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GEOLOGY OF THE MERSEY-FORTH AREA.

(Map Square No. 41-86)

Report for the Hydro-Electric Commission

by

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ABSTRACT

The area shows considerable relief and a complex land surface in which the following elements were recognised: a pre-Permian surface, an early Tertiary surface of mature river erosion, a flat, post-Tertiary basalt surface, a maturely dissected and a young plateau (Central Plateau). The area has been affected markedly by the Pleistocene glaciation which produced mammilated surfaces, U-shaped valleys, roche moutonnees, till and varves. The till in the Mersey and Forth Rivers has been cut into a well-developed set of river terraces which show a possible climatic control.

The rocks in the area are chiefly a thick sequence of regionally metamorphosed sediments of Precambrian age. These have been subdivided into several groups and formations. They are overlain by thin basal Permian sediments which have been intruded by a Jurassic dolerite sill. Tertiary volcanism has been active with the accumulation of 400' of coarse pyroclastics and 400'+ of basalts.

The regional structure is shown to be similar to that in several places around the edge of the Precambrian "nucleus". A major syncline occurs in this area with a major anticline to the north, the folds trending at 280°. Two fault systems are present; high-angle reverse faults striking at 280° and transcurrent faults striking at 315°. Schistosity is well-developed parallel to the bedding of the Precambrian rocks which also show lineation trending at 280°.

Geological observations were made to give regional data on possible hydro-electric developments. Preliminary observations showed the Howell's Plains dam-site to be satisfactory but the location of tunnels from the Mersey to the Forth involves several difficulties.

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INTRODUCTION

The area was mapped by a party of three, using Land-Rover transport in two periods of four weeks extending from late in December, 1955 to early March 1956. The geology was plotted directly onto 20 chain to the inch air photos. The base map was a two inch to the mile, 50 feet contour interval map, supplied by the Department of Lands and Surveys. Typical rock specimens were collected and are housed in the Geology Department of the University of Tasmania; the numbers in this report are those in the Geology Department catalogue.

LOCATION OF THE AREA

The area described is shown on the locality map, figure 1. It is located near the headwaters of the Mersey and Forth Rivers, immediately east of the Cradle Mountain Reserve, and south of Lorinna, Liena and Mole Creek. The eastern boundary is the Mersey River, the southern limit is at Howell's Plains, and the western is close to the Forth River and the northern at the Berriedale Plains.

ACKNOWLEDGEMENTS

The author must acknowledge the considerable help given by Mr. J. Davies of the University of Tasmania and Mr. J. Jennings of the National University in Canberra in the interpretation of the physiographic history of the area. Mr. I. McDougall assisted both in the field and the laboratory and Mr. J. Locker was field assistant.

PREVIOUS LITERATURE

There has been no previous work published on this area but literature relevant to the adjacent areas is available.

Ward (1909) included the area to the south in a general summary of the Precambrian rocks of Tasmania. Benson (1916) made some brief geological notes on the area around Cradle Mountain. Reid (1919) gave a general description of the Mount Pelion area and made some reference to the geology along the forth River immediately west of this area. Clemes (1924) described the glacial features of the Lake St. Clair district. Lewis included this area in his account of Pleistocene glaciation in an extended series of papers, particularly (1932) and(1944). David (1950) made a general reference to glaciation in this area. Elliston (1954) mapped the area to the north around Lorinna.

ACCESS

Access throughout the area is reasonably good as there are passable motor roads to the eastern and western boundaries. The area may at present be entered along a track which turns south off the road from Liena to Lorinna at Gad's Hill, 5 miles west of Liena. This is a moderately good quality road for the first five miles, as it has been graded and metalled. The metalled section turns off the main track and continues for about a mile before stopping altogether. The old track continues past the mill for eight miles to the Berriedale Plain. A normal car can cope with the track up to here in dry weather, but the continuation of the track into the Arm River and the Hydro-Electric Commission Hydrographic hut may only be traversed by Land Rover particularly in wet weather when it is extremely bad. Time by Land Rover from the Liena turnoff to the Hydro-Electric Commission hut, fifteen miles, is about one and a quarter hours in dry weather. This track continues for nine miles to the south along the Mersey to Howell's Plains.

The new road at present being constructed by the Forestry Department turns off the Mole Creek-Liena road, two miles before Liena. It is in very good condition as far as the Fisher-Mersey junction where a bridge is being constructed at the present time (July, 1956). The track is good enough for a Land Rover as far as the Mersey-Arm junction but this is as far as the road has reached at this time. A bridge is to be constructed here across the Arm. The road will pass up the Arm valley and will then climb Magg's Mount.

There is a pack horse track which runs from the present track to the Mersey from the Berriedale Plains, south into the Arm Valley. It is difficult to find south of the northernmost hut in the Arm plains but continues along the eastern side of the river for about three miles.

Innes' (1896) track to Mt. Oakleigh (thence to Zeehan) is partly traceable from the Berriedale Plains across the February Plains. It may be found just beyond the hut which is half a mile south of the open Berriedale Plains. This track was blazed again during February, 1956 and is now easy to follow once it has been found. Even though the timber here is light and apparently open, the undergrowth slows progress considerably and it is worth spending an hour if necessary finding the track.

The western side of the area is served by a moderately good motor road along the eastern side of the Forth River south from Liena. It is in good condition as far as the Pelion Wolfram Mine Hut which is about eight miles south west of Gisbourne's Hut, but the track is now blocked by a number of windfalls.

There is a poor foot track from the hut at the Arm bridge into the plains on the Arm and this was re-blazed during February, 1956. The new Forestry Department road is to follow this route.

The area is well covered by huts but few are in good condition. The Hydro-Electric Commission hydrographic hut on the Mersey, Gisbourne's Hut, and the hut on the northern side of the open paddocks on the Berriedale Plains are weatherproof. Those on the north end of Howell's Plain and that at the Arm bridge are in fair condition but are not weatherproof. The remaining huts (on the Arm plains and the south part of the Berriedale Plain) are in poor condition.

PHYSIOGRAPHY

The area is one of considerable relief being situated where the edge of the high Central Plateau has been dissected by the north-flowing Forth and Mersey Rivers. The land surface is complex, being controlled by a number of different erosive processes which have acted on different structures.

The following physiographic units have been recognised:

(1) Pre-Permian surface. A flat surface generally at about 2600 feet but dipping south, exposed in some places by the stripping off of the sediments.

(2) Pre-basalt (Magg's) surface. An undulating surface of fluviatile erosion dominated by a mature valley which was developed by modification of the pre-Permian surface.

(3) Post Tertiary-basalt (Berriedale) surface. A flat surface which is underlain by a variety of rocks and which descends from 3600 feet to 2350 feet in a northerly direction in 20 miles.

(4) Central Plateau. A high (4000'+) extensive surface controlled by a great resistant dolerite sill. It is bounded on the north by the Western Tiers, a steep line of cliffs.

(5) Fold-mountain surface. The strongly folded Palaeozoic rocks around Lorinna, Mt. Roland, Mole Creek etc., show a strong W-N-W "grain" with ridges and cuestas.

(6) Karst surface. An excellent, mature Karst landscape is developed in restricted areas near Mayberry which are underlain by Gordon Limestone.

The land surface owes its form to three processes:

(a) Normal (river) erosion has been dominant with the production of the present valleys and the pre-basalt surface while the pre-Permian surface is probably a peneplain owing much to fluviatile action.

(b) Glaciation during the Pleistocene Epoch has greatly modified certain parts of the area, particularly the top of the Plateau and the river valleys.

(c) Pediment action has been dominant in the formation of the Tiers during scarp retreat.

LAND SURFACES

1. Pre-Permian Surface

The surface upon which the Permian sediments were deposited has been exposed in some parts of the area lying between the Mersey River and the Plateau near the Mersey-Arm junction. It has been dissected by the Fisher River and its tributaties and remains as a flat top to a number of the hills. It descends from 2450 feet to 2200 feet feet altitude in a distance of six miles from north to south, there being a component of dip of the Permian sediments in this direction. Ford (personal communication) reports that this surface changes in attitude and dips north-easterly just south of Western Bluff. This surface, which is underlain by folded Pre-Cambrian and Lower Palaeozoic rocks, has had a profound effect, either directly or indriectly, on the development of all other surfaces in this area. As the Pre-Permian and pre-basalt surfaces are somewhat similar, it is possible that this is actually the Early Tertiary surface, which was once covered by basalt and has now been stripped. However comparing it with the basalt-covered Berriedale Plains, and considering the perfection of the surface and its dip to the south, this does not seem possible.

2. Pre-basalt (Magg's) Surface

This is defined as the land surface exposed immediately

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prior to the Early Tertiary volcanism. It has been buried by the basalt and its form was obtained by mapping the base of the basalt. The contour map, fig. 2, which shows the approximate configuration of this surface, was obtained by plotting the base of the basalt on a 200 foot contour interval map using the technique developed by Carey.

3. Berriedale Surface

This is the flat-topped divide between the Mersey and Forth Rivers extending north of Mts. Pillinger and Oakleigh, through the February Plains, Magg's Mount, the Berriedale Plains and extending beyond Gad's Hill.

Magg's Mount is the flat-topped divide between the Mersey and Arm Rivers. The sides are steep and the top is generally at 2800' although there are undulations up to 2975'. It is underlain by a flat sheet of Tertiary Basalt about 400' thick with a superficial layer of Pleistocene till, which may reach 100' in thickness.

The February Plains form the interfluve between the Forth and Arm Rivers north of the Mt. Oakleigh-Mt. Pillinger scarp. It reaches an altitude of about 3900' in the south but much of it lies at approximately 3600' altitude. It is ten miles long and triangular in shape being six miles across in the southern end and two miles across in the north. It is underlain by a thick dolerite sill and thus is structurally akin to the Plateau but it is generally about 400' lower and is separated from it by the Mersey River.

The Berriedale Plains are the flat extension northwards of the February Plains and lie between the Mersey and Forth Rivers at an altitude of 2850'. The plains are about two miles wide from east to west and five miles long from north to south. They are underlain by Tertiary Basalt with a surface layer of Pleistocene till and are structurally similar in every way to Magg's Mount.

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The Berriedale Plains descend gently to the north and after a slight depression become Gad's Hill. This has an altitude of about 2550' and is underlain by folded Precambrian and Lower Palaeozoic sediments, Devonian granite and Tertiary Basalt.

Thus as the section fig. 3 (a) shows, there is a long narrow surface (here defined as the Berriedale surface) which forms the interfluve between the Mersey and Forth Rivers and which descends from south to north. It lies at 3600' at the February Plains, 2850' at the Berriedale Plains, 2550' at Gad's Hill and 2300' to the east of Lorinna. It averages about four miles wide and falls 1300' in its length of 20 miles.

This surface is independent of structure and rock type. It descends to the north even though the dolerite and pre-Permian surface descend to the south at the February Plains; and it cuts acróss folded Palaeozoic and Precambrian rocks and Tertiary basalt. It owes some of its flatness to the upper surface of the basalt flows which filled up irregularities in a previously undulating landscape. It has been partly smoothed by the Pleistocene glaciation but fig. 3 shows the complexity of origin of this surface.

