THE GEOLOGY OF THE MT. ELEPHANT-PICCANINNY POINT AREA, TASMANIA

By

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(With nine text figures.)

ABSTRACT

The oldest rocks are very slightly metamorphosed Siluro-Devonian sediments (Mathinna Beds)—greywacke sandstones, siltstones and mudstones which are mainly of turbidity current origin. The Permian System (450 ft. thick) unconformably overlies the Siluro-Devonian System and consists of lacustrine sandstones, marine limestones, greywacke sandstones, siltstones and mudstones of Artinskian and Kungurian age. Overlying the Permian System, probably disconformably, are up to 850 feet of Triassic freshwater sub-greywacke sandstones with interbedded coal and mudstone that have been intruded by extensive sills and sheets of Jurassic dolerite. A small amount of basalt was extruded in the Tertiary.

The Middle Palaeozoic rocks were closely folded during the Devonian Tabberabberan Orogeny along axes trending north north-west. Towards the end of the orogeny, a hypersthene and sanidine bearing porphyry, and an adamellite stock were intruded into the Mathinna Beds. The porphyry is at least 800 feet thick, may be as much as 5000 feet thick and has been metamorphosed by the adamellite along its southern boundary.

INTRODUCTION

The area mapped consists of two ten thousand yard squares, 6087 and 6086, the Mt. Elephant and Piccaninny Point squares respectively, which are part of the St. Marys quadrangle (Fig. 9). The area is situated on the east coast of Tasmania, east of the township of St. Marys, which is approximately 80 miles by road from Launceston.

Part of the area has been mapped in a regional fashion by Keid (Hills et al. 1922), but his map, and in particular his interpretation of the structure is not accurate. Voisey (1938) carried out some detailed work on the Permian System at Elephant Pass, and Everard (in Hughes 1957) mapped the Berriedale Limestone around the southern part of Mt. Elephant. The Berriedale Limestone in the vicinity of Piccaninny Creek is also described in Hughes (1957).

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PHYSIOGRAPHY

The area around and east of St. Marys, with the exception of a narrow coastal plain, and the upper part of the Break O' Day Valley is of strong relief. Mt. Elephant is the highest point, rising from sea level to 2350 feet above sea level in three miles. St. Patrick's Head is 2227 feet high, and the hills west of the coastal plain between Lagoons and Seymour rise to over 2000 feet above sea level. The main hills are capped with dolerite.

Three separate drainage systems are represented. North and west of Gray and Mt. Elephant, all the streams drain west, combining to form the Break O' Day River which is part of the South Esk system. The Break O' Day is essentially a mature river flowing across a flood plain in a relatively broad level valley. In contrast, east of Mt. Elephant the drainage is to the east, and many small creeks descend rapidly through deep gorges with precipitous slopes to the sea. Whereas these creeks descend from over 1500 feet above sea level to sea level in 3 to 4 miles, the Break O' Day which at St. Marys is 900 feet above sea level travels over 120 miles before it reaches the sea. The watershed between these two drainage systems is gradually being worn down, and river capture by the east flowing streams in inevitable in the near future.

The south-western part of the area is capped with dolerite and forms a low plateau averaging 1500 feet above sea level. This area corresponds to the St. Clair level of Davies (1959).

The coastal plain has a width of more than a mile at the southern end of the Piccaninny Point square, decreases in width to the north, and is not present in the Mt. Elephant square. It widens just south of Seymour to more than two miles wide, and is generally underlain by sand and gravels which are of Recent or Pleistocene origin. A wide beach with bordering coastal dunes extends practically all the way down the Piccaninny Point square, but is broken by Piccaninny Point itself, which extends about a quarter of a mile into the sea. The creeks are barred for most of the year, and small lagoons are present near the mouths.

Several coastal levels, which probably represent old sea levels have been recognised. The best developed is approximately 20 feet above sea level and is represented by most of the coastal plain. Others are developed at 60 and 250 feet above sea level. The 60 foot level is well developed in the Mt. Elphant square where a platform up to a quarter of a mile wide has been cut in the St. Marys Porphyry just south of Four Mile Creek.

STRATIGRAPHY

SILURO-DEVONIAN SYSTEM

Mathinna Beds

The Mathinna Beds, the oldest rocks in the area, comprise the steeply dipping sediments unconformably underlying the Permian System. These beds may be a formation, but at present not enough is known to define them as such. A well exposed section occurs on the Tasman Highway between 058,676 and 045,683, but is incomplete and complicated by minor folding and faulting.

