pliocene. The age of those portions of the flood-plains still extant at the heads of Stockyard, Yallerong, Double, and Spring Creeks are probably of the same age as, too, is that near the head of Dodd's Creek (Fig. 54). Flood plains of three cycles are found in the valleys of the Bass Strait Stream System:—

(a) The early Pleistocene or Pliocene flood-plains.

(b) In Double and Spring Creeks, flood-plains that formed after the entrenchment of (a); they are probably represented by the fragments of the flood-plains on the sides of the valley of Main Creek.

(c) The flood-plain that formed in Main Creek following the entrenchment of (b); this has been entrenched near the outlet of that creek through the 15 to 20 feet fall of Postglacial sea-level.

The Drum Drum Alloc Creek capture is complicated by the cutting back of the subsequent tributary Splitters Creek. Drum Drum Alloc Creek (Fig. 51), called Drumnamullock, Toom Toom Alloc, and other variants of the native name, now empties on to the Nepean Peninsula; formerly it was a tributary of the western marginal stream at the point marked "N" in Fig. 19. It was diverted on to the Nepean Peninsula by a stream (Fig. 51) cutting back from Selwyn Fault across the marginal stream. Drum Drum Alloc Creek before the Arthur's Seat uplift had its source on Main Ridge when that drainage divide was further east than it is now. Its course then (L-H, Fig. 51) was through the notch "L" on Main Ridge and a notch on the Arthur's Seat Ridge on the pecked line. The subsequent erosion of Main Creek and its tributary Splitters Creek has removed nearly all traces of its former course. At "J" (Fig. 51) a tributary stream flowing south-west from its source alters its direction about half-a-mile from its confluence with the south-west flowing Main Creek and joins the latter as a north-westerly flowing stream. It is suggested that the part of this tributary flowing to the north-west may have been part of the captured valley of Drum Drum Alloc Creek before the Arthur's Seat Uplift. We are dealing, however, with what appears to be an old capture; the interpretation of such is always open to doubt.

The Recent uplift of the Arthur's Seat uplift of about 100 feet has been the cause of the cutting back of the short but relatively deep gorge (M, Fig. 51) through which Drum Drum Alloc Creek flows before it passes on to the Nepean Peninsula. Little evidence of the fluctuating sea-levels on the Port Phillip Sunkland is preserved in the Drum Drum Alloc Creek valley; it has been removed, apparently through drastic erosion. There is, nevertheless, in a section of the valley (Fig. 52) a shoulder that is evidence of an advanced cycle, possibly that of the Great Interglacial.

The cascades of Waterfall Gully, immediately south of Arthur's Seat on the Arthur's Seat uplift block, are due to that gully adjusting its gradient to its
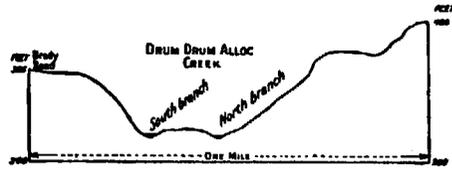
Fig. 52. Section of the Valley of the Drum Drum Alloc Creek. Scale 40 chains to 1 inch. Vertical Scale 200 feet to 1 inch.

lowered outlet on the sinking Nepean Bay Bar. The down-cutting stream in the gully has cut its gradient in the homogeneous granitic rocks of the uplift block; there is no cap-rock resting on the granite or resistant intrusive dyke-rock to account for the cascades.

(B) WESTERN PORT STREAM SYSTEM.

The stream system on the Western Port Sunkland is the mature system of the Moorooduc Plain let down on the fault block, and the submerged stream system joining the trunk-stream represented by the bathymetrical contours of Western Port, is its downstream portion. The outlet of the trunk-stream must have been a considerable distance south of the present coastline, for if its outlet had been near, the entrenchment arising from the 285-ft. lowering of sea-level (Daly 1934) during the last glacial stage, would have been more evident both on the Peninsula and in the bathymetrical contours.

It is estimated that the Western Port Sunkland has been lowered on the Tyabb Fault about 200 feet. The streams on the relative upthrow side of the fault have been rejuvenated from time to time back from the scarp of the fault: the deep valleys opening on to the Western Passage between Point Sumner and West Head owe their depth to this fact. The cumulative subsidence along the whole length of the fault has been of the order of 200 feet, for there is a general accordance of the highest points on the relative upthrow side with the 200-ft. contour. But the subsidence of the Sunkland was not a continuous movement; there are evidences of periods of standstill in terraces and hanging valleys on the sides of the main valleys, particularly that of Manton Creek. There was a relatively long period of standstill when the Sunkland had been lowered 100 feet. Those flood plains and terraces about the 200-ft. contour are representatives of the ancient stream system; those below it, of streams that cut back during periods of standstill. Due apparently to the resistance to erosion offered by particularly hard lava flows, the cutting back of the tributaries has been prematurely arrested producing cirque-like depressions on the sides of the valleys, a feature common to all the valleys of the Western Port and Bass Strait stream systems.

All the flood-plains of the streams entering Western Port have been entrenched a short distance upstream from their outlets through the Recent 15 to 20-ft. lowering of sea-level. This means that when sea-level was at its highest during the Postglacial Optimum, after which the entrenchment commenced, the flood-plains formed during the Optimum functioned and the streams flowing over them emptied into the Postglacial sea. But the flood-plain of the Optimum also formed in an entrenchment of an earlier flood-plain—an entrenchment caused by the continued subsidence of the Western Port Sunkland. As the flood-plain of the Optimum is the concluding phase of a mature cycle, the entrenchment in which

it formed is deemed to have started in the Pleistocene, but the flood-plain itself is certainly Pleistocene. These preliminary stages are evident in all the streams that enter Western Port, whether they enter it from the Sunkland or the relative upthrow side of the Tyabb Fault. There is an example of this on the Sunkland at Hann's Inlet as shown in Fig. 53.
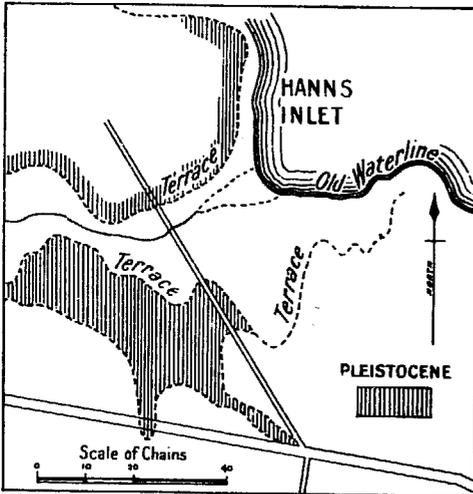
Fig. 53. Map showing Eustatic cycle following Tectonic cycle at Hanns Inlet.
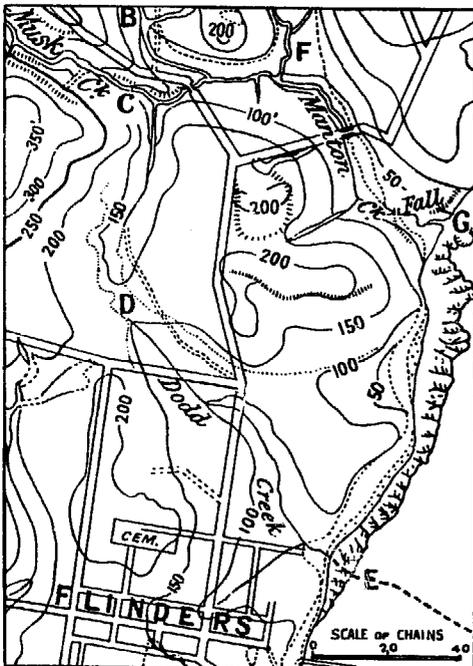
Fig. 54. Map showing the Musk Creek capture.

The sequence of events associated with the sinking of the Western Port Sunkland is as follows:—

(a) Beginning of subsidence of the Sunkland on the Tyabb Fault about the middle (Riss 2/1) of the Middle Pleistocene.

(b) Periods of standstill in the subsidence leading to the entrenchment of streams on the relative upthrow side of the fault and

formation of terraces, "hanging valleys," &c., in the valley of Manton Creek and other valleys.

(c) Development on the relative upthrow side of the late Pleistocene cycle to a stage of maturity when the last Pleistocene flood-plain was formed.

(d) Entrenchment of the Pleistocene flood-plain and formation of the flood-plain of the Postglacial Optimum.

(e) Entrenchment of the flood-plain of the Optimum through the 15 to 20-ft. lower-of sea-level.

Stream captures have altered considerably the drainage fall of the Western Port Stream System. A capture supplying evidence of the diversion of the older Bass Strait System into the newer Western Port System is the Musk Creek capture (Fig. 54).

Dodd Creek flowed uninterruptedly along the pecked course lettered "B," "C," "D," and "E" in Fig. 54, but Musk Creek, a tributary of Manton's Creek, was entrenched and captured its headwaters "B–C." At the same time, the lower reaches of Dodd Creek were also entrenched and the only portion of the old flood-plain remaining is the alluvial flat in the wind gap "D," probably contemporaneous with the old flood-plains at the heads of Spring, Double, Yallerong, and Stockyard Creeks (p. 57). Since the existing flood-plains of Manton's Creek and Musk Creek were formed during the Postglacial Optimum in an entrenchment of the Pleistocene flood-plain, the capture took place in the late Pleistocene. Thus in Fig. 54, three cycles are represented, the mature cycle of the old flood-plain at "D," the mature stage of the Pleistocene Cycle at "C," and that of the Postglacial Optimum also at "C."

A striking example of stream capture is the beheading of East Creek by Coolart Creek (Fig. 55). The headwaters of Coolart Creek west of the Merricks-Merricks North road were formerly the headwaters of East Creek; they were captured by a tributary of Coolart Creek that was entrenched
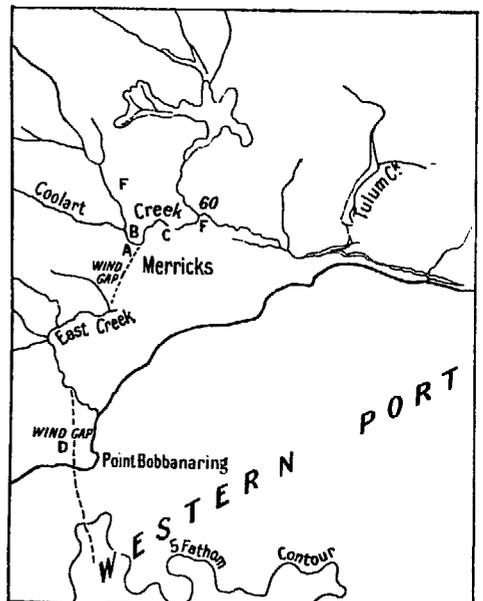
Fig. 55. Map showing the Coolart Creek capture. Point "A" is close to Merricks railway station.

through the subsidence of the Western Port Sunk-land. The pecked line "A" (Fig. 55) shows the original course of East Creek before the capture; "B" is the elbow of capture, and "C" the diverting tributary. The grade of the captured portions "E" is somewhat steeper than that of the downstream tributaries of Coolart Creek. The floor of the wind gap at "A" is a swampy flat; it is approximately 140 feet above sea-level and the confluence (F, Fig. 55) of the diverting stream is about 80 feet lower than the wind gap. Incidentally, the capture is on a line of weakness—the Main Spur Fault.

East Creek, near its outlet to Western Port, has been diverted from its original course (Fig. 55D) behind Point Bobbanaring, a course clearly indicated by the bathymetrical contours. Why East Creek changed its direction is not clear; the bathymetrical contours do not show a stream heading back toward its present outlet.

Coolart Creek about 1·7 miles from its outlet to the Western Passage flows on the landward side of a spit, the remnant of a wider spit that has been narrowed by foreshore erosion. The shore of the Western Passage, here being rapidly eroded, was, in the author's recollection, much wider and covered with Banksia trees. The spit was built up from sand carried as longshore drift and deposited in the sheltered water on the lee side of the rock platform off Po. t Sumner. It was built across the outlets of Coolart Creek and Tulum Creek (Fig. 56), both of which, before the Postglacial submergence, flowed to the south-west and joined the trunk-stream. It turned Coolart Creek to the eastwards across Tulum Creek and the latter became an engrafted tributary of the former. The flood-plains of both creeks have been entrenched through the fall of sea-level since the Postglacial Optimum; the spit was formed over the entrenchment and is therefore very recent.
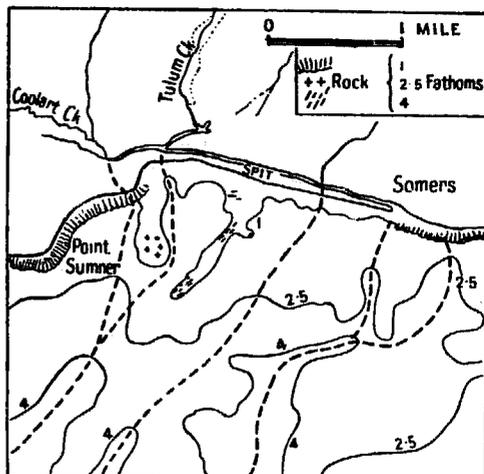
Fig. 56. Spits at the outlet of Coolart and Tulum Creeks.