4. <u>Central Plateau</u>

This is a major physiographic feature of Tasmania and extends over hundreds of square miles as a high level surface with a general altitude of 4000'. It rises to 4600' in some places and is bounded in the north and east by the steep scarp of the Western Tiers. The western boundary of the Plateau is indefinite but has been regarded as approximating to the eastern side of the Cradle Mountain Reserve; thus the rugged country in the Reserve with its peaks reaching

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over 5000', although structurally cognate, may be regarded as a separate physiographic unit. The upper surface of the Plateau is comparatively flat, especially towards Great Lake but is cut by many 600' deep valleys in the vicinity of the Walls of Jerusalem, where it has been strongly glaciated. There is an irregular, raised rim which reaches an altitude of 4600' and this is a characteristic feature of the Tiers.

The Plateau owes its form to a resistant dolerite sill which is over 1000' in thickness and from which practically all the roof sediments have been stripped. In some places (Liaweenee, Wentworth Hills) there are small areas of Tertiary Basalt resting on the upper surface.

The scarp of the Plateau constitutes the Western Tiers and is made up of an upper, dolerite cliff as much as 1000' high although generally not being more than 400', and a lower, steep slope up to 2000' high underlain by sub - horizontal Permian and Triassic sediments. Giant scree slopes of dolerite debris are a common feature.

The Plateau originally extended at least as far west as the Eldon Range and Mt. Dundas but the dolerite, together with the Permian and Triassic sediments, have been removed, except for a few small outliers. The reason for the abrupt change from a youthful, undissected plateau in the east to a mature strongly broken plateau in the west is not apparent and cannot be attributed to more abundant Tertiary faults in the west than in the east. Glaciation was active but chiefly enlarged valleys which had been in existence since early Tertiary. Most rivers e.g. Forth and Mersey are superimposed and show only a slight control by structures now visible and some e.g.

Mackintosh and Murchison show a trellised pattern which is probably a relict from the jointing of dolerite which originally overlay the basement.

The Western Tiers from Western Bluff to Table Mountain is unbreached by any major stream for about 80 miles and the major drainage from the youghful Plateau is to the south-west except where locally controlled by Tertiary faulting. The present Central Plateau is a small remnant of the surface which must have extended over at least two thirds of Tasmania during the late Mesozoic and it remains unbroken because of the lack of north flowing rivers. The different degree of dissection in various parts of the Plateau may be attributed to differences in the

(a) degree of fracturing and tilting of the roof of the sill resultant on the intrusive process,

(b) amount and direction of slope of the sill due to its discordant nature,

(c) regional tilting during the Jurassic or Tertiary epeirogeny

(d) faulting during the Tertiary epeirogeny.

It seems likely that the original Plateau had been partly dissected in the west even before the Tertiary faulting. It seems probable that the major rivers originally followed Jurassic faults and depressions in the roof rocks above the great dolerite sill. There is generally considerable structural disturbance of the roof as shown for example in the Wayatinah B tunnel. The original consequent streams would then be superimposed on the dolerite and partly modified by its joint pattern after they had cut through the roof. It is known that the thick dolerite sill is slightly transgressive and rises and falls within the layer of the Permian and Triassic with a general slope of about 1 in 6 and it is probable that streams would be modified by this slope.

The low regional dip of the Permian and Triassic sediments is probably due to the Tertiary Epeirogeny and tilting of large blocks would have had a considerable effect on river directions. It appears that the present Plateau remnant is chiefly preserved because of its tilt towards the south-west, whereas the Cradle Mountain area probably had a slope in a north-westerly direction. Where the surface of the Plateau sloped towards its scarp, a river system would rapidly develop and produce embayments and then dissection; but where the surface sloped back from the scarp, the streams could not attack the scarp. Thus the tilted plateau would show a youthful surface in its higher part but a dissected, mature form on the lower.

RIVER SYSTEM

The two chief rivers are the Forth and the Mersey and these show quite straight courses for 20 miles in this area. Both rivers show a long and complex history of development extending back to the beginning of the Tertiary Period.

Mersey

The longitudinal profile of the Mersey (see fig. 3) shows many of the characters typical of glacial valleys.

The Mersey rises high on the Plateau at Lake Adelaide and runs south-west across morainal ridges and glacial steps before descending rapidly down the scarp in a series of waterfalls which are well known attractions for hikers. In this section it descends 2000' in five miles in a U-shaped valley. Beyong the turn to the north at Cathedral Mountain, past Mt. Pillinger, Rugged Range to Howell's Plains it has a markedly different character. It meanders slightly across its broad, flat, alluvial covered floor which is up to one mile wide, and it has a characteristic U-shaped section with walls nearly 2000' high. The valley takes two right-angled bends. It has cut chiefly through Permian sediments in this section and spurs are lacking.

Between Howell's Plains and the Arm River junction, the valley is narrower, although the U shape persists (fig. 5c, 5d). The river here cuts through steeply dipping Pre-Cambrian sediments which strike obliquely across its course. Steep sliffs, truncated spurs and smoothed quartzite faces occur. Low rock bars cross the river in several places. The river terraces which are strongly developed in this section are described in detail later and are shown in fig. 6.

North of the Arm junction (fig. 5b) the river becomes narrower and has steep sides with a V-shaped section. The bottom is still rather flat in parts and some terraces are developed. While it is not obvious in the field, the contour maps show spurs which appear to be truncated but interlocking spurs occur just north of the Fisher-Mersey junction. Quartzite scree slopes are prominent in this section.

The valley becomes broader and flatter bottomed at Liena (fig. 5a) where the river has cut through Gordon Limestone. There is a gorge through the anticlinal ridge of Ordovician quartzite and then the river turns east where it occupies a broad flat bottomed limestone valley west of Mole Creek (fig. 5a).

<u>Forth River</u>

Although not studied in detail, the Forth River shows many features in common with the Mersey. It rises in the area around Mts. Achilles, Ossa and Pelion East and flows down a steep gradient west of Mt. Oakleigh. From here north to Gisbourne's Hut it occupies a broad, straight, deep, U-shaped, glaciated valley. North of Gisbourne's Hut the valley narrows and becomes V-shaped (although interlocking spurs are lacking) until north of the Dove junction where it passes out of the pre-Cambrian into Ordovician Quartzite and Limestone. In the vicinity of Lorinna it occupies a moderately

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broad valley which is underlain by limestone (fig. 6d).

Arm River

The Arm River is a tributary of the Mersey and is only about 14 miles in length. For the greater part of its length it occupies a very broad alluvial floored, U-shaped valley (fig. 6c) between the high February Plains and Magg's Mount. Spurs are truncated although two low rock bars cross the river. There is an abrupt change of character in the last 2½ miles before it joins the Mersey and here it descends rapidly with rapids and small waterfalls through a small gorge cut in the floor of the U-shaped valley.

EROSIVE PROCESSES

The most important agents responsible for the development of the present physiography were the Mersey and Forth Rivers, aided by the Arm, Fisher and Little Fisher Rivers. The area is youthful, being a complex plateau slightly dissected by young river valleys.

The effect of ice action during the Pleistocene glaciation while quite extensive, is probably quantitatively less important than river action. The glacial physiography will however be discussed in detail because its effects are for the most part much more important than has been recognised in the past.

The Plateau shows abundant evidence that is was covered by an ice cap of considerable magnitude and the complex effects are at present being studied in detail by J. Jennings of the National University, Canberra. At present it can be said that one centre of the cap was in the vicinity of the Walls of Jerusalem and that the extensive area of large and small lakes in this area represent the eroded zone with areas of deposition

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to the east and south. The ice spilled over the edge of the Plateau in many places and filled the previously existing Forth, Mersey and Little Fisher Rivers and covered the interfluves. The glacial nature of the Forth River was recognised by Davies in 1955 (personal communication) and all these rivers (together with the Arm) show clear evidence of glacial action. They possess U-shaped valleys with truncated spurs, hanging valleys, smoothed quartzite outcrops, and roches moutonnees on their floors. There are end moraines clearly shown in the Little Fisher Valley and varved shales occur in the northern part of the Arm, Fisher and Forth Rivers (south of Lorinna). In the Arm River, the main body of varve laps against moraine material but the characteristic form of end moraines is not very clear. Some varved shale lying between till indicates slight recession and re-advance of the glacier.

There are several more points of considerable importance which indicate that the ice in the Forth-Arm-Mersey area must have been nearly 2000' thick. In addition to the clearly demonstrated glaciation of the river valleys, the flat topped interfluves (i.e. Magg's Mount and February and Berriedale Plains) and the high steep sides of the valleys are covered with many feet of till. The nature of this material is described in detail later but briefly it consists of a mixture of round dolerite boulders in a fine matrix. This material rests on Tertiary basalt at Berriedale Plains and Magg's Mount and in the latter case there is no way that such large (up to 6') boulders of dolerite would be transported for ten miles across a flat plain except by glacial action.

It would then appear that the ice flowed off the Plateau along the Forth River but <u>across</u> the Mersey River, possibly covering Mt. Pillinger and Mt. Oakleigh and passed across Magg's Mount and the February and Berriedale Plains to the Forth River. It is possible that the upper parts moved in this direction while the movements at the base of the sheet were controlled by the underlying physiography and the ice there flowed northwards along the Forth, Arm, Little Fisher and Mersey Valleys. The ice would then be at least 1600' thick and probably not less than 1800' in the Arm-Mersey-Forth area. Many of the highest peaks in the Cradle Mountain Reserve show glacially smoothed sides and a sharp top with abundant evidence of frost action. This sharp difference suggests that the peaks might have projected through the upper surface of the ice cap as nunataks and that the altitude of the cap reached approximately 5000' in its thickest parts where it had a maximum thickness of 3000'. There is no doubt that frost attack is proceeding at present and that there has been sufficient time for the high dolerite peaks to have become jagged, but some parts of the Mersey valley e.g. Rugged Range, show sharp, rough outcrops immediately next to smoothed, glaciated areas and it is clear both on the air-photos and in the field that some places within the glaciated area have not been affected by glacial action. The altitude of the upper surface appears to have been about 4000' at Mts. Oakleigh and Pillinger and nearer 3000' at the Berriedale Plain.

It is difficult to estimate the extent of the valley glaciation although the ice undoubtedly flowed north along the valleys beyond the edge of the thick ice cap. The rivers are clearly glaciated as far north as a line (Gisbourne's Line) joining Gisbourne's Hut, the Arm-Mersey junction and just south of the Devil's Gullet, but there is some evidence that the valleys may be poorly glaciated for at least three miles north of this line. The moraines on the Little Fisher and the varves and moraine of the Arm are at this line. The varves in the Forth River are eight miles north of this line and 150' above river level and probably filled a lake dammed behind a

400' high terminal moraine at Lorinna, the remnants of which are vaguely recognisable on the sides of the valley. North of the line, the Forth, Mersey and Fisher (particularly in the Devil's Gullet) Rivers show V-shaped valleys lacking the typical glacial form, but as there is little evidence of extensive post-glacial river erosion, it seems that all these valleys must be feebly glaciated. There appear to be truncated spurs in the Mersey for nearly 10 miles north of this line but as the valley shows no abrupt changes in character in this section it is not possible at present to recognise the limit of the glaciation. Cross sections across the Mersey valley at several points and also the Arm and Fisher valleys are shown in figs. 1b, 4 and 5.

It is difficult to divide the glacial epoch into distinct stages but it is clear that apart from remnants of an early cirque-forming phase, there is a major ice cap and a later valley phase. With the limited data available at present, it is not possible to decide whether these are separate glaciations.

