December 1949

Mem. Nat. Mus. Vict., 16, 1949

https://doi.org/10.24199/j.mmv.1949.16.03

THE PHYSIOGRAPHY AND PALAEOGEOGRAPHY OF THE RIVER YARRA, VICTORIA

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Figs. 1-8.

(Received for publication August 4, 1947.)

Introduction

The normal drainage in Victoria is northwards from the Great Dividing Range to the River Murray, and southwards from the Range to the sea. The River Yarra flows from east to west, and it was early recognized that this paradox was due to a complicated history. Gregory (1903) maintained that the predecessor of the Yarra flowed southwards through the Gembrook Gap to the sea. Keble (1918) developed Gregory's idea. Edwards (1940) and the present writer (Gill, 1942) showed that the ancestor of the Yarra (the Wurunjerri River) flowed northwards on the east side of the Mt. Dandenong igneous complex, rounded this large monadnock at its northerly limit, then flowed southwards through Lilydale to the sea.

Nomenclature

It is suggested that the following natural divisions of the course of the Yarra be adopted:

1. *Upper Yarra*—from source to the commencement of the Warburton Gorge (see Fig. 1).
2. *Middle Yarra*—Warburton Gorge to the commencement of the Warrandyte Gorge.
3. *Lower Yarra*—Warrandyte Gorge to the sea.

These are terms originated by Gregory, but they are now given precise definition.

Upper Yarra

The River Yarra has its source in the Great Dividing Range on the remnants of a 4,000-ft. plateau. The surrounding prominences are Mt. Matlock 4,140 ft., Mt. Gregory 4,000 ft., Mt. Horsfall 4,000 ft., Mt. Observation 3,800 ft., and Mt. Donna Buang 4,080 ft. From its source to McMahon's Creek, the river flows approximately in a westerly direction. In this area the Yarra is carving out an intramontane basin. From the accompanying map (Fig. 1) it can be seen that the river flows through a valley bordered by more or less parallel mountain ridges (divides). The valley is almost mountain-locked, the river escaping through what I suggest be called the McMahon Gorge, between Reefton and McMahon's Creek. The flow of the river is at about right angles to the strike of the basement rocks, which consist of a series of marine sediments—mudstones, sandstones, and shales. The physiography of the Upper Yarra is essentially youthful. There are many rapids, and terraces of torrent gravels are in evidence in a number of places.

The second part of the Upper Yarra from the McMahon Gorge to the Warburton Gorge owes its most characteristic features to control by the latter gorge. As Edwards (1932) has described, dacitic lavas, a granodiorite intrusion, hornfels, and a group of acid dykes stand athwart the course of the river, resulting in the formation of a gorge, and the partial reduction of the country upstream from it. Big Pats Creek is a tributary which enters just upstream from the gorge. It is a stream marginal to the granodiorite intrusion and its metamorphic aureole of hornfels.

Middle Yarra

When the river emerges from the Warburton Gorge at Millgrove, it assumes a quite different character, and owes its form to different causes. It is for this reason that this section of the river is placed in a different category and called the Middle Yarra. The river flows through a mature valley with a wide flood plain. It receives at Yarra Junction the waters of the Little Yarra, at Launching Place those of the Don River, and at Healesville those of the Watts River. To the north the valley is walled by the igneous complex of Ben Cairn, and the Tool-be-wong granodiorite intrusion. To the south, granite and granodiorite outcrop (Baker, Gordon, and Rowe 1949). Obviously these rocks have played a major part in determining the direction of drainage in this area. In fact, the volcanic rocks of the Dandenong Ranges, and a series of granite and granodiorite intrusions to the east of it, are responsible for the westerly flow of the Yarra in its upper reaches (Fig. 2).

At Woori Yallock, the river changes course to a more or less northerly direction which is maintained for eight miles (measured in a direct line) to Healesville. The Woori Yallock Creek, which has a northerly course, flows more or less parallel with the Yarra from near Woori Yallock to its junction with the main stream north of Killara, three miles away. This is to be explained by the controlling effect of the nature and strike of the bedrock. Indeed, the country rock is the major factor in determining the course of the Middle Yarra between Woori Yallock and the Warrandyte Gorge. In early Tertiary times, when the present Yarra drainage system in this area was initiated, the extent of the Older Basalt lava field was the main factor. This, in turn, was determined by

(a) the igneous suites surrounding much of the Woori Yallock basin, and

(b) the prominence of bands of quartzitic rocks in the basement sedimentary series.

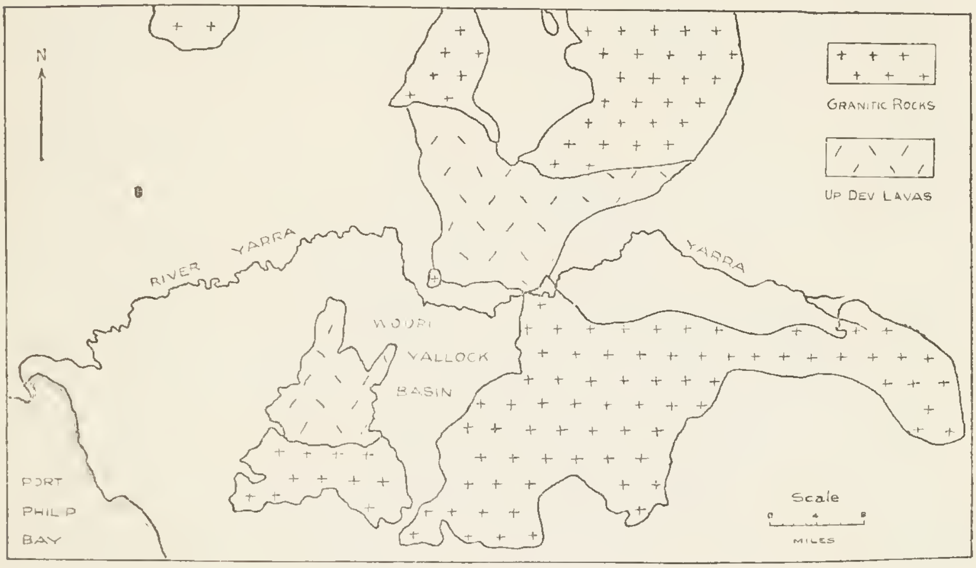

FIG. 2

Distribution of outcrops of granitic intrusive rocks and Upper Devonian lavas relative to the course of the River Yarra. These rocks account for the westerly flow of the river in its upper reaches.

The course of the Wurunjerri River, and the extent of the infilling lava flows has been discussed in a previous paper (Gill, 1942). As a direct result of the volcanic activity, the Wurunjerri River was blotted out, and the Yarra River developed in the north of this area as a stream marginal to the basalt. However, in the east it found a course to the east of the quartzitic Warramatte Hills instead of west of them as did the Wurunjerri River.

Eastern and Western Quartzites

Reference to the map (Fig. 1) indicates how the course of the Middle Yarra from Killara to Healesville is closely related to the strike of the country rock. The hills forming the west bank of this part of the river are constituted of quartzites and quartzitic rocks of resistant character. The same beds outcrop on the other side of the synclinorium and form the west bank of the Yarra from Yarra Glen to the Warrandyte Gorge. These rocks are a conspicuous series in the district and give rise to notable physiographic features. I therefore suggest that they be known as the Eastern Quartzites and the Western Quartzites respectively.

North of Healesville the Eastern Quartzites have a general meridional strike, but it is of the order of N. 20° W. for six miles south of Healesville, and then at Killara it varies considerably. It is obvious that the direction of the river is closely affected by the strike of this series of hard beds.

