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THE GEOLOGY OF THE KINGSTON AREA

By

GILLIAN C. PAXTON
University of Tasmania

(With five text figures and one plate)

ABSTRACT

In the Kingston-Blackmans Bay area, flatly dipping Permian marine sediments ranging in age from the Quamby Group (Upper Sakmarian) to the Ferntree Mudstone (Kazanian) are overlain, with slight angular discordance, by terrestrial Triassic sandstone. The sedimentary rocks have been intruded by Jurassic dolerite in the form of sills and transgressive sheets. Tertiary faulting, producing an approximately north-south parallelism of large-scale structures, preceded volcanic activity in which basalt flows covered much of the area.

INTRODUCTION

The area mapped lies between Bonnet Hill to the north and Flowerpot Point to the south and extends westwards from the coast as far as the powerline which supplies power to the Electrona Carbide Works. This area of approximately 10 square miles includes the townships of Kingston, Kingston Beach and Blackmans Bay. Soil types have been mapped by Loveday (1955).

Lithological boundaries were mapped onto aerial photographs in the field, then transferred to a 1000 feet to the inch base map produced by the Southern Metropolitan Master Planning Authority in 1958. Outcrop is good in cliff sections along the coast, but inland it is very poor.

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PHYSIOGRAPHY

Relief is largely controlled by lithology (see Fig. 1). To the west, hills composed of Permian sediments intruded by Jurassic dolerite rise to 900 feet. Bonnet Hill, capped by resistant dolerite, rises steeply to a height of 700 feet within 1¼ miles from the coast. This terrain contrasts with the undulating sandy hills on Triassic sandstone and the gentle hill slopes produced by basalt flows.

The coastline, consisting of steep cliffs of Permian sediments, broken by resistant dolerite headlands and two gently curved beaches, is controlled by the Tertiary fault pattern which is responsible for the Derwent Graben (Banks, 1958a). Lithology and the dominant directions of faults and joints allow the formation of sea caves, pebble beaches, a small stack on Flowerpot Point, the Blackmans Bay Blowhole and approximately horizontal rock platforms twenty to thirty feet wide.

Drainage is related to faults and lithological boundaries (see Fig. 1), and to the permeability of the underlying rocks (Farmer, 1963). Streams flow either east to Kingston Beach, often as tributaries to Browns River, or into North-West Bay. Mountain tract streams flowing east from Bonnet Hill are deep and steep-sided and end as small, cliff waterfalls on the coast.

STRATIGRAPHY

Permian System

Lower Permian Sediments

The oldest rock identified in the area outcrops along the Margate Road opposite the Howden Road turnoff. It contains *Pseudosyrinx*, a fossil which suggests correlation with the top of the Quamby Group or lower part of the Golden Valley Group (Upper Sakmarian). Other fossils identified from this locality are *Eurydesma cordatum* (sp. 85018)*, *Keeneia twelvetreesi* (sp. 85016), *Astartila pusilla* (sp. 85019), *Stenopora johstoni, Calcitornella* and *Grantonia* n. sp. (sp. 89154). *Peruvispira elegans, Keeneia ? ocula* and *Astartila* cf. *pusilla* were found in the first road cutting north of the Howden Road turnoff (see sp. 89161). The rock is a mudstone with irregular bands up to 1 m. thick of dark greenish grey, less fossiliferous siltstone in the lower parts of the section.

Between the latter rocks and the overlying Grange Mudstone occur approximately 100 m. of fossiliferous, marine sandstones and siltstones. Outcrop is poor and accurate thicknesses cannot be obtained. The sequence includes fenestellid siltstones; siltstones containing numerous marine fossils such as *Stenopora* and *Strophalosia;* a fine sandstone very rich in ostracodes with foraminifera (e.g., *Frondicularia*) and fragments of brachiopods; and a siltstone containing pelecypods (spp. 85020, 85022). A *Strophalosia* species also present in the Lewis Point Siltstone, the Brumby Marl, the Darlington Limestone and the Golden Valley Group (all Lower Permian), was found on the hill 30 m. above the Howden Road turnoff. *Stenopora crinita* (sp. 85020); *Schuchertella* (sp. 85021); *Peruvispira trifilata* (sp. 85023); *Stophalosia* n. sp. and a fragment probably of *Aviculopecten tenuicollis* (sp. 89156); *Protoretepora ampla, Ingelarella* cf. *ingelarensis, 'Spirifer' convolutus, Gilledia ulladullensis, Streblopteria* sp., *Astartila* n. sp. cf. *pusilla* and *Camptocrinus* sp. (sp. 89157), were also present at this locality. Although these individual fossils are not stratigraphically significant, the fossil suite is

* Numbers refer to specimens in the collection of the Geology Department, University of Tasmania.

characteristic of the Branxton Sub-group of New South Wales.

The Lower Permian section appears to be unfaulted and to conformably underlie the Grange Mudstone. It should therefore correspond to the Faulkner Group. However, the Faulkner Group in the Hobart area, for example at Porters Hill, is deltaic, whereas these sediments are marine. At Snug the Snug Mudstone is thought to be a marine equivalent of the Mersey Group, to which the Faulkner Group belongs (Banks, 1962a, p. 205). Thus it is probable that the shoreline at the time of deposition of the Faulkner Group was between Hobart and Kingston.

A belt of very poorly exposed sediments north of Parks Hill and west of the North-West Bay Fault have been tentatively mapped as Lower Permian. However, recent palaeontologic and stratigraphic work by the Department of Mines in Hobart indicates that this is part of the Malbina Formation.

Grange Mudstone

The Grange Mudstone is over 60 m. thick. The exact thickness at Kingston cannot be deduced due to a fault between the exposure of the basal beds and the top of the most complete section—that on Parks Hill—where a block of Grange Mudstone has been uplifted by the Jurassic dolerite. Although an attempt was made to measure a section along the track from (5127, 7071) to (5133, 7066) exposure is not sufficient for this measurement to show up more than gross differences along the saddle. Because of these differences a fault has been postulated which passes up the valley in a roughly north-south direction.