The Mathinna Beds are probably partly or wholly equivalent to the Scamander Slate and Quartzite (Walker 1957), and the Mathinna Group (Hills and Carey 1949), with which they are lithologically very similar. They have undergone low grade metamorphism, which was not strong enough to destroy the original textures.

The sediment consists of sandstones, medium to coarse grained siltstones and mudstones. The mudstone layers vary from a fraction of an inch to approximately six feet thick. The sandstones and coarse grained siltstones are poorly sorted, and individual beds vary in thickness from one inch to over three feet. In the sandstone layers all grade sizes from clay to medium sand occur and in the siltstone, clay is always present (seldom less than 30%). The grains are angular to subangular, and consist mainly of quartz, with subordinate fragments of quartzite, chert, mudstone, biotite, muscovite and plagioclase. Graded bedding is common in the coarser sediments where grading is from medium sand grade (Wentworth scale) at the base to silt grade at the top.

Sedimentary structures, particularly cross bedding are well developed in places. The cross beds are of the festoon type, and are extremely small, with laminations rarely thicker than 0.5 mm. The cross beds are often twisted and distorted, probably by turbidity current drag. It is extremely difficult to obtain reliable current directions from these cross beds in the field, and the directions obtained for the source of the currents varied from south to west.

Sole markings similar to those at Upper Scamander (Williams 1959) are well developed. In the Elephant Pass section, just above the saddle at 050,681, flute casts indicate currents from 210 degrees and at 045,675 flute casts indicate currents from 280 degrees.

The sandstones and coarse siltstones were deposited by turbidity currents (Kuenen and Migliorini 1950). The graded beds, disrupted nature of the sandstone, poor sorting and sole markings all support this conclusion.

The mudstones were deposited in quiet conditions from dilute fluid suspension. However, a considerable part of the fine sediment in the mudstones was probably transported by turbidity currents, but because of the fine size of the particles, settling continued long after the coarser sediment had been deposited.

Fragmentary plant remains were the only fossils found in the Mathinna Beds. They are poorly preserved, and unidentifiable, but occur in at least three places, notably 008,768; 005,750 and in the Elephant Pass section a few hundred feet below the unconformity. Cookson (1936) identified plant fragments from lithologically similar beds near Warrentina as possibly *Hostimella*, and considered the rocks to be of Upper Silurian or Lower Devonian age.

PERMIAN SYSTEM

The Permian System consists of 375 to 475 feet of sandstones, greywacke sandstones, siltstones, mudstones, conglomerates, and limestones, which have been divided into six stratigraphic units.

The Permian rocks dip gently in a southerly or south-westerly direction. The difference in elevation between the base of the Berriedale Limestone at the northern end of Mt. Elephant and Piccaninny Creek, after allowing for faulting, indicates a dip of one degree to the south.

A panel (fence) diagram of all the measured Permian sections and bore cores in and around this area is presented as Fig. 1. The sections used in the diagram were obtained from the following sources:—Rossarden—Blisset (1959); Avoca—Banks (1958); Killymoon Bore—Hills *et al* (1922); Harefield Bore—Hills *et al* (1922); Seymour Bore—Hills *et al* (1922); Ray's Hill—Walker (1957). All other sections have been measured by the writer.

Wardlaw Conglomerate

The Wardlaw Conglomerate consists of poorly sorted, unfossiliferous conglomerate and interbedded coarse sandstone. It unconformably overlies the Mathinna Beds and is conformably overlain by the Mt. Elephant Sandstone.

The Wardlaw Conglomerate outcrops boldly, usually as small cliffs, 5 to 10 feet high. Several good sections are exposed in creeks (054,652; 033,682; 041,702), but the most accessible section is on the Tasman Highway in the Elephant Pass (046,683), where it is possible to divide the formation into four members.

The basal member, (about 2 feet 6 inches thick), is a conglomerate, and consists of rounded pebbles (mainly Mathinna sediment) up to 8 inches long, set in a matrix of rock fragments, quartz and minor feldspar. The matrix is poorly sorted and the angular particles range in size from silt to granules 4 mm. in diameter.

Conformably overlying the basal member is a poorly sorted, yellow-brown coarse sandstone, which contains a few scattered, well rounded pebbles and closely resembles the matrix of the basal member. This second unit is 3 feet 6 inches thick, and has a fairly sharp boundary with the underlying unit.