The Western Quartzites have generally a meridional strike north of Yarra Glen, of about N. 25° E. for some eight miles to the Warrandyte Gorge, and then of about N. 10° E. along the Brushy Creek scarp. Once again the strike of the quartzites determines the directions of the streams. The Wurunjerri River impinged against the Western Quartzites (then the Wurunjerri Range) which deflected it southwards through Lilydale to the sea. The country between the Eastern and Western Quartzites has been considerably reduced by erosion, thus leaving them in relief by differential erosion. West of Yarra Glen the Western Quartzites form a large anticline, on each side of which are grey shales characterized by *Plectodonta bipartita*.

North of a line connecting Yarra Glen and Healesville, the Eastern and Western Quartzites are largely meridional in strike, but south of that line they splay out. This is due to the southerly pitch of the synclinorium, which thus brings in the younger beds of the Lilydale area.

Physiographic Problem of the Quartzites

Physiographers have discussed the problem of how the westerly flowing Yarra could breach the Western Quartzites and so flow on towards Melbourne. Keble (1918), Hills (1934) and others have discussed this problem. Actually the same problem applies to the Eastern Quartzites, for these are breached by the Yarra near Healesville. Hypotheses to explain these breachings are now offered.

Breaching of Eastern Quartzites

The Middle Yarra follows the Eastern Quartzites for eight miles before breaching them near Healesville. That it should breach them at this particular place calls for explanation. The early Tertiary Wurunjerri River was confined between the Wurunjerri Range on the west (formed by the Western Quartzites) and a range on the east (formed by the Eastern Quartzites) which might well be called the Anti-Wurunjerri Range, on the analogy of Lebanon and Anti-Lebanon Mountains, Taurus and Anti-Taurus Mountains, and so on. This valley was filled with Older Basalt, and a stream developed around the northern margin of the flow. It appears that this stream cut back across the Anti-Wurunjerri Range, and in so doing released the waters impounded behind it (see below). The first reason, then, for the position of this water-gap, is that the Older Basalt lava field extended to that point.

A second reason for the breaching of the Eastern Quartzites at Healesville is that there is an intrusion of quartz porphyry there. The river finds its way over the southern extension of this small boss. The intrusion has been fairly recently uncovered, as is shown by the fact that parts of it are still capped by country rock. The cutting on the west side of the railway tunnel (which pierces the porphyry) shows that there was some disturbance of the sediments by the intrusion. The broken bedrock would facilitate the breaching of the barrier at that point.

The Middle Yarra receives the waters of the Don River at Launching Place and the Watts River at Healesville. This greater volume of water is restricted in its passage through what may be called the Healesville Gorge, and so the river at this point is characterized by rapids. The widespread Healesville flats are evidence of ponding, and indeed at the present time they are flooded after heavy rains.

In Wurunjerri times, the ancestors of the Don and Watts Rivers must have carried their waters to the south of the Warramatte Hills and so connected with the Wurunjerri River. The infilling of the Wurunjerri Valley with basalt made this impossible, and the waters there must have ponded deeply to form a large lake until they were released by the breaching of the Anti-Wurunjerri Range. This ponding could be called the Healesville Lake. It is analogous to the Yarra Lake further west (represented now by the Yarra Flats), although the latter was probably never of the nature of a permanent deep lake like the former. The Healesville Lake probably stretched as far south as Woori Yallock, where residuals suggest this area to have been the margin of the Older Basalt lava field in this direction.

The alluvial flats from the Healesville and Yarra Lakes and the gorges which confine them are the most characteristic features of the Middle Yarra.

Breaching of Western Quartzites

How the Wurunjerri Range (the Western Quartzites) could be breached to allow the Yarra through has engaged the attention of physiographers, and the following theories have been adduced:

1. *Keble* (1918, p. 148): "The Wurunjerri Range was breached by a tributary of Watson's Creek, and the basin of the Middle Yarra was diverted through the breach."

2. *Hills* (1934, p. 169) mentions the possibility of ejectamenta from a volcano at Lilydale blocking the pre-Older Basalt river and so causing flooding over the Wurunjerri Range to establish the present course of the Yarra. This theory was later abandoned.

3. *New Hypothesis.* The Nillumbik Peneplain stretched eastwards to the Dandenong Mountains, and did not cease at the Wurunjerri Range as formerly believed (Jutson, 1911). The break in the Wurunjerri Range owes its genesis to lateral differentiation in the Western Quartzites facilitating reduction, and to some structural disturbance. In other words, the Wurunjerri Range did not have to be breached because it already had a very low saddle in it. The infilling of the Wurunjerri valley with basalt flows some 300 ft. thick raised the thalweg of the new marginal stream so that it was higher than the saddle in the Wurunjerri Range, and flowed over it with ease. Even after erosion through most of Tertiary time and all of Quaternary time, the residual at Lilydale stands 674 feet above sea-level, which is roughly 275 feet above the bed of the Wurunjerri River as exposed in the Cave Hill quarry. If once southerly drainage had developed again after the extrusion of the basalts, no factors were operative in this area sufficient to divert the river.

The Yarra Plateau

Gregory (1903) defined the Yarra Plateau which "once ran from the Strathbogie Ranges, across the present main divide between Mt. Disappointment and Mt. Arnold. It forms the old platform under the Dandenongs" (p. 84, fig. 49, p. 109). He defined it more narrowly when he said that the eastern border of the Plateau may be drawn through Queenstown, Christmas Hills, and Mooroolbark. "Most of the Yarra Plateau may be regarded as a shelf on the eastern border of the Melbourne basin" (p. 86).

Gregory thus presented two definitions of the Yarra Plateau which in reality refer to two different surfaces:

(a) The first definition refers to a pre-Dandenongs (viz., Upper Devonian) surface as shown in his fig. 49, i.e., a Palaeozoic terrain.

(b) The second definition refers to a shelf, the remains of which are at present clearly visible, i.e., a Cainozoic terrain. The second definition also limits the Plateau to a small area near Melbourne while the first refers to a large section of the State.

Gregory's first definition seems to have been largely disregarded by later writers. Jutson (1911), obviously taking the second

FIG. 3

The contours from the Military Map (Yan Yean and Ringwood Sheets) have been filled in between 600 and 650 feet to show the Yarra Plateau terrain on which the Kangaroo Ground Older Basalt stands (solid black); also between 400 and 450 feet to show the Nillumbik Peneplain on which the Lilydale Older Basalt stands (cross hatching). There are two monadnocks on this old peneplain—that formed by the resistant Western Quartzites, and that formed by the Older Basalt ("O.B." on map).

definition, suggested that country east of the Queenstown-Christmas Hills-Mooroolbark line be included (p. 474). Hills (1934, p. 163) has shown that Gregory was in error concerning the position of the ancient Divide. He also took Gregory's second definition, describing the Yarra Plateau as "the country from the Christmas Hills to the Plenty River, and from the Kinglake Escarpment to the divide on the Mitcham Axis."

In this paper Hills' definition is accepted, with a modification of the southern boundary of the Plateau. The map (Fig. 3) and sections (Fig. 4 a-c) show that the tops of the hills forming the old Yarra Plateau (as defined by Hills) as far south as Kangaroo Ground and Research are all about 600 feet to 650 feet above present sea-level. This is significant, because it is the level of the pre-Older Basalt terrain, as shown by the existing residuals. Diamond Creek as far as Hurstbridge plus Arthur's Creek on the west, and Watson's Creek on the east, are apparently streams that developed marginally to the Older Basalt flow. The upstream end of Diamond Creek, found north-east of Hurstbridge, is apparently a cross-cutting lateral. The ridges between these streams are apparently remnants of the old terrain which have been but recently stripped of their Older Basalt cover.