The name 'Grange Mudstone' seems unsuitable here where the succession includes several sand-grade beds, especially near the top. The name 'Grange Formation' would be more suitable. To illustrate this point, the main features of the 16 m. section measured to the west of (5128, 7071) on Parks Hill will be described below.

The basal 3 m. consists of a coarse, very poorly sorted rock containing 20-30% of quartzitic rock fragments up to 4 cm. long and some mica flakes (< 1%), (sp. 847). The matrix (70%) is a fine sand with an average sphericity of 0.7 and roundness of 0.3 (Krumbein and Sloss, 1958, p. 81). The rock is poorly bedded and jointed and is fairly brittle. The only fossils seen were a few fenestellids near the base. Overlying this unit is approximately 12 m. of a fairly well-sorted yellowish grey siltstone (sp. 843) containing < 1% mica and quartz grains and usually < 1% rock fragments (mainly quartzite). Parallel bands of polyzoans (especially fenestellids), give an impression of bedding. Sphericity to roundness ratio (S/R) is 0.7/0.3. This rock is interbedded with bands of coarser sediment which, in general, become thicker and coarser lower in the section. Specimen 845, from a coarse-grained band 20 cms. thick at a height of 6.75m. in the section, is a poorly fossiliferous, fine-grained sand, very hard and fairly well-sorted. One metre below the top of the section is a band of poorly sorted, medium light grey sand (sp. 844), containing angular quartz and fossil fragments. The upper part of the section consists of a thin band of fine sandstone, probably belonging to the Malbina Formation.

Although the western Parks Hill section is atypical of the Grange Mudstone it is correlated with this formation for the following reasons:—Sandstone and fine granule conglomerates near the top of the Grange sequence have been reported from South Arm by Green (1961); although on Parks Hill the sandstone beds are lithologically similar to those of the Malbina Formation, they are interbedded with Grange-type fenestellid-rich siltstone; the fossil assemblage is characteristic of the Grange Mudstone.

On the hill to the east of (5128, 7071) a section much more similar to the usual Grange Mudstone is exposed. The characteristic rock is a yellowish grey siltstone with some calcareous fossil fragments and a cherty appearance, presumably due to metamorphism by underlying Jurassic dolerite. Many beds are composed mainly of shell fragments, often concentrated near the top of the bed (e.g., sp. 849). Quartz grains and a few mica flakes (both up to 5 mm. long) are present. In contrast to the western section, some pectens (including *Aviculopecten tenuicollis* and *Deltopecten subquinquelineatus*, sp. 89158) are found. Fenestellids are common and again are concentrated in layers. Fossils are less abundant in the lower parts of the section.

Malbina Siltstone and Sandstone

There is little outcrop of the Malbina Formation in the area which was mapped. The small section of this formation on Parks Hill (5127, 7071) is a poorly-sorted, fine sandstone containing mica grains and quartzite fragments (sp. 855). The sand grains are sub-angular with a fairly high sphericity. (S/R =0.7/0.5).

Risdon Sandstone

No Risdon Sandstone was found in the area, but to the north of the cliffs below Taronga it outcrops as a sandstone formation 3 to 4 m. thick which overlies the Malbina Formation and underlies the Ferntree Mudstone. In weathering features and general appearance this rock (e.g., sp. 857) is similar to the Triassic sandstones. However, it can be distinguished by its small thickness, stratigraphic position and poor sorting.

Ferntree Mudstone

The Ferntree Mudstone is overlain by Triassic sandstone. Below Taronga it is underlain by the Risdon Sandstone, but the base of the Ferntree Mudstone is not exposed at Kingston. The thickness of the type section at Ferntree is about 185 m. As in the case of the Grange Mudstone, the Ferntree Mudstone should be called the Ferntree *Formation* as it contains sandstones and conglomerates. Because the mudstone at Kingston contains conglomerate beds, many erratics and possible turbidity current deposits, some manuscript maps show it as the Malbina Formation, overlain by the Risdon Sandstone. Evidence is strong that it is, in fact, equivalent to the Ferntree Mudstone as suggested by Lewis (1946, p. 141) and is overlain by Triassic sandstone. Firstly, it underlies sandstone—of which the thickness, good-sorting and siliceous nature indicate a Triassic age—with slight angular discordance. Secondly, the abundantly fossiliferous horizons found elsewhere at the top of the Malbina Formation (e.g., at Taronga) have not been found here but a band of marine fossils occurs about 30 m. below the top. These are rather poorly preserved large pelecypods, probable plant fragments and *Peruvispira* (sp. 85023). *Myonia carinata,* found near the top of the section and in Member E of the Malbina Formation, has been reported by Woolley (1959) from the Ferntree Mudstone near New Norfolk in which sandstones and beds with numerous erratics up to several inches long also occur. Thirdly, worm tubes, animal burrows and fan-like markings on bedding planes are very common and pyrite nodules are found. These are all characteristic of the Ferntree Mudstone.

If this *is* Malbina Formation, the Ferntree Mudstone is absent between it and the Triassic sandstone. Then either: after deposition of the Malbina Formation this area was an uplifted block on which Ferntree Mudstone was not deposited; or up to 185 m. of Ferntree Mudstone were removed by erosion before deposition in the Triassic; or there has been unusual faulting along the coast. This last explanation seems unlikely because if the base of the overlying sandstone is plotted using a dip of 5° and measured strikes, it coincides with the contacts found in the field. It seems, then, that the simplest and most plausible explanation is that this section is equivalent to the Ferntree Mudstone.

The coastal outcrop of Ferntree Mudstone consists, in general, of well-bedded and well-jointed fine sandstone alternating with narrower, more fissile siltstone beds. The fine sandstone beds are 0.3 to 1.5 m. thick. A 13 m. vertical section was measured along the cliffs south of Boronia Point (see Fig. 2 and appendix). Some interesting features are revealed in this section.

