Stratigraphy and Structure of the Pine Mountain Area, near Ipswich, South-East Queensland

by

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ABSTRACT. Pine Mountain is an early Palaeozoic inlier that is itself intruded by serpentinite and surrounded by Mesozoic sediments in the north-west of the Ipswich Basin. Mesozoic sediments in ascending order are: Mount Crosby Formation, Colleges Conglomerate, Hector Tuff, Cribb Conglomerate, Tivoli Formation (including Waterworks Coal Seam), Upper Ipswich Coal Measures (undifferentiated), Aberdare Conglomerate, Raceview Formation, Ripley Road Sandstone, and Walloon Coal Measures. Rocks of Tertiary age include basalt, siliceous limestone, and pisolite.

The major structure of the area is the West Ipswich Fault. Associated are the Coal Creek Syncline and Pine Mountain Anticline. The margin of the inlier is faulted (West Ipswich and Pine Mountain Faults). The Kholo Fault is the southerly continuation of the north-eastern margin of the Esk Graben; and the Borallon Fault separates the Bundamba Group from the Walloon Coal Measures.

Mesozoic sediments reflect a marginal environment in which fluviatile and lacustrine conditions alternated. Late Triassic movement along the Esk Graben is responsible for the existing structures.

INTRODUCTION

The Pine Mountain area lies to the north of Ipswich, approximately 30 miles from Brisbane, and is bounded on the south by the new Toowoomba highway and on the east by the Brisbane River. Westwards the area extends across the Brisbane Valley railway line, and the northern boundary is marked by an east-west line through Borallon Station.
The area was studied to determine its stratigraphy and geological structure. The basement (Neranleigh-Fernvale) rocks were not studied in any detail as these had previously been mapped by Wilkinson (1950). The maps accompanying this report are based on aerial photograph interpretation with the Ipswich 1 mile military map grid superimposed. Localities in this paper are referred to by six-figure references of this grid. All rocks and fossils cited have been catalogued in the University of Queensland, Geology Department Collections and are housed in the above collections.

Previous investigations
The earliest geological work in this area was an economic study by Rands (1894). Cameron (1899a and b) mapped the area as part of a comprehensive survey of the Ipswich Basin and considered the northern boundary of the basin to be faulted, Pine Mountain representing a faulted inlier. Reid & Morton (1922) assumed that Cameron's West Ipswich Fault had a downthrow to the east, and that northwards towards Pine Mountain it became an anticlinal axis, with a syncline developed to the east, near the Brisbane River. The same structure was considered by Cameron (1922) to be an axis of severe folding. Richards & Bryan (1924) likened the stratigraphy and lithology of the Pine Mountain inlier to that at Fernvale. Later, Denmead (1928) also compared these two localities.

Hill (1930) was of the opinion that the northern and eastern margins of the inlier represent unconformities whereas the western and southern margins are faults. The Borallon Fault was believed to be similar to the West Ipswich Fault of Cameron, both being faulted anticlines with a strong downthrow to the west, the West Ipswich Fault being the earlier of the two. The Tertiary siliceous limestones were correlated by Bryan & Jones (1946) with those of the Silkstone Formation, as developed at Limestone Hill, Ipswich. Wilkinson (1950) considered the western and eastern margins of the inlier to be faulted and the southern and northern to be unconformities. He thought also that the western margin was continuous with the West Ipswich Fault and that the Pine Mountain Fault which forms the eastern margin cut through the Mesozoic sediments to the south. Wilkinson (1953) discussed the serpentinites of Pine Mountain with relation to the serpentine belts of Eastern Australia.

The area adjacent to Pine Mountain area was mapped by Allen (1955, 1961), who formally subdivided the Kholo Sub-Group. Denmead (1955) believed the West Ipswich structure was a fault with a westerly downthrow. This structure was considered by Wilson (1958, 1960) to be an anticline, partially faulted in the south. The economic possibilities of the Waterworks Coal Seam were investigated by Mengel (1963), but, subsequent to Wilson, no further structural study had been conducted in the area.

Physiography
The southern portion of the area comprises high ridges and deep, steep-sided gullies with good outcrop, especially of conglomerate. Similarly the "Borallon Beds" give a rugged topography in the north-west. This was noted by Cameron (1899), who mapped the entire area as conglomerate ridges. Northwards the country is less rugged and wider valleys and better soil cover are developed. The Pine Mountain inlier is mainly of high relief except for its serpentinite, which is relatively low-lying. Southwards the basalt has provided flat to undulating country which is extensively used for agriculture.

In the extreme west of the area, the Ripley Road Sandstone and the Walloon Coal Measures form flat to gently undulating, well-vegetated country. The Borallon Fault has exerted structural control of the creeks in this area.

STRATIGRAPHY

Neranleigh-Fernvale Group
The metamorphic rocks of the Pine Mountain inlier and those to the east of the
Kholo Fault are part of the Neranleigh-Fernvale Group. Wilkinson (1950) mapped the inlier and reported that it was composed of jaspers, quartzites, andesites, greywackes, and limestones. The andesites, greywackes, and limestones are developed in the western portion of the inlier; the main elevated ridge to the east is formed of jaspers and quartzites. Ferruginous quartzite and siliceous haematite were formed by later metasomatic processes. An extensive belt of serpentinite occurs in the western part of the inlier.

To the east of the Kholo Fault, the metamorphics are similar to those found elsewhere in the Neranleigh-Fernvale Group. The metamorphics generally weather to form a poor soil, but basic rocks associated with quartzites give a deep red soil. Such a soil is abundantly found on the slopes of Pine Mountain and to the east of the Kholo Fault.