The relative positions of the 600 ft. summits suggests that those N.N.W. of the Kangaroo Ground basalt, and those forming a ridge between Arthur's Creek and the upper part of Diamond Creek, are the course of the pre-Older Basalt river. The ridge followed by the road from Panton Hill to Queenstown (which reaches 700 ft. in places) would then be the eastern side of the valley, and the ridge from Yarrambat to Doreen (which reaches 725 ft. at Doreen) would be the western side of the valley.

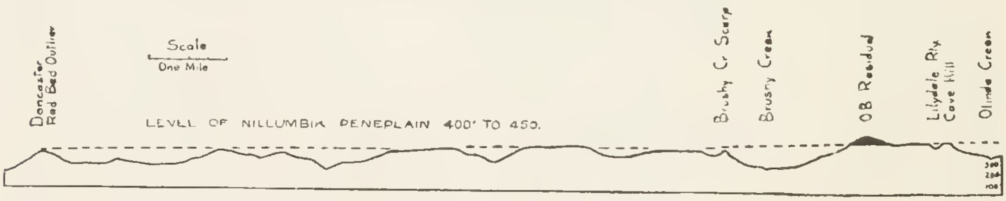

FIG. 4a

Section drawn from contours of Military Map, Ringwood Sheet, to show how the Nillumbik Peneplain stretched across as far as the Dandenong Ranges, and how the Older Basalt of the Wurrunjerri River flowed over it.

The general accordance of summit levels in this area gives indication of a definite terrain. As the Older Basalt and/or associated sands and gravels rest on these levels in a number of places, we know that this terrain is the pre-Older Basalt one, and so previous to the present Yarra River system. From Research for ten miles northwards (measured in a direct line) the hill summits are 600 ft. to 650 ft. For a similar distance in an east-west direction the same holds. This proves that the pre-Older Basalt terrain was a peneplain, and the river flowing over it was mature in that part at least of its course.

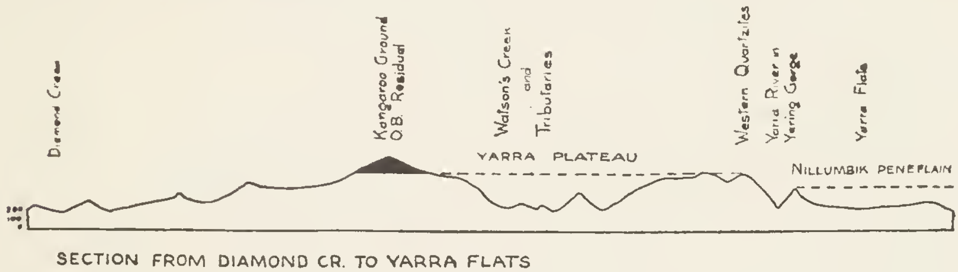

FIG. 4b

Section drawn from contours of Military Map, Yan Yean and Ringwood Sheets, showing the relationships of the Yarra Plateau and Nillumbik Peneplain levels at Yering Gorge.

These facts also show that the Kinglake Escarpment is a very old feature. The cutting back of the escarpment was effectively retarded by the formation of the Older Basalt lava field. The rapid back-cutting of the scarp could not be re-initiated until the lava field had been removed. This has been done and the streams are now actively cutting back into the escarpment.

The terrain represented by the summits of the hills, and covered in places by Older Basalt or associated fluviatile deposits, is the terrain (Gregory's "shelf") which is to be known by the term Yarra Plateau. However, it does not reach as far south as the Mitcham Axis but terminates at Research.

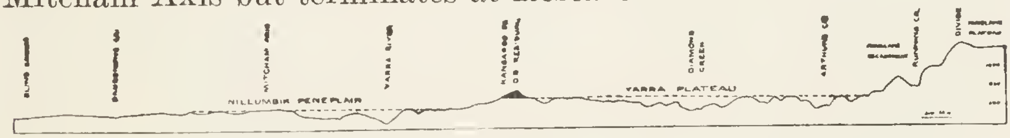

FIG. 4c

Section drawn from contours of Military Map, Ringwood and Yan Yean Sheets, showing the relationship of the Nillumbik Peneplain and Yarra Plateau to one another and the Kinglake Escarpment.

The Nillumbik Peneplain

When Jutson (1911) extended the Yarra Plateau from Gregory's Queenstown-Christmas Hills-Mooroolbark line to include the "Croydon Senkungsfeld" (i.e., the Croydon Lowlands and Yarra Flats) he gave the feature the new name of Nillumbik Peneplain (p. 477). Hills (1934, pp. 167-168, 173) adopted this term chiefly for the level of the stripped fossil plain, remnants of which are seen along the Mitcham Axis. Modifications in the definition of the Yarra Plateau require modifications in the definition of the Nillumbik Peneplain. I suggest that this name be used for the peneplain standing from 400 ft. to 450 ft. above present sea-level. The map (Fig. 3) and sections (Fig. 4, a-c) show the extent of this peneplain. In addition to the Mitcham Axis there is a ridge running north-west to Doncaster, and another running south-west to Tally Ho and Mt. Waverley (cf. Hart, 1913).

Very important is the fact that the peneplain caused a gap in the Wurunjerri Range. Fig. 3 shows a stretch of about three miles of the Brushy Creek escarpment south of the Yarra River with summits at the Nillumbik Peneplain level. The east side of the Yering Gorge (Fig. 4b; also Gill, 1942, fig. 3) and the hills to the north of Lilydale are likewise Nillumbik levels. Most significant of all is the fact that the Older Basalt residuals at Lilydale and north-west of Lilydale stand on the Nillumbik terrain. This means

(a) that the Nillumbik Peneplain stretched across to the Dandenong Mountains;
(b) that this area was not down-faulted in post-Nillumbik times as claimed by Jutson (1911);
(c) that the Lilydale Older Basalt is not a pre-Nillumbik peneplain lava flow, but one extruded after the formation of the peneplain.

Standing out from the Nillumbik Peneplain was a monadnock (or, if the plain were covered by sea, an island) which constituted the southern end of the Wurunjerri Range. This geographic feature owed its presence to the rocks of which it was composed—the Western Quartzites. As in the high country north of the Yarra, the elevated features are due to an anticline in the Western Quartzites.

On the other hand, the breach in the Western Quartzites where the Yarra passes through is due to

(a) lateral differentiation of the country rock;
(b) structural disturbance.

(a) Although there are no soft strata, the rocks in general are not so quartzitic as those, for example, on the Lilydale Highway where it descends the Brushy Creek escarpment.

(b) In the vicinity of Warrandyte, the Warrandyte Anticline divides into a number of small folds and then pitches out of existence. On the Wonga Park Road there are northerly dips for over two miles, indicating pitch. It is in this area that the higher levels give way to Nillumbik Peneplain levels. Also where the Yarra River crosses the Western Quartzites, they take a major change in strike, swinging round to the north-east.

Genesis of the Nillumbik Peneplain

As re-defined, the Nillumbik terrain is a true peneplain. It is remarkable that there should be so little disparity of elevation in the Nillumbik Peneplain in view of the enormous differences in rock types. Some of the summits are sandstones, some shales, some highly indurated quartzitic horizons, and some are soft mudstones such as under the Older Basalt at Lilydale. In spite of these great differences in hardness, all the summits are between 400 and 450 feet, except for the monadnock of quartzites north and west of Croydon. Wicklow Hill, at Croydon, reaches 650 feet, the height of the Yarra Plateau.

An adequate explanation of the wide and even planation (in spite of variant rock types) of the Nillumbik Peneplain is called for, and also of the difference in level (about 200 feet) between it and the Yarra Plateau. Two possible explanations of the peneplanation suggest themselves:

1. *That the plain is one of marine denudation.* This theory is encouraged by the relationship of this area to the sea (although it must be remembered that there was no Port Phillip Bay then), by the fact that the slopes on its seaward sides have Miocene marine beds on them, and that the Red Beds on the peneplain itself appear to be fluviatile sands and gravels spread along a shoreline. On this interpretation the gentle slopes on the seaward sides (south and west) of the peneplain would be a sloping sea-floor.