The old cirques which have been almost destroyed by ice moving across them during the ice cap phase occur further south on the Plateau and were not studied, and for this reason are not discussed here.

During the ice cap phase, the ice moved to the north-west across the interfluves as far north as the Gisbourne Line and extended further northwards along the valleys as tongues. It is difficult to recognise the terminal moraines of the ice cap althought the ground moraine covers the landscape. There is a vague moraine at Lorinna but it seems possible that the terminal moraines may have been removed by melt waters during an inter-glacial period.

The second phase was less severe and the glaciers were restricted to the valleys. Well developed glacial valleys were produced and striae and roches moutonnees show the ice to have moved northwards along the valleys. The Gisbourne Line marks the northernmost limit of the distinct U-shaped sections of the Mersey and Forth valleys, the till on the floor of the Mersey, the end moraines of the Arm and Little Fisher and the varves of the Arm.

At present it is not possible to decide whether the first and second phases were separated by an interglacial period or whether the ice cap merely shrank leaving valley glaciers which were active for a considerable period with minor advances and recessions.

River-Terraces

There is an extensive development of river terraces on the floors of the Forth and Mersey Rivers. The Mersey terraces are best shown in the two mile long section between the Mersey-Arm junction on Howell's Plains and these have been mapped in some detail as shown in fig. 7. Mapping was carried out using the pace and compass method for the base map and establishing heights by clinometer. The heights shown on the map are those above the river level at the nearest point. The terraces are generally well preserved and undissected with continuous, clear-cut flat surfaces. They are composed of a uniform, unsorted boulder-rich material and evidence produced later (p.68) indicates that this is Pleistocene till. The terraces range in height from 3' to 400' above river level, the lower, more perfect ones being cut in till and the higher, fragmentary ones being cut in the solid rock of the spurs. There is no doubt that the terraces have been <u>cut</u> and not <u>deposited</u> by the river.

The Mersey valley was occupied by a glacier during the last stage of the glaciation and was joined by a tributary glacier down the Arm. Removal of the ice left the floor of

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the Mersey valley covered with at least 160' of till which definitely extended as far north as the Mersey-Arm junction and probably as far as the Mersey-Fisher junction. Farther north at Liena the river terraces are composed of better sorted and rounded material which is probably fluvioglacial. The Arm contained 120' of till near its junction with the Mersey but this thinned rapidly upstream. It is difficult to estimate the actual thickness of till as the sides of the valleys and the interfluves are also covered. The terraces have been carved both in the valley walls and the till as the river cut down in post-glacial times.

The terraces do not show any marked differences in the type of material or soil development but may be divided into four groups. There are small, flat-topped, rock cut terraces at quite high levels on the side of the Mersey valley. North-west of the Arm-Mersey junction there are flats covered with waterworn quartzite and dolerite pebbles at 1800', i.e. 400' above present river level. There is a terrace at 1880' south-west of the junction above the Arm bridge. There are similar vague flats on the west side of the Mersey opposite the Fish River at 140'[x], 150'[x], 310'[x], 330'[x], 350'[x], and 370'[x], above river level. On fig.   are shown terraces at 160', 150', 145', 130', 120' and 95'.

The next group occur at 75', 65', 65'[x], 60' and 55'[x] and although they are fragmentary, they are better preserved and more extensive than the previous group. The 75' level is the highest cut in till and the 55' is the lowest rock-cut terrace.

The next group occurs at 45', 40' and 35' and these are very extensive, well preserved surfaces. All the previously mentioned terraces are too fragmentary to say whether they are matched or unmatched across the river, but although the 45', 40' and 30' are well developed, once again this point is not clear. In some places the 45' and 35' are clearly matched

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[x] denotes rock-cut terraces.

across the present river but as fig. shows, it is likely that the 45' on the west bank slopes down to 40' on the east bank and back to 30' on the west. Since the 65' level the river has progressively occupied less and less of the valley floor, and between the 40' and 30' level there was a distinct straightening of the river leaving truncated meanders and other parts of the course perched on the terraces. The river meandered around several low rocky hills on the 45' and 40' levels but these also were left stranded as the river straightened and cut downwards.

The group 30', 26', 10' and 3' are narrow and follow the present river course very closely. At the points marked T.B.L. there are marked constrictions of the course by islands and although there is continuity of surface of the terrace there is rapid decrease in height of 45' to 30' and lower from 40' to 30'. Above the constriction the surfaces of the terraces have a gentle slope indicating a flat grade with rapids across the temporary base level where the course narrowed and was held up by the hard quartzite bed rock.

There are two nodes showing restriction in the course of the river since the 45' and 30' levels.

The constant height of the upper surfaces of the terraces above the present river levels indicates that the Mersey has not appreciably changed its grade since the 45' definitely and probably the 65' also. The Arm terraces however are more complex and show that the grade was much flatter at the 120' and 20' - 30' levels than at present; this is clearly shown by the terrace which is 30' above river level at the junction with the Mersey, but only 19' above at a point half a mile upstream. By contrast the 40' terrace of the Mersey is constant for half a mile and the 33' - 35' terrace rises only about 2' in almost one mile.

At the close of the glaciation the Arm was left as a hanging valley perhaps 60' above the Mersey and the 120' and 110' terraces show it to have had a shallow gradient near the junction. However, as the Mersey cut quickly down through the till since the Pleistocene the Arm had to erode its quartzite floor and has produced a 60' gorge with waterfalls and rapids just above the Arm bridge. In the zone at the Mersey-Arm junction there is a complex set of terraces shown in fig. 7 but no attempt has been made to interpret these.

A study of the river terraces reveals something of the history of the area since the Pleistocene and although the picture is by no means clear, the following interpretation seems likely.

The high level rock-cut terraces are probably post-glacial as they occur in unprotected positions in areas which were clearly covered by ice and yet retain a cover of water-worn pebbles. It is possible that the valley contained till up to the 400' level and that the river meandered across this as it cut down in post-glacial times. Under these circumstances the meanders might cut nicks in the side of the valley wall in various places. This explanation requires a long period of active meandering and down-cutting and a great thickness of till in the valley.

It seems more likely that the flats were cut by meltwater streams flowing along a depression at the contact of the glacier with the valley wall. These periglacial streams would be quite active. The varves in the Fish River were probably deposited in a lake dammed by the Mersey glacier at this time.

After the disappearance of the ice from this stretch of the river the Mersey proceeded to cut steadily down through at least 75' of till. This indicates a gradual alleviation of the climate and as the river showed no tendency to cut a gorge through the soft till it seems that there was neither a sudden release of meltwater nor a period of excessive rainfall.

The river has since cut a series of meander terraces as it swung from side to side, occupying progressively less and less of the valley floor. There was a slight change at the 55' level but the only distinct break in the river's history was at the 30 - 40' level. The river had been held up by two local base levels (shown in fig. 7) and had meandered behind them, but rejuvenation led to a straightening of the course and a rapid downcutting. The series of terraces in 5' steps from 0 to 30' is probably related to the removal of local base levels further downstream.

It is unlikely that changes in sea level either during or after glaciation would affect the river near its headwaters at a distance of 40 miles from the sea and 1600' altitude, and it seems that any rejuvenation must be related to increased rainfall as there is no possibility of any major river capture further upstream.

Gill (1955) has summarized evidence for climatic changes in Victoria during Recent times and this is shown in p. 30. Although there is not necessarily any close relation between the climates of Victoria and Tasmania during this time, the Mersey terraces are placed in their approximate time positions. If the correlation is correct, the period from the 75' to the 55' terrace would correspond to the gradually warming up from glaciation to the Post-glacial Thermal Maximum and this seems a reasonable fit. The rejuvenation at 30' would be associated with increased rainfall after the dry Thermal Maximum leading up to the Little Ice Age. The reconstruction here will not be clear until the history of the lower part of the river and the sequence of eustatic changes of the coastline are determined. One should not overlook the possibility of rejuvenation of the rivers due to isostatic recoil of the area following the removal of a large ice cap. Daly (1938)

029 stated that this recoil had only been recorded for ice caps at least 300 miles across and 3,300' thick whereas this ice cap would have been much smaller.

Figure 7.

	WORLD CLIMATE	SOUTH-EAST AUSTRALIA	MERSEY TERRACE HEIGHTS		
0 yrs.	(Drier)		0, 5		
1000 yrs.	Warming		10		
2000 yrs.			15	Group IV	
		Maribyrnong terrace formation	20		
3000 yrs.	"Little Ice Age" (Wetter)	Higher lake levels	25		
4000 yrs.			30		
		Dry lakes			
5000 yrs.	Post-glacial Thermal Maximum (Drier)	Loess formation	35	Marked Rejuvenation	
		Higher sea level	40	Group III	
6000 yrs.		River terrace oxidation			
			45		Period of abundant
7000 yrs.			55		
8000 yrs.	Warming		60		
9000 yrs.		Keilor terrace formation	65	Group II	rainfall, meandering
		Lower sea levels			
10000 yrs.	Glaciation (Wetter)	Higher lake levels	75		and steady erosion.

A possible correlation of the Mersey terraces with rainfall changes following the climatic reconstruction of Gill, 1955.

GEOMORPHIC EVOLUTION

By the end of the Mesozoic Era, following intrusion of dolerite during the Jurassic Period and denudation during the Cretaceous Period it seems likely that the West-North-West trending Tiers were breached in this area by the north-flowing Mersey River. By both fluviatile action and pediment erosion, the Tiers retreated towards the west and east leaving an embayment. The softer Permian sediments were stripped off easily where not protected by the dolerite and the rivers eroded this material until the underlying harder Precambrian sediments were reached. Thus by the early Tertiary (perhaps Oligocene) a mature river system had been developed within this Mersey-Forth embayment. The surface owed its form partly to the stripped pre-Permian surface. The dolerite of the February Plains stood above this level to the west and that of the Plateau to the east. The ancient Mersey occupied a channel cut through this surface. The channel is not recognisable at Howell's Plains, but where it is exposed in the Arm, it is 400' deep and at Gad's Hill possibly 6-800'. The Forth was quite probably a tributary which joined the Mersey near Gisbourne's Hut.

In the early Tertiary the basalts were poured out along the valley line, filling the valley and then covering the adjacent flatter landscape. The occurrence of a several hundred-feet thick layer of coarse breccia and tuff on the floor of the buried valley suggests that the centre of volcanism may have been located somewhere between Gisbourne's Hut and Liena and that the lava flowed upstream towards Howell's Plains as well as downstream. This is supported by the fact that no source was found in the Howell's Plains area. Fig 8 shows the probable variation within the volcanics along the old Mersey valley.

The Mersey became displaced by the basalt and cut a channel along its eastern margi-n thus taking up its present position. The Forth became a large river along the western boundary of the basalt. The Tiers of Western Bluff at this time would have been immediately east of the Mersey. Since the extrusion of the basalt, the following have occurred:

(a) the Forth has cut a valley 2000' deeper,

(b) The Mersey has cut out a valley 1600' deeper,

(c) the Arm has appeared,

(d) the Tiers south of Western Bluff have retreated 3 miles exposing a pre-Permian surface which is not covered by basalt,

(e) during the Pleistocene the valleys were smoothed and deepened possibly as much as 200'. The interfluves were possibly a little eroded but were more likely positions of deposition and possibly 100' of till was deposited on Magg's Mount.