The bathymetrical contours of the shoal-water between the shore and the Middle Bank (Fig. 57) show the lower reaches of Coolart and Tulum Creeks, the submerged downstream portion of the mature stream system of the Moorooduc Plain let down on the Western Port Sunkland. All the soundings in the shoal water, except those inshore, bottomed on sand, obviously the dune surface levelled by wave-action. The scour hole (Fig. 36) outside the Western Port entrance was scoured-out during the Postglacial submergence in the Flinders Bank, the southern extension of these sands; its position 2½ miles outside the entrance indicates where the first Postglacial outlet was; the outlet of the tideway of the Western Passage is now about a mile north of the entrance.
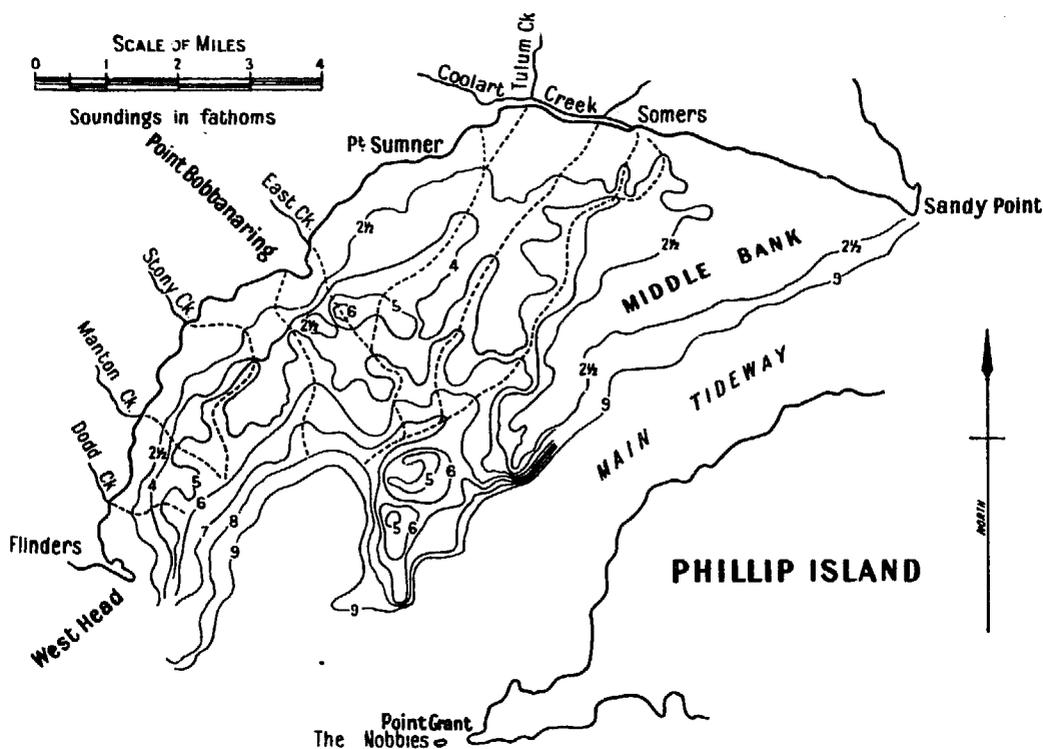
Fig. 57. Bathymetrical chart of the shoal-water between the shore of Western Passage and Middle Bank.

The bathymetrical contours showing the course of Stony Creek (Fig. 57) before its lower reaches were submerged suggest that it flowed to the south-west before it joined the trunk-stream. Stony Creek has features suggestive of a subsequent origin; its headwaters have pushed the drainage divide to the north-west and its valley has generally a younger appearance than the valleys to the north and south of it.

(c) PORT PHILLIP STREAM SYSTEM.

Since the position and the direction of the western marginal stream on the north-west side of the lava plain (Fig. 19) is indicated by the remnants of the pebble beds on the Arthur's Seat granitic area (Fig. 35), it is obvious that the drainage divide between the Western Port and Port Phillip Stream Systems was, before, during, and for some time after the extrusion of the Older Basalt, west of that marginal stream. The divide then approximated to a line through the Arthur's Seat, Mount Martha, and Mount Eliza granitic areas west of the contact ridges on their east sides of Mount Martha and Mount Eliza (Fig. 50); nearly all of the surface south of the Mount Eliza scarp was in the Western Port Basin. The subsidences of the Port Phillip Sunkland on Selwyn's Fault and the alternating falls of sea-level were responsible for the encroachment of the streams of the Port Phillip System into the Western Port Basin. This pushed back, by headward erosion, the drainage divide to its present position in the middle of the Peninsula. The strip between the former and the present drainage divides was then added to the Port Phillip System.

Whether the trunk-stream that flowed over the floor of Port Phillip when at times the sea receded and it was a land surface was a marginal stream or not, it was a reality (Fig. 43); its tributaries, Brokil Creek and Balcombe Creek, were periodically rejuvenated and terraced through the emergences of the Port Phillip Sunkland. The Kangerong Basin (Fig. 49), the low-lying area between Arthur's Seat and Mount Martha, owes its existence to its floor being normal, readily eroded sedimentary base-rock over which Brokil Creek cut back, its tributary Tubbarubba Creek and its truncated tributary Dunn's Creek, and other streams. Between the Mount Martha and Mount Eliza granitic areas, the granitic rocks

extend as far north as Balcombe Bay where they have been penetrated by a bore at a depth of 100 feet. There is no bore near the shore between Balcombe Bay and Mount Eliza, but 2·2 miles east-south-east of Mornington Jetty, Bore 9 Moorooduc passed into normal sedimentary base-rock at 183 feet. Kitson (1900) reports the existence of a small outcrop of Palaeozoic sediments in the bed of Tanti Creek, near the bridge in the town of Mornington. This indicates the extension seawards of a tongue of easily eroded rock between these two granitic areas; on it was eroded the valley in which the Balcombian marls were deposited.

At Baxter Gap (Fig. 49), the competition between tributary streams of the Western Port and Port Phillip Systems is evident. There the competition started before the marine transgression, for marine beds have been deposited in both the competing valleys. These marine beds consist of fossiliferous, sandy clays in the valley of Watson Creek opening out to the east towards Western Port, and Balcombian marls in the valley opening out to the west towards Port Phillip.

Balcombe Creek, when the Baxter Sandstones were accumulating, flowed through the gap (Fig. 58) 2½ miles east-north-east of Mount Martha into the Kangerong Basin; before it entered the gap it was joined by Devilbend Creek (Fig. 58). Towards the close of the Miocene or the beginning of the Pliocene, the Baxter Sandstones were faulted. They were then dissected by subsequent streams flowing south-south-west or north-north-east guided by the fault lines. These streams were diverted into another stream flowing west-north-west along a cross fault—the Chechingurk Fault (Fig. 58). Thus the streams in the central portion of the Peninsula conform to a trellised pattern (Fig. 58). The deeply entrenched stream flowing along the Chechingurk Fault, now represented by the lower portion of the Balcombe Creek, the Tuerong Creek and the whole of Devilbend, form the lattice now flowing on base-rock. The upper portions of Balcombe Creek and Tuerong Creek still flow south-south-west over the Baxter Sandstones coincident in direction with the strike of the underlying base-rock; they, apparently, were guided by strike faults—Balcombe Fault,
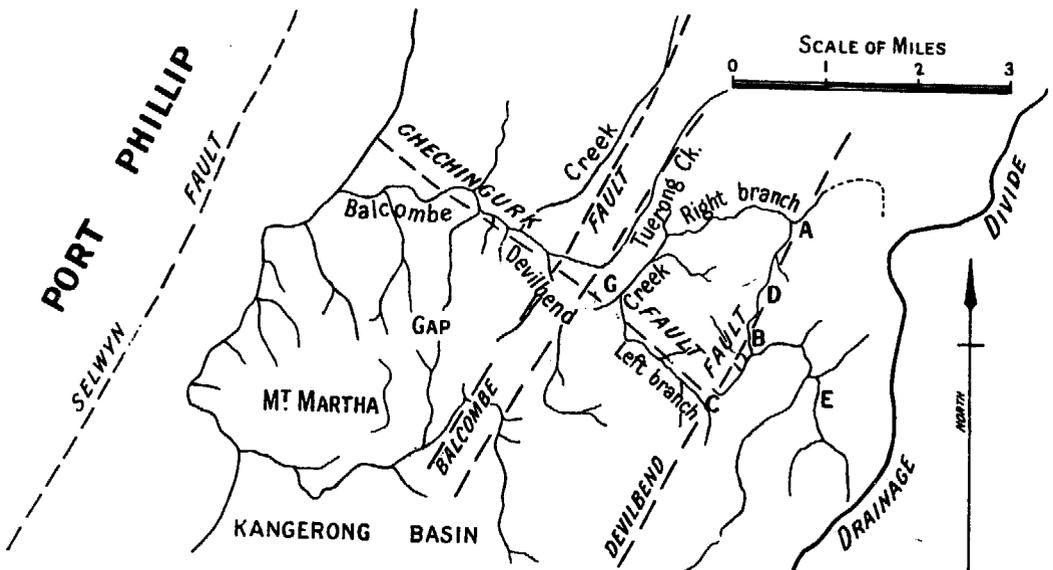
Fig. 58. Trellised stream pattern of the central part of the Peninsula. The fault coincident with Tuerong Creek is the Tuerong fault.
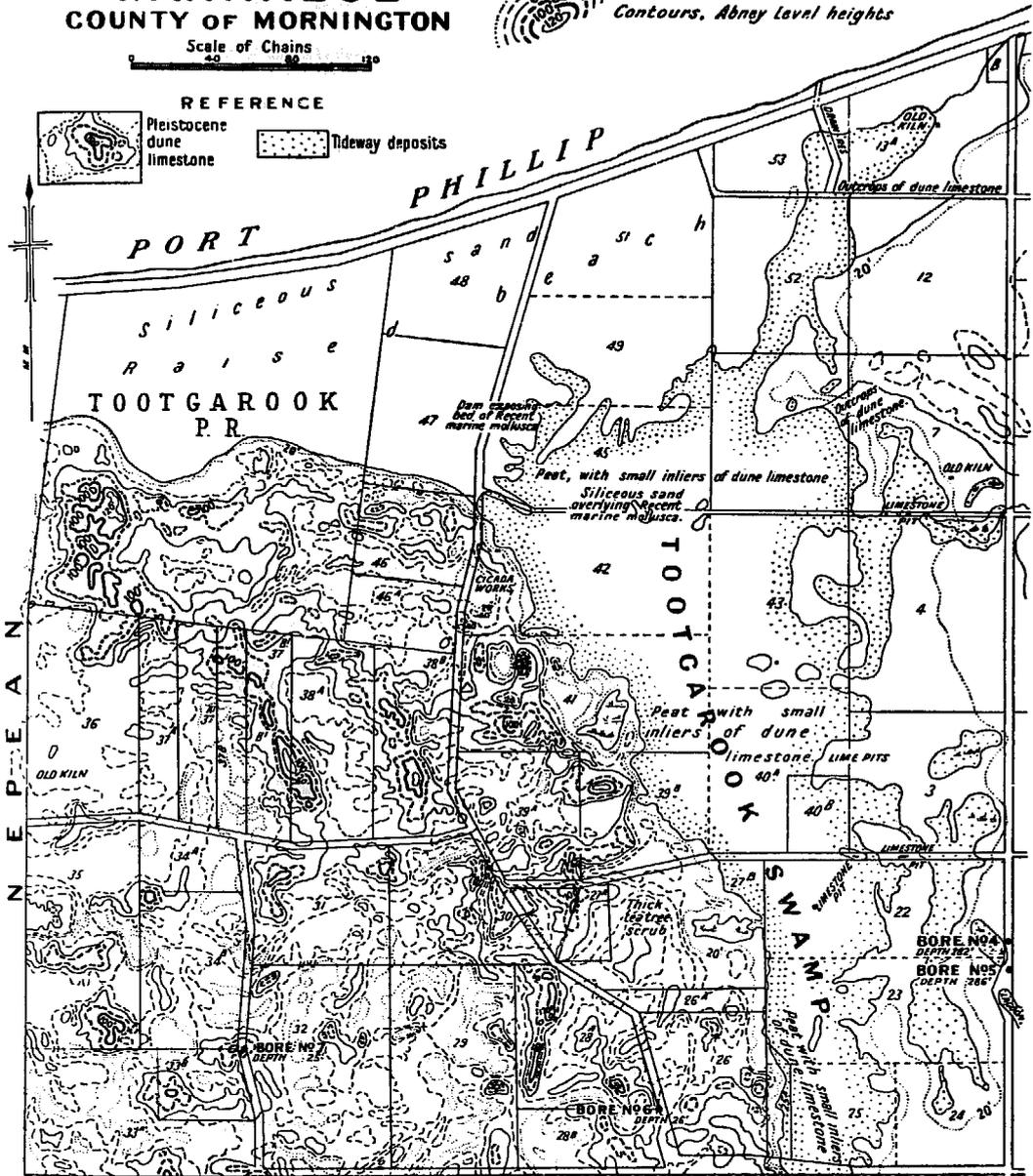
Fig. 59. Contour survey of part of the Nepean Peninsula.

Tuerong Fault, and others in base-rock that dislocated the overlying sandstones. About the same time, there was a period of instability, for the movements on the cross faults were contemporaneous with those on the strike faults.