In criticism of this interpretation, it may be pointed out that Richthofen, followed by many eminent geologists, has denied that marine planation is possible, except on a subsiding land area. They have claimed that "waves can cut into a still-standing land mass only to a very moderate extent before they will exhaust themselves on the shallow beach which they have carved." More recently, Wentworth has concluded from studies in Hawaii that marine erosion cannot be a factor in peneplanation. However, in the case of the Nillumbik Peneplain, it could be argued that it was a gradually subsiding land (or rising sea) that caused the transgression by the sea which resulted in the deposition of the Miocene beds. Hall (1900, p. 40) envisaged such a process occurring.

2. *That the plain is one of subaerial denudation.* Alternatively, the Nillumbik Peneplain could have been formed by reduction to base-level by subaerial agencies. The slopes on the seaward sides and their Miocene strata are consistent with this interpretation too.

But the cause of the planation of the Nillumbik Peneplain needs to be considered along with the cause of the planation of the Yarra Plateau, and the difference in height between the two. If the Nillumbik Peneplain were cut by the sea and so covered by it, then the Yarra Plateau could have been formed by subaerial denudation. However, the difference in height of 200 feet does not favour this interpretation. Their relationships would be something like those of the present Port Campbell plain to the sea. Such difference in elevation would lead to dissection and not favour planation. Alternatively, the Nillumbik Peneplain and Yarra Plateau could have been one continuous peneplain which was disrupted by faulting. However, direct evidence of such faulting has not yet been found in the field.

Another possible explanation of the seaward slope to the south of the Nillumbik Peneplain is that it was originally part of the peneplain, but was involved in the warping (see Singleton, 1944) believed to have taken place to form the basin in which the Altona-Parwan lignites were deposited (Fig. 5).

Age of the Nillumbik Peneplain

The evidence for age is as follows:

1. The peneplain is older than the Older Basalt which filled the Wurunjerri River. The Older Basalts are believed to be from Oligocene to Lower Miocene in age. On palaeogeographical grounds (opp. page), it is believed that the Older Basalt at Balcombe Bay is part of the Wurunjerri flow or flows. The basalt at Balcombe Bay is overlain unconformably by Balcombian (Middle Miocene) marls. This means that the Nillumbik Peneplain is much older than Jutson thought (1911, pp. 477-478) when he first described it.

2. The peneplain is younger than the Lower Devonian marine sediments and the Upper Devonian igneous rocks of the Dandenong Ranges, both of which are affected by the planation. Fig. 3 shows how a ledge has been formed on the edge of the Dandenong lavas.

3. When the physiography of the State is considered, and the peneplanations which have been effected and then raised to higher levels, it is clear that the Nillumbik Peneplain must have been formed in Tertiary times.

At the close of the Eocene and in Oligocene times, it appears that the land gradually sank in relation to the sea, and in wide low-lying areas great quantities of lignite accumulated, especially in south central Victoria and southern Gippsland (see Fig. 5).

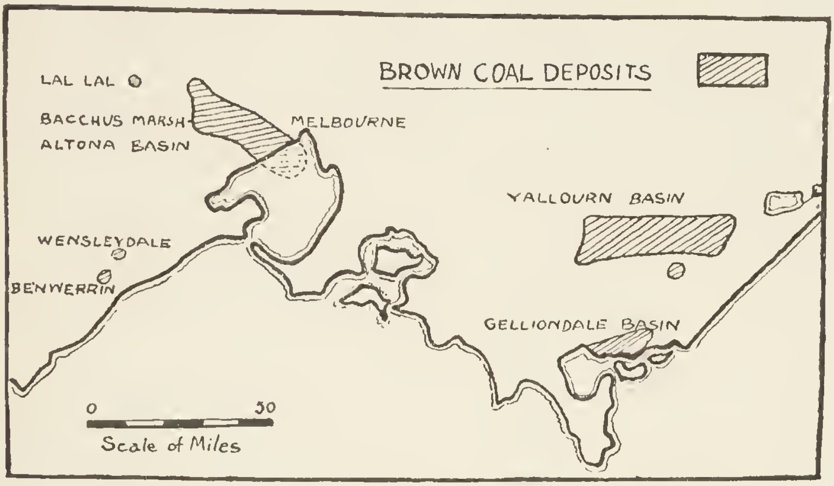

FIG. 5

Map showing extent of lignitic deposits in southern Victoria. The alignment of the Bacchus Marsh-Altona basin indicates the direction of early Tertiary drainage in that area.

The sinking was contemporaneous with considerable volcanic activity, and the two events may be not unconnected. The relative lowering of the land continued so that there was an extensive transgression of the former land surface, with deposition of Eocene, Oligocene, and Miocene marine beds on what is now the land. A number of the basalt flows were in part covered with these marine sediments. In this cycle of events the Nillumbik Peneplain was formed, and the Wurunjerri flow of basalt extruded upon its eastern extension.

In Lower Pliocene times the sea began to recede, and the rejuvenation of streams brought down copious torrent gravels and sands which were spread over the Nillumbik Peneplain to form the Red Beds, remains of which are seen as cappings on the hills to the north of the peneplain, and as a continuous cover further south. Still later, in an arid period, siliceous sand dunes were constructed over the Brighton-Sandringham area. They covered the Miocene marine deposits and Pliocene fluviatile-marine Red Beds. The recognition of the trend lines in the physiography of this area as dune lines (Whincup, 1944) explains a number of features Hart (1913) found it difficult to account for.

The Mitcham Axis

Jutson (1911) gave this name to an east-west ridge running from north of Camberwell to Croydon. It is the divide between the Yarra river system and the streams to the south. Jutson claimed that this ridge is a warp axis, but admits that there is no evidence of this in the strike of the country rock. He depends on the difference in the slopes north and south of the axis, but this is due to the relative strengths of the streams on the two sides of the divide. If there were any recognizable late Tertiary warping, it would show in the deformation of the Nillumbik Peneplain.

The Mitcham Axis or Ridge is a feature of the present erosion cycle, and is due to back-cutting of streams from the rejuvenated Yarra (i.e., rejuvenated relative to the Nillumbik Peneplain) to the north, and streams entering Port Phillip to the south-west.

The Mount Waverley Ridge

An equally large and important ridge or divide runs from Mitcham to Mount Waverley, with a branch running down through Glen Waverley to Wheeler's Hill (Fig. 6). The ridge is flat-topped, and averages about a mile wide. The flat top is part of the Nillumbik Peneplain, recently bared by the stripping away of the Red Beds. Remnants of the Red Beds are still to be seen in places as a thin veneer of gravel. The Mount Waverley ridge constitutes the western border of the large Dandenong Creek physiographic basin, which was carved out of the Nillumbik Peneplain.

If the main Mount Waverley ridge is projected, the line extends through Oakleigh to Highett and Black Rock. This is a well-marked ridge of high country, as is seen by following the 100 ft. and 150 ft. contours on the military map (Ringwood Sheet). The map also shows how this ridge constitutes a divide. It was called the Cheltenham Axis by Hart (1913).

Early Tertiary Divides

Since Oligocene times, the Older and Newer Basalts have been the chief physiographic determinants in south-central Victoria. Before that time the granites and granodiorites (or rather, as Mr. R. A. Keble has pointed out to me, the metamorphosed rocks around them), along with the Upper Devonian volcanic suites, were the chief physiographic determinants. When these are plotted on a map they are seen, on the whole, to trace out the divides. The actual courses of the pre-Older Basalt rivers can be largely recognized from the residuals of the lava flows that ran down them.