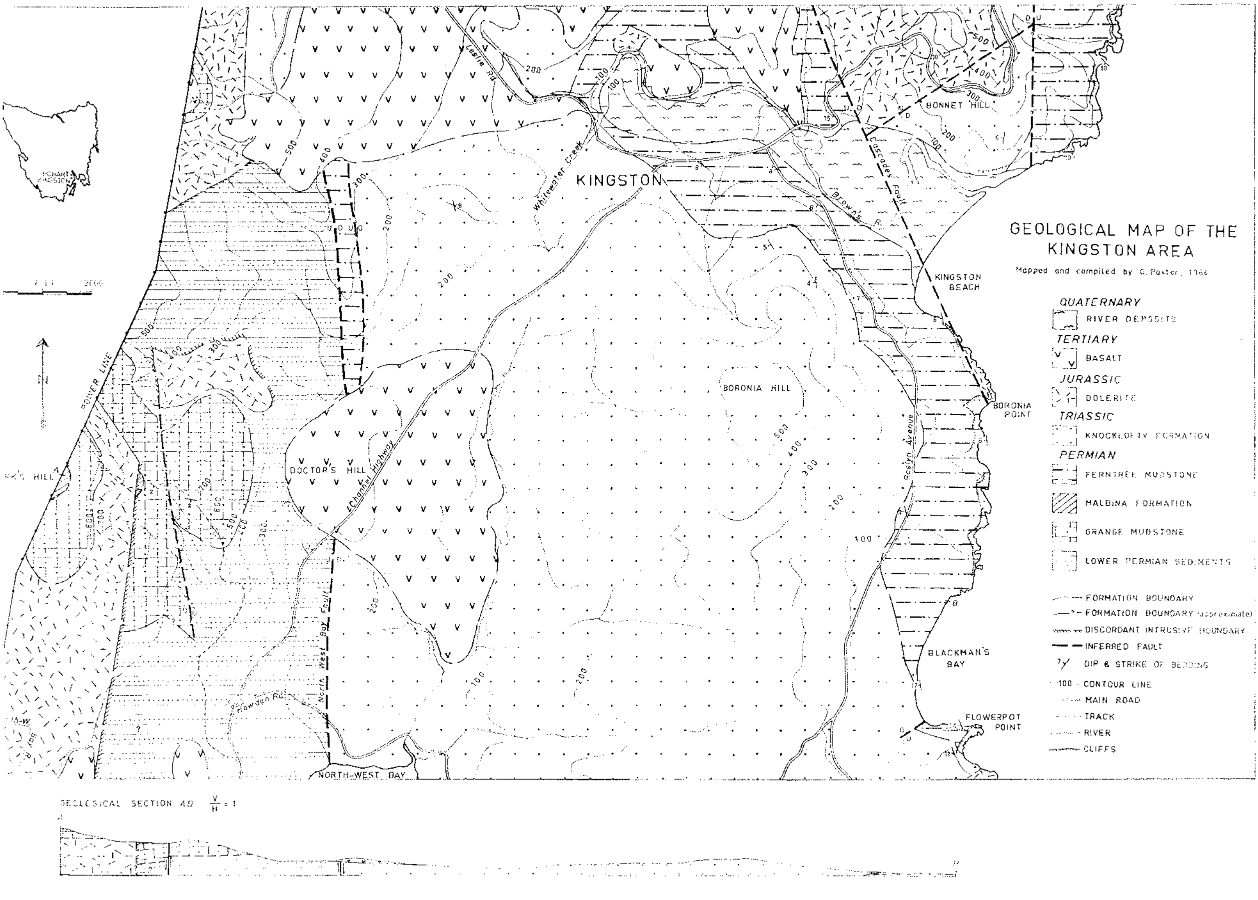


FIG. 1

1. Animal burrows are present throughout. Near the top they occur in fine, black, fissile beds which alternate with harder, fine sandstones. They usually project downwards from the surface of the bed. Near the top of the section the burrows are in the form of sandy cylinders 1-2 cm. in diameter and up to 5 cm. long. The material contained within the cylinders is much coarser-grained and less well-sorted than the surrounding sediment (sp. 906). They may be worm or pelecypod burrows, although no pelecypods were found in them. In the lower part of the section the burrows occur at the surfaces of successive beds. They are very much more numerous than above, of a finer material and with a regular, dumb-bell shaped cross section (Plate 1, Figs. 1 and 2).
2. There is a band of large, oval, concretions in Unit H (see appendix). The concretions are up to ¾ m. long and ½ m. wide. Some are double. They were formed *in situ* because one sampled contains angular erratics similar to those in the surrounding rock. The bed below appears to have been bowed down slightly by the growth of the concretion (Plate 1, Fig. 3). Unfortunately the concretionary rock is very porous due to leaching of the constituent minerals which suggests that it contained carbonate—either siderite or calcite. Siderite is more probable because the concretions are surrounded by a narrow limonitic rim.
3. Erratics are very numerous in the Ferntree Mudstone. They are mainly quartzite, but shale, mica schist, sandstone and a porphyrite have also been found. The porpryrite erratic (sp. 866) is approximately 10 cms. in diameter, contains quartz and orthoclase and is similar in texture to the St Marys Porphyrite (sp. 4652). However, sp. 4652 contains plagioclase and biotite as well as quartz as phenocrysts. If the erratic is of St Marys Porphyrite, it may indicate movement of icebergs from the north-east. Many of the erratics found in the Ferntree Mudstone, especially the larger ones, are probably ice-rafted. North of Kingston Beach there are numerous angular erratics of sandstone and quartzite, ¼ cm. to 10 cm. long, which often have a vertical long axis and bend the laminations in fine-grained beds. However, in the measured section there are beds of pebbles, up to 12 cms. long. The long axes are usually horizontal and the sphericity and roundness are very varied. The origin of these will be discussed below.