Devilbend Creek consists of two branches that unite at point " G," in Fig. 58, 1½ miles upstream from its confluence with Balcombe Creek. When these were rejuvenated, the right branch cut back from " A " on the shatter belt of the Devilbend Fault, and by way of " D," captured the headwaters "B–E " of the left branch. The left branch formerly flowed by way of " E," " B," " C " to " G." The diverter " D " is in a relatively youthful stage of erosion compared

with the mature erosion at " E ": the entrenchment of " D " did not reach " E." Quite recently, the left branch has recaptured, at " C," one of its old tributaries.

The oscillations of sea-level and the movements on Selwyn Fault show in the entrenchments of all the creeks flowing westerly. Tubbarubba Creek and Bulldog Creek, for example, have been terraced to their sources.

From Frankston to Arthur's Seat, the coast has receded by marine erosion from the line of Selwyn Fault, which is up to 1½ miles from the shore and covered by the waters of Port Phillip. The western portions of the Arthur's Seat, Mount Martha, Mount

Eliza, and Oliver's Hill granitic areas have been lowered on Selwyn Fault and submerged by Port Phillip; this has left the relative upthrow side of the areas open to the cutting-back of streams from Port Phillip and its deep dissection. The contact ridges have been submerged and there has been no hindrance to the dissection. That the metamorphic aureoles responsible for the contact ridges protected the granitic areas from erosion is well exemplified on the east and south sides of Mount Martha and Mount Eliza; no streams from these quarters have cut back into them (Fig. 50). The south and east sides of the Arthur's Seat area are more or less covered with Older Basalt. The Red Hill-Shoreham Spur is a contact ridge partly covered by Older Basalt. The tributaries of East Creek head on it and flow away from it to the east towards Western Port; Stony Creek hugs its western slope and flows southeast to Western Port. The high area north from the Moorooduc scarp is not an uplift block, but owes its elevation to the protection of the scarp, a contact ridge that kept the tributaries of Balcombe Creek from encroaching on it. The direction of the drainage divide in this portion of the Peninsula coincides generally with that of the scarp; all the creeks rising in it fall to the north-west. From Frankston to Mornington the creeks are the Tangenong, Naringalling, Ballar, Kackeraboite, Gunyong (or Grice), Manmangur, and Tanti (Fig. 49). The Tanti Creek rises south of the scarp, the others on the scarp itself. Kitson (1900) gave other names to the creeks but those given here are taken from Selwyn's map published in 1856. All these creeks pass on to the Baxter Sandstones covering much of the Mount Eliza and Oliver's Hill granitic areas, and have cut through the sandstones in places on to the granodiorite, or, in the lower reaches of Ballar, Kackeraboite, or Gunyong Creeks, on to the Older Basalt, the sub-basalt deposits, or the Middle Miocene marine beds. All of their valleys have a youthful appearance but none of them show in the bathymetrical contours of Port Phillip.

The Nepean Peninsula (Fig. 41) shaped like an elongated foot between King Bay on the south, and Port Phillip on the north side; its western extremity is Point Nepean and it extends east to the scarp of Selwyn Fault. Its area is about 45 square miles, consisting wholly of dune material. Its eastern portion is locally known as The Cups, an apt description for a surface with hollows and closed contours between dune-ridges and knolls. Fig. 59 is a contour survey of part of the area.

A few of the dunes or dune-ridges east of Rye rise over 100 feet above sea-level, but at Sorrento, St. Paul's, a consolidated dune, rises to 176 feet, and, Gregory (1901) records a height of 225 feet near Point Nepean.

There are no permanent watercourses on the Nepean Peninsula; the dune-rock is too porous to hold meteoric and fluviatile waters. The bottoms of The Cups are sometimes covered with swamp grasses but never with water. Flood water coming down the blunted scarp of Selwyn Fault has scoured out channels in the dune-rock at the foot of the scarp, as, for example, the lower reaches of Drum Drum Alloc Creek, but these only carry water while the flooding lasts; an hour after it subsides the channels of the watercourses are quite dry. Drum Drum Alloc Creek found an outlet through the Tootgarook Swamp over the clays in the Swamp; these apparently were tilted, the tilting being associated probably with that previously mentioned in connexion with the eustatic terraces of the Inner Basin.

Only a few depressions on the Nepean Peninsula hold water. They are the Tootgarook Swamp near Rosebud and some small swamps west of Sorrento. The clay or marl as it was described by Chapman (1919) in the Tootgarook Swamp that held the water is impervious. The peat there was formed in shallow water, the level and composition of which influenced the decay of the vegetable matter. The swamp occupies the channel of the old Tootgarook Tideway, the entrance of which to Port Phillip has been cut off by a small bay-bar (Jutson 1931). The so-called marl is doubtless silt deposited in the tideway similar to the silt dredged from the tideways of Port Phillip. (Cf. p. 47.)

XIX. COASTLINE

East and north-west of Selwyn Fault, the Bass Strait coastline presents marked contrasts. That stretch east of the fault is referred to here as the Flinders–Fingal coastline, the fault passing through the Parish of Fingal; the portion to the north-west is referred to as the Nepean Peninsula coastline. The Flinders–Fingal coastline consists of bold cliffs of dark nearly horizontal basaltic lava flows and is indented at a few places by small bays, such as Bushranger's Bay, with shingle beaches. The Nepean Peninsula coastline consists of light-coloured cliffs of dune-rock indented with many bays with beaches mainly of siliceous sand derived from the dune-rock. At some places the beaches are of considerable length.

The whole coastline has receded through marine erosion. Where coastal erosion has cut into the nearly horizontal lava flows, we should expect to find vertical cliff-faces, but, although at some places they are vertical, at other places they slope steeply upwards from high tide-level and become vertical near the crest (Photo No. 32). Where the level of a soil parting coincides with tide-level, the parting has been removed, uncovering the surface of the underlying flow which extends some distance seawards as a wave platform (Photo No. 27). There may be a decided hip (Photo No. 27) at the base of the cliff where there is a clay parting. The sapping of the parting weakens the flow overlying it, the flow disintegrates and portions of it slip on to the wave-cut platform, there to be broken up by wave action. On or near the shore platform are partly-consumed stacks, such as Pulpit Rock (Photo No. 29) and Elephant Rock at Point Barker, and rocks that are dislodged portions of the flows. Dislodged portions extend (Fig. 60) seawards from the Flinders Limestone and where Selwyn Fault crosses the coastline (Fig. 60). The soft limestone and the clay in the fault channel appear to have restricted abrasion.

The cliffs from Cape Schanck to Selwyn Fault rise in places to over 300 feet above sea-level. They are of basalt overlain by dune-rock.

27. Hip on wave platform, West Head, Flinders-Fingal coastline.
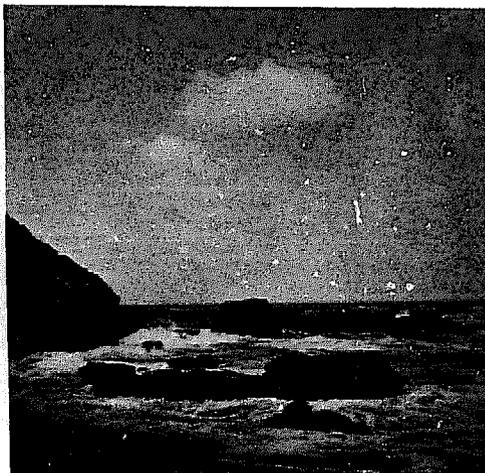
28. West Head. Stacks of basalt, partly consumed.

The elevations east of Main Creek are somewhat less. The height of the cliff at Point Barker is 200 feet, the cliff on the east side of Stockyard Creek 255 feet, and that on the east side of Yallerong Creek 260 feet. All the cliffs east of Main Creek present a basalt face consisting of lava flows separated by soil partings. The lava flows are tilted slightly seawards, but how far cannot be determined. Dykes parallel with the coastline have intruded fissures, but there is no evidence of displacement along these, nor is there evidence of faulting of the graded platform (Fig. 61) to the 20-fathom contour. On the amount of tilt hinges the problem of where the high sea-level of the Postglacial sea started to attack the tilted lava flows, and how far the cliffs have receded. On a sustained

Fig. 60. Maps of rocks inshore opposite Flinders limestone and Selwyn fault.

angle of tilt of 2 degrees (actually 2 deg. 10 min.) the fall of the lava flows is about 200 feet to the mile. The angle of tilt measured in the cliff faces north of Cape Schanck and up Main Creek slightly exceeds 3 degrees. The highest cliff east of Main Creek is 260 feet above sea-level. If the Recent uplift of 100 feet (Fig. 43) has to be allowed for, as well, too, as adjustments for changing sea-level, the Postglacial shoreline was approximately half a mile south of the present shoreline. Needless to say, evidence of the 15 to 20 ft. shore platforms has disappeared with the recession by coastal erosion.

The soundings for the Admiralty Chart from the shore to the 12-fathom contour bottomed on rock, probably the abraded surface of the lava. The soundings from 12 to 20 fathoms, with a single exception,

bottomed on sand. At some stations a fine grey sand was obtained with magnetite and other minerals. This sand probably consisted of quartz derived from the dune-rock, the magnetite and other minerals coming from the lava. On a coast like that between Cape Schanck and West Head, exposed to full-sized waves, the to-and-fro movement of sand and gravel on the bottom between 12 and 20 fathoms indicates some abrasive action.

Fig. 61. Profiles of the wave-cut platforms off the Flinders-Fingal and Nepean Peninsula coastlines to the 20-fathom contour, a little more than 8 miles south. The soundings are at wide intervals.

The following are the approximate grades of the streams entering Bass Strait:—

Creek.				Grade, feet to mile.
Burrabong	..	..	..	250
Main	..	..	..	70
Stockyard ..	..	..	..	135
Yallerong ..	..	..	..	140
Double, north branch		..	..	135

All these creeks belong to the dismembered Bass Strait System and are adjusting their valleys to the level of the sea that drowned their lower reaches. The head of Stockyard Creek, for example, is 540 feet above sea-level, 4 miles from where it enters Bass Strait through a deeply-cut gorge-like valley.

Formed by marine erosion and circulating underground water, the Angel Cave, about high-water level in the cliff-face under the Cape Schanck Lighthouse, is due to the removal of one of the soft partings between the lava flows. Baker and Frostick (1947), in their contribution on pisoliths and ooliths, have described the cave and its contents, and the reader is referred to this for a more complete description; the following details have been taken mostly from their contributions.
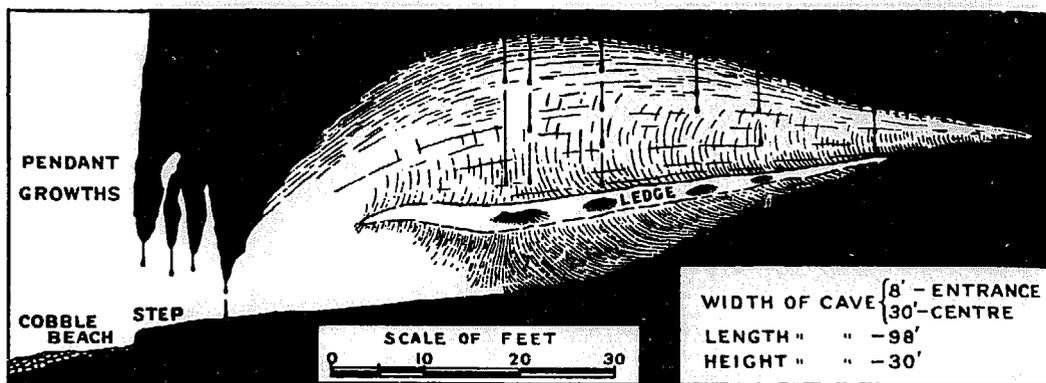
Fig. 62. Diagrammatic longitudinal section (N.E.-S.W.) through Angel Cave, Cape Schanck. [After Baker and Frostick.]

The cave entrance has an outer and an inner portal. The outer opening, 14 feet wide, is surmounted by a series of pendant carbonate growths. Similar pendant growths reduce the inner portal to 5 feet in height, and a width of 8 feet. Farther in from the inner portal, the cave increases in size until, some 40 feet from the cliff face, it is 30 feet high and 30 feet wide (Fig. 62). The roof and wall north-west of the inner portal are liberally ornamented with clusters of short, narrow, tubular stalactites averaging 5 cm. long and 5 to 7 mm. in diameter. About half-way up the wall, just behind the inner portal, a much larger stalactite and stalagmite have united to form a column; this has developed into a structure said to simulate, under certain lighting, the figure of an angel with folded wings, hence the name "Angel Cave." The depredations of vandals, early settlers informed the writer, have altered considerably the appearance of the cave which formerly contained many fine examples of stalactites and stalagmites.

The group of pools along the ledge (Fig. 62) contain a large number of discrete calcareous concretions, pisoliths and ooliths. A few dozen of these pools occur in the cave. They vary in size from 2 inches to about 2 feet across, and up to 4 inches deep; they contain as few as three up to as many as 2,000 or more pisoliths and ooliths. In pools full of them, the larger ones, about 20 mm. long, occur at the top, flush with the edge of the pool, while the smaller ones, down to a millimetre in length, are on the bottom.