**Serpentinites**

The serpentinites at Pine Mountain occur within the inlier, with the same NNW. trend as the metamorphics. They form a slightly arcuate outcrop of about 1½ miles in length and weather to give steep boulder-strewn slopes with poor soil cover. The serpentinite clearly intrudes the Neranleigh-Fernvale Group (Wilkinson, 1950) but does not intrude the Mesozoic rocks.

Wilkinson (1950) reported two types of serpentinite, massive serpentinite and serpentinite schists. The latter have well-marked schistosity characteristically developed at the margins and trending NW. to NNW. The serpentinite shows considerable evidence of shearing and sheared surfaces are often polished and slickensided. The serpentinite is also observed to have small disseminated grains of chromite in places, but the chromite is of no economic value.

At 856811, an outcrop of a glassy green rock occurs. This is a silicified serpentinite which (thin-section, R. 8003) has retained the structure of serpentinite but contains abundant opaline silica. This outcrop occurs very close to the basalt boundary, and the author considers that basalt originally covered this serpentinite and that the silica from the basalt has migrated to the serpentinite and altered it.

**Ipswich Coal Measures**

The Ipswich Coal Measures comprise over 4,000 feet of freshwater sediments, including mainly shale and sandstone with some conglomerate, breccia, tuff, and basalt, especially towards the base of the sequence. The shales contain numerous coal and ironstone bands, and iron-staining is fairly widespread. A characteristic feature is the lenticularity of the beds, especially the sandstone.

The Ipswich Coal Measures contain a rich fossil flora that is considered to be of Middle Triassic age (Jones & de Jersey, 1947). Two very prolific insect horizons occur: in the Mount Crosby Formation and in the upper part of the Blackstone Formation.

The subdivision of the Ipswich Coal Measures is as follows:

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackstone Formation</td>
<td>800 ft</td>
</tr>
<tr>
<td>Cooneana Formation</td>
<td>800 ft</td>
</tr>
<tr>
<td>Tivoli Formation</td>
<td>1,600 ft</td>
</tr>
<tr>
<td>Waterworks Coal Seam</td>
<td>70 ft</td>
</tr>
<tr>
<td>Kholo Sub-Group</td>
<td>1,150 ft</td>
</tr>
<tr>
<td>Cribb Conglomerate</td>
<td>60 ft</td>
</tr>
<tr>
<td>Hector Tuff</td>
<td>120 ft</td>
</tr>
<tr>
<td>Colleges Conglomerate</td>
<td>800 ft</td>
</tr>
<tr>
<td>Mount Crosby Formation</td>
<td>110 ft</td>
</tr>
<tr>
<td>Blackwall Breccia</td>
<td>30+ ft</td>
</tr>
<tr>
<td>Weir Basalt</td>
<td>35+ ft</td>
</tr>
</tbody>
</table>

Denmead (1955) has further subdivided the Tivoli, Cooneana, and Blackstone Formations.
Mount Crosby Formation

The best development of this formation occurs in the type area near Mount Crosby, where it has been studied by Allen (1955, 1961). In the Pine Mountain region the Mount Crosby Formation crops out to south-west of the Kholo Fault, where only a small outcrop of shale occurs. As the Colleges Conglomerate rarely contains shale and never in such thickness as is seen here, this shale is referred to the Mount Crosby Formation. The formation crops out in a band widening to the north-west and is cut off by the Kholo Fault in the south-east.

The shale is dark greenish to brownish grey and is hard and blocky. In thin section the bedding is shown by ferruginous material forming discontinuous dark brown bands and elongate plagioclase, quartz, and muscovite grains. The original shale has been subjected to shear during faulting, causing some recrystallization of the rock and a poor cleavage developed parallel to the bedding.

The Mount Crosby Formation is considered, on its flora, to be of Middle Triassic age. Neither fossil plants nor the characteristic insect fauna have been found in this formation in the Pine Mountain area.

Colleges Conglomerate

The Colleges Conglomerate has been studied by Allen (1955, 1961) in the type area at Colleges Crossing, where the formation crops out in high cliffs along the south bank of the Brisbane River. Allen also gives a comprehensive summary of previous work on this conglomerate and discusses its petrology.

In the Pine Mountain area this conglomerate has, in the past, been erroneously mapped as completely enclosing the Pine Mountain inlier. This conglomerate is faulted out by the West Ipswich Fault and the conglomerate to the west is completely different lithologically from the Colleges Conglomerate.

The Colleges Conglomerate crops out over a very extensive area and gives a rather typical topography. In the south it forms rugged conglomerate ridges with deep gullies and steep slopes, and northwards it tends to be less rugged with more mature drainage.

Throughout the area the conglomerate has a fairly uniform lithology. The grain size of the pebbles varies considerably from quite small to the largest seen, which was more than one foot across. Numerous sandstone bands are interbedded in the conglomerate and very occasional lenses of shale are seen. The percentage of pebbles of different lithologies present was studied and very little variation occurred from one locality to another. The pebbles were present in the following average percentages:

- Quartzite: 23 per cent
- Volcanic (rhyolite and trachyte): 20 per cent
- Chert: 17 per cent
- Greywacke: 13 per cent
- Metamorphics: 26 per cent
- Breccia and shaly material: 1 per cent

A few pebbles of tuff, basalt, and conglomerate were also found. This agrees quite well with the lithology given by Hill (1930), except that very few jasper pebbles were found. Hill however included the conglomerates to the west of the West Ipswich Fault in the Colleges Conglomerate and these are very rich in jasper.