There is strong evidence for deposition by swiftly moving muddy currents. On Flowerpot Point, at the south end of Blackmans Bay and about 30 m. below the base of the Triassic sandstone, are two conglomerate bands, approximately 15 cms. thick and 0.5 m. apart (sp. 861). The rock is grey and very friable containing fragments from 1 mm. to 5 cm. long in a clay-grade matrix. The framework is open. The clastic fragments are generally in two grainsize ranges, 1-2 mm. and about 5 mm. Roundness varies from 0.1 to 0.7 and sphericity from 0.5 to 0.9. The smaller grainsize fraction is composed mainly of quartzite fragments which have an average sphericity to roundness ratio of 0.7/0.3. The larger grainsize fraction is composed of shale and sandstone fragments from 0.5 to 5 cm. in length. $S/R = \frac{0.5\text{—}0.7}{0.1}$. There is a slight tendency towards grading within the conglomerate beds.

A theory which may explain the origin of these beds, over- and underlain by normal siltstones, was offered by Carey and Ahmad (1961). Thus, a till, deposited in the 'grounded shelf zone' by a wet-base glacier, may develop an unstable submarine slope at its seaward edge. Resulting mud slides cause redeposition of the till at lower levels and interstratification with normal deep sea sediments. Numerous ice-rafted erratics in the Ferntree Mudstone establish that the required glacial conditions prevailed at the time of deposition. Unfortunately, no definitely striated or faceted pebbles were found at Kingston and the bathymetry of the Ferntree Mudstone is uncertain.

Specimen 878 was taken from the Ferntree Mudstone south of Boronia Beach. In a polished and a thin section of this rock, small-scale festoon cross-bedding can be distinguished (Plate 1, Fig. 4). The rock is a poorly-sorted sandstone with fragments of generally low sphericity and high angularity. It consists of 70% matrix containing 30% fragments (including quartz 40%, feldspar possessing the optical properties of bytownite (20%) and 10% muscovite and opaque minerals. The cross-bedding, poor-sorting, low sphericity and high angularity of grains in this rock again suggest deposition under turbulent conditions. Laminations bend over and under the clastic fragments but do not appear to be broken by them.

Although fossils are not abundant in the Ferntree Mudstone, a bed several metres below the conglomerate beds on Flowerpot Point contains *Megadesmus grandis*, *Astartila intrepida* and *Vacunella curvata* (identified by Dr B. Runnegar, University of Queensland, see Runnegar, 1967, fig. 1 and p. 11). *Stenopora crinita* and silicified coniferous wood were identified from the north end of Blackmans Bay. *Stutchburia compressa* and *Astartila intrepida*, present in the Ferntree Mudstone at Kingston, are characteristic Upper Permian fossils.

In the Ferntree Mudstone north of Kingston Beach there are numerous nodules containing pyrite as small cubic crystals (sp. 901). A variety of sulphate minerals have accumulated as a result of the action of water on the sulphide (similar to that suggested by Schlar, 1961). The minerals are listed in Table 1.

The soda alum gives a somewhat similar X-ray diffraction pattern to that of potash alum, but a flame test gives a positive result for sodium. The presence of soda alum is interesting because it is rare as a naturally occurring mineral. Mendosite, which has the same composition as soda alum but is not isometric, does occur in nature (Dana, 1957, p. 764), but has not been indexed in the

TABLE 1

Mineral	Formula	D-Spacings, Angstrom Units					
		Measured			From A.S.T.M. Index		
melanterite	$FeSO_4 \cdot 7H_2O$	4.87	3.76	3.25	4.90	3.78	3.23
potassium aluminium sulphate hydrate (potash alum)	$KAl(SO_4)_2 \cdot 12H_2O$	4.28	5.04	5.45	4.30	3.25	4.05
soda alum	$NaAl(SO_4)_2 \cdot 12H_2O$	4.29	3.24	4.06	not recorded		

A.S.T.M. index. Another sulphate mineral identified in the Kingston area is epsomite, $MgSO_4.7H_2O$, encrusting joint surfaces in a cliff-cave south of Boronia Beach. The crystals are well-formed, orthorhombic fibres.

Triassic System

Although there are few outcrops of Triassic sandstone, a white quartz sand derived from it covers a large area. The thickness of Triassic sediments is at least 85 m. in the Boronia Hill section. Triassic sandstones lie with slight angular discordance on Permian sandstones and siltstones. There is a regional dip of 5° to the south-west. The dip is slightly less than that of the underlying Permian beds (dip 7-8°) but the strike is the same. The base of the Triassic sediments can be traced from the centre of Blackmans Bay Beach north to the Channel Highway, where it is at an altitude of approximately 30 m. It can also be seen on the cliff above Flowerpot Point. By using the measured dip and strike for Triassic rocks on Boronia Hill, the Triassic-Permian contact may be plotted. This coincides with the points at which the actual contact can be seen, e.g., on Roslyn Avenue.

Further study is required to establish whether the Triassic rocks in the Kingston area can be correlated with the Knocklofty Formation or with the Springs Sandstone. Correlation is hampered by lack of outcrop, intrusion of dolerite and faulting. McLeod (1961), called the Triassic rocks at Whitewater Creek the Ross Sandstone of Lower Triassic age. This is following the nomenclature of Jennings (1955) who used this name for the basal 100 m. of the Triassic System.

The basal beds above Flowerpot Point and in the cutting behind Blackmans Bay Beach (spp. 909-911) are a greyish orange, micaceous and graphitic, fine to medium sandstone. They contain white, subangular quartz in a yellow clay matrix. Iron staining produces an irregular banded appearance. Several feet higher in the section the sediment is a coarse to very coarse sand containing fairly well-rounded quartz grains (S/R = 0.7/0.7) in a fine grained matrix. Mica and graphite flakes are not as common as they are in the lower beds. Cross-bedding, indicating a current from the west, is present and there is a small fossil stream bed exposed in the section. This is ½ m. wide by ¼ m. deep and extends at the top into a narrow horizontal band of pebbles. The pebbles are chiefly quartzite and there is slight vertical grading. The sandstone characteristically weathers to rounded outcrops which are red due to iron staining in weathered specimens. The clay matrix is probably removed by leaching processes leaving a white quartz sand which is used commercially.