The dune-rock in the cliffs of the Nepean Peninsula coastline varies between fairly pure limestone and dune limestone of average quality. The wind-slopes are at all angles and the soil partings are thin and impersistent. As in the case of the Flinders–Fingal coastline, marine erosion has been most active along the soil partings, causing dune-rock masses to slip and fall on to the wave platforms where they are speedily

29. Pulpit Rock, Cape Schanck. The Rock is the dark-coloured, circular rock in the middle distance.

30. "London Bridge" an arch of dune rock, Nepean Peninsula coastline.
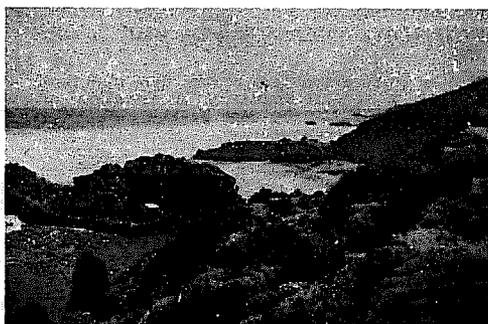
31. Nepean Peninsula coastline. Partly consumed stacks, arches and detached masses of dune rock.

broken up. It also has the effect of opening up the laminae of the dune-rock like the leaves of an open book, which aids in its disintegration.

The coastline east-south-east from Point Nepean to the Divide is a young coast formed since the Post-glacial rise of sea-level. Inshore are stacks in all stages of reduction, reefs that are unconsumed stacks or detached masses of dune-rock, arches, caves, blow-holes, and other features of youth. From the Divide, east-south-east to about a mile from Selwyn Fault, the shore has the appearance of being more mature, although it is no older. From there to Selwyn Fault is an unbroken line of cliff face rising to a height of 350 feet in the vicinity of the Fault and with stacks and detached masses inshore.

The wave-cut platform is nowhere more than a quarter of a mile wide. On the graded platform inshore from the 10-fathom contour, the soundings bottomed on both rock and sand; between 10 and 20 fathoms, on sand. As there are no streams entering Bass Strait from the Nepean Peninsula, the waste on the graded platform has come from coastal erosion.

Inside Port Phillip from Point Nepean to White Rocks, the shore is comparable with the coastline outside Port Phillip, but beaches are more in evidence, cliffing less so. This portion of the coast has been described by Hills (1940) and has been discussed in previous chapters. The shore platforms at the foot of Oliver s Hill, Frankston, and a mile north-east of Tanti Creek, Hills regards as "raised" abrasion plat-forms. The origin of the platform at high tide-level on the face of the cliffs overlooking Dromana Bay, he considers, is not clear. He points out that at Frank-ston and Mornington, water-worn pebbles rest on the raised platforms cut into the granite rocks some feet above high water-level; at Dromana Bay the presumed

32. Flinders-Fingal coastline near Flinders. Unconsumed stack of Older Basaltic lava.

raised platforms rise as table rocks above the normal shore platform and are covered with pebbles. He states:

"It may be observed in a profile view that these table rocks have a general similarity in elevation, although rising gently towards the base of the cliff. There the raised platform is better preserved (loc. cit. Pl. III., Fig. 2) and in one locality a well-marked notch is situated at the junction of the cliff face with a platform remnant. The tops of the preserved platform remnants range from about 1 ft. 6 in. to 3 ft. 6 in. above the platform now being formed, and are still subject to wave attack."

He points out that the platform remnants become lower and smaller to the north-north-east until they disappear. The platform is not horizontal either along the coast or in profile, and is in part above high-tide level. This may imply that emergence was accompanied by tilting and that wave erosion above the present high-tide level has been responsible for its seaward inclination. Jutson's (1940) summary of his contribution on the shore platforms stretching from the north-east corner of Dromana Bay to beyond Mount Martha is as follows:—

At the northern and southern ends of the granodiorite dome of Mt. Martha the rock at the coastline is decomposed (" soft "), but between these outcrops it is fresh (" hard ").

An almost horizontal platform (the normal platform) cut in the soft rocks at each extremity and backed by steep cliffs of the same class of rock is exposed at low tide.

The coastline of the hard rocks is broken into a series of tiny bays and gulches, between which are pronounced buttresses. A platform cut in this hard rock by the waves slopes steadily seawards and its fall is so comparatively rapid that, except at the heads of the small bays and gulches just mentioned, it is not exposed at low tide, thus offering a marked contrast with the normal platform. It coincides with wave-cut platforms of the text books and, since it appears to be both an original and (as regards the present cycle of erosion) a final form, subject to its gradual lowering if not protected by marine deposits, it is termed a primary ultimate platform.

The normal platform, although it is advancing at its landward edge, yet is being destroyed at its seaward edge, and another platform, due to such destruction, is being cut in the soft rocks at a lower level and appears to slope steadily. This lower platform is another type of the ultimate platform but, since it is of secondary origin, it is termed a secondary ultimate platform.

The decomposed rocks favour the formation of a coastline, mostly smooth in outline; of the normal and secondary ultimate platforms; and of steep cliffs with scanty vegetation. Geological structure has apparently little influence on the making of those features. On the other hand, the hard rocks and their geological structure favour the formation of the contrasted crenulated coastline; of the primary ultimate platform; and, except in their lower portions, of sloping cliffs with abundant vegetation.

The normal platforms are due to wave planation, and the ultimate platforms to the quarrying action of the sea and wave planation combined.

The following is relevant to a discussion of the marine erosion of this portion of the coastline of Port Phillip. Several streams flowing north-westerly empty into Port Phillip and have cut their valleys through the decomposed " soft " granodiorite into the fresh " hard " granodiorite on the seaward slope of Mount Martha. As Jutson has remarked, his primary ultimate platform has a steady fall seaward, but how far depends on the position of the shoreline at the commencement of the present cycle of marine abrasion. Although the sea-bottom off Mount Martha is recorded in the chart as sand, none of the valleys of the streams draining the seaward slope show in the bathymetrical contours of the floor of Port Phillip. The same is true in regard to its floor off the Mount Eliza granitic area. It would seem that the streams cut back from the Postglacial shoreline when Port Phillip assumed its present shape in the Postglacial. Nevertheless, it is improbable that there was no Pleistocene drainage system on the slope of Mount Martha, for these slopes were in existence then and during the latter part of the Tertiary. Showing

clearly in the bathymetrical contours are the valley of Balcombe Creek and its tributaries to the north of Mount Martha.

At Point Bobbanaring facing the opening of the western passage of Western Port and about 5 miles north of it, the radius of the arc through which full sized waves can reach the shore ranges from south-south-west to south-south-east. But they pass over a shallow floor and so much of their energy is absorbed in friction that they are much reduced in size. The surf at Point Bobbanaring is due to the fact that the waves approach the shore over the relatively deep water in the drowned valley of East Creek.

Baker (1945) described the black sands on the beaches of Davy Bay, Canadian Bay, and near Mount Martha, all in Port Phillip: also on the Balnarring beach of Western Port. He tabulated the following facts concerning them:—

Locality.	Range in Size of Grain.	Average Grain Size.	Ratio of Opaque to Colourless Heavy Constituents.
	m.m.	m.m.	m.m.
Davy Bay	0·24-0·64	0·32	80 : 1
Canadian Bay	0·24-0·94	0·40	60 : 1
Mount Martha Beach ..	0·16-0·50	0·24	6 : 1
Balnarring	0·08-0·56	0·16	4 : 1

He pointed out that these, mainly of small lateral and vertical extent, are beach concentrates, " high-tide mark " types of heavy beach sands; they occur largely as " rill mark streaks."

At Davy Bay, several patches cover areas, at places, as much as 5,000 square feet in extent and up to several inches thick. Such are seasonal, being removed by flood tides or periodically covered by quartz sand. At Davy Bay and Canadian Bay, the sands consist largely of ilmenite, and contain some magnetite, but anatase, garnet, and tourmaline are rare. Zircon is found in the Davy Bay black sands, but is not present in those at Canadian Bay. At Mount Martha, the heavy mineral assemblage is chiefly magnetite and ilmenite; other minerals occasionally present are andalusite, tourmaline, and zircon. On the Balnarring beach where the assortment is most varied, the preponderant number of opaque grains consists of ilmenite, but small amounts of augite, cassiterite, cyanite, epidote, garnet, hypersthene, monazite, rutile, staurolite, topaz, and zircon are also present.

The dark coloured minerals in the sands at Davy Bay were probably derived partly from the granodiorite outcropping in the cliffs at Oliver's Hill and partly from the basalt there; those from Canadian Bay presumably came from the Baxter Sandstones forming the cliffs overlooking that bay, some of them from the Mount Eliza granitic area, and others probably from submerged basaltic rocks being disintegrated by wave action. The heavy black sand on the Mount Martha beach came from the granodiorite coastal cliffs and the streams draining the Mount Martha granitic area with its associated thermo-metamorphic rocks. The Balnarring black sand was derived from many sources, such as Tertiary basalt, granites, and their associated metamorphic rock, and the unaltered sediments of the Peninsula and the islands of Western Port. Coolart Creek, which had its outlet into Western Port through the spit near Tulum, has its source in the Balnarring granitic stock.

There are also black sands on the Bass Strait beach of the Nepean Peninsula. As the cliffs behind the beach are dune limestone, their source is presumably the basalt cliffs east of Selwyn Fault.

XX. MINERAL RESOURCES OF THE MORNINGTON PENINSULA

LIMESTONE.

Dune limestone covers the whole of the Nepean Peninsula west of Selwyn Fault (Fig. 35) except a small area behind Rosebud; it also covers to a thickness of a 100 feet or more the higher elevations (Fig. 35) south of the Cape Schanck-Flinders road and west from Main Creek to Selwyn Fault. In Bore 4, Wannaeue (Fig. 40), a short distance west of Selwyn's Fault, it extends to a depth of over 117 feet, with an interruption of 9 feet of clay, and in the Sorrento Bore (Fig. 40) uninterruptedly to a depth of 57 feet; these depths may be taken as a measure of its surface thickness on the Nepean Peninsula. Its average calcium carbonate content may be taken as 75 per cent., the residue being mostly a medium grained, wind-blown sand. Because of their proximity to possible sources of shale for cement manufacture, surface samples were taken at places along the west side of Selwyn Fault.

Sample.	Locality.	Calcium Carbonate CaCO₃ (Per Cent.)
825/1926 ..	Allotment 18, Parish of Fingal ..	77·52
826/1926 ..	Allotment 18, Parish of Fingal ..	85·03
827/1926 ..	Allotment 49, Parish of Fingal ..	76·81

Dune limestone has been burned for upwards of a hundred years on the Nepean Peninsula, using ti-tree as fuel. When this diminished and the crystalline limestone at Lilydale and other places was burned, the burning of dune limestone on the Peninsula eventually ceased. The lime was formerly shipped from Rye, Sorrento, and other places in small sailing craft, and the extent of the industry on the Peninsula is indicated by the number of old kilns found there.

Freshwater limestone with a minimum of adventitious material is found in the valley of Burrabong Creek (Fig. 38); it accumulated in a lake or swamp formed by the damming of the old valley of that creek. The dam, which must have been about 100 feet high, was somewhere south of the present outlet of the creek.

The limestone is of two kinds:—

(a) Soft, plastic, and impervious, with an argillaceous consistency and very little siliceous material.

Up the valley this merges into

(b) a soft pale-yellow absorbent limestone, with the consistency and hardness of chalk.

The soft limestone (a) is exposed on the west side of the creek at its mouth in a face at least 75 feet high. It was sampled at various levels above high water mark (H.W.M.), and the percentage of calcium carbonate determined (614-624/1926):

Sample.	Above H.W.M.	Calcium Carbonate CaCO₃. (Per Cent.)
621	A few feet above	60·1
623	12 feet above	84·9
620	14 feet above	82·2
619	23 feet above	75·5
624	30 feet above	84·6
618	33 feet above	80·6
622	33 feet above	88·1
617	43 feet above	81·9
616	53 feet above	80·7
615	63 feet above	73·6
614	73 feet above	64·3

Samples of the chalky limestone (b) gave the following percentages of calcium carbonate:—

Sample.	Above H.W.M.	Calcium Carbonate CaCO₃. (Per Cent.)
626	Allotment 21, Parish of Fingal, approximately 40 chains north-north-east of creek mouth	91·4
625	From near the same place	89·4

Having accumulated in a lake or swamp, the deposit may be assumed to be level-bedded and wedge-shaped, tapering towards the head of the valley; it extends upstream probably for at least 2 miles and is about 10 chains wide. The average calcium carbonate content in 51 feet of the face at the outlet of the creek is 81 per cent., and the average of all the limestone is 87 per cent. An estimate of the quantity available (averaging over 80 per cent.) at 1,000,000 tons is a conservative one, but this should be confirmed by bores. Overlying it on the sides of the valley is dune limestone of average quality and containing 75 per cent. of calcium carbonate.

Burrabong Creek in its lower reaches is a perennial stream free from the sodium and magnesian chlorides present in most Peninsula streams.

Polyzoal limestone occurs at Flinders on the ocean foreshore south of the golf links there, and on the Western Port shore where it is exposed between tides. A sample taken from the low cliff exposed on the ocean foreshore contained 85·2 per cent. of calcium carbonate; the residue consisted mainly of finely divided silica. Even if they could be worked, the deposits are too limited in extent to be a potential source of limestone.