All divides, being elevated above the surrounding country, are subject to strong attack by subaerial erosion. Thus the divides of Oligocene times, having withstood erosion from then till now, will be much reduced and not so readily recognizable. Fig. 6 shows the reconstructed divides, and the river system, ancestral to the Yarra, which it is believed was in existence in early Tertiary times. The following are the divides which concern the present paper:

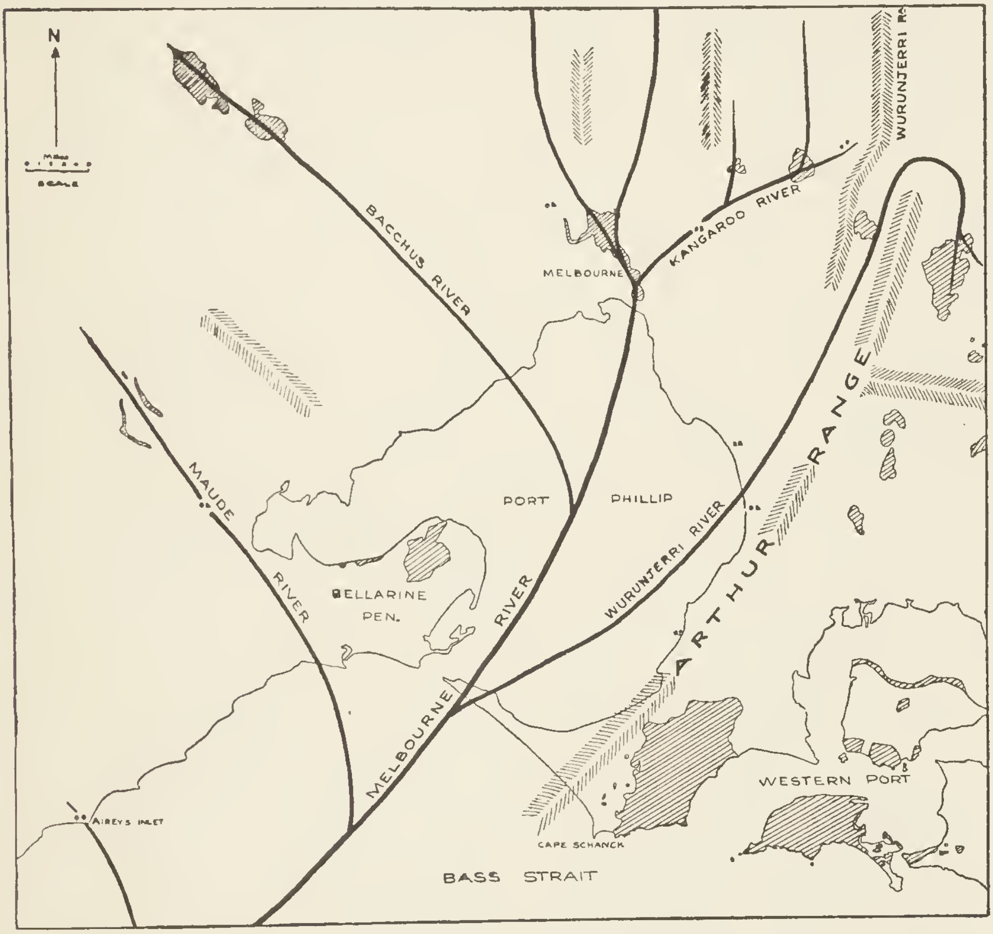

FIG. 6

Semi-diagrammatic map of the palaeogeography of the river system in early Tertiary (pre-Older Basalt) times which was ancestral to the Yarra River system. The areas cross-hatched represent Older Basalt outcrops.

(1) *Mt. Arthur-Dandenongs Divide.* This stretches from Mt. Arthur through Mt. Martha, Mt. Eliza, Lysterfield Hills (all of these are of granitic rocks) to the Dandenong Ranges (Upper

Devonian lavas and altered tuffs). In Oligocene times this must have been a prominent and important divide. It separated the Port Phillip area (then a land area) from the Western Port area (also a land area at that time). This divide is now very much reduced and is breached east of Carrum. Being a palaeogeographic feature of such size and significance, a special name for it is desirable. I propose that it be known as the Arthur Range, after Mt. Arthur.

The limit of this divide to the north is the termination of the Upper Devonian lavas at Coldstream, round which the Wurunjerri River flowed (Gill, 1942). How far the divide continued south-westerly towards King Island cannot be determined from our present knowledge, but it is probable, I think, that south-west of Cape Schanck the Western Port pre-Older Basalt river joined that of the ancestral Yarra (Melbourne River).

(2) *Dandenongs-Warburton Divide.* A line of granodiorite and granite intrusions stretches from the Dandenong Ranges to the Baw Baw Plateau (Fig. 2), and this determines the present westerly course of the Middle and Upper Yarra. In early Tertiary times the Woori Yallock Basin was in existence, and it was from there that the Wurunjerri River flowed (Edwards, 1940, Gill, 1942). The granitic intrusions to the east of the Dandenong Ranges therefore formed a divide in early Tertiary times, but probably only as far as the Warburton Ranges. The Upper Yarra is very young, comparatively, and one assumes that the Wurunjerri River drained only the Woori Yallock Basin.

(3) *Wurunjerri Range.* Later information shows that this did not merge into the Arthur Range as described by Keble (1918). The Wurunjerri River flowed between the two ranges.

(4) *Morang Divide.* The granite at South Morang was the core of a small divide between the early Tertiary Kangaroo River and the Melbourne River (see Fig. 6). It is marginal also to the Newer Basalt flow in that area.

(5) *Mt. Gellibrand Divide.* As the Morang Divide bordered the Melbourne River on the east so the Mt. Gellibrand Divide bordered it on the west. Once again a granite intrusion marks the line of the divide. There is some evidence to suggest that Older Basalt flows passed down each side of this prominence (see distribution in Fig. 6). Newer Basalt flows surround the Mt. Gellibrand intrusion, which in early Tertiary times must have been a prominent landmark exercising an important physiographic control.

(6) *Anakies-You Yangs Divide.* This divide separated the river which flowed from the direction of Bacchus Marsh and the Maude River (see Fig. 6). The Anakies and You Yangs both consist of granitic rocks. They must have constituted a prominent range in early Tertiary times. They are still very prominent monadnocks. The ?Oligocene lignite in the Bacchus Marsh-Altona Basin (Fig. 5) indicates the alignment of the drainage at that time.

Further south-west the palaeogeography has not been studied sufficiently to indicate the pre-Older Basalt divide or divides. Since then the Otway Ranges have been uplifted, as is indicated by their very young physiography. This has naturally greatly complicated the reconstruction of the early Tertiary terrain.

However, the basalt at Airey's Inlet indicates the valley of some stream there. Probably the presence of tuff indicates that there was a vent at no very great distance.

Early Tertiary Rivers

(1) *Wurunjerri River.* This flowed from the Woori Yallock Basin round the northern end of the Dandenong Ranges igneous complex, southwards through where Lilydale now stands and, following the Arthur Range, through Frankston and Mornington, and so to the main north-south stream—the Melbourne River.

Older Basalt residuals and associated fluviatile deposits are found in the Woori Yallock basin (Edwards, 1940) and in the Gruyere and Lilydale districts (Gill, 1942). Older Basalt is also preserved in the lower part of the course of this ancient stream by location below sea-level and by protection from overlying rocks. The basalt has been found in bores near Mordialloc and near Frankston in the Carrum Swamp area. It also occurs in Balcombe Bay where it is covered by the type Balcombian strata.