The second member grades into a pebbly sandstone above with a decrease in the grainsize of the matrix and an increase in the number of pebbles. This pebbly sandstone is 4 feet 6 inches thick, with pebbles comprising about 15 to 20% of the rock. The pebbles are rounded, consist mainly of

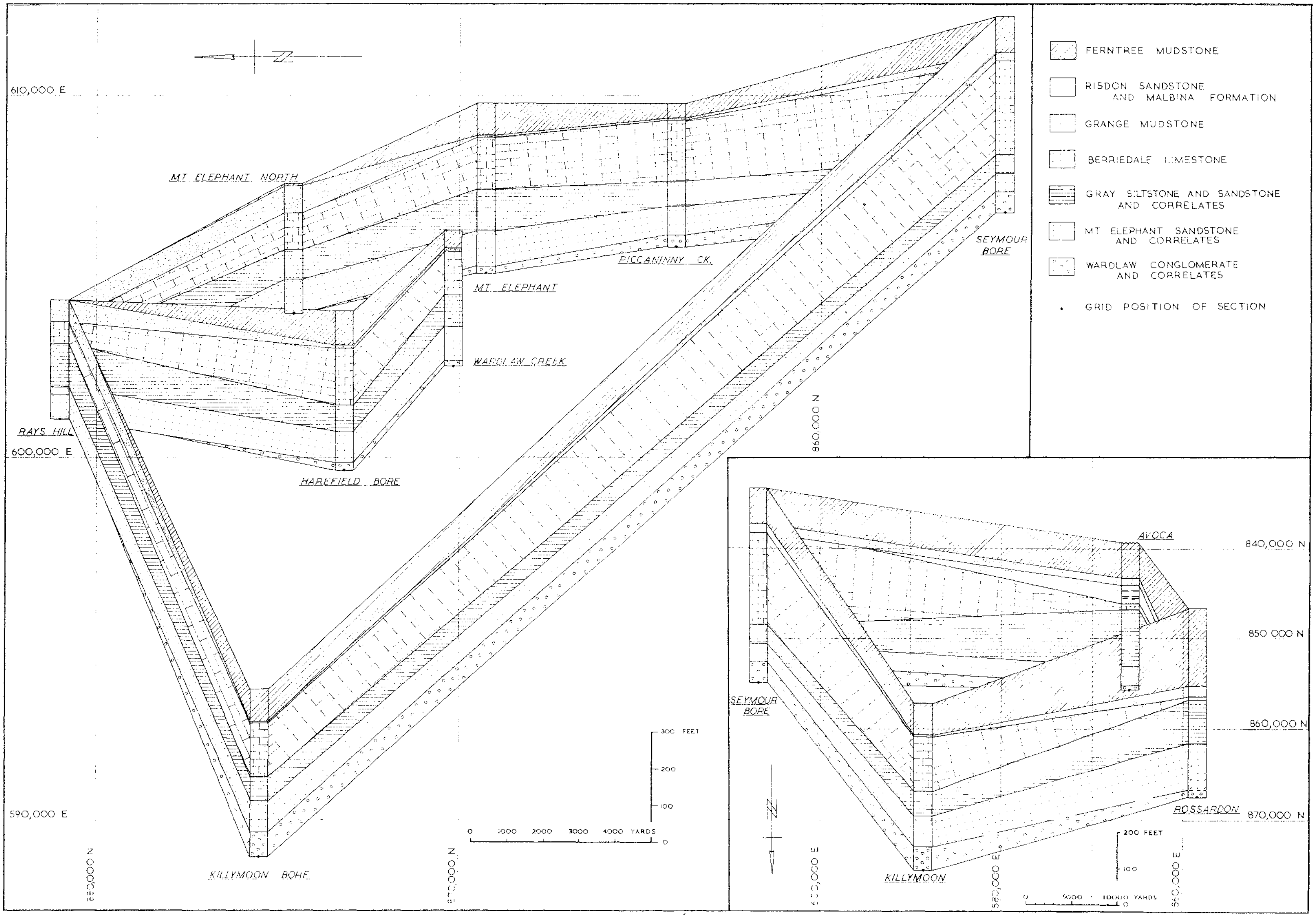


FIG. 1.—Panel (fence) diagram of Permian sections in the St. Marys-Seymour area. The inset is a panel diagram relating Periam sections in the St. Marys area to Permian sections in the Avoca and Rossarden districts.

quartz and Mathinna sediment with rare granite fragments, and vary from about half an inch to one foot in diameter. The matrix is angular and consists of quartz (75%), rock fragments and feldspar (15%). The upper boundary of this unit is distinguished by an increase in the number of pebbles per unit volume.