MARL.

The so-called marls at Balcombe Bay have been discussed (p. 37). Because the marls are confined to certain bands of limited width and these occur in an inaccessible locality, they have no apparent value. The same applies to the so-called marls at Grice and nearby creeks between Frankston and Mornington.

BROWN COAL.

Proximate analyses of brown coal or lignite at Tyabb (T), Langwarrin (L), and Flinders (F) are as follows:—

Sample.	Depth.	Moisture.	Results Calculated to Actual Moisture Content.			
			Volatile Hydro-carbon.	Fixed Carbon.	Ash.	Lime in Ash.
	Feet	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
T1 ..	95–99	37·40	15·30	9·40	37·90	..
	99–101	31·10	9·40	3·43	56·07	..
	101–103	29·55	7·65	3·40	59·40	..
	103–106	45·80	12·40	10·20	31·60	..
	106–108	32·05	10·00	6·65	51·30	..
T2 ..	178–191	42·5	9·9	7·8	39·7	..
	191–201	36·0	7·8	6·0	50·2	..
T3 ..	148–154	29·15	5·65	4·0	61·20	..
	161–164	46·00	11·15	8·25	34·60	..
T4 ..	180–184	58·85	14·50	10·85	15·80	..
	196–205	38·10	11·25	7·65	43·00	..
T6A ..	..	13·75	21·50	5·55	59·20	..
T6B ..	..	11·90	11·30	2·30	74·50	..
L1 ..	122–129	37·65	8·50	5·46	47·39	..
F1 ..	Surface	48·32	6·98	22·36	22·34	1·10
F2 ..	Surface	6·8	11·78	24·28	57·14	2·64

T1–T6B from bores in the Parish of Tyabb; L1 from bore in the Parish of Langwarrin; F1 from outcropping brown coal at Flinders Jetty, upper layers; F2 from same place, lower layers. Analyses of Tyabb and Langwarrin samples by Mines Department Laboratory; Flinders samples by S. R. Mitchell.

Sample T6A was from a lignite seam between layers of basalt, but the actual depth is not given; T6B was from lignite actually enclosed in a lava flow. Both these samples are of an Eocene lignite and considerably older geologically than the lignite of samples T1–T4 and L1. In the lignitic material of T6B were inclusions of a white calcareous material, and the analyst suggested that some of the volatile matter might be accounted for by the presence of lime carbonate. It has been pointed out that the volatile hydrocarbon figure given would include combined water from the clayey material present as well as the CO_2 from the calcareous matter. The first remark applies to all the proximate analyses given here. The summations of the volatile hydrocarbon, fixed carbon, and ash in each of the samples T6A and T6B are respectively 86·25 to 88·10; the higher ash in the second sample implies, perhaps some distillation of the volatile hydrocarbons when the lignite was caught up in the molten lava flow.

PEAT.

Peat from the Tootgarook Swamp was tested at the State Laboratory. Table C, below, is a tabulation of the results of the tests calculated to a dry basis of the samples as received from the pit:

It will be seen that the moisture content of the samples as received was high.

Peat from allotment 73c, Parish of Langwarrin, analysed (510/1921) at the Mines Department Laboratory gave the following percentages:—

—				510A.	510B.
Total nitrogen—N.	..	..	..	0·39	0·29
Nitrates ..	..	..	..	Faint trace	Nil
Lime—CaO ..	..	..	..	0·40	0·29
Potash—K₂O	..	..	..	5·09	5·25
Phosphorus—P₂O₅	..	..	..	Trace	Trace
Water 110° C.	..	..	..	29·55	29·95
Ash	..	..	..	59·00	72·50

Obviously, the samples were a peat ash.

Phosphate.

It has been stated that the septaria at Balcombe Bay contain up to 5 per cent. of phosphoric acid, but the following analyses of them made at the Mines Department Laboratory (Keble 1917) do not bear this out:—

—	I.	II.	III.	IV.	V.
Phosphoric acid ..	0·29	1·25	1·66	0·46	0·13
Lime	40·40	41·40	40·57	36·66	26·60
Magnesia ..	Small amount	Small amount	Trace	Large amount	Trace
Specific gravity ..	n.d.	n.d.	2·604	2·390	n.d.

I. to III., and V., from Balcombe Bay. IV. from Grice's Creek.

The guano on Mud Islands has been worked out. What appeared to be phosphatic seams, nodules, and inclusions in the Ordovician shales on the Chechingurk pre-emptive right were tested for phosphoric acid, but gave no reaction.

FULLER'S EARTH.

Fuller's Earth, in the wide application of the term, was obtained from between tides, on the low point immediately south of Tulum on Western Port. It is a soft, decomposed volcanic ash that grinds into a light-brown powder with a smooth feel like that of talc. Apparently the Balnarring fuller's earth was a natural bleaching powder that was adsorptive. Whether there is still a market for it or whether it has been supplanted by chemically treated bentonite or ordinary bauxite is not known. The soluble alumina

Table C.

—					As Received.	Dry.	As Received.	Dry.	As Received.	Dry.	As Received.	D.	As Received.	Dry.
H₂O ..	..	..	..	..	68·9	..	47·4	..	66·2	..	75·1	..	67·0	..
Loss on ignition	..	..	..	}21·6	69·5	27·7	53·7	21·9	64·8	..	..	..	..	
Organic matter	..	..	..											
Ash ..	..	..	..	..	9·5	30·5	24·9	47·3	11·9	35·2	..	..	..	..
N. ..	..	..	..	..	0·76	2·45	0·50	0·95	0·65	1·91	0·65	2·6	0·7	2·1
pH ..	..	..	..	..	8·1	..	8·5	..	8·6	..	..	..	..	..

in the Balnarring product is 2·9 per cent. The material available at Balnarring is small, and any quite like it is not known to exist elsewhere on the Peninsula.

A report (1927/1024) on the Balnarring fuller's earth by the Mines Department Laboratory stated that when applied to coloured aqueous solutions, it had good decolorising properties and should have a value in bleaching sugar solutions, wines, &c. Its deodorising and discolouring effect on oil was small.

BUILDING STONE.

The Dromana granite is a colourful building stone with bright-green and pinkish-brown felspars contrasting with the quartz and darker minerals in the stone. It is quarried about 2 miles south-east of Dromana Jetty. The largest block that has been obtained was 23 feet by 17 feet by 6 feet (Dickinson 1941) but the spacing of the joints is not usually favourable to the quarrying of such large blocks. The principal joints are closely and irregularly spaced and usually at an angle with the quarrying grain of the stone; unsuspected "drys" or incipient joints frequently occur also in large blocks. An amount of dead work is entailed in the quarrying of large blocks.

Most of the following facts concerning the stone were taken from particulars given by McInerny (1929). The green colour comes from abundant felspar crystals that are apple-green; these crystals are rectangular and stand out almost as phenocrysts from a finer grained ground-mass in which the felspar is creamy-yellow in colour. Zoning in some of the green felspars can be seen with the unaided eye. Their average size is slightly less than one-twentieth of an inch; although some of the larger felspars stand out prominently, the granite ranks as a fine grained building stone. Veins of honey coloured quartz crystals up to half an inch thick occasionally show on the polished surfaces, but there is an absence of the basic segregations that mar other granites, such as those from Harcourt and especially Dandenong. Specks of gold were noticed in the polished surfaces.

Microscopically, the rock is holo-crystalline and even grained. The minerals present include felspar, quartz, hornblende, biotite, and very small quantities of apatite, zircon, magnetite, copper, and other pyrites. The alteration of some of these minerals has given rise to others—chlorite from changes in the biotite and hornblende, kaolin and sericite from the felspars, and limonite from the minerals containing iron. Minute flakes of chlorite occurring in the felspar are doubtless responsible for the green colour of the stone. Orthoclase felspar showing perthite intergrowth with another alkali type is present, together with plagioclase approaching labradorite. The proportion of orthoclase to plagioclase felspar is less than 1 : 2.

In the quarry of Geo. Atyeo and Sons, the stone is exposed in a face 40 feet in height. The blocks are transported to their works at Preston by road. Standard Quarries Pty. Ltd. is obtaining stone from a boulder formation near the top of the hill overlooking the first-mentioned quarry-boulders produced by the weathering of the granite in situ, their size being regulated by the spacing of the joints. The stone is transported to their works at Footscray by road and rail.

Because of the hardness of the stone and the irregular size of the blocks, masoning costs are high. The stone spalls well and works to a fine edge; it polishes easily, the green tint then showing to better advantage.

Two tests were carried out on specimens obtained when the quarry was opened. Dry cubes, measuring approximately 2 cubic inches, crushed under loads of 17,850 lb. and 13,300 lb. per square inch or respectively 1,149 tons and 1,048 tons per square foot. The stone broke with the columnar fracture usual with granitic rocks. These values are high, and, since the two tests gave results of about the same magnitude, it may be assumed that the strength of the Dromana stone is sufficient for any purpose. After immersion for three days, a small, smooth, rectangular block increased in weight by only 0·18 per cent., it was practically impervious. The specific gravity of the stone is 2·6053 and the weight 163 lb. per cubic foot.

A conspicuous example of the use of the Dromana stone is the Bank of New South Wales, Collins-street, Melbourne, a building that received the medal of the Royal Institute of Architects for street architecture. Other buildings are the English, Scottish, and Australian Bank, Royal Bank Branch, Collins Street; Commonwealth Bank building, Bourke Street; Provident Life Building, Queen Street; London and Lancashire building, Collins Street; Argus Office, Elizabeth Street, and others. The stone has also been used in buildings at Geelong, and Adelaide, South Australia. For monumental work it has been extensively used in Victoria.

The granodiorite from Mount Martha is a light-grey stone, lighter than that from Harcourt and finer grained. It was used in a building, now demolished, erected where the road to the Mount Martha Hotel leaves Point Nepean Road, and doubtless elsewhere. This stone is stated to have been quarried from a ledge in the granodiorite cliffs overlooking Port Phillip about half-way between Dromana Bay and Martha Cliffs. The blocks in the buildings were masoned, but in small sizes. In the author's recollection, the stone was not marred by basic segregations.

Dune limestone has been used at many places on the Peninsula as a building stone. The Cape Schanck Lighthouse was built of it, quarried from a little south of where Selwyn Fault crosses the coastline (Fig. 60). There are houses at Sorrento, Portsea, and on the Rosebud–Cape Schanck Road built of it that were erected during the middle decades of last century. The stone for some of the houses on the Rosebud–Cape Schanck Road was quarried on allotment 18, Parish of Fingal. The dune limestone when quarried is soft and is cut into building blocks with a hand saw. Placed in position in the walls of the building and exposed to the atmosphere, it puts on a "skin" that effectively resists fretting. As far as known, the absorption or crushing tests of the dune limestone have never been determined. The church of St. Mark at Dromana is built of it; this church was erected in 1892 and its fabric affords a good example of the stone's weathering qualities.

Sandstone has been masoned and used in culverts near Hastings on the Frankston–Hastings Road; the culverts were built upwards of 80 years ago. The stone came from small quarries at Golden Point, north of Crib Point. The coping is red Baxter sandstone, the basement greyish Silurian sandstone outcropping near high-water mark at Golden Point.

Although basalt or bluestone occurs in unlimited quantity in the southern portion of the Peninsula south of Balnarring and east of Main Creek, layers that could be quarried are not common. On the west side of the Punty Road south of Tuck's Road, some fairly massive flows outcrop, but these would have to be opened up to ascertain whether they could be worked economically.

BAUXITE.

Bauxite is found on the Mornington Peninsula at a number of places, but the quantity available and its average quality has to be proved by boring and sampling.

Sample 244/1926, a yellow clayey material, was obtained from J. Wilson's property, allot. 23, Parish of Wannaeue; it was classed as a ferruginous bauxite. The analyses of this sample and a sample from Boolara (Raggatt, Owen, and Hills 1945) are as follows:—

244/1926.			Boolara.		
		Per cent.			Per cent.
Insoluble matter	..	9·1	SiO_2	.. ..	5·0
Alumina–Al_2O_3	..	44·8	Al_2O_3	.. ..	53·0
Titanium Oxide–TiO_2	..	4·6	TiO_2	.. ..	4·5
Oxide of iron–Fe_2O_3	..	16·5	Fe_2O_3	.. ..	6·5
Loss on ignition	..	25·4	Loss on ignition	..	31·0
		100·4			100·0

The alumina in the Wannaeue sample was determined by the caustic soda method.

The following tests, 49-55/1925, were samples of volcanic tuff, decomposed basalt, &c., from the Western Port fall. The acid used for determining the alumina was strong sulphuric; the soluble alumina would probably be about 10 per cent. higher than if determined by the caustic soda method.

—					Acid Soluble Alumina.	Ferric Oxide.
					Per Cent.	Per Cent.
49	..	..	..	..	21·2	26·0
50	..	..	..	..	26·6	23·4
51	..	..	..	..	34·6	20·6
53	..	..	..	..	28·4	2·2
54	..	..	..	..	22·9	10·3
55	..	..	..	..	22·7	10·5

49—allot. 8, Township of Balnarring; 50—allot. 11, Parish of Flinders; 51—same allotment; 53—near Merricks Railway Station; 54—allot. 90, Parish of Balnarring; 55—south side of Manton's Creek, Parish of Flinders.