STRATIGRAPHY

SUMMARY

Beneath a widespread blanket of Pleistocene drift the area is underlain by a thick sequence of metamorphosed sediments of Precambrian age. These are overlain unconformably by very thin subhorizontal Permian sediments which have been intruded by a sill of Jurassic Dolerite. Tertiary volcanics occur above these rocks in a discontinuous meridional strip running through the centre of the area.

PRECAMBRIAN ROCKS

Within the restricted area there is approximately 14000' of quartzites, mica schists, (some with garnet or albite) phyllites and slates. The structural thicknesses as measured at the present time may be many times greater than the stratigraphic thickness due to pronounced thickening during folding. Exposures are poor so that the detailed structure cannot be determined and as the stratigraphy must follow the structure (not vice versa as in most structurally simpler rocks), it is not possible to unequivocably find the stratigraphic sequences. One structural peculiarity which causes considerable difficulty, is the lack of repetition of beds on the opposite limbs of major folds. As the sequences on the northern and southern limbs of the Mersey Syncline are quite different one must presume that there has been strike-faulting; there is no way of knowing whether either of the sequences is complete.

The best that can be done at present is to recognize the existence of separate groups possessing characteristic lithologies and to attempt to put these in their correct order. It must be emphasised that differences in the apparent degree of metamorphism of two rock-types (e.g. garnet-schist and slate) does not necessarily mean that the more altered one is older and separated from the less altered by an unconformity.

Howell Group

This group is probably the oldest in the area investigated although the stratigraphic position is rendered obscure by faulting. It probably exceeds 5000' in thickness and consists of mica schists, garnet-mica schists, albite-mica schists, mica-quartzites and pure quartzites. These all show pronounced evidence of regional metamorphism. The type locality from the formation is along the western wall of the Mersey valley at Howell's Plains. It also occurs along the southern end of the track to the Pelion Wolfram Mine on the Forth river.

Fisher Group

This group probably lies above the Howell Group and lies below the Arm Schist. It exceeds 5000' in thickness and consists of interbedded formations of slate and of dominant quartzite averaging about 1000' thick. The type locality is the western side of the Mersey River between the Fisher River and a point half a mile north of the Arm River. The group is well exposed on the Forth River for several miles south of Gisbourne's Hut.

The slates have a very characteristic appearance being black with thin (¼") bands of light quartzite showing contortion and possessing a moderately well-developed cleavage oblique to the bedding.

The major quartzites are massive and pure, and show well-preserved ripple marks and even cross-bedding.

Arm Schist

There is about 2000' of muscovite, garnet and albite schist with minor quartzites occurring at the Mersey-Arm junction and lying above the Fisher Group and below the

Mersey Quartzite. This formation is probably represented on the other side of the Mersey Syncline by the garnet and albite schists occurring along the western side of the motor track half to one mile south of the Hydrographic Hut on the Mersey River.

Mersey Quartzite

Massive to well-bedded quartzites occur in the centre of the Mersey Syncline and are exposed along the Mersey River motor track for one mile north of the Hydrographic Hut. The formation overlies the Arm Schist and thus is the youngest found in this area. Folding in the axial zone of the Syncline makes the measurement of the thickness of the quartzite quite impossible but there is probably in the order of 2000' exposed.

The quartzite is generally massive and thickly bedded but some species are vitreous, saccharoidal, ripple-marked, laminated, schistose or lineated. Tourmaline needles along the bedding-schistosity of one specimen give an appearance similar to that of the Raglan Quartzite (Spry, 1955).

Dove Schist

There are dull-green mica schists on the Forth River just south of the Dove-Forth intersection and these are correlated with about 5000' of garnet and mica schist exposed along the Mersey Forestry Road extending north of a point about half a mile north of the Mersey-Fisher junction. From their structural position on the flank of the Fisher Anticline, lying below the Lower Palaeozoic strata, this could be the youngest formation in the area.

The following correlation with the Frenchman's Cap area is tentatively advanced although no confidence can be placed in it at present.

Mersey Area	Frenchman's Cap	
	Fincham Group	
Dove Schist	Cardigan Schists	Franklin Group
Mersey Quartzite	Raglan Quartzite	Franklin Group
Arm Schist & Quartzite	Basal Schist	Franklin Group
Fisher Group	Mary Group	
Howell Schist & Quartzite	Joyce Group	

LOWER TO MIDDLE PALAEOZOIC ROCKS

Although not represented in this area there are Cambrian (Dundas Group), Ordovician (Owen Conglomerate, quartzite, Gordon Limestone) and Devonian (Dalcoath Granite) rocks to the north around Lorinna, Liena and Mole Creek.

Devonian (?) granite intrudes the Precambrian rocks along the Forth River towards the Pelion Wolfram Mine.

PERMIAN SYSTEM.

1. Forth Section

A total of 250' only of Permian rocks overlie the Precambrian unconformably along the upper slopes of the Forth River, west of the February Plains. The Permian is poorly exposed but sections are visible in some of the steep creeks which flow down from the February Plains into the Forth. The lithology of this basal Permian is quite unusual when compared with exposures elsewhere in Tasmania, although it is typical of the area between Western Bluff and Cradle Mountain. Apart from a general induration due to the Jurassic Dolerite which has intruded just above the rocks, they are characterised by their white colour, well rounded pebbles with depressions due to percussion , or solution and lack of fossils.

The basal conglomerate is 50' thick and contains well-rounded quartzite and schist pebbles up to 3" across in a white sand-silt matrix. Towards the base there are beds of sandstone one foot thick and at the top the proportion of matrix decreases and the rock is a typical quartz conglomerate.

The conglomerate passes upwards into a light-grey micaceous sandstone 120' thick which weathers to a red colour.

This passes upwards into a light-grey, shaley, micaceous siltstone 40' thick which becomes sandy and pebbly and passes into a buff pebbly sandstone. The last formation is only visible for a few feet as Jurassic dolerite has intruded at this level.

2. Arm Section

There are Permian rocks exposed in the bed of the southernmost tributary of the Arm from the west. It is very probable that Permian sediments occur along the western side of the Arm valley where it shows a series of distinct benches but the whole is covered with a persistent layer of Pleistocene till.

The lowest bed appears at an altitude of 2320' and is a buff coloured sandstone, with streaky grey irregular bedding and abundant rounded pebbles, usually 1" across. It is massive to flaggy in outcrop. After 10' of this the rock becomes less pebbly for 10' then the next 10' is much more pebbly and fossiliferous. There are pectens (up to 3" across), spirifers and martiniopsids.

The next bed is 30' thick and is tillite with abundant boulders in a sandy matrix.

This is followed by 10' of "Fontainbleu" sandstone with scattered pebbles. It is a medium-grey greywacke sandstone with large glittering plates of calcite and is described in detail on page 57.

The last bed begins at 2390' but outcrops cease after a few feet until dolerite appears at 2600'. The last bed is a tillitic greywacke which is dark grey and very massive with abundant large boulders up to 4' across.

JURASSIC SYSTEM

The Jurassic Period was one of intrusion, and the thick dolerite sill of the February Plains intrudes the Permian strata only about 250' above the base. The dolerite has been eroded towards the north, but at Mt. Oakleigh is thick.

TERTIARY SYSTEM

The rocks found during this period are almost entirely volcanic in origin, the only exception being a small patch of fluviatile breccia on the northern end of Magg's Mount at 2415' altitude.

There is about 10' of this breccia visible but it may extend for 50' - 100' up the hill. It is horizontal and rests with marked unconformity on the eroded surface of the steeply dipping Precambrian quartzites. The lowest 2' is sandy and well cemented with abundant angular boulders up to 3" across. The rock is poorly sorted. This grades upwards into a bed with abundant rounded and angular boulders in a sandy matrix. Many of the boulders stand on their ends.

The volcanic rocks may be divided into two main parts. The lowest portion exposed only in the bottom of the buried valley between the Arm and Forth Rivers consists of coarse volcanic breccia (with bombs and fragments up to 3' across, although commonly not exceeding 6") with vitric tuffs and some white clays. This reaches 400-440' in thickness in the

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Forth Valley.

Overlying this is between 400 and 440' of basalt being composed of at least ten flows.

The section in the Arm valley contains more basalt (600'?) and the pyroclasts consist only of tuff probably only 100' or so in thickness.

PLEISTOCENE EPOCH

The rocks formed at this time were all glacial. Much of the landscape is covered by a layer of till which is probably normally not more than 20' thick but reaches 50' in places and would certainly be 120' in parts of the Arm, Fish and Mersey Valleys.

There is at least 10' of varved clay in the Arm valley and probably more in the Forth valley. At the bridge near the Dove Mill, on the Forth river, varves 20' thick cover the Precambrian rocks and further downstream, about three miles south of Lorinna the varves occur in a road cutting about 150' above the present river.

In the Arm River there is about 3' of varve forming a layer within a thick till which is overlain upstream by the main thickness of varves.

STRUCTURE

REGIONAL STRUCTURE (See figs. 9,10, 11)

The regional structure here, is similar to that shown near Deloraine, Tullah and Frenchman's Cap i.e. around the edge of the Precambrian nucleus. The Precambrian rocks are regionally metamorphosed and show a pronounced bedding-plane schistosity and a lineation which is parallel to the axes of broad folds. The axes of these folds are parallel to those in the overlying lower Palaeozoic sediments which are generally unmetamorphosed. An angular unconformity between the Precambrian and Palaeozoic rocks does not occur in most places despite the fact that there was a period of considerable metamorphism and deformation before the deposition of the Dundas Group.

The Cambrian is missing against the nucleus and a sandstone facies of the Ordovician overlies the Precambrian and is followed by the Ordovician Gordon Limestone. In this area (as near Tullah) there is a granite with a lithology similar to the Devonian granites, intruded along the unconformity between Precambrian and Ordovician.

The Lower Palaeozoics are folded with the same trend as the Precambrian. In the core of the first major anticline away from the nucleus, thick Cambrian sediments and volcanics of the Dundas Group occur and in this zone the lowest Ordovician is represented by a very thick Owen Conglomerate. The lower Palaeozoics here are strongly deformed and tend to be over-folded and thrust towards the Precambrian nucleus.

The similarity in dip of the Precambrian and Lower Palaeozoic rocks across the unconformity and the parallelism of the fold axes in rocks of both ages indicates that the major part of the folding in the Precambrian occurred simultaneously with that in the Palaeozoics during the Tabberabberan Orogeny.

The Precambrian rocks are regionally metamorphosed and thus there was a period of metamorphism and orogeny before the Palaeozoic. Before the Tabberabberan orogeny, the Precambrian rocks would have been subhorizontal with a schistosity parallel to the bedding and a pronounced lineation parallel to broad folds which were increased in amplitude during the Tabberabberan.

The faulting is closely related in direction to the fold axes and the major faults are probably high-angle reverse types with minor transcurrents.

Folds

The major structure in the Precambrian rocks is a synclinorium which plunges at about 20° in a direction 100° and this is named the Mersey Syncline. There is a major anticline (named the Fisher Anticline) which has a faulted axis running parallel to that of the Mersey Syncline and which crosses the Mersey River about half a mile north of its junction with the Fisher. The general synclinal form is complicated by minor folds of all sizes and these may be grouped in the following way. The synclinorium is the first order fold about ten miles in wavelength. There are second order folds about a quarter of a mile across. Third order folds about 10 to 100 yards across are quite common. The fourth order folds are small, apparently incongruent

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flow folds looking like strongly distorted drags about one foot across. The fifth order is represented by fine crenulations which extend down to microscopic dimensions.