The fourth member, which is 12 feet thick, is a medium to coarse, poorly sorted conglomerate, which grades into pebble sandstone near the top. The size of the pebbles is much larger than in any of the previous units, and varies from ½ an inch to 18 inches or more. They are rounded with poor sphericity, and are mainly of Mathinna sediments. The matrix is light coloured with orange and yellow streaks, and consists of quartz (75%) rock fragments (20%) and feldspar (5%). It varies in size from silt grade to coarse sand. Conformably overlying this unit are the basal sandstones of the Mt. Elephant Sandstone.

Several other sections of this formation have been measured and they indicate that the proportion of sandstone to conglomerate varies enormously, but in general, conglomerate predominates over sandstone.

In a cliff section at 037,697 cross bedding (3 feet across) and graded bedding occur in a sandstone bed. The graded beds are localised, about 6 inches thick, and grade from very coarse sand at the base to fine sand at the top. Crude graded bedding is also represented in the conglomerate at 056,744.

Mt. Elephant Sandstone

The Mt. Elephant Sandstone is 100 feet thick at the Elephant Pass and consists of quartz sandstone, with interbedded mudstone and shale. Voisey (1938) refers to this formation as part of the St. Marys Basal Stage. Two sections were measured and are summarised in Fig. 2. A is exposed in road cuttings on the Tasman Highway at 046,583, and B in the upper reaches of Wardlaw Creek at 028,706.

Marine fossils are generally absent, but in scattered blocks of sandstone belonging to the Mt. Elephant Sandstone south of St. Marys (005,735), several fenestellids were identified. Fragmentary plant fossils are abundant in a few localities, in association with carbonaceous shales. Spores from these carbonaceous shales have been identified, and indicate that the Mt. Elephant Sandstone is partly or wholly equivalent to the Mersey Group of north-western Tasmania (Banks 1962).

The basal part of the formation is a coarse sandstone 10 to 20 feet thick, with interbedded thin conglomerate beds. The conglomerate beds are approximately 1 foot thick, and are composed of well rounded pebbles (averaging 1 inch in diameter) of quartz, quartzite and Mathinna sediments. Graded beds 3 to 4 inches thick are often well developed in the coarse sandstones. Festoon cross bedding is characteristically developed and is particularly abundant at 055,744. The cross beds are 2 to 3 feet thick and indicate currents from approximately 300 degrees. Individual laminae are extremely coarse—up to 1 cm. thick, indicating that they were formed in very shallow water.

At, or near the top of the basal sandstone, there are one or more bands of dark grey to black shale, about 3 to 9 inches thick, which contain abundant carbonaceous matter. An extremely carbonaceous band of shale (6 inches thick) in a cliff section at 036,696 has previously been referred to as coal, (Voisey 1938). The basal sandstone is followed (in the area to the south and west of Mt. Elephant) by up to 80 feet of medium to fine sandstone with interbedded mudstone. The amount of mudstone in the formation varies considerably from section to sesction, rarely exceeds 40% of the rock, and is at a maximum in the Gray-Dalmayne area. The sandstones are often finely laminated, showing alterations of sandstone and mudstone or carbonaceous material. The number of alterations varies, and up to 30 per inch occur. Where the rock is predominantly mudstone or shale, the sandstone is often represented as thin flat lenses, about 1 mm. thick. Graphite and mica are very abundant in association with the shales.

Shale partings have been reported in the sandstone in the Harefield and Killymoon bores, and some may be present in the Seymour bore, but Walker (1957) did not report any from Ray's Hill. North of a line through 040,750 and 056,740 the formation is composed entirely of sandstone.

Fifteen feet from the top of section B, there is a pebbly, shaly siltstone, (2 feet thick), which is very similar to the Gray Siltstone and Sandstone. Above this bed, the sandstone contains abundant shale partings and is pebbly in distinct contrast to the rest of the section which lacks pebbles.

The character of the formation changes northwards and at the northern end of Mt. Elephant it rests directly on St. Marys Porphyry or Mathinna Beds. The lower part of the formation in this area consists of very coarse grained sandstone. The coarse sandstones are 20 to 30 feet thick, and grade into medium to fine grained sandstone above. Shale partings are rare, but mica is plentiful, and pebbles are present in small numbers.