CLAYS.

At the Mines Department Laboratory about 30 clays from the Mornington Peninsula have been tested from time to time to determine their refractory or ceramic properties. Of these, the following have been selected as having some economic value.

The clays were tempered with water to produce a workable body. After scouring for several days, they were made up into standard bricklets and tiles. The test pieces, after drying, were burned at various temperatures to observe their burning colour, fire shrinkage, and their general behaviour on firing. No indication of the reserves of these clays was obtained; that was left to those interested. The following reports on the tests are simply records of the fact that clays of the classes determined exist at the localities given.

Nearly all the test pieces were burned in an oxidizing atmosphere; if in a reducing atmosphere, that fact is stated. *In the following tabulated tests, S. signifies shrinkage, T.S. total shrinkage, F.S. fire shrinkage, and A. absorption. The figures following each of these symbols give their measure in percentage.*

From Moorooduc samples of clays (192-4/1916) about 50 lb. in weight, consisting of granitic material with a large amount of clear quartz grains in two samples (192 and 194) and in the other a lesser amount, were tested. (Table D.)

The crushed material of samples 192 and 194 worked up readily into firm hard test pieces. They showed no signs of fusion at the temperatures of the tests and the shrinkage was generally low. They are classified as good refractory fireclays that will probably stand a much higher temperature. Sample 193 was slightly vitrified, although the edges of the test pieces were quite sharp; its shrinkage was greater.

Analyses of the three samples were made:

—			192.	193.	194.
SiO_2	..	..	70·61	59·80	69·70
Al_2O_3	..	..	19·03	24·12	19·63
Fe_2O_3	..	..	1·29	3·09	1·15
FeO	..	..	0·19	0·19	0·19
MgO	..	..	Sl. tr.	Trace	Sl. tr.
CaO	..	..	Nil	Nil	Nil
Na_2O	..	..	0·07	0·10	0·17
K_2O	..	..	0·39	0·47	0·36
H_2O-(110° C.)	..	..	1·42	2·26	1·03
H_2O+	..	..	6·85	9·19	7·37
TiO_2..	..	..	0·51	0·66	0·51
			100·36	99·88	100·11

The Moorooduc clay was bored near the Moorooduc railway station. In all fourteen holes were put down and in seven of them a good, white, plastic clay was located; the overburden averaged 6 ft. 6 in. The white clay rested on a pink clay free of grit. A sample of

Table D.

—	192.	193.	194.
Test O	S.4, firm, hard tile ..	S.8, firm hard tile	S.4, firm hard tile
Test A, muffle 1,100° C. ..	Light-pink, soft biscuit burn, S.6	Light-pink, soft biscuit burn, S.10	Light-pink, soft biscuit burn, S.6
Test B, wind furnace after muffle, 1,340° C.	White infusible, S.9	Brown, speckled, slight vitrification, S.14	White infusible, S.10
Test C	White infusible, S.10	Brown, speckled, slight vitrification, S.14	White infusible, S.10

the clay from six bore holes was submitted to tests by the Mines Department Laboratory which reported it to be an exceptionally refractory clay. It was adjudged by another expert as a clay that

"will be of great value to a refractory business, but not suitable for making a cheap general brick alone."

Used as a bonding clay, there was estimated to be sufficient reserve for the manufacture of 20,000,000 standard bricks.

Presumably, the pink clay rests on the floor of the old valley of Balcombe Creek. It and the overlying white clay are seemingly sedimentary clays and may be expected to occur in some quantity. They were laid down before the Baxter Sandstones, hence their gritlessness. They are composed of the transported denuded material from the Mount Eliza Scarp and for the most part the normal shales and sandstones to the north. Samples 192-4 obtained nearby are stated to have consisted of granitic material, colluvial clay from the Mount Eliza granitic area. The fluxing impurities from alkali felspars are relatively small in the Moorooduc clays. Apparently, the higher percentage of Fe_2O_3 in sample 193 and its physical condition were responsible for the slight vitrification of what was the least siliceous and highest aluminous sample of the three tested.

Several clays from Bittern were tested (Table E):

539/1923, a putty colored clay when dry, grey when moist, coarse grained with 35·3 per cent of grit, highly plastic and readily slaking.

566/1924, top clay, a foot from the surface.

567/1924, clay 4 feet from the surface.

629/1931, a medium grained clay with 27·6 per cent of grit, drab both dry and moist, of high plasticity, the water of plasticity 22 per cent, readily slaking.

539 was highly plastic, easy to work, and made up readily into different shapes. The green test pieces possessed good tensile strength, and could be handled without much loss or breakage. The grit consisted of fine grained, well rounded, white sand. In a reducing atmosphere, when burned at the highest temperature available at the laboratory, it produced a body that cannot be scratched with a knife. At 1330°C the test pieces show several blebs of a pale grey slag or glaze suggesting the presence of a small amount of fluxing impurities, probably sodium or potassium compounds. The clay showed a very low fire shrinkage, suggesting a high silica content. The absorption values are low.

The high plasticity and good bonding properties should allow of the addition of silica—sand or ganister—to produce a silica clay refractory. The laboratory tests show that at 1330°C, the clay is only moderately refractory.

Chemical analyses were made of samples 566 and 567.

	566	567
SiO_2	68·30	75·16
Al_2O_3	17·06	16·09
Fe_2O_3	2·04	0·68
CaO	0·44	0·50
MgO	Tr.	Tr.
Water $H_2O - 110°C$. ..	5·68	3·30
Loss on ignition $H_2O + 110°C$	6·20	4·00
	99·72	99·73

The proportion of clayey matter to sand in each sample is large enough to produce, in the unburned condition, firm hard bricks which have good tensile strength. The clays are plastic, easily worked, and may be moulded into various shapes. 566 burns to a " flashed " dark-brown, hard, semi-vitrified body, while 567 burns to a brown, dense brick, with a fine grained surface, retaining a good shape with arrises. 629 was classed as a refractory clay.

From Bittern, two clays (499-500/1921), the first fat, the second lean, were analysed:

—	499.	500.
SiO_2	80·05	86·77
Al_2O_3	10·08	6·79
Fe_2O_3	1·62	0·70
MgO	Tr.	Nil
CaO	Tr.	Tr.
Na_2O	0·77	0·87
K_2O	0·11	0·03
$H_2O +$ above 110° C.	4·00	2·65
$H_2O - 110°$ C.	2·56	1·25
TiO_2	1·15	1·22
	100·34	100·28

The Bittern clays came from a shallow valley heading in an old ridge that has never been covered by basalt. The clays are probably admixtures of both sedimentary and residual clays; like the clays at Moorooduc, they are composed mainly of base-rock material. From their generally higher silica percentages, the base-rock at Bittern apparently consisted mainly of

Table E.

—	539.	566.	567.	629.
Test O, air-dried ..	Cement colour, S.5, firm bond, good tensile strength	Drab, S.7 firm body good bond	Grey, S.7, firm body, good bond	Cement colour, S.7·5, firm bonding power, tile warped
Test 1, 1,050° C. ...	Cream, T.S.5, F.S.1, A.14·6, soft biscuit	Buff, T.S.9·5, F.S.2·5, A.12·6, firm brick	Cream, T.S.9, F.S.2, A.13·2, firm brick	Strong-cream, T.S.9, F.S.1·5, A.11·91, firm brick
Test 2, 1,110° C.	Cream, T.S.6, F.S.1, A.14·1, soft biscuit	Buff, T.S.10·5, F.S.3·5, A.9·9, firm brick, minute cracks	Cream, T.S.10, F.S.2, A.11·8, firm brick	Pale-buff, T.S.9, F.S.1·5, A.11·86, firm brick
Test 3, 1,150° C.	Cream, T.S.6, F.S.1, A.13·7, moderate brick	Buff, T.S.11, F.S.4, A.9·6, firm brick, minute cracks	Cream, T.S.10, F.S.3, A.10·8, firm brick	Pale buff, T.S.9, F.S.1·5, A.11·84, firm brick
Test 4, 1,210° C.	Strong-cream, T.S.6, F.S.1, A.13·4, moderate brick, cracked	Buff, T.S.12, F.S.5, A.9·3, firm brick, minute cracks	Cream, T.S.11, F.S.4, A.10·7, firm brick	Pale-buff, T.S.8, F.S.0·5, A.11·74, firm brick
Test 5, 1,270° C.	Strong-cream, T.S.6, F.S.1, A.12·6, moderate brick, cracked	Buff, T.S.12, F.S.5, A.9·3, firm brick, minute cracks	Cream, T.S.11, F.S.4, A.10·5, firm brick	Buff, T.S.8, F.S.0·5, A.11·31, firm brick
Test 6, 1,330° C., reducing atmosphere	Dark-grey, T.S.7, F.S.2, A.10·7, hard brick	Reddish-brown, T.S.13, F.S.6, A.2·5, steel hard, egg shell glaze	Brown, T.S.12, F.S.5, A.6·7, hard brick	Strong-buff, T.S.9, F.S.1·5, A.12·2, firm brick

sandstone; none of the clay was derived from a granitic source, a fact reflected in the small percentages of fluxing impurities present.

Stoneware clays (Table F) came from the Langwarrin and Baxter districts (123/1920, 512/1947, 808/1923) and one such clay from Dromana (493/1930). The Langwarrin and Baxter clays are apparently bedded deposits and occur in some quantity; the Dromana clay came from a decomposed dyke in Digger's Creek east of Bald Hill.

123, white semi-plastic clay containing a small percentage of grit; it slaked readily requiring 30 per cent. of water to form a workable body.

512, cream coloured, fine grained, semi-plastic clay.

808, white, micaceous, siliceous, semi-plastic clay; it slaked readily and required 18 per cent. of water to temper.

493, medium to coarse grained clay, white when dry, dull white when moist, it slaked readily, was moderately plastic, and required 29 per cent. of water to temper.

Test 2	white, stained
1110°C	T.S.10 F.S.3.A.19·1 firm biscuit, warped.
Test 3	white, stained
1150°C	T.S.12 F.S.5.A.17·2 hard brick, warped.
Test 4	white, stained
1210°C	T.S.13 F.S.6.A.14·2 hard brick, warped.
Test 5	pale grey
1330°C reducing atmosphere	T.S.17 F.S.10.A.0·9 steel hard, vitrified, dense body, sharp arrises.

The sample dried quickly without warping or cracking when made up into various shapes and sizes. The burning colour is good but is marred by a slight yellow stain caused by the presence of a trace of vanadium compounds. The stain only comes after the test pieces have been moistened with water.

From the Balnarring district, a clay (134/1945) classified as a ball clay was reported. The precise locality was not given by the sender, but he stated that it came from 4 to 20 feet below the surface. It

Table F.

—	123.	512.	808.	493.
Test 0, air-dried	White, S.3	Cream, S.1, firm bond ..	White, S.3	White, S.2·5, moderate bond slight warp
Muffle heat, 1,000° C.	.. .. ..	Faint-pink, T.S.1, F.S.0, A.30·2, firm biscuit		
Muffle heat, 1,050° C.	Cream, T.S.6, F.S.3, A.21, firm biscuit	Faint-pink, T.S.1, F.S.0, A.26·8, firm biscuit	Strong-cream, T.S.6, F.S.3, A.9·1, firm biscuit	Pale-cream, T.S.6, F.S.3·5, A.16·5, firm biscuit, slight warp
Muffle heat, 1,100° C.	.. .. ..	Off-white, T.S.2, F.S.1, A.23·3, smooth, hard tile	.. .. ..	Pale-cream,T.S.6, F.S.3·5, A.12·9, firm biscuit, tile cracked and warped
Muffle heat, 1,150° C.	.. .. ..	Off-white, T.S.3, F.S.2, A.19, smooth, hard tile	.. .. ..	White, T.S.9, F.S.6·5, A.8·7, hard biscuit, tile warped
Muffle heat, 1,200° C.	.. .. ..	Off-white, T.S.6, F.S.5, smooth, hard tile	.. .. ..	Dull-white, T.S.12, F.S.9·5, A.1·9, hard body, vitrified, tile warped and cracked
Muffle heat, 1,270° C.	.. .. ..	.. .. ..	.. .. ..	Dull-white, T.S.12, F.S.9·5, A.0·4, vitrified, dull glaze, tile warped badly
Muffle heat, 1,340° C, once burned	Light-grey, T.S.12·5, F.S.9·5, A.1·0, vitrified	Ivory, T.S.14, F.S.13, A.0, steel hard, vitrified	Light-grey, T.S.8·5, F.S.5·5, A.0·3, vitrified	

Sample 123 was classed as a common stoneware clay, 512 as suitable for white vitrified ware, 808 as a stoneware clay. Sample 493 was classed as a stoneware clay, lacking in highly plastic properties, but easy to handle and work into various shapes. Its bonding power and tensile strength when green could be improved; the coarse and fine grained grit, the cause of the cracking and distortion, could be removed. The clay shows a sharp vitrification range and would require careful burning after 1,200°C; it apparently contains a small percentage of fluxing impurities, probably alkali silicates, that produce a dull egg-shell glaze at 1,270° and a bright, glazed surface after 1,350°.

A bluish, gritless, white clay (567/1910) from midway between Somerville and Moorooduc burned to a white, vitrified body of a porcellanous nature at 1,180°C. The shrinkage was low.