The thick, massive quartzites usually show only first and second order folds and one example of the second order occurs about half a mile north of the Arm-Mersey junction; the thin quartzites and interbedded quartzites with slate or schist show second, third and fourth order. Third order folds are common in the Mersey Quartzite north of the Hydro-Electric Commission hut. Fourth order folds are excellently shown by schist and thin quartzite of the Howell Group half a mile south of the Hydro-Electric Commission Mersey hut; fifth order folds are best shown by the slates of the Fisher Group and schists of the Dove and Howell Group.

Foliation

The Precambrian rocks have been recrystallized during a period of regional metamorphism characterised by very strong penetrative deformation which has impressed a strong schistosity on most rocks. It is, of course, less apparent in the quartzites which lack mica and is best developed in the slates and schists.

There are several completely different types recognizable and many of the rocks show two foliations. Most prominent is the schistosity which is parallel to the original bedding planes; this is produced by parallel muscovite flakes. There is considerable evidence in the schists that this is a direction of slip.

Many schists and quartzites show a second, poorly developed cleavage at about 30° to the bedding. This is due to the growth of late biotite and chlorite.

A third type of cleavage is developed at varying angles to the bedding in the slates of the Fisher Group. This is a "false" cleavage due to attenuation and close packing of the limbs of tiny asymmetrical folds where the bedding plane foliation has been crenulated.

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Lineation

Lineation is well developed in most rocks, but particularly in the schists and quartzites of the Howell Group. It occurs as a streakiness of mica flakes on the schistosity plane, as a ribbing in quartzites or as a crenulation and is parallel to the fold axes of third order folds. The Arm schist about half a mile south of the Hydro-Electric Commission hut, right on the track, shows a broad crenulation parallel to the axes of third order folds together with a fine crenulation perpendicular to the axes.

The lineation commonly strikes parallel to the axis of the main fold but plunges flatly in the opposite direction i.e. the fold plunges 20° towards 100° but the lineation is commonly plunging 30° towards 280°.

Faults

Three distinct sets of faults have been tentatively identified:

(a) Major Precambrian, or Tabberabberan high-angle reverse(?) fault system trending at 280°.

(b) Minor sets of Precambrian or Tabberabberan transcurrent faults trending at 315°.

(c) Possible set of Tertiary faults trending at 340°.

(a) It was seen here that the rocks on the opposite limbs of the major folds differed in character, particularly in the case of the Fisher Anticline. This has been repeatedly observed in many areas of Precambrian rocks in Tasmania and has been interpreted in the Frenchman's Cap area by Spry (1955) as being due to high-angle thrust faulting of large magnitude along the fold axes. If this is also true in this area, then there is a large fault striking at 275° half a mile north of the Mersey-Fisher junction. As there is a much larger width of outcrop of the Mersey Quartzite north of the major synclinal axis than there is to the south, it seems that a similar fault has removed part of the southern limb of the

Mersey Syncline. On the northern limb of the Mersey syncline, the Fisher Group underlies the Arm Schist, but on the southern limb, the Howell Group lies below the Arm Schist.

Various explanations are possible e.g.

(1) The Howell lies between the Arm and the Fisher but has been faulted out on the north limb,

(2) The Fisher lies between the Howell and the Arm and has been faulted out on the south limb,

(3) The Howell and the Fisher are equivalent.

Of these, the second alternative is preferred. The third is unlikely because, as is shown in the petrology and stratigraphy sections, there are very great differences between the Fisher and Howell Groups, and it is extremely unlikely that they are equivalent.

The first is unlikely because the swing in strike of the Fisher-Arm contact between the Mersey and Forth Rivers makes faulting unlikely. These faults do not displace overlying Permian strata and are closely related in direction to folds in the Precambrian rocks and thus would be either Precambrian or Tabberabberan in age.

(b) The Fisher Group rocks on the east side of the Forth valley, a mile south-west of Gisbourne's Hut appear to be cut by several faults trending at 315°. These cause considerable drag in a horizontal direction and are thus interpreted as transcurrent faults. Although it is not proven, it appears that the base of the Arm Schist is twice displaced for half a mile by these faults, but this cannot be proved at present because of the difficulty in locating the boundary between the Arm Schist and the Fisher Group.

(c) The dolerite of the February Plains, like that of the Plateau, is traversed by a prominent system of fractures which are clearly visible on the air photos. It was not possible to view these in the field but from their persistence and great length (8 miles maximum) it seems unlikely that they are merely tensional joints. The physiographic expression is simply a shallow, linear depression with no apparent topographic displacement or fault scarp. No displacement of the Permian sediments is visible on the air photos. It seems possible that they are Tertiary faults of very small throw but this could be verified by field observations where they cross the Permian rocks beneath the dolerite. They may well be persistent Tertiary shear joints with very slight horizontal movement.

Joints

Some Tertiary basalts show columnar jointing which may be divided into two types:

(a) Normal, thick (2' across), hexagonal columns which are vertical and have parallel sides and regular cross-jointing which may be planar or ball and socket.

(b) Twisted, narrow (6" - 1') columns which vary considerably in attitude and which do not have parallel sides, being fluted and irregular.

The Jurassic dolerite and Permian strata show prismatic joints but no special observations were made.

Apart from the possible shear joints mentioned above, the dolerite shows prominent joints on the air photos and these trend at 310° and 350°.

The Precambrian rocks are well jointed in many directions but it was not possible to find much regularity. The small folds in the quartzites frequently show perfect joints normal to the fold axis ("ac") or vertical joints symmetrically disposed to the axial plane as shown in fig.

The quartzites particularly show as many as five different joint directions in a single outcrop and there did not appear to be any regional joint pattern.

Joints are closely spaced in some quartzites but are broadly separated in many schists, slates and massive quartzites.

PETROLOGY

The chief petrographic characteristics of the rocks met in this area are summarized and criteria given for recognizing various types. Extensive petrological investigation of the genesis of these rocks is not particularly relevant to this investigation and so is not given here, but is being carried out as part of the normal research programme of the Geology Department of the University of Tasmania. The specimen numbers given in this section are those in the collection of the University.

PRECAMBRIAN ROCKS

These are regionally metamorphosed sediments, originally chiefly arenites and pelites, which have suffered considerable deformation. The members of the Howell Group, Dove Schist, Arm Schist and Mersey Quartzite belong to the garnet zone but the slates of the Fisher would belong to the chlorite zone.

Howell Group

This is a sequence of schists and quartzites. The schists are generally coarse and glossy, and rich in muscovite with knots of garnet and albite. There is a good bedding-plane-schistosity with an irregularly developed fracture cleavage at about 30°. Lineation is well shown in some speciments. Typical examples are: 7386, 7387, 7388, 7399, 7408.

Specimen 7408 is a glossy, contorted schist with a lineation rather than a schistosity. In thin section it is coarse grained and consists of quartz and muscovite with about 10% of albite and a little biotite and accessory zircon and tourmaline. No. 7387 is coarse and platy with some knots but no lineation. It differs from the previous specimen in containing more albite (large poikiloblastic porphyroblasts with Carlsbad twinning), some chlorite and accessory rutile, apatite and zircon.

Specimen 7388 is an excellent example of these schists. It is an albite-rich, quartz, garnet, muscovite schist with much chlorite which has replaced garnet and possibly biotite. This shows slip planes at an angle to the major schistosity with quartz and chlorite growing along them.

The quartzites are rather fine grained rocks forming beds a hundred or so feet thick. They tend to be platy with thin bands of muscovite schist and are characterised by a strongly developed lineation.

Fisher Group

This group consists of alternations of quartzite and slate in beds about a thousand feet thick. Details of some quartzites from the Mersey are given as this rock would be the foundation and portal material for the tentative tunnel-lines C and D mentioned later.

The quartzites e.g. 7389, 7394 and 7405 are white, massive and thickly bedded with well developed ripple marks and even cross-bedding in some specimens. Despite the preservation of these sedimentary structures the rocks show evidence of complete internal reconstitution and deformation. The original coarse clastic quartz grains have been broken down in size giving the typical "mortar" texture of cataclasites i.e. large, xenoblastic or lenticular quartz grains showing undulose extinction and "Boehme" lamellae set in a fine grained matrix of regenerated quartz with a strong preferred orientation.

Specimen 7389 is a somewhat schistose quartzite with about 15% of albite and 10-15% of very fine muscovite.

Numbers 7394 and 7405, from the western bank of the Mersey River, about one mile south of its junction with the Fisher are characteristic examples. They are massive in the hand specimen with tiny white spots which are seen to be feldspar by examination under the microscope. The rocks are fine grained with a strongly crushed texture in which the quartz shows sutured margins. Most notable is the presence of about 20% of feldspar, microcline and albite (this is the first record of microcline in Precambrian rocks in Tasmania). The feldspars are quite rounded and show undulose extinction, bent twin planes, are clouded with inclusions and have a thin peripheral layer of muscovite flakes. These feldspars differ sufficiently from the metamorphic feldspar in the adjacent schists that it is not unlikely that it is original clastic feldspar. The preservation of such relics in a rock which contains recrystallized quartz has been recognised elsewhere many times. This fact is important because it means that the original sandstones were at least feldspathic and in some examples, arkosic.

The slates of the Fisher Group are lithologically distinctive and are the distinguishing feature of this group. The name "slate" is used to separate the rocks from the schists and phyllites of the area even though the term might not strictly be correct. The rocks are dark grey and fine grained with alternating pelitic and arenaceous layers averaging about ⅛" thick. The thin layers are puckered into tiny crenulations and there is a distinct cleavage, oblique to the bedding, visible in the hand specimen. Most examples are glossy and coarser than the average slate and might be better termed phyllites.

In thin section e.g. numbers 7406 and 7390 they are seen to be very fine grained rocks consisting chiefly of quartz and sericite with accessory zircon and iron ore. The cleavage is due to the presence of parallel mica laths and elongated quartz crystals and clearly transgress the alternating mica and quartz-rich layers which are the bedding.

<u>Arm Schist</u>

The garnet, mica and albite bearing schists of this group together with their schistose quartzites are sufficiently similar to those of the Howell Group as to warrant no further detailed description.

The quartzite specimens, 7397, 7400 and 7402 are described in detail as they are taken from the outcrops on the Mersey which form the dam-site and portal for the tentative tunnel lines A and B described later.

These quartzites are massive to slightly platy with a distinctive saccharoidal to glassy appearance and a moderate lineation.

In thin section the rock is moderately fine grained with an even texture and consists chiefly of quartz with a little fine-grained muscovite and biotite with no preferred orientation. Despite the outward massive appearance of the rock, the quartz is quite distinctively fractured. It does not show elongation, undulose extinction, Boehme lamellae or "mortar" texture of the other quartzites in the area, but the quartz grains are cut by a network of quite irregular cracks which are outlined by an extremely thin intergranular layer of opaque, presumably ferruginous material.

While the rock appears to be hard and strong it might be advisable to test it further if it is to be used as a foundation for a very heavy dam.

Mersey Quartzite.

This quartzite is generally thickly bedded but there are laminated and very massive varieties. Some specimens show glossy muscovite along the bedding which is a schistosity direction and some have a lineation across the schistosity. An outcrop about half a mile south of the Mersey-Arm hut shows tourmaline needles along the bedding and thus shows distinct similarities with the Raglan-Franklin Quartzite of the Frenchman's Cap area.