At the north end of Kingston Beach the basal beds contain mica and needles of tourmaline, and contain a band about 3 cms. thick composed of quartz pebbles up to 4 cms. long in a sand-grade matrix. Higher in the section the sediment is harder, more compact and finer grained. Specimen 918 is composed of 80% quartz in a clay matrix (kaolinite or muscovite), with rare crystals of plagioclase approximately 0.4 mm. in diameter. The quartz has straight, or in come cases undulose extinction. Some grains are composite but have no inclusions. The grains are about 0.4 mm. in diameter and their sphericity to roundness ratio is 0.7-0.9/0.3. There is little variation in grainsize.

Triassic sandstone with an even and close bedding is taken from the quarry on Kingston Road, Bonnet Hill, for use as paving and building stones (spp. 926, 924). This is part of a small 'island' of Triassic sediment surrounded by the Bonnet Hill dolerite, but it is not appreciably metamorphosed by the dolerite. It dips at 10° to the north-west with a strike of 330°. Bedding is from 3 cms. to 45 cms. thick and the outcrop is well jointed. Two main rock types are exposed in the quarry. The lower one is a fine sand which is very pale orange and consists of sub-angular quartz grains in a clay matrix. Overlying it is a medium-grained sand in which bedding is less well developed. Cross-bedding is absent. The relationship of these Triassic sediments to those on Tyndall Road and south of Kingston cannot be determined because the section is broken by the dolerite intrusion.

In all outcrops seen in this area, the current direction, as determined from cross-bedding measurements, appears to have been from the west. The fossil stream bed above Flowerpot Point indicates flow of water from either the west or the east. A westerly current direction agrees with observations elsewhere in Tasmania except at Dover where the current apparently had an easterly source (Hale, 1962). The coarse sandstone sequences, the current bedding and the fossil stream bed are characteristic of deposition in shallow water. It has been suggested (Hale, 1962, p. 230), that the sediments are of fresh water origin due to lack of marine fossils and the presence of terrestrial plants in Triassic sediments in other parts of Tasmania.

IGNEOUS ROCKS

Jurassic Dolerite

Tholeiitic dolerite, of Middle Jurassic age (McDougall, 1962) intruded into Permian and Triassic rocks in the form of sheets and sills.

Intrusion appears to have been at two stratigraphic levels:—Into the Lower to Middle Permian, in particular the Grange Mudstone; and into Triassic sandstone. The trend of the discordant contacts is roughly parallel to that of the major faults. This will be discussed in a later section.

Exposed on the point at Boronia (5187, 7077) are fine-grained dykes (sp. 933) intruded into the coarser dolerite. The thickest dyke is 1.6 m. thick, narrowing to approximately 0.7 m. at its highest outcrop in the cliff. The contact is irregular and stepped, but the general trend is 70°. About 30 m. to the south a series of dykes from 5 cms to 15 cms. wide trend at 80°. The dykes are cut by the strong regional jointing at 310° (see structure section), but another near-vertical set of joints has developed within the dykes and roughly parallel to their margins. These are probably caused by stresses during cooling. The dyke rocks are composed of multiply-twinned laths of labradorite (50%), subhedral pigeonite crystals (45%) and an opaque mineral, probably ilmenite, in a groundmass of mesostasis containing numerous opaque grains, small feldspar laths and rounded pyroxene grains. The texture is ophitic. The composition of this specimen is similar to that of the coarser-grained dolerite in the area.

Tertiary Basalt

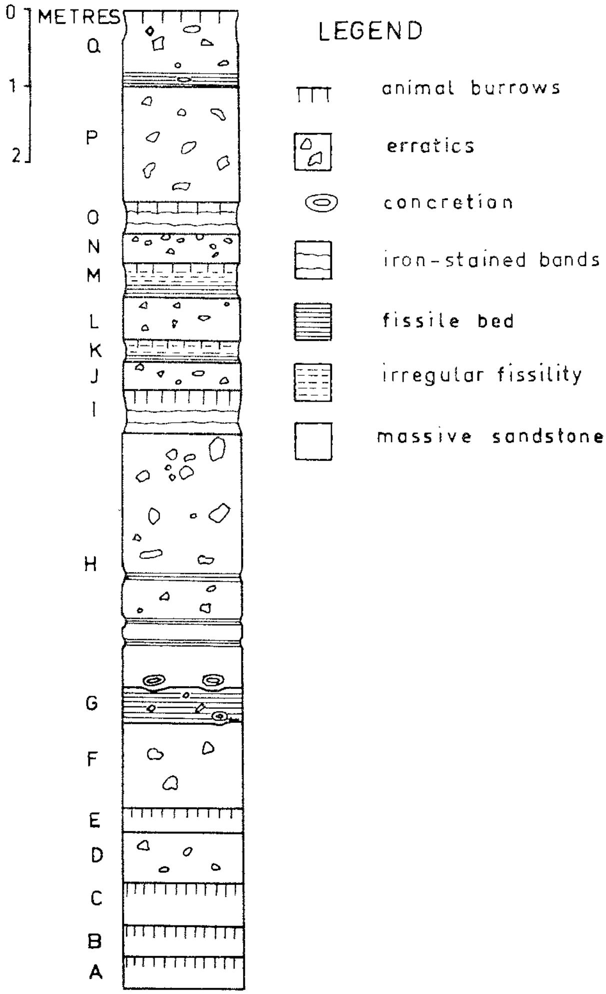
Olivine basalt (spp. 940, 941), which post-dates the Tertiary faulting, covers much of the mapped area. There is little outcrop as most of the basalt is covered by a rich, red-brown soil. There are three main basalt masses:—The Mount Pleasant basalt exposed on Leslie Road, the Browns River Road basalt and the Doctors Hill basalt. From structural evidence it would appear that these three masses are remnants of a single flow. Thus, if approximate contours of the pre-basalt topography are plotted (assuming that the basalt post-dates the faulting), there is a steady fall in altitude from the north-west and flow lines within the basalt are consistent with this direction. Nevertheless, the Mount Pleasant basalt is mineralogically distinct from the other two masses. The Browns River Road and Doctors Hill basalts are oligoclase basalts according to the classification of Edwards (1950). In thin section they are seen to be composed of olivine phenocrysts which have been largely (but often incompletely) altered to iddingsite. The iddingsite is brown with slight pleochroism, high birefringence and high relief. The oligoclase laths are flow-aligned, especially in the Doctors Hill specimen, and rough banding up to 1 cm. wide is visible. Ilmenite is present as small, even-grained granules scattered throughout the section. The texture is intergranular.