From the New Lay Mine, 4 miles from Dromana, a moderately plastic, fine grained clay (696/1924) was classed as a faience clay. It was white when dry, dull white when moist, slaked slowly, requiring 31 per cent. of water. The fire tests were as follows:—

Test 0 air dried	white, S.7, firm bond.
Test 1 1050°C	cream, stained T.S.9 F.S.2.A.21·6 firm biscuit, warped.

was a fine clay with a small amount of grit, grey when either dry or moist, that slaked readily, the water of plasticity being 21 per cent.

Test 0 air dried	grey, S.6, firm bond.
Test 1 1000°C	light stone T.S.8 F.S.2.A.10·5 hard biscuit.
Test 2 1050°C	light stone T.S.10·5 F.S.4·5.A.8·3 hard tile.
Test 3 1100°C	light buff T.S.10·5 F.S.4·5.A.8·6 hard tile.
Test 4 1150°C	light buff T.S.10·5 F.S.4·5.A.4·8 hard tile.
Test 5 1200°C	light buff T.S.10·5 F.S.4·5.A.9·2 dense, hard tile.
Test 6 1340°C reducing atmosphere	yellowish-pink T.S.10·5 F.S.4·5.A.10·5 dense, hard tile.

The clay when fired is reported as showing no signs of vitrification, warping, or cracking, and the colour is pleasing.

GOLD.

The Mornington Peninsula, like other parts of Victoria, has had its gold rushes. The late the Hon. A. Downward informed the author that there have been three rushes to the Tubbarubba Creek and Bulldog Creek diggings. The fact that only one auriferous reef, rich while it lasted but soon lost on a slide, has been worked near the head of Bulldog Creek, and that no payable reefs have been found on Tubbarubba Creek, presents a problem as to the source of the gold. It is an important fact that much of the strata in which these creeks cut their valleys is that in which highly productive reefs at Bendigo, Castlemaine, Daylesford and other goldfields are found. The nearest locality to the Mornington Peninsula where similar strata reappears is on the Blackwood Goldfield, 100 miles to the north west.

Laminated highly mineralized reefs, such as would be considered favourable on any of the goldfields mentioned, occur at Bulldog Creek and Tubbarubba Creek but Griffith's reef near the head of Bulldog Creek, the one reef worked, was a somewhat unattractive fissure reef cutting diagonally (Fig. 63) across the strata;

its strike is north 31° west and that of the strata north 35° east. The gold was in the form of thin flat plates encased in ferruginous material and occurred where the fissure reef intersects a strong band of dark-blue slate. This suggests an indicator lode, such as the highly productive indicator reefs of the Welsh and Slater and Rocky Lead Mines, west of Daylesford, which occurred in beds of the same age. The dark-blue slates cross to Tubbarubba Creek to where the best alluvial gold in that creek was obtained. In a section of the beds exposed in Tubbarubba Creek, there are thin bands of highly mineralized black slates suggestive of indicators.

There is probably another indicator belt 24 chains downstream from where the fissure reef crosses Bulldog Creek (Fig. 63); there a rich patch of alluvial was taken from Barnes's workings and it was reported that a 17-oz. nugget was found during the first rush. This indicator belt, if it is such, crosses the middle reaches of Mosquito Creek (Fig. 63), a tributary joining Bulldog Creek from the south-east, a little over half a mile downstream from Barnes's workings. Two classes of gold were obtained in Mosquito Creek one consisting of more or less rounded pieces which

Ordovician ☐   Miocene Sandstone ⌗   Alluvium ▦   Terraces ▨

Scale of Chains
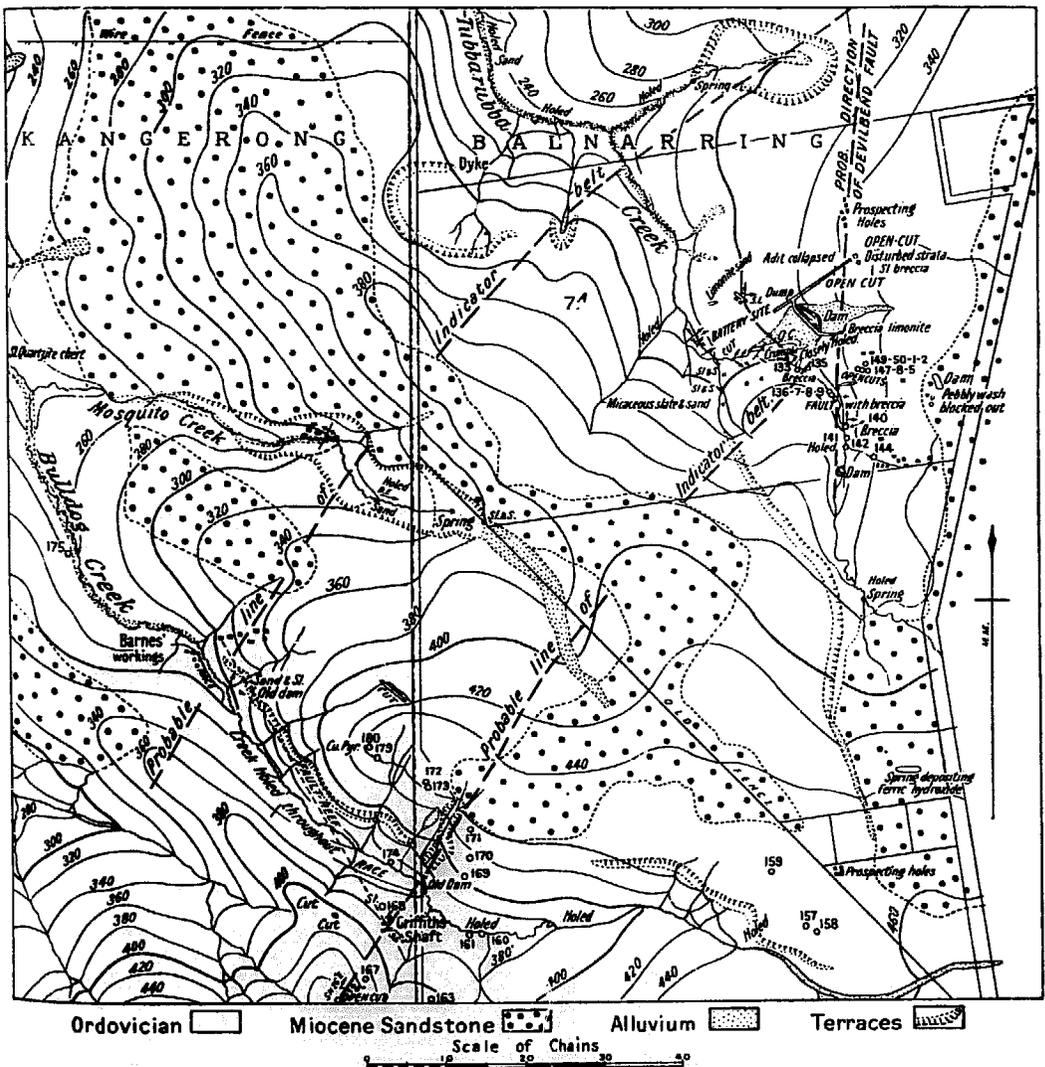
Fig. 63. Tubbarubba and Bulldog Creek diggings.

were evidently resorted, the other in ragged, flat pieces, retaining their sharpness, and showing no evidence of attrition; apparently they had come from a reef close at hand. The gold ranged in weight from a few grains to 4 or 5 dwt. pieces.

It is significant that this supposed indicator belt would cross to a tributary coming in on the right bank of Tubbarubba Creek from the north-east, about 30 chains downstream from the old battery site on that creek (Fig. 63). A quantity of alluvial gold appears to have been won from this gully, for all the alluvium has been turned over. It is apparent that this gold was shed from a lode within the tributary's catchment basin; its source was distinct from that shed upstream in Tubbarubba Creek, where the other indicator belt crosses. The open cut and adit put in from near the battery cut a reef; portions of this reef on the mullock tip suggest that it was well defined—a mineralized fault reef with slickensided surfaces. If it was in the fault channel of Devilbend Fault (Fig. 63) and persists it crosses the head of the tributary gully.

Although most of the alluvial gold found at Tubbarubba and Bulldog Creeks doubtless came from indicator lodes, the source of some of it may have been the pebble beds of the old marginal stream which crossed in the vicinity.

It is not generally known that alluvial gold was obtained on the east shoulder of Arthur's Seat. The gullies there were worked by Chinamen for many years; their workings are still visible. The gold was shed from the Pebble Beds (p. 43).

SAND.

Sand on the Peninsula is of two kinds, that on the Nepean Peninsula and near Cape Schanck, a calcareous sand, and that elsewhere on the Mornington Peninsula a siliceous or quartz sand. Where the calcareous matter in the former has been removed, as in the coastal dunes of Bass Strait and Port Phillip, the residue is closely comparable with the latter. The siliceous sand across the north end of the Mornington Peninsula does not appear to be of any great thickness, for the base-rock outcrops at many places through it.

The constituents of two samples of what appeared to be a reasonably clean sand were determined at the Mines Department Laboratory—I., sand brought to the surface in sinking a well on allotment 12, Parish of Tyabb; II., a highly siliceous, soft sandstone from Bore 3, Tyabb (Fig. 23):

—		I.	II.
Silica or quartz (SiO_2)	..	90·30	91·06
Alumina (Al_2O_3) ..	..	6·15	..
Ferric Oxide (Fe_2O_3)	..	0·11	0·11
Combined water ..	..	3·44	..

OIL.

The compactly-folded base-rock of the Mornington Peninsula can be excluded as a possible source of oil. About 70 per cent. of the oilfields of the world are in Cretaceous and Tertiary marine sediments, generally on or near the flanks and in the closely folded portions of the Tertiary orogenic belts. In regard to the Tertiary beds on the Peninsula, it has been pointed out (p. 29) that the Older Basalt lavas show little evidence of deformation and this holds for the Tertiary marine sediments; there is no possibility of a Tertiary dome or anticline favourable for oil concentration.

Concentration where the ends of tilted beds rest against a fault scarp or unconformably against an old land surface, has been an important source of oil in many parts of the world. What are probably gently tilted Tertiary sediments, over 1,100 feet thick, were penetrated by the Sorrento Bore, but no evidence of oil concentration was found. If there has ever been a concentration in these beds, it may have migrated eastwards towards Selwyn Fault to the upper ends of the tilted beds.

The bores put down in the Parishes of Wannaeue and Fingal on the downthrow side of Selwyn Fault were not deep enough to reach the Tertiary. The marine Tertiary beds at Balcombe Bay, Grice Creek, Tyabb, Flinders, and other places are quite unfavourable for the accumulation of oil, and those at Balcombe Bay and Tyabb have been closely bored.

XXI.   UNDERGROUND WATERS

The water of most of the streams on the Mornington Peninsula is to a greater or less degree brackish, especially that on the Older Basalt or in any way influenced by it. The water from springs is likewise generally brackish, indicating that they are surface springs and the water in passing along fissures has not parted with much of its contained saline constituents. Exceptions to the general brackishness of the streams are Burrabong Creek, near Cape Schanck, the catchment of which is wholly in limestone, and some watercourses on granitic rocks.

Underground water in the base-rock and granitic rocks on the Peninsula circulates mainly along fissures. As the base-rock and granitic rocks are in most places covered with residual soil, the fissures are seldom exposed on the surface. The direction and underlay of the fissures in the base-rock is to some extent influenced by the direction of the anticlinorium and the dip of the strata, but there is no way of determining where the fissuring is, or whether it is open for the circulation of underground water. The general silicification of the older strata on the Peninsula makes them impervious, and water is present only where they are fissured.

The direction and underlay of the fissures in the granitic rocks follow no set rule. Water from a fissure covered by residual soil finds its way to the surface by a seepage or soak, but the supply from the fissure, if it is tapped, depends on the size and height of the hydraulic head. A fissure with a low underlay is more readily located by sinking or boring than one with a steep underlay.

In the Older Basalt, underground water is found in the fragmental basalt in some of the Plateau flows at a relatively shallow depth. The Plateau flows

are south of a line along Manton Creek bearing in the direction of Rosebud, i.e. south of the Flinders Fault (Fig. 19). North of the Flinders Fault it is possible with relatively shallow boring to pass through the basalt into the underlying fluviatile and lignitic beds where the basalt covers an old valley, or into the old residual soils of the base-rock or granite on the sides of the old valley.

In the old covered valleys the chance of obtaining water is greater, but there is no criterion as to whether the water will be drinkable or otherwise. The Hastings Bore passed, for example, through the Older Basalt into lignitic and fluviatile beds beneath the basalt, but although there was a strong flow of underground water from the sub-basaltic deposits, the water was saline.

The bores put down on the shore of Balcombe Bay passed through marl, sands, basalt, lignite, and lignitic clays into granitic rocks, but the flow of underground water was negligible. The Balcombian marls are impervious and flows of underground water do not usually come from them.

Boring for water in the Baxter Sandstones is more likely to be successful than in the older rocks. The Baxter Sandstones cover extensively the base-rock, granitic rocks, marls, and the fringe of the Older Basalt near the Flinders Naval Base. Where the underlying beds were a land surface before deposition of the sandstones and where these cover an old valley or "gutter," there is often a circulation of underground water. The sandstones themselves have formed by the successive accumulation of sand, later compacted in sandstone, on old land surfaces dissected by valleys which were later filled with sand. These "false bottoms," as they are termed, function as channels in the circulation of underground water. There is however, no indication on the surface as to where a "false bottom" may occur.