Specimen 7385 from just north of the Hydro-Electric commission hut on the Mersey is a white saccharoidal quartzite with feldspar visible as tiny white spots. It is a fine grained quartzite consisting chiefly of quartz but with about 10-15% of xenoblastic albite and some fine muscovite. The quartz shows a distinct preferred orientation with some elongation parallel to the schistosity marked by parallel muscovite flakes. The albite is lenticular to tabular in shape with the C-axis tending to be parallel to the schistosity.

Dove Schist

Although these rocks do not occur within the mapped area they outcrop well along the Forestry Road on the east side of the Mersey, north of its junction with the Fisher, and as they are petrologically interesting, a few of the characteristic features are described. Examples are 7362, 7366, 7368, 7370, 7371, 7372, 7378 and 7383.

This formation is a very thick mass of mica schist with garnet and albite in varying amounts and contains very little quartzite. Lithologically the rocks show a strong resemblance to the schists of the Howell Group.

Typical is 7370, a fine grained, dark grey, knotted, glossy schist. In thin section it is schistose with alternating thin layers rich in quartz and muscovite. Small porphyroblasts of garnet occur with larger ones of albite. There are sheafs and flakes of chlorite, much athwart the schistosity. Accessories are tourmaline and iron ore.

No. 7382 is an excellent example, and differs from 7370 in containing biotite, much of it growing along a second cleavage which is sporadically developed at about 35° to the major schistosity.

In no. 7372 and others, the bedding plane schistosity is crenulated and a second fracture cleavage is developed across the tightly squeezed limbs of the tiny folds.

Thermal Metamorphic Rocks

The Devonian granite intrudes along the unconformity between the Dove Schist and the Ordovician quartzite on the Mersey River and here some schist has been hornfelsed. These rocks clearly show the effects of thermal metamorphism superimposed upon regional e.g. 7384, 7377.

These are dense, reddish brown rocks with a vitreous lustre and a hackly fracture. A thin section shows the original compositional layering to be present but the schistosity has been obliterated by the random growth of large quartz, muscovite and biotite crystals. There are numerous round and prismatic masses of very fine sericite and these are clearly pinite pseudomorphs of some metamorphic mineral which from the form is presumed to be andalusite. As these pseudomorphs only appear immediately next to the granite, the andalusite would be a thermal not regional metamorphic mineral.

PERMIAN ROCKS

These are flat-lying, generally unmetamorphosed clastic sediments most of which have marine and glacial affinities. The basal rocks on the Forth River west of the February Plains are unusual and so will be described in some detail.

Specimen 7322 is from 50' above the base of the Permian in the Forth River and is a tough, massive, white non-friable sub-greywacke sandstone with mica flakes visible in the hand specimen. It is composed of 70% of quartz, 5% muscovite and a little biotite and iron ore and 25% of fine grained clay matrix which has been recrystallized by the adjacent dolerite to a mesh of interlocking flakes. The quartz grains average 25 mm. in diameter and are angular but with a medium to high sphericity. The muscovite flakes range up to .5 mm.

The matrix of the underlying conglomerate is very similar and this rock has also been baked by the overlying dolerite sill which is only 200' away. The conglomerate is characterized by containing abundant well rounded quartzite and schist pebbles with a high sphericity. The quartzite pebbles are peculiar in that a high proportion of them show small circular depressions about 1 cm. across, on their smooth surfaces. These depressions were also found in pebbles from this horizon below Western Bluff, about 10 miles to the north-east.

The Permian beds in the south-western portion of the Arm valley are tabulated elsewhere but one particular rock is distinctive and is described in detail here.

Specimen 7361 is a light grey sandstone with a calcite cement which forms crystals over a centimetre across enveloping the clastic grains, and which reflect the light giving bright flashes. It is composed of angular fragments between .2 mm. and .5 mm. across of quartz (50%) plagioclase (10%) muscovite flakes and rock fragments (slate 10%, schist 10%, chert and basaltic rocks) with a calcite cement comprising 15% of the rock. The plagioclase is an acid andesine such as would be derived from the Devonian granites and some grains have been partly or wholly replaced by authigenic calcite. The calcite enclosed the grains with a seive structure and apparently has completely replaced an original clay matrix. The apparently high degree of sorting is due to the replacement and disappearance of the smaller particles. The rock is a sub-greywacke with a structure somewhat like that of a Fontainbleu Sandstone due to the addition of calcite by the adjacent dolerite.

Metamorphism of the Permian Rocks

The intrusion of the Jurassic dolerite has caused some slight alteration to the sediments close to the contact. The rocks are hardened and in some cases the clay cement has been recrystallized to a fine mesh of illite (?) or there has been a metamosomatic addition of calcite to cement and replace the clay matrix.

TERTIARY VOLCANICS

The volcanic rocks are chiefly basalts with pyroclastics occurring in the north-east of the area.

Pyroclastics

The thickest (400'?) pyroclastic is a very coarse volcanic breccia which outcrops from 2000' to 2400' on the eastern side of the Forth River just below the Berriedale Plains and one mile north-east of Gisbourne's Hut. It is the movement of this material which resulted in the landslides mentioned on p. 75 and the instability of the breccia is due to

(a) low cohesion,

(b) high permeability, allowing lubrication by surface waters,

(c) chemical instability, causing weathering to clay.

The breccia contains blocks and bombs of basalt and tachylyte up to 3' across, with the majority being about 6" in diameter. Many of the fragments are scoriaceous and the rock is loosely compacted and partially cemented with zeolite.

This breccia occurs on both the east and west sides of Gad's Hill on the road from Liena to Lorinna and appears to be confined to the centre of the pre-basaltic river valley.

Further up this valley, where it intersects the northern side of the Arm, the pyroclastics are thinner and finer grained, and on Magg's Hill they seem to be absent beneath the basalt, as shown in fig. -

The tachylyte tuff 7411, from the north side of the Arm, is rather weathered, with dark glassy fragments in a clay-rich cement. A thin section shows that the particles are tachylyte containing crystallites cemented by opal, calcite and a ferruginous weathering product.

Basalts

The basalts occur as flows varying from about 25' to 150' in thickness and reach a maximum thickness of 350' and possibly 400' on the Berriedale Plains. They vary from dark grey to black in colour when fresh but become light grey and brown when weathered. Most are fine grained and massive but some are completely scoriaceous and others are massive with a scoriaceous top. Jointing is chiefly in a rectangular primatic form but a few flows show a platy flow structure; some have regular hexagonal prisms about 18" across. One variety which occurs in situ on the southern end of Magg's Mount and as large masses on the top and sides of Magg's Mount shows a strong development of curved and twisted columns from 6" to 12" across, with the columns commonly horizontal.

From a petrological examination of thirty thin sections it appears that there are four chief types. The specimens were collected by traversing up the steep creeks which cut the sides of the Forth, Arm and Mersey valleys. Twelve specimens were collected up the creek which passes from the Berriedale Plain into the Forth River, one mile north of Gisbourne's Hut; nine were taken up the creek from the Berriedale Plain into the Arm River one mile north of the northern hut on the Arm Plains; seven were collected up the slope on the northern end of Magg's Mount.

The most common variety is a porphyritic olivine basalt with black "glass" e.g. 7353, 7350, 7340, 7332, 7327, 7335, 7354, 7342, 7356, 7346. This type has olivine phenocrysts (5% - 20%) averaging 1.5 mm. across, but ranging from .5 mm. to 2.5 mm., in a fine grained groundmass of pyroxene, plagioclase and black "glass", showing intergranular structure or a parallel flow structure e.g. 7332. There is generally 5% of brown and green or even orange opal and some calcite and chalcedony either as amygdale fillings or as intergranular patches. The olivine is almost invariably partially or wholly pseudomorphed by a brown carbonate which has the optical properties of calcite. The proportions of pyroxene and plagioclase vary, depending on the amount of glass present, but they each constitue from 30 - 50% with the pyroxene in excess of plagioclase. The plagioclase usually forms small laths about .2 mm. long but may form phenocrysts up to 2 mm. across; it shows twinning on the Albite and Albite plus Carlsbad laws and is labradorite varying in composition from Ab_{42} to Ab_{50}. The pyroxene is pale green to colourless with a low 2V around 35° is generally from .05 to 2 mm. across, but reaches 2.5 mm.

The black "glass fills the intergranular spaces and consists chiefly of tiny closely packed granules and rods of opaque iron oxide. Between this is visible in some rocks a green isotopic material, presumably glass e.g. 7340, in others is a dense aggregage of tiny pyroxene microlites and in others e.g. 7357 there are crystallites of plagioclase and pyroxene.

The second type is the porphyritic olivine basalt without glass e.g. 7358, 7333, 7329. These differ chiefly from the previous group in lacking the black glass, but in addition appear to contain a little less olivine (10%) which is generally unaltered and flow structure is more abundant.

The third type is the semi-ophitic basalt e.g. 7325, 7409, 7355, 7339, 7326 and 7341. These rocks are rather fine grained with phenocrysts of olivine in a groundmass of pyroxene, plagioclase, a little glass, opal and calcite. Pyroxene is abundant (up to 60%) and forms crystals from .2 to 1.2 mm. across or aggregates of granules up to 2 mm. across enclosing laths .2 mm. long of plagioclase in an ophitic manner. The plagioclase usually does not exceed 35% and forms small crystals with sporadic phenocrysts up to 2 mm. long. The pyroxene is pale green to colourless and is characterized by having a low 2V, measurements ranging from 30° in 7339 to 40° in 7355. Olivine phenocrysts (5 - 20%) range up to 1.5 mm. across and are mostly fresh with some alteration to carbonate or opal in a few specimens. One example (7325) contains up to 15% of brown opal; another (7339) contains yellow and green opal, chalcedony and dark glass; 7355 shows amygdales with a lining of opal and a core of calcite and contains black "glass".

The fourth type is a glomeroporphyritic basalt e.g. 7343, 7345, 7332, 7344. These are glomerophorphyritic in texture with large (3.5 mm.) aggregates of pyroxene crystals (.5 mm. across) and phenocrysts of plagioclase (up to 3 mm.) in a holocrystalline, groundmass of pyroxene and plagioclase. Olivine is generally not present but there is a very little, completely altered olivine in some specimens. Glass is lacking and there is usually about 10% of brown opal or chalcedony. Amygdales (e.g. 7345) have a rim of opal and a centre of calcite. The plagioclase ranges in composition from labradorite Ab_{45} - Ab_{32}.

The distinguishing characteristics of the four groups are summarized below:

	I	II	III	IV
Texture	Intergranular and Porphyritic		Semi-ophitic	Glomeroporphyritic
Olivine	Common		Common	Olivine lacking
Alteration	Olivine altered to Carbonate		Olivine fresh	
Glass	Black	Lacking	Brown to black	Lacking

One of the purposes of the petrological examination was to endeavour to correlate flows between the Forth, Arm and Mersey Rivers, and this has been found possible to a certain extent. The highest flow (2780' - 2810') of the Forth section is similar to the highest (2820') of the Arm section in that they are porphyritic, olivine basalts but the Forth rocks contain up to

10% glass whereas the Arm rock has none.

The next specimen (2760' Forth, 2780' Arm and 2765' Magg's Mount where it is the highest flow) are all semi-ophitic basalts and thus could be the same flow.