Hill records that the interbedded sandstones are of two types, green and brown sandstones, but in the Pine Mountain area the green type of sandstone is predominant, there being only one occurrence of brown sandstone. The brown sandstone occurred as a lens in a green sandstone band and it was very rich in indeterminate plant remains. Sandstone R.8005 (876782) is composed predominantly of quartz, chert, and quartzite, with a little feldspar and some lithic fragments. The quartz is commonly highly fractured and two types are recognized; one is non-strained, showing no undulose extinction; the other is a metamorphic strained quartz. An occasional grain of
obiite is present, generally distorted and altering to magnetite. In places the biotite appears to be moulded around larger grains, indicating some deformation of the rock.

The Colleges Conglomerate is conformably overlain by the Hector Tuff, but its relationship to the Neranleigh-Fernvale metamorphic rocks is unconformable. Much evidence of movement can be seen in the Colleges Conglomerate towards the boundary with the metamorphics. The formation is folded into the Coal Creek syncline and the Pine Mountain anticline.

It is generally considered that the formation formed as a fanglomerate, and the persistence of the conglomerate laterally to the margin of the basin and its apparent wedging out and rapid downdip thinning (Allen, 1955) are characteristic of a fan or compound fan adjacent to an escarpment (Pettijohn, 1957).

Hector Tuff

The Hector Tuff has been defined and studied by Allen (1955, 1961) in the type area along the old Mount Crosby railway line, where a maximum thickness of 120 ft is developed. Eastwards the formation decreases in thickness to only 40 ft. To the west in the Pine Mountain area, it thins rapidly westwards and the thickness of the formation on the west limb of the Coal Creek Syncline is 78 ft. The sequence becomes less tuffaceous, being mainly tuffaceous sandstone and shale with occasional bands of tuff. The conformable nature of its boundaries with the Colleges and Cribb Conglomerates is well displayed throughout this area. At its western limit the Hector Tuff has been faulted out by the West Ipswich Fault.

The tuff R.8007 is grey and very fine-grained and consists of quartz, altered feldspar, and volcanic lithic fragments set in a fine matrix that has conspicuous glass shards showing alteration and devitrification. The tuffaceous sandstone R.8008 (877781) is very fine-grained and contains very fine tuffaceous material with small grains of quartz. This rock shows no relict shard structure.

The sharp change in lithology from Colleges Conglomerate to Hector Tuff indicates that the supply of gravel and sand was cut off. The tuff beds were deposited in quiet lacustrine conditions giving coal and carbonaceous shales when volcanic activity ceased temporarily (Allen, 1961). Volcanic activity of an explosive nature intermittently occurred giving tuff. No lava is reported in this area.

Cribb Conglomerate

The Cribb Conglomerate forms the uppermost formation in the Kholo Sub-Group and has been studied by Allen (1955, 1961) in the type section at Cribb Gully. This conglomerate varies lithologically from a coarse, white, pebbly conglomerate to a feldspathic, quartzose sandstone. Eastwards the Cribb Conglomerate is predominantly sandstone but in the Pine Mountain area it is predominantly a pebble conglomerate. Its westward extent is limited by the West Ipswich Fault. Eastwards from this it is folded into the Coal Creek Syncline and crops out eastwards across the Brisbane River at 880790, causing the river to shallow and rapids to form. This position is one of the points at which its junction with the Waterworks Coal Seam is clearly seen.

In the Pine Mountain area the Cribb Conglomerate is thinner than in the type area. On the western limb of the Coal Creek syncline, the thickness is 37 ft. The composition of the conglomerate is generally uniform. Interbedded shale lenses are fairly common. The percentage of pebbles of different lithologies present was studied and little variation was found to occur. The average percentages are as follows:

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartzite</td>
<td>36 per cent</td>
</tr>
<tr>
<td>Volcanics</td>
<td>31 per cent</td>
</tr>
<tr>
<td>Indurated mudstone</td>
<td>22 per cent</td>
</tr>
<tr>
<td>Chert</td>
<td>4 per cent</td>
</tr>
<tr>
<td>Greywacke</td>
<td>2 per cent</td>
</tr>
<tr>
<td>Sandstone</td>
<td>4 per cent</td>
</tr>
<tr>
<td>Iron concretions</td>
<td>1 per cent</td>
</tr>
</tbody>
</table>
The volcanic pebbles include tuff, and coarse-grained rocks containing double-headed quartz crystals.

The conglomerate R. 8006 (876780) contains abundant quartz, chert, and lithic fragments. The quartz present reflects four different source rocks. The most abundant quartz is metamorphic sheared, showing composite grains with highly sutured edges and undulose extinction. A second type, of similar origin, is a strained metamorphic quartz which contains sericite inclusions; no composite grains occur and the extinction is poorly undulose. A relatively unstrained type of quartz is also present showing angular grains and a very slightly undulose extinction. These last two types probably are metamorphic quartz that has been partially recrystallized, although the angular quartz could be a volcanic quartz that has been slightly strained during the faulting and folding movement. The remaining type of quartz is chalcedonic quartz (radiating bundles of fibres of quartz). These are associated with the chert, which is fairly abundant.

The abundance of feldspar in the Cribb Conglomerate may indicate rapid mechanical erosion and deposition. As the conglomerate thins to east and west and is limited in thickness, it is suggested that the conglomerates are derived from volcanic rocks to the north or north-east and the metamorphics to the north, and that they are deposited as alluvial gravels at the mouth of a large river or of a number of smaller rivers.

*Tivoli Formation*

The Tivoli Formation has been studied by Denmead (1955) and is the lower of the two main productive coal sequences in the Ipswich Coal Measures. At the base of the formation occurs the Waterworks Coal Seam, which attains a maximum thickness of 70 ft.