The siliceous dune sands in the northern part of the Peninsula may also cover old valleys in the baserock, but there are no "false bottoms" in dune sand. From bores put down in the calcareous dune-rock of the Nepean Peninsula, more particularly near Selwyn Fault, excellent drinking water has been obtained. This, no doubt, is partly due to the proximity of Selwyn Fault, and the presence of an impervious bed at a shallow depth to hold the water. To the north-north-west, this impervious bed is tilted in that direction and is deeper.

It is apparent from the foregoing facts that boring or sinking for water on the Mornington Peninsula may, in some places, be more successful than in other places, but even if water is found, one must take the chance of it being drinkable.

XXII. APPENDIX

THE OLDER BASALTIC LAVAS

The following is taken from the descriptions by Edwards (1938) of the types of basalt on the Mornington Peninsula.

Titanaugite Basalts.

Crinanites and crinanite-basalts—doleritic olivine-analcite basalts—occur in the lowermost flow of the Cape Schanck bore (700–850 feet).

"They are coarsely ophitic rocks, and consist of a few embayed phenocrysts of olivine, which may be fresh or altered to serpentine, in a coarsely intergrown groundmass of plates of purple titanaugite up to 3mm. across, and laths of labradorite (Ab_{30}-Ab_{40}) about 1·0-1·5 mm. long, coarse rods of ilmenite and needles of apatite, and interstitial analcite. The titanaugite sometimes encloses the olivine crystals. It is optically positive, with 2V about 60°, and pleochroic with X=purple-brown, Y=purple, and Z=yellow. Where it is in contact with analcite it may be altered to green aegirine-augite or even aegirine. The analcite is sometimes water-clear, but is more often cloudy and weakly birefringent. Flakes of biotite sometimes occur in association with the analcite and in cracks in the olivine."

The *Moorooduc type*, a group of closely comparable titanaugite basalts, is found in several bores—No. 8 Moorooduc from 135–200 feet, No. 2 Bittern from 130 feet, No. 6 Tyabb from 404 feet, the Flinders Bore from the surface to 99 feet, 409 feet, from 536 to 671 feet and from 874 to 1,135 feet, the Cape Schanck Bore from 43 feet, from Balnarring and from Balcombe Bay. Edwards states that

"these rocks are finer-grained than the previous groups. Olivine is the only mineral which forms phenocrysts. It may be fresh, corroded or, more frequently, altered to serpentine. The crystals range from 0·5 to 2·0 mm. in diameter, the smaller sizes being the more common. They are set in a medium-grained groundmass of violet titanaugite (2V about 60°), ophitic towards plagioclase laths

(Ab_{40}), and abundant interstitial glass which is usually green, but sometimes yellow or brown. This glass is frequently devitrified and birefringent, and is either chloritic or serpentinitic in composition. The degree of ophicity varies, as does the depth of colour of the titanaugite, and in chilled phases the pyroxene does not appear, but is replaced by an opaque glass which is packed with iron ore globules and is a purple or black colour. This glass resolves under high magnification into a colourless base crowded with trichytes or iron ore. Such chilled phases are found at . . . . , Moorooduc, Flinders, and Tyabb."

In a flow at Balnarring

"the amount of green glass is diminished, and phenocrysts of titanaugite up to 3 mm. in diameter are present. The groundmass is coarser, and the unusually elongated laths of the plagioclase have segregated into sheaves."

From a specimen about half a mile east of Arthur's Seat brown glass is absent.

Iddingsite Basalts.

The *Mirboo type* is an iddingsite-bearing basalt that is found in the Flinders Bore as several flows at depths about 160, 215, 300, 500, and 850 feet, also in the Cape Schanck Bore. As defined by Edwards

"these basalts are all fine-grained, slightly glassy rocks, consisting of phenocrysts of olivine altered to iddingsite, set in a groundmass of plagioclase laths (Ab_{40}), granular to idiomorphic crystals of colourless or pale violet pyroxene, iron ore grains, and a variable amount of green glass. . . . . . . The alteration of the olivine to iddingsite is of uniform extent, and pre-dates the crystallization of the pyroxene of the groundmass, since iddingsitized olivine crystals are frequently observed enclosed by aggregates of pyroxene. Small grains of iddingsite are present in the groundmass . . . . . . The olivine cores may or may not be altered to serpentine. Such serpentine as is formed is often bright-green, pleochroic to a yellow-green. In the Flinders specimens the olivine crystals reach dimensions such as 3-4 mm. across.

with a very thin rim of iddingsite, and in one of the higher flows at this locality the iron ore forms coarse octahedra larger than the individual pyroxene grains.

In the Flinders rock from the 215-ft. core, the iddingsite is the yellow variety. It is strongly pleochroic and shows straight extinction. A vein of iron-oxide stained rock appears in the slide. As this vein is approached the yellow iddingsite makes over to red iddingsite. Chalcedony is again present as vesicles and veins."

Olivine–Basalts.

The *Keilor type,* a distinctive glassy olivine-basalt, consists, according to Edwards of

" microphenocrysts of slightly corroded fresh olivine, set in a groundmass of laths and microlites of plagioclase (Ab$_{38}$), minute grains of pyroxene, octahedra of iron ore, and abundant brown glass which constitutes over half the rock."

It is found in the Cape Schanck Bore at 32 feet where it is, Edwards says, rather more crystalline than the specimens from the type locality and other places; the felspar laths are longer and the pyroxene grains larger and more numerous, while the amount of brown glass is less.

The *Buckland type* was selected from a dyke at Buckland Gap, near Harrietville, and Edwards describes it as containing

" numerous phenocrysts of plagioclase, augite and olivine, in a fine-textured groundmass. The plagioclase is labradorite (Ab$_{48}$), and frequently forms rectangular crystals. They are commonly corroded at the edge and at the core. The augite occurs as greyish-brown, idiomorphic crystals, sometimes 2-3 mm. in diameter. The cores of these crystals are sometimes pleochroic from pale-green to yellowish-green. In other instances they are ' spongy'

with inclusions. Olivine crystals are smaller and less numerous, and are slightly altered to serpentine. The groundmass shows no fluxion structure, and consists of minute rectangular and lath-shaped crystals of labradorite, small grains of augite and olivine, and an interstitial base of minute grains of augite, iron ore, and glass. . . . . The Cape Schanck rock is closely comparable with Buckland Gap specimen, except that its pyroxene is a purple titanaugite. A somewhat comparable rock occurs at Grange quarry, Double Creek, near Flinders, but here the phenocrysts are solely of a brownish-violet augite, up to 2 mm. in diameter, and the fine-grained groundmass shows fluxion structure."

The *Flinders type* Edwards characterizes by

" the presence of considerable amounts of green glass, generally devitrified, when it appears to be serpentine. It differs from the Moorooduc type in the absence of titan-augite and ophitic structure, but intermediate variations are to be found. Olivine is usually the only mineral occurring as phenocrysts. In some of the Flinders bore cores it forms crystals 2-3 mm. across, but is generally smaller. The olivine crystals are nearly always corroded and partially altered to serpentine. Occasionally micro-phenocrysts of brown augite and plagioclase accompany the olivine. Sometimes,. . . . . the plagioclase is more abundant. The groundmass frequently shows fluxion structure, and is an intergranular growth of pyroxene granules, laths of plagioclase (Ab$_{40}$), iron ore, and the intersertal green glass. The pyroxene varies from colour-less to pale violet, when the rock grades into the Moorooduc type. The grain size is rather variable at different localities, and in some instances the green glass is present in only small amount, or may be lacking entirely."

Edwards states:

" this, the most widespread of the Older Volcanic basalts which does not carry titanaugite, occurs at Flinders (bore),. . . . . Grice's Creek,. . . . . Cape Schanck (bore),. . . . . . Moorooduc (Bore No. 9, 109-119 feet). . . ."

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FIGURES

PHOTOGRAPHS

1. View from Arthur's Seat, looking north across Dromana Bay. The low ground in the middle distance is the fringe of the Kangerong Basin. On the north side of Dromana Bay is Mount Martha, with Mount Eliza in the distance.

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5. Tuerong quarry. North pitching strata.

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11. Koolamadoo Island. Face of Silurian strata 12 feet high, on west side of island.

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15. Mount Martha raft. Faulted aplite intrusion; high-angled fault with downthrow to south-west.

16. Mount Martha raft. Portion of Palaeozoic sediments north-east end of raft, showing jointing and " fold " structure.

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18. Mount Martha raft. Aplite veins following small faults that have displaced lighter bands of Palaeozoic sediments altered by alkali metasomatism.

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23. Fossil plant, *Eucalyptus praecoriacea*, figured by Deane.

24. Selwyn fault, where it crosses the Bass Strait shore-line, 1·5 miles north of Cape Schanck. On the right, the cliff face is the fault scarp that has receded by coastal erosion. In the foreground is the clay debris in the fault-channel.

25. Balcombe Bay. Low cliff of Miocene marl.

26. Mornington. Cliff of Baxter Sandstone and the beach resulting from its disintegration.

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28. West Head. Stacks of Basalt, partly consumed.

29. Pulpit Rock, Cape Schanck. The Rock is the dark-coloured circular rock in the middle distance.

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31. Nepean Peninsula coastline. Partly consumed stacks, arches, and detached masses of dune-rock.

32. Flinders-Fingal coastline near Flinders. Unconsumed stack of Older Basaltic lava.

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Figs. 1 – 2e

See 35 mm jacket

WESTERN PORT

GEOLOGICAL SURVEY OF VICTORIA

Fig. 1

AUSTRALIA 1:63,360

NO. 868 ZONE 7

WESTERN PORT

FRENCH ISLAND

PORT PHILLIP

- EAGLE ROCK
- CRAWFISH ROCK
- BARRILLIER I.

River

The Dark Island

Palmer Point

Star Point

LONG ISLAND

SANDSTONE ISLAND (KOOLAMADOO I.)

MT. WELLINGTON

Golden Point

Crib Point

Blue Gum Point

THE PINNACLES

Stony Point and Hands

HANNOP HILL

Freeman Point

WESTERN INLET

PELICAN I.

Stockyard or Settlement Pt.

Tortoise Head

Red Bluff

Balnarring Beach

Point Sumner

Peck Pt.

ELIZABETH ISLAND

Sandy Point

BIRD ROCK

Long Pt.

RAMS I.

COBB BLUFF

CORINELLA

Point Leo or Bobbanaring

Honeysuckle Point

WESTERN PORT

Penguin Rock

Mussel Rock

Observation Point

Cobb Bluff

McHaffie Reef

Bluff

Fisherman Point

REEF I.

Stony Pt.

West Head

Long Pt.

CHURCHILL ISLAND

WOOLAMAI

Scale 1 Mile to 1 Inch

CHAINS 80 40 0 1 2 3 4 MILES

METRES 1000 500 0 1 2 3 4 5 6 KILOMETRES

Contour Interval 50 Feet

INDEX TO ADJOINING SHEETS

MORNINGTON	CRANBOURNE	DROUIN
SORRENTO	WESTERN PORT	KORUMBURRA
	WOOLAMAI	WONTHAGGI

Quaternary

Recent
- Sandy beaches
- Mangrove
- Salt Marsh
- Abandoned beach deposits with sand ridges and dunes

Pleistocene
- Swamp and younger fluviatile deposits
- Fluviatile clay, silt, sand and gravels
- Sand ridges and sheets
- Sand, clay and silt

Tertiary
- Pliocene
- Miocene
- Oligocene
- Eocene

Mesozoic
- Epi-Devonian

Palaeozoic
- Silurian
- Ordovician (Upper, Middle, Lower)

SORRENTO
GEOLOGICAL SURVEY OF VICTORIA

AUSTRALIA 1:63,360

NO. 867 ZONE 7

BELLARINE

PAYWIT

SWAN BAY

MUD ISLANDS

PHILLIP

PORT

Queenscliff
Shortland Bluff
LONSDALE BAY
Point Lonsdale

THE RIP

SOUTH CHANNEL ISLAND

Martha Point

DROMANA BAY

Point Nepean
NEPEAN HILL
NEPEAN BAY
Observatory Point
PEARCE
TICONDEROGA BAY
WEEROONA BAY
Point Franklin
COLLINS BAY
Point MacArthur
Point King
Borg Rocks
Sierra Nevada Rocks
London Bridge
Sphinx Rock
Darby Rock
Pulpit Rock
Garden Rock
Jubilee Point
DIAMOND BAY
Barnes Point
The Dogs Head
Pelly Point
Spray Point
Koroon Point
Glenn Point
The Divide
Orr Point

Sorrento
The Sisters
SULLIVAN BAY
CAMERON BAY

Dromana

McCrae
Rosebud
Rosebud West

Rye

Tootgarook

BASS STRAIT

Borg Rocks
Rowley Rocks

Castle Rock
Elephant Rock
BUSHRANGER BAY
Cape Schanck
Pulpit Rock
The Arch

Scale 1 Mile to 1 Inch

Contour interval 50 feet

INDEX TO ADJOINING SHEETS

SORRENTO

NO. 867 ZONE 7