The basalt from Leslie Road contains phenocrysts of olivine and colourless augite with some irregular-shaped ilmenite crystals in a groundmass of labradorite, greenish-brown glass and a little quartz. The texture is intersertal to intergranular. There is no marked flow orientation in this specimen. This basalt best fits the Mersey Type according to Edwards' classification, although the glass is greener and more abundant.

Where the southern extremity of the Doctors Hill basalt crosses the Channel Highway (5141, 7067) an interesting contact between the basalt and Lower Permian sediments is exposed in a road cutting. The contact is steeply dipping and a narrow band of red scree material separates the slightly thermally metamorphosed sediment from the weathered basalt. This exposure may be explained by postulating a pre-basaltic valley cut in Lower Permian sediments, down which the basalt flowed.

A specimen of clay taken from a vertical joint in the outcrop at the Howden Road turnoff was shown by differential thermal analysis to be a *nontronite*. It has probably formed from the olivine in the Doctors Hill basalt and has subsequently migrated into joints in the underlying sediment. Allen and Scheid (1946) suggested that weathering under conditions of poor drainage is essential for the formation of nontronite.

FIG. 2



STRUCTURE

The area can be conveniently divided into two structural units separated by the North-West Bay Fault which extends N.N.W. (strike 350°) from the northern end of North-West Bay. The fault is concealed by the Doctors Hill basalt flow but appears to bifurcate where it emerges north of the flow, introducing a narrow wedge of Ferntree Mudstone between the Triassic and Lower Permian sediments. Both blocks are downthrown to the east. A fault which cuts Leslie Road at (5135, 7098) has a similar displacement (400 + m.) to that of the North-West Bay fault. Its southern extremity is hidden by the Mt Pleasant basalt but it is probable that it is an extension of the North-West Bay Fault.

Eastern Structural Unit

In the eastern unit a north trending fault has brought into contact Permian rocks (Ferntree Mudstone) to the west with Jurassic dolerite to the east, i.e., it is downthrown to the east. On Boronia Point the dolerite-Ferntree Mudstone contact is probably an extension of this fault. This conclusion is supported by the medium-grained character of the dolerite and a similar vertical displacement to that near the Kingston Golf Course clubhouse (5175, 7097). The adjacent sediments do, however, seem to be slightly thermally metamorphosed. The strike of the contact at Boronia Point is 332°. The movement is probably Jurassic and associated with the dolerite intrusion, but its trend is parallel to the preferred direction of Tertiary faulting (Banks, 1958a).

Kingston Beach occupies a graben formed by the previously described fault and a north-east trending fault which abuts onto it. A small meridional fault with a throw of probably less than 16 m. brings a coastal strip of Ferntree Mudstone into contact with Triassic sandstone on Bonnet Hill. Minor faulting can be seen along the coast and two small faults are exposed in the cliff section of Ferntree Mudstone north of Kingston Beach (5193, 7094). One strike (37°) is almost vertical with the east side downthrown by about 2 m. Nearby, a fault with a throw of 0.3 m. dips 60° to 287°.

Western Structural Unit

The discordant contacts in the western unit and in the area to the south-west mapped by McDougall (1962) have the same trend as the large Tertiary faults, suggesting a relationship between the Jurassic and Tertiary movements. A fault, roughly parallel to the North-West Bay fault, has been postulated to explain the discontinuity of the Grange Mudstone between the east and the west of the valley at (513, 707). The west side has been downthrown with respect to the east, the reverse of most faults in the area. Probably this is a Jurassic fault associated with the dolerite intrusion. Dip measurements of sediments on Parks Hill indicate that the dolerite body to the north may extend under the Grange Mudstone and dome it slightly. The slight thermal metamorphism of the Grange Mudstone is a result either of the underlying dolerite or a surface extension of the Doctors Hill basalt which has subsequently been eroded away.

Jointing

Where exposure permits, joint directions have been measured to investigate correlation between jointing, faulting and intrusion of dolerite. The results, plotted on a Schmidt equal area net, are shown in Figs. 3, 4 and 5. Measurements were made chiefly along the coastal sections and in road cuttings.

Jointing in Lower Permian Rocks

Fig. 3 shows joint measurement in Lower Parmian rocks exposed in a road cutting at the Channel Highway-Howden Road junction. Two sets of joints are well developed at right angles to the bedding planes. There are two maxima, at 75° (strong) and 165° (diffuse), corresponding to joints striking at 345° and 75° respectively. The strike of the bedding is 30° and that of the nearby North-West Bay Fault is 350°. It is noticeable that one of the joint maxima is close to the strike of the North-West Bay Fault.

De Sitter (1956, pp. 128-130) described similar jointing in lignite beds in which there are two sets of joints approximately at right angles. The main set is parallel to the dominant fault direction, the other set is perpendicular to it. The joints are *shear joints* and are due to the same stress conditions as the normal faults. Thus it seems that jointing in the Lower Permian rock is associated with the development of the North-West Bay Fault which is probably a Tertiary movement.

Jointing in the Dolerite and Upper Permian Rocks

There are several well-developed sets of joints in both the Jurassic dolerite and the Ferntree Mudstone on the coast at Boronia Point (see Figs. 4 and 5). The average values for the strike of the main sets are tabulated below:—

Ferntree Mudstone	55°	310°	15°	80°
Jurassic dolerite ..	60°	310°	15°	(155°)

In addition, the dolerite contains a set of almost horizontal joints (dipping at about 7° to the north) which are interpreted as cooling joints. Joint directions in the sediment adjacent to the dolerite tend to cluster about 55° and 310° but those south along the coast are more variable. The coastal joint directions differ from those measured in the Lower Permian rocks.