In the Pine Mountain area the Tivoli Formation crops out to the east of the West Ipswich Fault, in the south-east part of the area, and extends eastwards just south of the Kholo Bridge on the Brisbane River. The formation consists mainly of interbedded shales and sandstones with occasional conglomerate and conglomeratic sandstone bands. The shales are generally of a grey colour that varies with their carbonaceous content. Some pink or fawn shales occur that are rich in needles of iron carbonate. The shales often contain plant remains, but these are generally too fragmentary for identification. The sandstones are white and weather orange to brown; coarse to fine-grained ironstone concretions and iron-staining as concentric bands in joint blocks are common.

Identifiable fossils were not plentiful in this area. *Cladophlebis australis* (F. 45032, F. 45033) and *Dicroidium odontopteroides* (F. 45034) were recognized.

Several faults of limited extent have been found in the Tivoli strata, but displacement is generally small. Good examples of the faults are seen in cuttings along the new highway to Toowoomba.

*Waterworks Coal Seam.* The Waterworks Coal Seam, at the base of the Tivoli Formation, conformably overlies the Cribb Conglomerate. In some places a thin (15–20 feet) shale band lies between the conglomerate and the coal seam. The seam consists of a thick sequence of shale and coal bands, the shale bands forming 80 per cent of the sequence. Mengel (1963) studied the coal from the economic aspect and found it to be of inferior quality grading into carbonaceous shale. His conclusions were that the seam offers no prospect, under present economic conditions, for open-cut mining, but that later it may prove suitable for underground gasification.

In the Pine Mountain area the Waterworks Coal Seam has very good outcrops particularly in the Coal Creek area and along the banks of the Brisbane River at 880790. The coal shows numerous small faults, with slip planes showing slickensides; ironstone concretions are in abundance. In Coal Creek the axis of the Coal Creek Syncline can be traced from the dip of the coal beds.
Upper Ipswich Coal Measures (undifferentiated)

West of the West Ipswich Fault a thick belt of sediment striking NNW.—NW. underlies the Aberdare Conglomerate. The sequence consists mainly of sandstone, conglomeratic sandstone, and shaly sandstone and reaches an approximate maximum thickness of 2,000 ft. The few coaly strata that have been observed are mainly of carbonaceous shale and occur towards the base of the sequence. It is believed that this sandstone sequence is equivalent to the sandstone sequence underlying the Aberdare Conglomerate at the Thomas Street Railway Station (Reid & Morton, 1922).

The disconformity between the Aberdare Conglomerate and this sequence is not observed as the outcrop is poor, but the coal shales at the base of the sequence have been sheared by the West Ipswich Fault and are much distorted and disrupted.

This sequence, based on thickness, must correspond to the Blackstone Formation, Cooneana Formation, and part of the Tivoli Formation. However, the sequence is much coarser than these formations and no true coal strata are observed. This has made it impossible to subdivide the sequence into formations, and so it has been grouped as Upper Ipswich Coal Measures.

Bundamba Group

Overlying the Ipswich Coal Measures disconformably is the Bundamba Group which has been studied by Wilson (1960). The sequence is subdivided into three formations (Staines, 1964):

- Aberdare Conglomerate
  - 5–100+ ft
- Raceview Formation
  - 310–520 ft
- Ripley Road Sandstone
  - 737 ft

The Bundamba Group is considered to be of Upper Triassic age, the group containing a similar flora to that of the Ipswich Coal Measures.

Aberdare Conglomerate

The Aberdare Conglomerate is widespread in the Ipswich Basin but is very variable both in lithology and thickness. It can consist of cobble and pebble conglomerate, sandstone, siltstone, and thin carbonaceous shale. Denmead (1955) traced the Aberdare Conglomerate continuously from Thomas Street Railway Station to the north of the old Toowoomba road where the apparent thickness was 500 ft. However, at this time, the Raceview Formation had not been defined and the author believes Denmead has included some of this strata in the Aberdare Conglomerate. Wilson (1958) considered that the Aberdare Conglomerate was 40 ft thick at the new Toowoomba highway, but the author considers that the conglomerate that he mapped is at the top of the Raceview Formation and the Aberdare Conglomerate is further east.

In the Pine Mountain area the Aberdare Conglomerate crops out in a NW. direction from the new Toowoomba highway. The conglomerate is a coarse pebble conglomerate with occasional coarse sandstone bands. Pebbles are well-rounded and range in size from 5–60 mm, or more. The disconformity at the base of the formation is not observed.

The Aberdare Conglomerate has a predominantly siliceous composition and the average pebble composition is as follows:

- Quartzite: 47 per cent
- Chert: 10 per cent
- Indurated shale: 22 per cent
- Greywacke: 10 per cent
- Jasper: 7 per cent
- Sandstone: 4 per cent

The northward extent of the conglomerate is hard to trace as the entire sequence between the West Ipswich Fault and the Ripley Road Sandstone becomes coarser northwards and more conglomerate appears, which makes it impossible to define the limits of the formation.
For several reasons, the Aberdare Conglomerate is considered to crop out at 866772 and not at 863770 as suggested by Wilson (1958).

1. The Ripley Road Sandstone in the type area is underlain by approximately 400 ft of shales and sandstones of the Raceview Formation. If the conglomerate were where Wilson suggested, there would not be any Raceview Formation between the Ripley Road Sandstone and the conglomerate.

2. The Aberdare Conglomerate of Wilson is a small band that appears to be conformable on the underlying sediments and is conformably overlain by the Ripley Road Sandstone, not disconformably as it would be if the Raceview Formation was eroded away before the deposition of the Ripley Road Sandstone.