(2) *Kangaroo River.* The Yarra Plateau, as defined in this paper, was traversed by a river whose deposits are to be seen under the Older Basalt at Kangaroo Ground and in adjacent areas. When a river valley is filled with basalt, its thalweg naturally has the thickest covering of lava over it. For this reason the thalweg is usually the last part to be eroded. Marginal streams are set up which gradually work in to the centre, and cross laterals divide the flow into residuals. Applying this idea, we may infer that the curved string of hill-tops at Yarra Plateau level north of Kangaroo Ground indicates the course of the pre-Older Basalt river (Fig. 3). These are uncovered residuals (Keble, 1918) and, being the last to be uncovered, we may assume that they once

occupied the thalweg of the pre-Older Basalt valley. I suggest that this early Tertiary stream be known as the Kangaroo River. It drained the Kinglake escarpment and the Yarra Plateau.

Instead of continuing directly south, following the strike of the country rock, it appears that the Kangaroo River was deflected south-west to join the Melbourne River. The Geological Survey of Victoria geological map of the Parish of Sutton shows the lead under the Older Basalt at Kangaroo Ground turning to the south-west. On just what evidence that was based is not now known. However, the Warrandyte area directly to the south of Kangaroo Ground is one of highly indurated country rock, due to numerous intrusions, many of which have been mined for gold (Whitelaw, 1895). South-west is the general direction of drainage in the country between the meridians of Melbourne and Ringwood, and this was probably so in early Tertiary times owing to the strong influence of the Melbourne River (*q.v.*). The Melbourne River was a central stream of which all the others mentioned in this section were tributaries.

The Older Basalt at Ivanhoe is probably a marker of the main course of the Kangaroo River, while the residuals at Greensborough and north-east of Kangaroo Ground are indications of the position of branch streams. Both the Greensborough and Ivanhoe residuals are at a lower level than the Kangaroo Ground residual, and from this it is inferred that they were lower down the course of the river. However, if the Yarra Plateau owes its higher elevation to the Nillumbik Peneplain to faulting, then this has to be taken into account.

(3) *Melbourne River*. On the meridian of Melbourne there is a fossil valley of early Tertiary age. The Moonee Ponds Creek has now cut through the covering rocks in a number of places to this ancient valley, which has been preserved first by a sheet of Older Basalt, and then by a sheet of Newer Basalt. For instance, a section in the Moonee Ponds Creek at North Essendon reveals:

Newer Basalt (youngest).
Quartzite, sands, and gravels.
Older Basalt.
Sands and silts.
Silurian bedrock.

The bedrock at this point is about 67 feet above sea-level, and, like the Silurian inlier on which part of Melbourne is built, constitutes a section of the east bank of what I propose to call the Melbourne River. Skeats' (1909) figure 2 shows part of this river bed, mostly below sea-level. Older Basalt still remains in the lower parts of the valley. It occurs between 70 feet and 80 feet below datum (i.e., L.W.M. for Hobson's Bay) at Spencer Street bridge, Melbourne.

Keble (1946) has suggested that the Melbourne River flowed over the Bellarine Peninsula and so down towards Cape Otway. Further information now obtained indicates that it probably flowed to the east of the Bellarine Peninsula because—

(*a*) Judging by the Older Basalt residuals further north, the thalweg of the Melbourne River was hundreds of feet below sea-level at Port Phillip Heads, whereas the Older Basalt on the Bellarine Peninsula (Daintree, 1861; Diamond Drills in Victoria, 1885) is far too high to fit in with this physiographic pattern.

In connection with bridge-building projects, traverses of bores have been made across the River Yarra at Melbourne as follows:

	Location of bores	Authority	Depth of bedrock in feet below datum.
i	Punt Road	Country Roads Board	57·57
ii	Swan Street	Ditto	62·6
iii	Russell Street	Ditto	70·33
iv	Spencer Street	Victorian Railways	82·8

The locations are shown in Fig. 7. The present Yarra, the pre-Newer Basalt Yarra, and the Kangaroo River (i.e., from early Tertiary times till now) have all passed over the same course in the area where the bores were sunk. This was due to constriction between the hard Silurian outcrops represented at present by Government House Hill and Russell Street Hill (Fig. 7).

i. The Punt Road section shows mostly silt above the bedrock, but a little sand is intercalated.
ii. The Swan Street section is also mostly silt, but on the south bank of the river the bores penetrated basalt.
iii. The Russell Street section reveals basalt on the north bank of the river. A seam of "drift sand" at about the level of the top of the basalt separates upper and lower silts over the thalweg of the river bed in the bedrock.
iv. The Spencer Street sections have been published by Chapman (1929). They show in order from below up bedrock, Older Basalt, clay, Newer Basalt, lignite, shell marl, drift sand, and mud. The position of the Older Basalt indicates that the bedrock is the level of the pre-Older Basalt River (Kangaroo River) at this point, and so probably also in the other sections quoted.

The figures in the above table show an average declivity in the thalweg over the two miles between Punt Road and Spencer Street of 12·6 feet per mile. If this average declivity is assumed for the 36 miles from Spencer Street to the Port Phillip Heads, then the pre-Older Basalt river there must have been 454 feet lower, i.e., 536 feet below datum. The declivity of a stream is commonly reduced in its lower reaches, especially as the coast is reached.

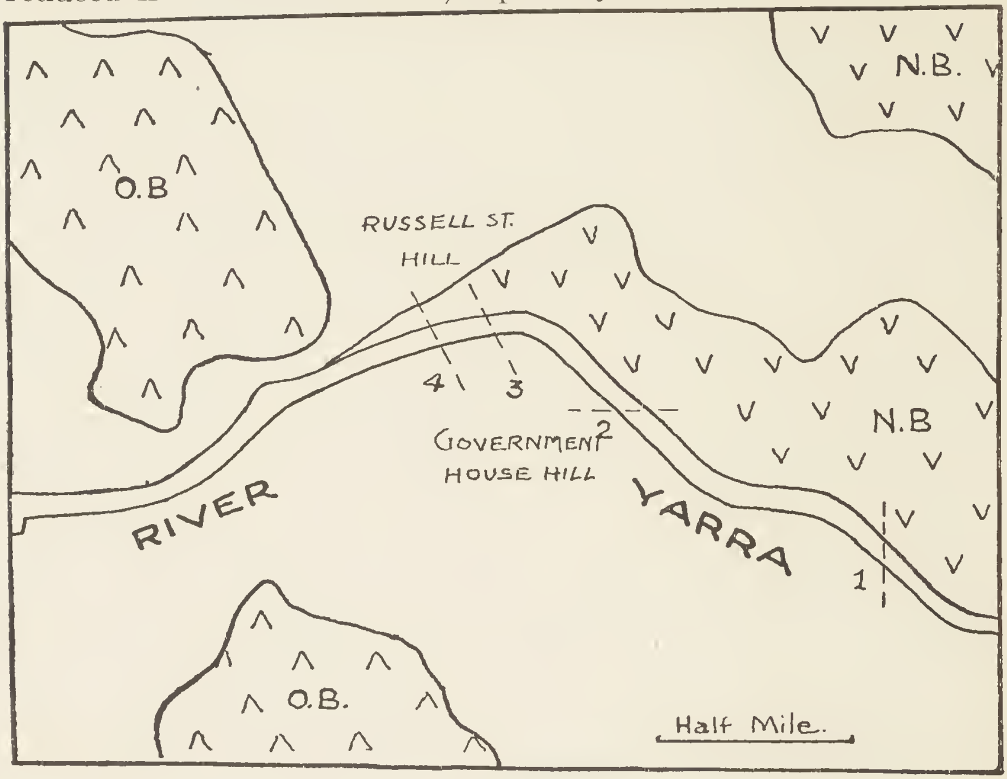

FIG. 7

Map to indicate positions of bore traverses across the River Yarra at Melbourne. 1 is Punt Road, 2 is Swan Street, 3 is Russell Street, and 4 is Spencer Street. O.B. = Older Basalt. N.B. = Newer Basalt.