Beneath these in the three sections are porphyritic olivine basalts. No. 7333 at 2700' on the Forth lacks glass but otherwise all are similar and we may correlate the specimens on the Forth ranging from 2700' down to 2500' with those on the Arm at similar heights and on Magg's Mount with rocks collected at 2765, 2740 and 2710 feet (lack of outcrop prevented collection of specimens just below this).

The porphyritic olivine basalt at 2500' on the Forth may be correlated with the lowest flow found, at 2525', on Magg's Mount.

The lowest flows before the underlying basement or breccia is met, on the Forth section, are glomeroporphyritic, and outcrop at 2490' and 2460'. These are below the base of the basalts on Magg's Mount, but there is at least 50' of glomeroporphyritic basalt (no. 7345) on the Arm section at about 2500'.

A lower porphyritic olivine basalt (no. 7352) occurs in the Arm section at about 2300' and is the lowest found.

Lack of definite correlation is due to the fact that all individual flows could not be recognized and sampled in each area, and all that was done was to collect from every flow recognized, or at 50' vertical intervals, which ever was the less distance. Differences in height between specimens collected from one flow at different localities is probably due to sampling at different levels in thick flows.

As far as can be determined, the flows are horizontal as the contact between the upper two flows is at 2770' at the Forth and 2760' at Magg's Mount, four miles away. This suggests a very slight descent to the south implying that the lavas may have flowed upstream, but the difference is of the same order as the error in height determination by barometer and thus is not regarded as being significant.

There is a similar difference between the similar lavas at the Forth River (2500') and Magg's Mount (2525').

The following general sequence holds quite well for the three sections:

50' glomeroporphyritic basalt	(top)
250' porphyritic olivine basalt	
20 semi-ophitic basalt	
60' porphyritic olivine basalt	(base)

PLEISTOCENE TILL

Introduction

The following investigation was carried out on a specimen of till taken from the 40' high river terrace on the western bank of the Mersey, half a mile north of the Hydro-Electric Commission hydrographic hut and 15' above river level. The till is variable and this specimen may not be characteristic of all the till although it was chosed as a typical specimen. The sediment is tough and well consolidated; it lacks bedding and comparatively speaking is not friable. The reference to toughness and non-friability are comparative as the rock is well lithified for Pleistocene material and is tougher than most Tertiary sediments but is inferior to most unweathered Permian and Triassic sediments.

The till consists of pebbles of all sizes (up to many feet in diameter) commonly several inches across, set in a matrix of sand and silt. Both the cumulative curve and the histogram indicate it to be very poorly sorted. The first and third quartiles are spread over 6.24 Wentworth grades. The histogram is bimodal and there is very little clay and silt present. The larger particles are of dolerite with a little quartzite; the sand size is of fine grained dolerite, quartz, pyroxene and feldspar and the silt of quartz, pyroxene and plagioclase. The particles are fresh and unweathered, and of low roundness and sphericity.

The mechanical analysis was carried out by using seives and the pipette method on the dis-aggregated material.

Analysis of the Individual Fractions

Each of the fractions was analysed under the binocular microscope as far as possible. In the fractions with the grain size greater than 0.5 mm. the material consisted of rock fragments while those with grain sizes less than 0.5 mm. were composed mainly of individual crystals. In all cases in which the fragments were crystal aggregates dolerite was the main rock type (usually about 70%). The rest consisted mainly of quartzites with an occasional fragment of mica schist. In the finer fractions pyroxene (augite and pigeonite) made up about half the total while the rest was composed of feldspar (plagioclase) and quartz with a little magnetite and muscovite. The rock fragments are usually angular to sub-rounded with the sub-angular fragments predominating. Some pebbles had distinct flat surfaces (facets?) while there were several dolerite pebbles which were flat slivers.

Due to the difficulty in recognizing the different minerals in the fractions with grain size less than 0.5 mm., it was necessary to carry out a heavy mineral separation using bromoform and then examining the individual fractions.

Size	No. of particles examined	Composition, Roundness
+1"	6	Dolerite, 1 very well rounded, 1 sub-rounded, 4 angular.
-1 + ¾"	6	angular dolerite (67%)
	2	angular quartz-mica schist (22%)
	1	angular quartzite (11%)

Size	No. of particles examined	Composition, Roundness
-½" + ⅜"	56	angular to sub-angular dolerite (71%)
	22	angular, white and grey quartzite (28%)
	1	sub-angular, quartz schist
-⅜" + ¼"	200	angular-sub-rounded dolerite (71%)
	74	angular quartzite (27%)
	3	quartz mica schist (1%)
	3	angular basalt (1%)
-6.35 mm. + 4.72 mm.	145	angular-sub-angular dolerite (few basalt?) (70%)
	59	angular quartzite (27%)
	6	quartz muscovite schist (3%)
-4.72 mm. + 2.06 mm.	358	angular-sub-rounded dolerite fragments (75%)
	108	white, pink, grey angular quartzite fragments (23%)
	10	quartz muscovite schist - usually cleavage flakes (2%)
-2.06 mm. + 1.68 mm.	202	angular-sub-rounded dolerite fragments (74%)
	58	white angular quartzite fragments (22%)
	15	grey cleavage flakes of quartz mica schist (4%)
-1.68 mm. + 1.005 mm.	267	sub-angular-sub-rounded dolerite fragments (69%)
	108	angular-sub-angular quartzite fragments (29%)
	6	quartz mica schist cleavage flakes (2%)
-1.005 mm.+ 0.501 mm.	93	sub-angular-sub-rounded dolerite fragments 10 of which consist essentially of plagioclase with a small amount of pyroxene (80%)
	19	white to pink quartzite fragments (17%)
	3	quartz mica schist cleavage flakes (3%)

The quartz is present as irregular colourless grains having a vitreous lustre. Some grains have a central sub-rounded core surrounded by a later thin growth of quartz in optical continuity with the centre.

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Muscovite occurs as colourless to slightly turbid cleavage flakes and has a biaxial negative figure with a low 2V.

Now, assuming a density of 3.3 for the heavy fraction and using the % by weight of this fraction a volume is $\frac{45.5}{3.3}$ = 14 (cc.).

Thus on a volume scale the % of the heavy fraction in the total = 40% ($\frac{14}{34}$ x 100) and the % of the light fraction in the whole = 60% $\frac{20}{34}$ x 100).

Now assuming the average volume of the particles is the same, then from the count of 180 particles in the light fraction the percentages of the different minerals in the whole is

plagioclase	48%
quartz	11%
muscovite	1%

and from the heavy fraction the percentages of the minerals in the whole is

pyroxene	39%
iron ore	1%

i.e. an approximation to the mode is therefore

plagioclase	48%
pyroxene	39%
quartz	11%
muscovite	1%
iron ore	1%

In the smaller fractions it is very difficult to differentiate between the feldspar, quartz and pyroxene crystals under the binocular microscope, so a heavy mineral separation was carried out using bromoform.

Heavy Fraction

This fraction consists dominantly of pyroxenes which are generally a pale translucent yellow brown and rarely almost colourless. Commonly the crystals are encrusted with white earthy material (clay?). On clear faces the lustre is resinous to sub-vitreous while the cleavage is generally not obvious, although many fragments have cleavage faces, which they lie upon making it almost impossible to obtain centred figures. Under the microscope a very fine twinning in one direction is observed on many grains. Most fragments show some alteration but the extent is quite variable. The pyroxenes are biaxial positive with a 2V ranging from nearly zero to about 60° - 70° and thus it is considered that both pigeonite and augite are present, the actual proportions of each being difficult to determine. Due to the lack of centred figures and the presence of two different pyroxenes it was found that accurate refractive indices could not be obtained. The range of the refractive indices measured was from 1.690 to 1.715.

Magnetite comprises perhaps 2% of the heavy fraction. It is opaque (black) and present both as distinct crystals (octahedrons) or as irregular grains.

A few fragments of a pale green mineral occurred in the heavy mineral fraction. Under the microscope it is colourless but slightly turbid and is lath shaped. One good cleavage is present parallel to the length of the crystal with a second one developed at right angles to it. Extinction of the cleavage was 16° while the figures obtained were poor but appeared to be biaxial. One R.I. was just less than 1.664 and the other considerably less. The properties would indicate olivine but the oblique extinction tends to rule this out as a possibility.

Light Fraction

The light fraction consists of plagioclase, quartz and muscovite and in a count of 180 grains 80% of them were plagioclase, 18.5% quartz with the remaining 1.5% muscovite.

The feldspar occurs as opaque white to translucent laths having a sub-vitreous lustre on fresh faces. Alteration resulting in turbidity of the fragments is commonly present. Two cleavages, approximately at right angles are developed and albite twinning is present. In the majority of cases the refractive indices lie in the range 1.550 - 1.570 indicating a plagioclase of labradoritic composition. Several fragments of plagioclase were recognized with one RI = 1.5295 and another less than 1.5295 and from these it is inferred that the fragments are albitic in composition.

Assuming the quartz and muscovite came primarily from the Precambrian rocks the remaining constituents recalculated to 100% are:

plagioclase	54.5%
pyroxene	44.3%
iron ore	1.2%

This corresponds to the mode of dolerites quite well, allowing for the absence of the mesostasis, which would break down very easily and would have a finer grain size than this fraction. The calculated mode therefore supports the results obtained in the coarser fractions that the greater part of the sediment resulted from the break down of dolerite.

Conclusions

From both the histogram and cumulative curve it can be seen that there is a considerable spread of sizes. There is about 80% of the total in the pebble, granule and sand grades with the silt and clay grades comprising only about 20%. These facts are brought out by the statistical treatment of the curves also. Thus the geometric quartile deviation QDg (the ratio between the quartiles) and known as the sorting coefficient

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(So) is 8.87. Trask found that a value of S_o less than 2.5 indicates a well sorted sediment, a value of about 3.0 indicates a normally sorted sediment, while a value greater than 4.5 a poorly sorted sediment. Thus a value of 8.87 indicates a very poorly sorted sediment which bears out the direct observation from the curves.

This result can be better visualized by application of the phi scale to the quartile deviation (Krumbein 1936). In this scheme each Wentworth class limit is an integer and the phi scale increases with decreasing grain sizes. Since the phi values are expressed in Wentworth grades as units, the difference between the quartiles indicates directly how many Wentworth grades lie between the first and third quartile and half this value is the quartile deviation (QD_ϕ). Thus in this sediment the first and third quartiles are spread over a distance of 6.24 Wentworth grades and consequently the curve is decidedly drawn out. Krumbein and Pettijohn (1938) cite an example of a glacial till in which the spread is 4.9 Wentworth grades. The value QD_ϕ may be converted to QD_g the geometric quartile deviation (So) by the relationship $QD_\phi = \log_2 QD_g$

i.e. $QD_g = 8.82$ which is the value for So shown previously.

The advantage of this method of expressing the results is that it may be used directly in comparing the relative spread of two or more curves as QD_ϕ is a logarithm.

Thus it can be seen that the sediment is very badly sorted. The histogram is bimodal but not distinctly so; one mode lies in the pebble range and the second in the fine sand grade. From the results given above, therefore, the sediment may be glacial till but the small amount of material in the silt-clay grades is surprising. This may be explained by the fact that the material was derived from hard crystalline rocks and not much rock flour was produced. Another explanation could be that the material was of glacial origin but in the erosion of it by the River Mersey to produce the terraces, much of the fine material was washed out.