3. The conglomerate, as mapped here, is continuous with the Aberdare Conglomerate of Denmead (1955) further south.

4. The Aberdare Conglomerate, as mapped here, overlies a sequence of sandstone and shaly sandstone, with conglomerate and sandstone interbedded. This sequence is also found to the south near Thomas Street Railway Station.

**Raceview Formation**

Until quite recently (Wilson, 1958) the 400 ft sequence of shale and sandstone overlying the Aberdare Conglomerate was not recognized as a separate formation. Since then it has been recognized all over the Ipswich Basin and has been named Raceview Formation (Staines, 1964).

In the Pine Mountain area this formation crops out from the new Toowoomba highway north-westwards to the basalt. It consists of a thick sequence of sandstone, shale, and interbedded carbonaceous shale and is best displayed in the road cutting at 863770-865771 on the new Toowoomba highway.

The sequence contains shales, which are generally carbonaceous to some degree, and massive, often lenticular sandstone; occasional conglomerate bands occur. The strata dip steeply west and conformably underlie the Ripley Road Sandstone. The formation can be traced as far north as Muirlea, where it is covered by basalt. North of the basalt the formation becomes coarser and cannot be differentiated.

**Ripley Road Sandstone**

Staines (1964) proposed this name for the red sandstone at the top of the Bundamba Group. In the Pine Mountain area this formation crops out in a north-west direction along the Brisbane Valley Railway. It is uniform in lithology and its eastern boundary is relatively straight. The dip is very variable. In the east of the area of outcrop the dip is steeply to the west, but in the western portion the dips are steeply reversed. This change of dip is believed to be caused by folding which has produced a syncline in the east and an anticline in the west. This anticline has been faulted by the Borallon Fault. Sparse outcrop has made it impossible to determine the axes of these folds.

The sandstone is massive, medium-grained, slightly friable, and shows cross-bedding. Occasional thin conglomerate bands occur, and the formation shows numerous fractures and small faults.

**“Borallon Beds”**

“The extension of the Aberdare Conglomerate as a narrow horizon up past Pine Mountain for eight miles is erroneous, as a wide conglomerate belt develops as the old strand line is approached, the width in the environs of Pine Mountain being at least one mile of very steeply dipping to vertical conglomerate beds” (Reid & Morton, 1922).

The author mapped this area described by Reid & Morton and found that the conglomerate does extend up past Pine Mountain, between the metamorphics and the Ripley Road Sandstone. Along the road to the east of Borallon, the road cuttings show an almost continuous conglomerate section of westward dipping beds. Very occasional sandstone bands occur, and a shale is developed very close to the metamorphic boundary.
Southwards the sequence becomes finer, and interbedded sandstone becomes more abundant, but conglomerate still forms the greater part of the sequence. In the south, the conglomerates are covered by basalt which separates the "Borallon Beds" from the formations to the south. To the west, the conglomerate is interbedded with sandstone and is gradational to the Ripley Road Sandstone. To the east the sequence consists of strata that are more shaly, i.e., sandstones, sandy conglomerates, and shales.

In the author's view these conglomerates are not only Aberdare Conglomerate. They are equivalent to the Upper Ipswich Coal Measures, Aberdare Conglomerate, and Raceview Formation. South of the basalt these formations tend to become coarser northwards; thus the author considers that the "Borallon Beds" represent the three formations in the south becoming coarser northwards. The Upper Ipswich Coal Measures are represented by the shaly sequence in the east; the Aberdare Conglomerate continues in the central section of coarse conglomerates and sandstones; and the Raceview Formation is represented by the interbedded sandstone and conglomerate, grading into the red sandstone of the Ripley Road Sandstone.

The boundaries of the three formations cannot be traced north of the basalt as the lithology has changed, and outcrop is poor just north of the basalt, breaking the continuity of the beds. The sequence to the north of the basalt has therefore been called the "Borallon Beds," and this includes all the strata underlying the Ripley Road Sandstone and bounded on the east by the metamorphics and the West Ipswich Fault.

The composition of the conglomerates very closely approximates that of the Aberdare Conglomerate and the average composition is as follows:

- Quartzite: 50 per cent
- Chert: 12 per cent
- Indurated shale: 11 per cent
- Jasper: 14 per cent
- Siliceous sandstone: 4.5 per cent
- Greywacke: 8.5 per cent

At 852808 some pebbles of Permian rock have been found containing Permian fossils, fragments of Bryozoa and Brachiopods. This possibly indicates that the sediments came from further up the Brisbane Valley around Northbrook, as the strata there form the nearest Permian to Pine Mountain.

The "Borallon Beds" are quite distinct from the Colleges Conglomerate. The "Borallon Beds" are quartzitic and contain shale beds and white, iron-stained, relatively mature sandstone. The Colleges Conglomerate on the other hand is mainly composed of metamorphic pebbles, contains rare shale lenses and immature, dark-coloured sandstones.

**Walloon Coal Measures**

The sedimentary rocks of the Walloon Coal Measures crop out in the western part of the area mapped, to the west of the Borallon Fault (Swindon, 1956). This country is flat or very gently undulating, and outcrops are very rare.

The Walloon Coal Measures are represented by sandstones, mainly soft and feldspathic, that weather to a friable iron-stained sand. They differ from the sandstones of the Bundamba Group in that they are more friable and are feldspathic. The Walloon rocks are only noted as present; no further study has been conducted on them.