Jointing in Triassic Sandstone

Well developed joints in the freestone quarry on Bonnet Hill have been measured and their directions and dips plotted and contoured. There is a direction maximum at 312° with the joints dipping at approximately 60° to the north. There is a weaker maximum at right angles, in which joints dip at approximately 75° to the east.

Jointing in Basalt

A very prominent set of joints is seen in the basalt where the Electrona powerline crosses the Longley Road. These dip at 20-40° south-east with a strike of 10-20°. At right angles to this there is a poorly developed set. The variation in dip and the curvature of these joints suggest that they are a cooling phenomenon and are probably roughly parallel to the original topographic surface over which the basalt flowed.

Jointing in Lower Permian Rocks, Channel Highway.
80 readings

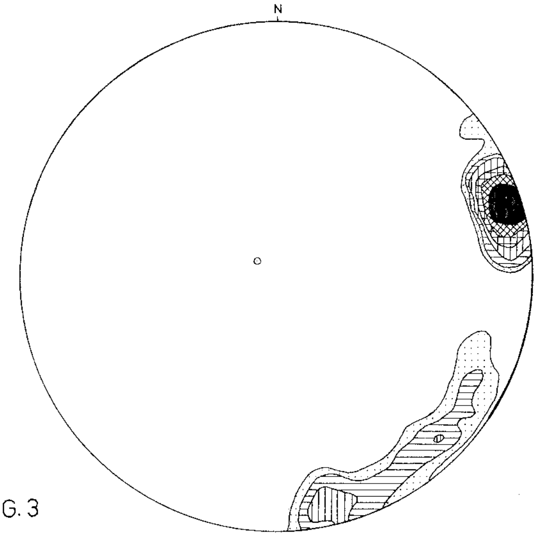


FIG. 3

Jointing in Ferntree Mudstone, coastal outcrop.
50 readings.

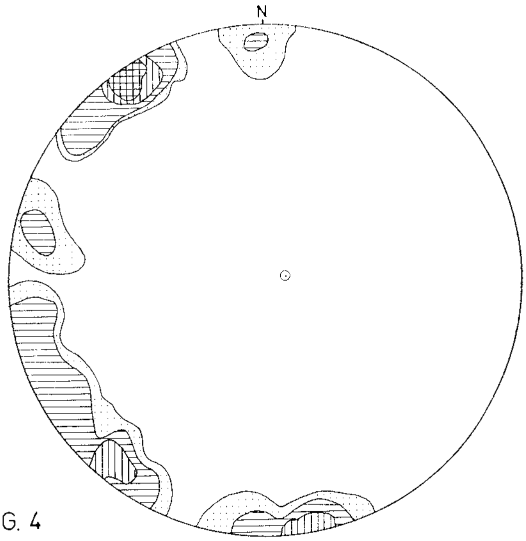


FIG. 4

Jointing in Dolerite, Boronia Point.
55 readings.

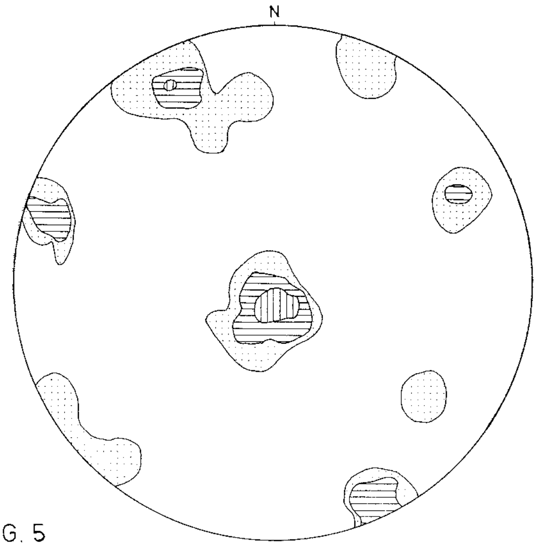


FIG. 5

LEGEND

Percentage

- 2 – 5
- 5 – 10
- 10 – 15
- 15 – 20
- 20 – 25
- >25
- ⊙ Pole of bedding

FIG. 3

Summary of Structure

In the Kingston area there is a marked parallelism of Jurassic and Tertiary structures. The trend of these is approximately 330° (N.N.W.), which is also the general strike of the bedding in Permian and Triassic rocks. Jointing can, in some cases, be correlated with the Jurassic and Tertiary movements.

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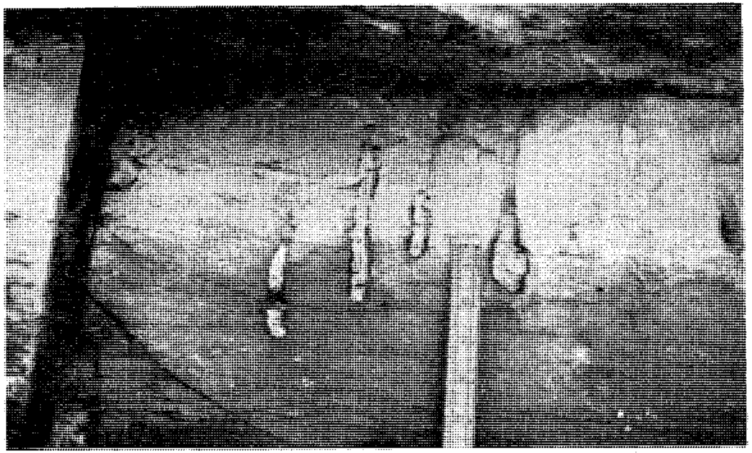
APPENDIX

(See Fig. 2)