The minerology of the sandstones throughout the formation is fairly uniform. The basal sandstones are moderately well sorted, and consist of quartz, quartzite, chert (80 to 90%), feldspar (5%), and rock fragments (5 to 15%). Where matrix is present (as in the basal parts of some graded beds) it is usually of fine sand grade, and consists of quartz and chert particles. Clay or silt size particles seldom constitute more than 5% of the rock.

The upper sandstones are lithologically similar to the basal sandstones, but are uniformly fine grained, the particles averaging 0.2 mm. in diameter. The average grain size throughout the formation decreases upwards from coarse to very coarse sand at the base, to fine sand and very fine sand 50 to 70 feet above the base.

The rocks within this formation include both lithic sandstones and orthoquartzites (Pettijohn 1957), but the majority of sandstones are transitional between the protoquartzite suite and the orthoquartzite suite.

Bedding surfaces are extremely irregular, and individual beds vary in thickness from fine laminations to several feet.

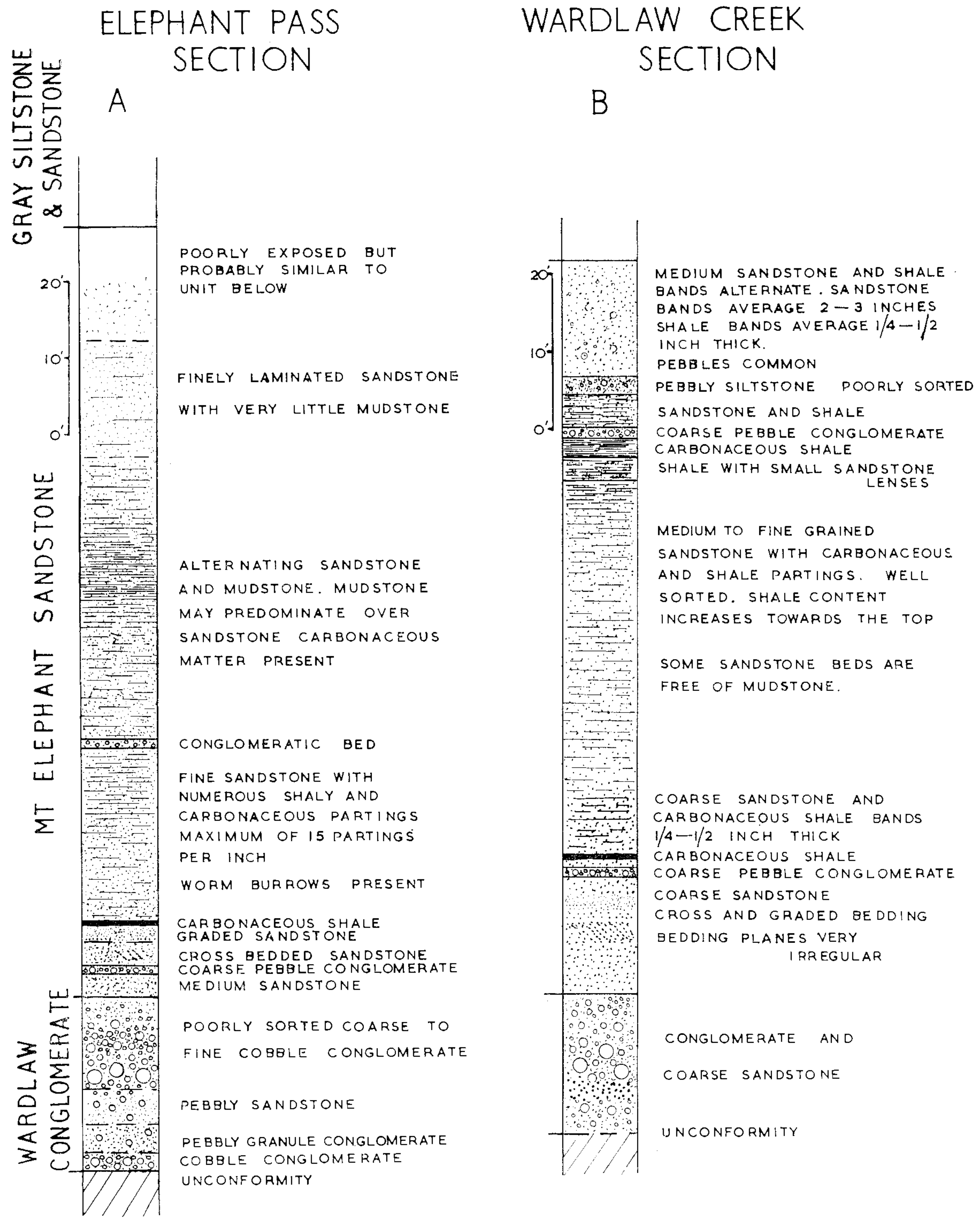


FIG. 2.—Sections through the Wardlaw Conglomerate and Mt. Elephant Sandstone at Elephant Pass and Wardlaw Creek.