**Tertiary deposits**

In and to the east of Ipswich the Tertiary deposits are divided into two formations. The Redbank Plains Formation, probably of Eocene age, consists of several hundred feet of sandstone, clays, and fissile shales. The Silksstone Formation lies conformably on the Eocene deposits and is considered to be of Oligocene age. It consists very largely of alternations of basalt and limestone. Tertiary rocks are fairly abundant in the Pine
Mountain area and include Tertiary sediments, basalt, siliceous limestone, and pisolite and are probably equivalent to the Silkstone Formation.

**Basalt and Tertiary sediments**

Basalt with interbedded sediments occurs in the southern part of the area, from 882770 to 873769 on the new Toowoomba highway and northwards to 875774. As outcrops are poor the exact extent of these sediments is doubtful.

The basalt in thin-section R. 8009 (877770) is predominantly plagioclase and titanaugite with some olivine and good ophitic and sub-ophitic texture. The plagioclase forms subhedral laths and has the composition of An_{53}—labradorite. The titanaugite occurs as anhedral grains partly or wholly enclosing the plagioclase laths. The shales are partly indurated by the basalt.

This basalt is considered as distinct from the basalt at Muirlea as it is of different composition and occurs with sediments.

**Basalt**

This basalt occurs south of Pine Mountain and extends in a north-south direction for approximately 2 miles. The boundaries of the basalt are hard to define and generally they have been mapped on change in soil type from a black basaltic soil to a brown, sandy soil over the sediments. In the Pine Mountain area the main region of cultivation is on the basalt, and it is very noticeable that the tree line generally marks the edge of the basalt.

The basalt is variable, ranging from an olivine basalt to a labradorite basalt. The southernmost basalt is an olivine basalt R. 8011 (856778). The rock contains small phenocrysts of olivine in a groundmass of predominantly plagioclase laths of composition andesine to labradorite. Northwards the basalt becomes vesicular, with numerous chalcedony vesicle fillings. South of Pine Mountain the basalt is a dense and fine-grained olivine basalt. Its plagioclase laths have the same composition as R. 8011 but tend to show some preferred orientation. In the far north of the basalt mass a labradorite basalt occurs. The rock R. 8016 (865811) shows large euhedral phenocrysts of plagioclase, up to 15 mm in length, showing lamellar twinning. The plagioclase composition is approximately An_{55}—labradorite. Some olivine and magnetite are also present.

The basalt could represent one flow, with vesicular basalt representing its upper surface. The stratigraphic thickness of the basalt is unknown but it does not appear to be very great. That the basalt overlies the West Ipswich Fault suggests that the lava may have come up this zone of weakness.

**Siliceous limestone**

The siliceous limestones at Pine Mountain were first noted by Rands (1894) as “a bed of cherty magnesian limestone” that “contains too much magnesia to be of service in the manufacture of cement”. Wilkinson (1950) also mapped these rocks at two positions, one on Neranleigh-Fernvale rocks and the other to the south of Pine Mountain overlying Mesozoic rocks. The latter has been remapped by the author and is found to be overlying basalt. A number of other outcrops of siliceous limestone have been mapped overlying basalt. Thus, Wilkinson’s (1950) statement that the limestones are associated with Neranleigh-Fernvale rocks is in general not true. They appear to be closely associated with the basalt.

The limestones are highly silicified and chaledonized, and in outcrop there are generally only isolated boulders and pebbles. The silica of the pebbles and boulders weathers differentially to give a reticulate network on the surfaces. The limestone has a strikingly brecciated appearance due to large angular fragments of limestone set in a silica cement which is of three kinds:

1. Normal quartz;
2. Chalcedony, often spherulitic;
The siliceous limestone at Pine Mountain is very similar to that at Limestone Hill, Ipswich, which is referred to the Silkstone Formation. (Bryan & Jones, 1946). The most striking similarity is the brecciated appearance. Bryan & Jones (1946) have collected numerous shells of the minute freshwater gastropod Planorbis from the Silkstone Formation limestones. Wilkinson (1950) reports finding one specimen of a gastropod referable to this genus at Pine Mountain. It is therefore reasonable to suppose that the Pine Mountain limestones are equivalent to the Silkstone Formation and are therefore probably of Oligocene age.

It is generally considered that the Pine Mountain siliceous limestones were originally deposited as impure limestones in freshwater lakes studding the basaltic lava plains. Several authors (Whitehouse, 1940; Bryan & Jones, 1946; Wilkinson, 1950) suggest that they would form in a period of little rainfall when the lake waters could be sufficiently charged with lime to precipitate CaCO₃. The limestones have since been successively dolomitized and silicified by solutions whose intersecting courses have produced the brecciated appearance. The silica is probably derived from the basalts and, in the Pine Mountain area, to a limited extent from the quartzose Neranleigh-Fernvale rocks.

Pisolite

A number of small outcrops of pisolitic rocks are associated with the basalt. Grain size is variable, ranging from sand size to 10 mm in diameter. Red soils are developed from these rocks. In thin-section R.8017 (860808), the pisoliths are composed of opaline silica which in some cases has been altered to microcrystalline quartz. A large percentage of iron material is included in the pisoliths, which show radial cracks (possibly desiccation cracks). Some pisoliths have a coating of opal around the outside. Cement is partly ferruginous and partly opaline material, some of which is changed to microcrystalline quartz.

The pisoliths have previously been mentioned by Rands (1894) and Wilkinson (1950), but no work has been done on them. They are found only as small deposits in association with the basalt. The author suggests that the deposits formed in small basins on the basalt surface. Silica-rich waters, derived from the basalts during the weathering processes, collected in the basins and deposited silica around nuclei of lithic fragments, forming pisoliths of varying size. After deposition, the pisolite sediment was enriched in iron and cemented with ferruginous material and opaline silica.