Although the degree of sorting is not unlike that of some river gravels, the composition (particularly its content of fresh, sand-silt size, pyroxene and plagioclase) is quite different.

ENGINEERING GEOLOGY

SUMMARY

Apart from a regional geological survey, geological data were collected relevant to a possible Hydro-Electric scheme involving a dam on the Mersey and a tunnel from the Mersey to the Forth as shown in fig. 14. This preliminary investigation shows that the area is satisfactory as a reservoir, that the Mersey site is suitable for a dam, that roads may be easily constructed, that there are ample supplies of some constructional materials but that the location of tunnel lines is a problem.

POTENTIAL DAM-SITE (HOWELL'S PLAINS)

A sketch map of the dam-site is shown in fig. 15. It shows an anticlinal ridge of quartzite which crosses the river causing a marked constriction. There are rapids in this area and the river is only 6' wide except under flood conditions. A transverse profile sketch is shown in fig. 15. There is a ten foot fall across the first constriction followed by a series of steep rapids extending for about three hundred yards downstream. The bar stands above terraces 10' (upstream) and 22' (downstream) above river level. The river at one stage passed through the gap in the quartzite now occupied by the road but with the straightening of the river course discussed on p. the Mersey was directed to its present course leaving a cut-off meander 40' above river level. The bar is still acting as a local base level (fig. 4) and controls the form of the river for many miles upstream. Well developed meanders in a broad, long flood plain (Howell's Plains) occur immediately upstream from the rapids and the form of the river is quite different from that downstream. The marked and long standing control of the river by this quartzite testifies to its mechanical and chemical resistance to erosion. This rock appears to have excellent foundation properties as it is a hard, dense quartzite, with

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few joints. It is somewhat schistose in parts and has some very thin mica schist layers. Solid rock is exposed almost completely across the full valley floor. The valley is narrower here than in most parts and shows more bed-rock than any other portion of the valley floor for more than 5 miles upstream and 2 miles downstream.

There are no comparable sites on this stretch of the river as the floor is quite wide in most places and bed-rock is rare. Fig. 7 shows the form of the river terraces composed of Pleistocene Till covering the floor of the valley. The terraces are by no means unsatisfactory for foundation purposes and have some favourable qualities. They are composed of a till which is rich in sand and silt grades with abundant boulders but lacking clay. This results in a tough, compact material which is comparatively impermeable. Despite the fact that it forms river terraces its strength is such that it could support considerable loads and would be satisfactory for powerhouse foundations. It could not be excavated by bulldozer. The unsorted nature of the rock lowers its permeability and porosity. Some Pleistocene tills in Switzerland make unsatisfactory dam foundations due to the fine clay being removed by water passing through the rock under pressure. This results in cavitation and considerable loss of water under the dam and may result in collapse. This till lacks clay and has a low permeability and therefore should not suffer from this deficiency.

Possible Tunnel Lines

The problem of tunnelling from the Mersey to the Forth is a complex one and a number of difficulties are apparent. Four possible routes are discussed.

The proposed tunnel line A is unsatisfactory in respect to the outlet portal and the detailed map, fig. 17 shows that the portal is located in an extensive landslide area. The base of the Tertiary volcanics varies between 2000' and 2400' on the eastern side of the Forth Valley, but basaltic debris has slipped down almost 1000' lower than this. The bracken-covered slopes east and north-east of Gisbourne's Hut have the characteristic hummocky appearance of landslides, streams disappear underground, and in the upper parts, the typical arcuate slip circles are visible (these are visible in airphoto of Fun, Mersey). The largest slip circle is over half a mile long and is situated right on the edge of the Berriedale Plain; it forms a depression 120' deep.

The debris extends downhill beyond the motor track along the Forth. Its thickness is not known but 30' would be a minimum and it might reach 200'.

The degree of dissection and size of some gum-trees suggests that there has been no movement of the lower parts for some tens of years but the area must be regarded as dangerous and it seems inevitable that further slides (perhaps on a very large scale) would occur if there were excavations in the landslide debris for a portal.

It is suggested that the portal be relocated to B, three quarters of a mile to the south thus swinging the line of the tunnel through about 10°. This does not alter the inlet portal position, the length of the tunnel, nor the type of strata traversed, but the portal would be located on a clean slope underlain by solid Precambrian quartzites and slates. The north-west trending group of transcurrent (?) faults occurs in this area and several faults, almost parallel to the tunnel line, lie within half a mile. The position shown in fig. 14 is only a few hundred yards from what appears to be a large fault and further detailed work is required to clarify the structure here. Unfortunately, outcrop is not abundant on the steep, densely vegetated slope.

At present, the inlet portal does not appear to involve any difficulties and would be located in very solid quartzite.

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From the inlet portal the tunnel should traverse massive quartzite for about 1000', followed by contorted garnet-mica schists with thin quartzites for about 7,000', schists 2,000 then somewhat closely folded but massive quartzites for about 4,000" schist and quartzite 6,000' then interbedded slates with thin quartzites for the last 3,000'. Details of lithology and structure of the rocks are given in the petrological, structure and stratigraphy sections and it is emphasised that the above predictions of the types of rocks occuring along the tunnel cannot be relied upon without considerable further investigation.

It is not possible to predict where faults may be met in the structurally complex and strongly faulted Precambrian rocks, but it is possible that two may occur as shown in the section. Nor is it possible to predict the behaviour of any faults to be met in tunnelling. Some of the older faults have crush breccia zones which have been strongly silicified and would cause little difficulty; others however could be open and allow considerable influx of water. There is little surface run-off from the Berriedale Plains and Gad's Hill so that much of the heavy rain of the area may pass down through joints in the basalt and thence along joints or faults in the underlying Precambrian rocks. Tunnelling may not be as dry as in Jurassic Dolerite and may well be very wet.

The major syncline could have a large fault along its axis and as the tunnel should meet this below the Arm River valley, this fault may carry a considerable amount of water.

The tunnel would be chiefly cut through schists and slates interbedded with minor quartzites and these are comparatively soft, particularly compared with the massive quartzites which will occur along about a quarter to a third of the tunnel's length. The quartzite should be considerably harder to tunnel than Jurassic dolerite.

One major difficulty is that the direction of the tunnel (310°) is close to that of the strike of the steeply dipping, schistosity and cleavage (280°) of the rocks. These pronounced weaknesses in the roof of the tunnel may lead to considerable overbreak and roof collapse, and the roof will probably need close supporting even in the quartzites. The schists near the outlet should result in much easier tunnelling.

As shown in fig. 2 the Tertiary basalt has filled an old valley and it is not impossible that deep basalt-filled channels exist beneath the present basalt plateaus. This possibility has been investigated and it seems unlikely that the pre-basalt valleys extended below 1800' in their deepest part, and this places them well above the tunnel line. In addition the tunnel line avoids the deepest part of the buried valley located.

The tunnel lines C and D were not investigated in any detail, as they lie outside of the area mapped and the following remarks are based on a traverse along the Mersey, the Forth and the Berriedale Plains road.

Tunnel line C has several attractive features; both its inlet and outlet portals lie in quartzite. The inlet end is located in a thick, massive quartzite of the Fisher Group and the outlet is placed in the solid quartzite (Fisher Group?) ridge just north of the landslide area on the Forth. The beds at each end dip in opposite directions so that the tunnel would cross the faulted axis of the Fisher Anticline. There is a possible fault a few hundred yards from the inlet and this would meet the tunnel about half a mile from this end. There is a gap in the Tertiary basalt cover above this tunnel line and it should be possible to determine the structure and lithology to be met. This alternative is much shorter than A and B, does not pass below a major river valley, (i.e. Arm River) and would be located in quartzites and slates of the Fisher Group.

The tunnel should not meet the mica and garnet schists which occur elsewhere in the area and which would be expensive to tunnel through because of the strong schistosity and the tendency to deep weathering. One difficulty may lie in the extensive quartzite-scree deposits on the steep slopes of the Mersey River shown on plate . Excavation in these screes or blasting associated with the construction of a dam could cause extensive movement of this material. The screes may be extensive enough to provide useful constructional material.

Tunnel line D appears on the present state of knowledge to be a very bad choice. It lies either along, or very close to, a major fault between Fisher quartzite and Dove schist. The rock would probably be very broken with shattered quartzite and strongly weathered schist and the zone could carry a large amount of water.

Tunnel line D has the advantage that a dam placed at this point on the Mersey would catch the waters of the Fisher without extra tunnels or diversion but geologically appears to be very dangerous. It lies very close to, and partly along, a major fault between Fisher Group quartzite dipping south and Dove Schist dipping north. This fault zone would be wide and would contain shattered quartzite and deeply weathered schists and should be avoided.

LOCATION OF ROADS

Most of the roads in the area are along the flat-topped river terraces of the Mersey, Arm and Forth Rivers, and these have quite good foundation properties, the main difficulty lying in their poor drainage.

Although the till of the terraces is quite sound, the varves associated with it in the Arm valley (see pp. 40 and 41) should be avoided. This material is generally damp, due to its low topographic position, but when it is wet after being dried out, it swells rapidly and crumbles. Material of this kind in Europe has been found to be very sensitive and may flow badly. Although the material stands in vertical faces 10' high in cuttings in the Arm and Forth valleys it should be classed as unreliable and avoided if possible. It would be dangerous to place bridge foundations on this material.

The access road via Gad's Hill passes across basalt for considerable distances and although this is quite satisfactory, difficulties may be met in passing from the basalt plateau to the valleys because the slope along the base of the basalt is prone to landslide.

Some steep slopes underlain by quartzite develop thick screes with an angle of rest of 40° (e.g. east side of Mersey, between Arm and Fisher) and these would slide if excavated near the base.

<u>Constructional Materials</u>

There are ample supplies of clean quartzite for concrete aggregate as shown on the map no. 1. Basalt is also abundant and varies in character from massive to closely jointed or scoriaceous types. The basalt has the disadvantage of being located above the 2000' level, and usually above 2500' so that it may have to be crushed and carted considerable distances for most purposes. Supplies of quartzite could be found almost anywhere in the valleys.

Unconsolidated coarse material is not abundant. In a few places there are quartzite screes, but the volume is too small to warrant consideration of their use in any major project although they could be utilized for road construction where they occur locally. The till in the river terraces is a tough, unsorted silt-sand-boulder mixture, unsuitable for aggregate and probably also not satisfactory for earth-fill dams. Large deposits of unconsolidated river pebbles and sands occur north of the Forestry Commission camp on the Mersey River. This material is probably too remote to consider its use on tunnels A and B but is only a few miles along a good road from tunnel C. There is only very limited amounts of clean sand in the Mersey and Forth Rivers.

The varved clays of the Arm and Forth Rivers contain a considerable amount of silt, and swell when first wetted but should be a satisfactory source of clay material.

FURTHER INVESTIGATION

As no detailed work has been done in the area around tunnel lines C and D, this should be regarded as necessary to the evaluation of those works.

Lack of surface exposures make it quite impossible to predict what rock types may be met along the tunnel line, and this could only be determined by a series of diamond drill holes along the line. One drill should certainly be placed where the tunnel B is to pass below the Arm River to find out the thickness of glacials and of solid rock above the tunnel.

The configu-ration of the base of the basalt on the Berriedale Plains and on Magg's Mount could be checked by seismic work. The thickness of glacials in the Arm valley might need to be checked by the same method if tunnel B is considered.

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