Beds	Thickness (metres)	Description
A.	0.43	Sediment similar to C.
B.	0.43	Sediment similar to C. A few larger erratics near the top—up to 2″ in diameter, angular, and at different orientations with respect to the bedding planes. Contains numerous burrows which can be seen well in section on the wave-cut platform. Burrows occur in the top 6-9″.
C.	0.56	(specimen 883). Contains very numerous burrows in the top 6″. These are smaller and of finer material than those in bed E to the north.
D.	0.69	(specimen 882). Contains no burrows; erratics are up to 3″ in diameter, S/R = 0.3/0.5. The sediment is hard and white.
E.	0.31	(specimens 874, 881). Contains numerous animal burrows which are about 1½″ in diameter. They extend almost to the base of the bed and are filled with sandy, very poorly sorted material containing quartzite and shale fragments.
F.	1.14	Sediment is similar to H.
G.	0.46	(specimen 880). A fairly soft and fissile bed; lensing from 1′ 6″ to 6″; erratics are a few small quartzite pebbles which are fairly well-rounded.
H.	3.35	A fairly homogeneous sediment containing three narrow (6″) bands which are more fissile although of similar rock type; erratics are much larger and more frequent at the top; their shapes are very variable; in the lower 2′ is a band of large concretions.
I.	0.56	(specimen 875). Contains very numerous sandy animal burrows which are thick and almost vertical; the bed varied in thickness along the strike; it is slightly graded and has iron-rich bands near the base; fissile; erratics mainly of quartzite.
J.	0.36	A turbidite bed containing numerous erratics; sphericity is very variable, R = 0.3; very poorly sorted, erratics are granite, quartzite, shale, sandstone and fine conglomerate.
K.	0.31	(specimen 878). Animal burrows are not numerous; an irregular fissility; contains numerous small quartzite erratics (½ cm. in diameter) which are fairly well rounded (S/R + 0.7/0.5); there are also larger, angular erratics up to 3″ in diameter. See plate and description.

Beds	Thick-ness (metres)	Description
L.	0.56	(specimen 876). Similar to J but with smaller and fewer erratics; contains small flakes of white mica and a ferro-magnesian mineral.
M.	0.43	(specimen 885). Contains animal burrows; a dark, very fine sandstone with long tapered wafers of a coarser sediment similar to the bed below, suggesting currents which broke off part of the underlying sediment; the fragments are roughly horizontal.
N.	0.38	(specimen 879). Dark grey, with white, irregular streaks; at the top are numerous angular erratics up to 2″ across; contains several sandy cylinders with a circular cross-section; they extend up to 2″ into the bed from the upper surface and may be animal burrows.
O.	0.43	Fairly regularly laminated with sparse burrows and narrow iron-rich bands.
P.	1.52	as M.
Q.	1.02	Sediment similar to M; burrows in the top 1″; erratics are bigger and more numerous towards the top.

Plate I



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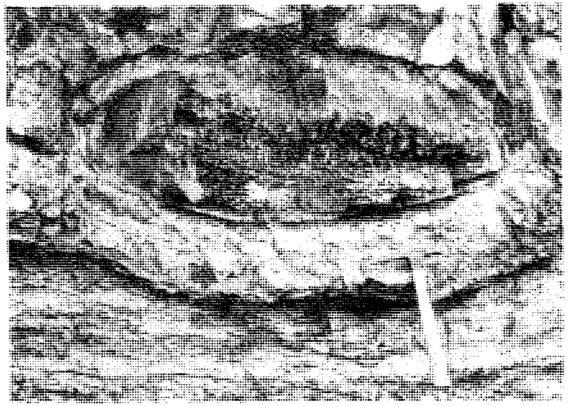

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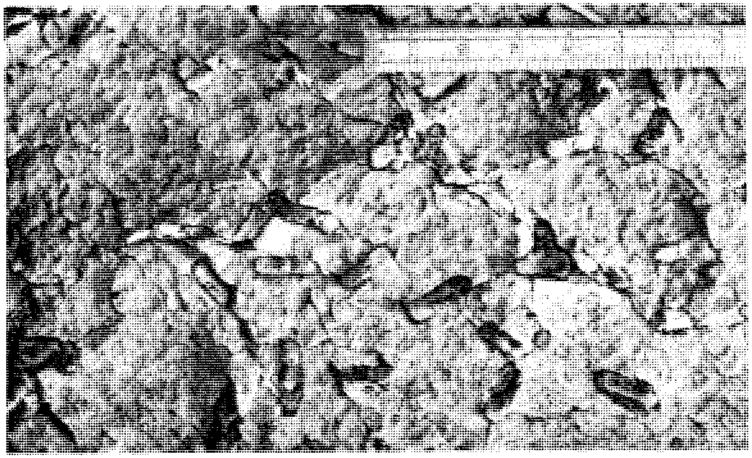

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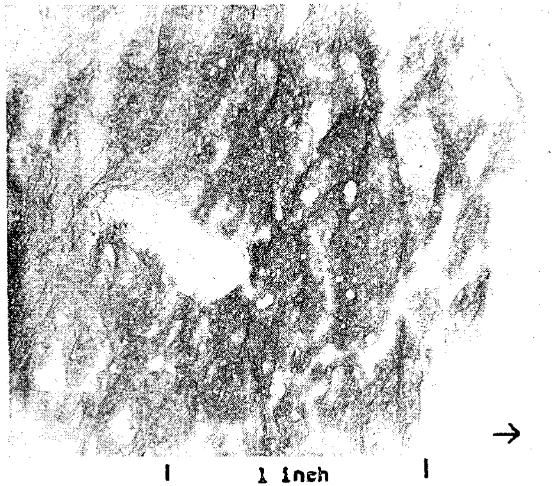

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Fig. 1.—Animal burrows in Ferntree Mudstone, Kingston. Vertical section.
Fig. 2.—Animal burrows in Ferntree Mudstone, Kingston, Horizontal section.

Fig. 3.—Concretionary structure in Ferntree Mudstone, Kingston.
Fig. 4.—Specimen of Ferntree Mudstone showing rock fragments and small-scale cross-bedding. (Arrow indicates direction of underlying bed)