Alluvium

Extensive alluvium is not developed in the Pine Mountain area. River gravels are deposited on the eastern banks of the Brisbane River, and the western bank is being scoured away. A few swamps are developed in the larger creeks, e.g., Coal Creek, but in general the creeks are dry for most of the year and little alluvium is developed. The alluvium generally consists of silts and sands with a small amount of gravel.

GEOLoGICAL STRUCTure

The structures of this area all show the same general trend. Both folds and faults have a NNW.—NW. trend. They roughly parallel the structures to the east (Allen, 1955) and those in the southern and central parts of the Ipswich Basin.

Kholo Fault

The Kholo Fault, previously mapped by Hill (1930) and Wilkinson (1950), is developed to the north-east of Pine Mountain and separates the Palaeozoic Neranleigh-Fernvale rocks from the Mid-Triassic Mount Crosby Formation and Colleges Conglomerate. Its strike is shown by a steep ridge of Neranleigh-Fernvale rocks adjacent to low-lying poorly outcropping Mesozoic strata. The Mount Crosby
Formation, which is quite fractured, has been truncated by the fault plane and the shales have been partially recrystallized and the components reorientated parallel to the bedding.

The fault is considered to have a downthrow to the west, but its displacement is unknown. It dies out to the south-east and is not evident on the east bank of the Brisbane River (Allen, 1955, 1961). There seems to be little doubt that the boundary between Mesozoic strata and the Neranleigh-Fernvale Group is a fault rather than an unconformity. This is supported by the relatively steep dip of the younger rocks and by the fact that their strike is at a distinct angle to the boundary.

**Pine Mountain Fault**

This fault marks the eastern and southern margins of the Pine Mountain inlier; westward the fault is obscured by basalt. These margins have been variously considered as faults and unconformities. Cameron (1899) considered them as faults, but Hill (1930) mapped only the southern margin as a fault. Wilkinson (1950) named the eastern margin the Pine Mountain Fault. This does not extend southwards into the Triassic sediments but continues west to form the southern margin of the inlier.

No definite fault plane is observed, but the fault is considered to be present on structural evidence. The Colleges Conglomerate beds strike at various angles to the Neranleigh-Fernvale rocks and dip quite steeply. The southern part of the fault truncates the Pine Mountain Anticline. Much evidence of movement can be seen in the Colleges Conglomerate. The fault has a downthrow to east and south.

**Borallon Fault**

This fault was proposed by Cameron (1899) but was not named until 1930 when Hill proposed the name Borallon Fault. Hill believed that the Borallon Fault was a faulted anticline with a strong downthrow to the west. The presence of the fault is based on the following evidence:

(a) There is structural control of Ironpot Creek and the creek to the north. Their tributary gullies are almost at right angles, and the creeks are very deeply cut.

(b) To the west, the rocks of the Walloon Coal Measures have a shallow westward dip, while the strata of the Ripley Road Sandstone dip steeply east.

(c) The Ripley Road Sandstone in the west contains numerous shear planes.

(d) The difference in composition of the rocks of the Walloon Coal Measures and the Ripley Road Sandstone is seen to occur across the proposed line of the fault.

The Borallon Fault is believed to be a faulted anticline with a downthrow to the west.

**West Ipswich Fault**

It has long been recognized that a major structure occurs south from Pine Mountain. This has been variously considered as a fault, an anticline, and an axis of severe folding (Cameron, 1899, 1922; Hill, 1930; Reid & Morton, 1922; Wilkinson, 1950; Wilson, 1958). However the author considers that this is a fault, cutting across the western limb of the Pine Mountain Anticline and having a westerly downthrow.

The West Ipswich Fault forms the western margin of the Pine Mountain inlier and southwards is covered by basalt. It is believed to extend southwards to near the Thomas Street Railway Station (Denmead, 1955). South from the new Toowoomba highway the fault is covered by Tertiary basalt and sediments. Northwards it truncates the Waterworks Coal Seam, Cribb Conglomerate, and the Hector Tuff near the axis of the Pine Mountain Anticline. West of the fault sandstone, shales, and conglomerates of the Upper Ipswich Coal Measures crop out with constant NW.—NNW. strike. These sediments cannot be correlated with the sediments to the east of the fault line. Several small coal seams at the base of the undifferentiated Upper Ipswich Coal Measures are truncated by the fault and show numerous folds, small faults, slips, and
considerable steepening of dip. These coal seams are faulted against the conglomerates of the Colleges Conglomerate.

Further evidence of this fault is provided by the structural control of gullies in the vicinity of 865787, the gullies following the line of the fault zone. Small faults associated with the West Ipswich Fault are seen in the Hector Tuff at 875776. North of the basalt covering, the fault zone is less distinct and tends to parallel the strike of the Triassic sediments. Evidence of the faulting is seen in the metamorphic and serpentinite rocks, which are extensively disrupted by folding and faulting movements of high magnitude (Wilkinson, 1950). A little distortion and disruption is seen in the Triassic sediments to the west.

The northern limits of this fault are unknown to the author, but the fault is believed to form the northern margin of the inlier, connecting with the northern extension of the Pine Mountain Fault.

The fault shows variable displacement. Below Pine Mountain, the Upper Ipswich Coal Measures are downthrown against the Colleges Conglomerate. Southwards these sediments are downthrown against successively younger rocks until the fault dies out near the Thomas Street Railway Station. The author postulates that the West Ipswich Fault originated at the Pine Mountain inlier and developed southwards as a tension release fault when the Pine Mountain inlier rose relative to the Triassic sediments.