However, the coast then was probably in the vicinity of Cape Otway (as in the Pleistocene), and 12·6 feet per mile is already a low declivity, i.e., 1 in 420. So the figure arrived at is probably of the right order.

In a previous paper (Gill, 1942), the declivity of the Wurunjerri River was calculated to be 15 feet per mile. Applying this figure to the 56 miles from Lilydale to Port Phillip Heads gives 840 feet, from which must be subtracted 378 feet which is the elevation of the thalweg at Lilydale above sea-level, viz., 462 feet below datum.

Comparing the figures from the Wurunjerri River (462 feet) and the Kangaroo River (536 feet), we may assume that at the site of the present Port Phillip Heads, the pre-Older Basalt river system was of the order of 500 feet below datum. As further information is obtained about the thalwegs of the above rivers and the other rivers of the system, it should be possible to determine fairly accurately the depth below present sea-level of the Melbourne River at that point. When this is done, it will be possible to determine how much depression is there due to eustatic low sea-levels and how much due to faulting along Selwyn's Fault and others, if any. As the declivities are measured in tectonically stable areas, the difference between the calculated level of the bedrock and its actual depth will be a measure of the faulting that has occurred. The Sorrento Bore (Chapman, 1928) penetrated 1,680 feet of sediments and aeolian materials without reaching bedrock. On present knowledge, it may be said that 500 feet of this depth is due to eustatic emergence resulting in down-cutting of the river bed to that depth below present sea-level, while 1,180+ feet is due to faulting.

A further check on the depth to which the pre-Older Basalt river system eroded below present sea-level may be obtained by a study of the palaeogeography of the Western Port Older Basalts. These are also found far below sea-level, although once again there has been faulting. However, the declivities can be worked out from the stable areas. The Western Port system apparently drained into the Melbourne River south-west of Cape Schanck, and so the depth of the thalweg of its main stream should fit in with those of the Port Phillip system.

The depth of the pre-Older Basalt river system below present sea-level has not always been taken into account in the geological interpretation of some areas. For example, Older Basalt is found below sea-level between Mornington and Frankston, and this has been attributed to down-faulting. That some faulting has taken place is indicated by the dip of Tertiary rocks at Frankston. However, the depth of the Older Basalt is no doubt due chiefly to the position of the pre-Older Basalt river bed.

From the foregoing paragraphs it is clear that the Melbourne River could not have passed over the Bellarine Peninsula, unless that has been up-faulted to the order of 500 feet. There is no reason to hypothecate this.

(*b*) A second reason for considering that the Melbourne River flowed east of the position of the Bellarine Peninsula is that such a course follows the middle of the early Tertiary river valley. I consider the Older Basalt on the Bellarine Peninsula and at Balcombe Bay to be residuals on the flanks of the ancient valley. They indicate that the Older Basalt had a thickness of the order of 1,000 feet, because the Older Basalt on the Peninsula reaches 470 feet, and the bottom of the valley was something like 500 feet below present sea-level. Older Basalt over 1,000 feet thick occurs in Western Port.

(4) The disposition of the Older Basalt residuals north-west of Melbourne suggests (as one would expect) that a tributary of the Melbourne River drained the country on the west side of the Mt. Gellibrand granitic intrusion.

(5) Another stream flowed from the direction of Bacchus Marsh, called the Bacchus River in Fig. 6. Borings at Altona did not show any Older Basalt, but probably it was worn away from that area as from most of the lower part of the river system. Pleistocene low sea-levels resulting from glacio-eustatic emergence rejuvenated the post-Older Basalt streams so that most of the Older Basalt was stripped away. The low patch between Mornington and Frankston remains because the Wurunjerri River was diverted to form part of the Yarra system. No stream of any importance was therefore rejuvenated over this part of the Older Basalt lava field.

(6) Yet another stream flowed from the direction of Maude, as shown by the Older Basalt residuals there. This is called the Maude River in Fig. 6. It is the ancestor of the Barwon River. The relationship of the basalt residuals to the Tertiary rocks shows (according to Singleton, 1941) that the lava flows at Maude and Curlewis (on the Bellarine Peninsula) were not contemporaneous. Either the two deposits belong to different valleys, or/and the lava to different eruptions. The palaeogeography of this area has not been worked out, and the course of the Maude River shown in Fig. 6 must be regarded as tentative.

(7) Basalt and tuff at Airey's Inlet indicate the presence there in early Tertiary times of a valley, as lava, like water, always seeks the lowest levels. Ash volcanoes are generally found near the coast, as they very often originate from hydro-explosions. It is interesting to note this general rule holding for the ?Oligocene vulcanism, for apparently all the inland volcanoes were effusive ones, while those producing tuff are to seaward.

Noetling (1910), Dannevig (1915), and Keble (1946) have discussed the drainage of the Bass Strait area in Tertiary and Quaternary times.

Post-Older Basalt River System

The extrusion of the Older Basalt lava flows apparently brought about the following changes:

(1) In the Woori Yallock Basin the Wurunjerri River was succeeded chiefly by a stream which flowed along the northern boundary of the lava field. This stream was diverted over a saddle in the Wurunjerri Range, and linked with a stream flowing along the southern margin of the Kangaroo Ground lava field. As no Newer Basalt lavas were extruded in these areas, this stream is the same as the present Yarra River. It is thus seen that the Yarra consists of parts of three early Tertiary rivers (or more accurately, their post-Older Basalt successors), viz., the Wurunjerri, the Kangaroo, and the Melbourne.

(2) The pre-Newer Basalt Plenty River has been traced by Jutson (1910), i.e., the stream which was established after the extrusion of the Older Basalt. It was probably on the eastern margin of the Melbourne River lava field. New streams usually start along the margins of lava flows, and so the position of the post-Older Basalt streams may, on the whole, indicate the extent of the Older Basalt lava field.

(3) The Melbourne River lava field was a broad one, and a new stream developed down the middle of it—the pre-Newer Basalt Yarra. Possibly the great thickness of basalt in this field caused a slight slumping which would cause the water to take this course.

The River Yarra flowed along the north of the Woori Yallock Basin lava field, over the saddle in the Wurunjerri Range, along the southern margins of the lava fields represented by the Kangaroo Ground and Ivanhoe residuals, through the present suburbs of Fairfield, Collingwood and Burnley, and so to the city area, where it flowed along the edge of the Older Basalt past the Botanical Gardens and across the Albert Park lakes (i.e., skirting the Older Basalt on which South Melbourne is built), and so down the middle of the Melbourne River lava field to the sea. This course, in its lower reaches, was deeply entrenched by low eustatic sea-levels in the Pleistocene.

(4) The Dandenong Creek no doubt developed as a stream marginal to the Older Basalt in the valley of the Wurunjerri River. Pleistocene low sea-levels would make this stream a very active one, and its work was not interfered with by Newer Basalt flows as in other parts of the drainage system of Port Phillip. Dandenong Creek has carved out a more or less circular physiographic basin north of Dandenong, because it is constricted at the

latter locality between the southerly extension of the Western Quartzites and a granitic intrusion (part of the old Arthur Range). The basin is one of differential erosion, and it is to be noted that a branch of the Dandenong Creek south-east of Ringwood has succeeded in breaching the Western Quartzites at a weak place and in corroding a young valley west of the main quartzitic horizon.

The headwaters of the Dandenong Creek are very little different in level from Brushy Creek, which flows into the Yarra. In a short time, from a geological point of view, the Dandenong Creek will capture Brushy Creek and reverse its direction of flow, so that the Yarra will flow down the Dandenong Creek. Thus the early Tertiary drainage system of the Wurunjerri River will be re-established. However, the constriction at Dandenong will no doubt cause flooding, and the river will cut a gorge there.