**Minor faults**

Throughout the area numerous small faults occur, but more especially in the Tivoli Formation. These faults represent the final adjustment in the area after the major folding and faulting movement.

**Coal Creek Syncline**

This syncline was first observed by Cameron (1899) and later by Reid & Morton (1922) but was unnamed. It is believed to extend from the Kholo Fault to south of the Brisbane River, becoming shallower to the south and dying out in the Tivoli Formation.

Evidence of the syncline is seen in the outcrop of the Tivoli Formation, Cribb Conglomerate, Hector Tuff, and Colleges Conglomerate, where the strike of the strata is consistent with a syncline. In Coal Creek continuous change of dip is observed in the Waterworks Coal Seam indicating the position of the trough of the syncline. The axis of the syncline is similarly observed to the north and south of Coal Creek. In the south the fold is very steep, and the Tivoli strata are very disrupted, and small faults and folds are developed. Northwards the syncline becomes broader and less distinct. The exact position of the axis of the syncline is hard to define as Colleges Conglomerate has limited exposure.

**Pine Mountain Anticline**

The presence of this anticline has been suspected for some time (Cameron, 1899, 1922; Wilson, 1958; Hill, 1930; Reid & Morton, 1922). It lies to the west of the Coal Creek Syncline and plunges to the south. It is limited by the West Ipswich Fault in the south, which cuts across the west limb of the anticline, and the Pine Mountain Fault in the north.

Evidence of the anticline is seen mainly in the change of strike and dip of the folded strata. However, outcrop is too limited to define the exact position of the axis of the anticline.

**Other folding**

Evidence of folding is also seen in the Ripley Road Sandstone, where it is believed that a syncline and possibly an anticline are developed. Limited exposure makes it impossible to define the nature of the folding present.
COAL CREEK SYNCLINE & PINE MTN. ANTICLINE

CRIBB CONGLOMERATE
HECTOR TUFF
COLLEGES CONGLOMERATE
UPPER IPSWICH COAL MEASURES
IVOLI FORMATION
Waterworks Coal Seam

SCALE in Yards
0 100 200 300
GEOLOGICAL HISTORY

Following the Lower Triassic movement along the Esk Graben, which produced the Ipswich Basin, sedimentation in Middle Triassic times formed a sequence of entirely non-marine sediments with a characteristic *Dicroidium* flora. Marginal breccia and basalt developed, followed by conglomerates, shale, sandstone, and tuff of the Mount Crosby Formation. The conglomerates formed as a marginal composite fan and reflect high relief and limited transportation. Sedimentation continued with a thick sequence of fanglomerates of the Colleges Conglomerate, developed marginally to the northern shoreline of the basin. A change in the depositional environment from fluviatile to lacustrine conditions resulted in the abrupt change in lithology from conglomerate to tuffaceous sediments and coal. Only intermittent, local volcanic activity occurred as the tuff beds are not extensive laterally. A return to fluviatile conditions in the depositional area resulted in the formation of the conglomerates and sandstones of the Cribb Conglomerate. These conglomerates are more mature and contain abundant volcanic material.

Intermittent lacustrine conditions returned to the basin and the strata of the Tivoli, Cooneana, and Blackstone Formations were deposited. In the main part of the basin, coal was formed from transported vegetative debris (Denmead, 1955). Marginally, the sediments were coarser and the lower strata of the “Borallon Beds” were deposited in the Pine Mountain area.

At the end of Middle Triassic times, an erosional break occurred separating the Coal Measures from the overlying Bundamba Group.

Following the erosional episode, the Aberdare Conglomerate and Raceview Formation were deposited. In the Pine Mountain area, these formations contain material from the Esk Valley to the north-west (Permian fossils were found in a number of pebbles) and become coarser to the north, forming the upper strata of the “Borallon Beds”. The Upper Triassic concluded with the deposition of the red sandstone of the Ripley Road Sandstone.

At the end of the Triassic or in the early Jurassic, it is believed that a major movement in the Esk Graben occurred. Lowering of the basement blocks about the “Pine Mountain” topographic high caused the sediments to sink, and folding parallel to the margin developed (Coal Creek Syncline, and Kholo Anticline [Allen, 1955, 1961]). The Kholo Fault forms the eastern margin of the Graben in this area and developed during downwarping and folding. It is thought that the “Pine Mountain” topographic high moved upwards at the same time producing a faulted margin. The Pine Mountain Anticline was caused by the draping of sediments over the southern extension of the “Pine Mountain” topographic high. Less severe folding developed to the west, producing the syncline in the Ripley Road Sandstone. Continued movement in the basement produced tension in the rocks to the south of Pine Mountain. This was released by the formation of the West Ipswich Fault.

The Borallon Fault is considered to have developed later than the West Ipswich Fault movement, as the Walloon Coal Measures (Jurassic) are faulted against the Ripley Road Sandstone (Upper Triassic). The Walloon rocks are relatively unfolded and have only a low regional dip. The Borallon Fault is thought to be of Late Jurassic or early Cretaceous age, and although it follows the regional trend of the Esk Graben it is not known whether this fault is due to movement along the Graben.

No further sedimentation occurred until Tertiary times when renewal of volcanic activity produced basalts and associated sediments. Basalt has covered the southern, low-lying part of the Pine Mountain inlier and caused silicification of the serpentinite. Later, small basins developed in the basalt plain and limestones containing the fossil *Planorbis* were formed in some and pisolitic material in others. The limestones are considered to be derived from the calcium-rich basalts. Subsequently these sediments have been silicified by ground water action.

Subsequent erosion has produced Quaternary alluvial deposits along the Brisbane River and other watercourses of the area.
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