FIG. 8
Map to indicate extent of Miocene marine transgression. Nearly all deposits are found below the level of the Nillumbik Peneplain.

Tertiary Marine Transgression

After the Older Basalt had been eroded (a time interval of unknown duration), a marine transgression of the land on a large scale took place. Figure 8 shows the approximate extent of this transgression in Victoria. The whole of the seaward half of the Port Phillip river system was drowned, the Yarra was betrunked, and former branches (like the Barwon) became independent streams.

The physiographic effect of the transgression was the opposite of rejuvenation (physiographic senescence, if a term may be coined), with the result that the products of erosion were relatively small. Widely distributed deposits of limestone, originating chiefly from the calcareous tests of marine organisms, were laid down. All in the area concerned in this study are Miocene in age.

The Miocene deposits contrast strongly with the succeeding Pliocene Red Beds, which consist of sands and gravels resulting from the rejuvenation of streams following recession of the sea. At Beaumaris, on Port Phillip Bay south-east of Melbourne, remains of a Cheltenhamian (Upper Miocene) beach have been found above the Middle Miocene limestone. This suggests that regression of the sea was in progress in Upper Miocene times.

The Red Beds

Regression of the sea meant rejuvenation. Sands and torrent gravels were swept down the valleys and spread out on the former sea-floor left bare by the retreating sea. They thus formed a coastal plain covering the Nillumbik Peneplain and seaward slopes.

The regression of the sea also meant the engrafting of the river system, so that a condition like that figured by Gregory (1903, fig. 50) obtained. This was, of course, before the formation of Port Phillip.

Glacio-Eustatic Changes

During the Pleistocene Period, the eustatic low sea-levels caused intense rejuvenation which resulted in the reduction of the Older Basalt lava field. The sections across the Yarra River described earlier in this paper show that the Older Basalt was practically stripped from the bed of the Kangaroo River at Melbourne. Hall (1909, p. 30) records that at Port Melbourne a bore pierced 170 feet of deposits before reaching the bedrock. As already indicated, the low sea-levels resulted in corrosion to a depth of the order of 500 feet on the site of the present Port Phillip Heads.

Another process at work during low sea-levels was the building of calcareous sand dunes now consolidated, and a notable feature of the coast (Hills 1939, Coulson 1940, Gill 1943, Keble 1946). These dunes partly filled the estuary cut by the rejuvenated river system, but the dunes themselves were planated when the sea advanced again. Later new dunes were built on the planated bases of the old ones.

The fact that the Newer Basalt was also stripped away from the bed of the Yarra at Melbourne during eustatic low sea-level or levels indicates that the flow or flows there are of Pleistocene age. The lignite, shelly marl, and such beds are evidence of alternation of conditions. The high eustatic levels would bring about the deposition of estuarine beds. The Sorrento Bore also provides ample evidence of alternation of conditions (Chapman 1928, Keble 1946).

Genesis of Port Phillip Bay

The bay owes its origin chiefly to Selwyn's Fault, which developed probably in Holocene times and is still active. The fault runs along the eastern margin of much of the bay (Keble, 1946, fig. 2), and has brought about a block-tilting effect which allowed encroachment by the sea. The crowding of the submarine contours on the eastern side of the bay (see Keble's figure 2) is probably due to the faulting plus the scouring developed thereby. However, if the bay originated by faulting alone, the deepest water would be along the fault line, but this is not so. The deepest water is in the middle of the bay. This is due to the fact that a deep and wide valley was carved out during eustatic low sea-levels, so that when the sea came to its present level a large estuary had already been formed. The fault has increased the area of encroachment. Keble (1946) has given the name Bellarine Fault to the hinge of the tilt-block.

In late Pleistocene times, dune building established a bar across the present Port Phillip Heads. The mouth of the Yarra migrated to different places between Mount Arthur and the Bellarine Peninsula, for as one exit was blocked by dune-building, another had to be found. Keble (1946) has described the Bay Bar and the various debouchements which can be traced in the submarine contours. The infilling of the Pleistocene valley of the Yarra is still proceeding in the bay, although negatived to a certain extent by movement along Selwyn's Fault.

The formation of Port Phillip Bay by flooding of the Pleistocene valley and movement on Selwyn's Fault betrunked the Yarra river system, so that streams which once flowed into the Yarra now debouch into the bay.

Newer Basalt Cycle

The present cycle of erosion was precipitated by the extrusion of the Newer Basalts. The Upper Yarra and Middle Yarra were not affected, and thus their courses are much older. The Lower Yarra was forced against its southern valley wall, and its thalweg raised considerably. The gravels and other fluviatile deposits found beneath the Newer Basalt at Burnley and Collingwood show that the pre-Newer Basalt river bed was well below sea-level at those points. This suggests that the basalt was extruded in a glacial low sea-level period.

Ponding of the Yarra River occurred at Fairfield, where the river was obstructed by the lava flows. Similar ponding occurred in some tributary streams with resultant deposition of alluvium. The shell-beds of the Williamstown area, a product of a post-glacial eustatic sea-level, repose on the Newer Basalt. (Hills, 1940a.)

Main Conclusions

1. The Upper Yarra owes its westerly flow to a line of granitic intrusions, i.e., to differential erosion.
2. The Middle Yarra breached the Eastern Quartzites at Healesville because that was the edge of the Woori Yallock Basin lava field, and the site of a disrupting quartz porphyry intrusion.
3. The Lower Yarra breached the Western Quartzites through post-Older Basalt drainage being diverted over a saddle in the Wurunjerri Range. This was possible because the lava was some 300 feet thick and lifted the thalweg of the stream above the level of the saddle.
4. Two pre-Older Basalt peneplain surfaces are described—the Yarra Plateau (600-650 feet) and the Nillumbik Peneplain (400-450 feet).
5. The pre-Older Basalt river system and divides are described in outline.
6. The thalweg of the main stream (Melbourne River) was of the order of 500 feet below present sea-level on the site of the present Port Phillip Heads. The remainder of the depression shown by the Sorrento Bore is due to Selwyn's Fault.
7. After extrusion of the Older Basalt, marine transgression over a large part of the State betrunked the ancestral Yarra River system, and brought about physiographic senescence. The seaward basalts were covered with Tertiary strata, which were mostly limestones, because the depressed river system brought comparatively little material for deposition.
8. Retreat of the sea brought rejuvenation and the deposition of the Red Beds sands and gravels which resulted therefrom.

9. Pleistocene eustatic low sea-levels caused streams to deeply erode the Older Basalt. The Newer Basalt at Melbourne lies in a valley below sea-level, and is itself affected by corrosion extending far below sea-level. It is therefore Pleistocene in age. During low sea-levels also, extensive calcareous dunes were built. High sea-levels have resulted in deposition within the low sea-level valleys, and in the planation of dunes.

10. The Lower Yarra valley which was carved out by Pleistocene eustatic low sea-levels was flooded to form an estuary. The sea encroached still further to form Port Phillip Bay when (probably in late Holocene times) the development of Selwyn's Fault caused block-tilting.

11. The extrusion of the Newer Basalts caused ponding at Fairfield, and the forcing of the Lower Yarra against the southern wall of its valley as a marginal stream.

12. This study is far from complete. It is but a step along the long road of research to a complete account of the physiography and palaeogeography of the River Yarra.

Acknowledgements

I am indebted to Messrs. I. J. O'Donnell, O.B.E., B.C.E., and W. Ozanne, M.C.E., of the Country Roads Board, for information relative to River Yarra bores, to Dr. D. E. Thomas of the Mines Department for information concerning Survey bores, and to Mr. M. Teese of M.M.B.W. for drafting Figure I.

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