Gray Siltstone and Sandstone

The Gray Siltstone and Sandstone consists of fossiliferous and poorly sorted fissile siltstone and sandstone. It is 115 feet thick at Elephant Pass and is probably Artinskian in age.

The formation has previously been referred to as part of the Gray Stage (Voisey 1938) which included the Gray Siltstone and Sandstone, and the overlying limestone, mudstone, and sandstone. In hand specimen the rocks are yellow-ochre to grey-brown in colour, and very poorly sorted with abundant pebbles up to 1 cm. in length. The pebbles are well rounded with poor sphericity, and consist of quartz and rock fragments (Mathinna sediments). Rare large fragments of feldspar up to 2 mm. in diameter, flakes of biotite and muscovite, carbonaceous streaks and shell fragments are present. Feldspar is especially abundant in the lower part of the formation (up to 10%).

The siltstones consist mainly of angular grains of quartz, some of which show undulose extinction and contain small grains of apatite and rutile. Muscovite, biotite, calcite, magnetite, plagioclase and clay size fragments are also present. The siltstones contain 5% of sand size particles.

The majority of rocks within this formation are, according to Pettijohn (1957, p. 291), greywackes or greywacke sandstones. Rare graded bedding was noted, the beds grading from medium to fine sand at the base to siltstone at the top.

Marine fossils are present throughout the formation and are abundant in the top 10 to 20 feet. Fragments of brachiopod shells and ostracods occur in the lower beds, while *Polypora, Fenestella,* fenestellids, spiriferids, productids, *Stenopora* and stenoporids are abundant in the upper sandstone and shale beds. A pelecypod from 10 feet below the Berriedale Limestone at 043,702 was identified by Mr. M. R. Banks as *Conocardium australis.* At the northern end of Mt. Elephant a very fossiliferous layer about 2 to 3 inches thick occurs near the base of the formation. The fossils, which include ostracods, stenoporids, fenestellids, brachiopods and small corals, are fragmentary and have abundant pebbles associated with them.

The Gray Siltstone and Sandstone probably corresponds to the Rayner Sandstone and the Nassau Siltstone of southern Tasmania. There is no fossil evidence on this point, except a pelecypod, *Conocardium australis* which occurs in the top of the Gray Siltstone and Sandstone, and in the Nassau Siltstone. The lower parts of the Gray Siltstone and Sandstone and the Raynor Sandstone are very similar in lithology, are extremely poorly sorted, and contain considerable feldspar.

Berriedale Limestone

The Berriedale Limestone has been correlated by Banks (1962) with the Berriedale Limestone in the Hobart area. The Enstone Park limestone of Walker (1957), which occurs at Enstone Park, Falmouth, and at Ray's Hill near St. Marys, is also equivalent to this formation.

The formation consists of alterations of shale, fissile siltstone and limestone, the limestone predominating. It outcrops almost continuously as a fringe to Mt. Elephant, and along the hills south of Gray. A small outcrop of limestone occurs on the western slopes of St. Patricks Head. The limestone often forms cliffs 50 to 60 feet high.

Thirteen chemical analyses of the limestone are given in Hughes (1957) from the Gray area, and calcium carbonate content varies from 54 to 86%, the average being 70%. Percentages of magnesia, alumina and iron are quite small, but the acid insoluble portion varies from 13 to 41%. Nye, in 1926, investigated the limestone deposits in the vicinity of Piccaninny Creek, and six analyses from this area are recorded in Hughes (1957). Average $CaCO_3$ is about 75%, but SiO_2 is high, averaging 20%.

The shales and siltstones within the Berriedale Limestone are calcareous, extremely rich in bryozoans and brachiopods, and resemble the uppermost siltstones in the Gray Siltstone and Sandstone. The limestones range from calcirudites to calcilutites, and are seldom pure, with abundant sand grade and larger impurities. Pebbles up to 6 inches in diameter are common on some horizons and consist of quartz, quartzite and subordinate schist and Mathinna sediment.

Gradations of fossil fragment size within one bed were noted at several localities. At 060,717 at least two and probably three graded beds are present within one massive limestone bed. Each graded bed is approximately six inches thick and the fossil fragments range in size from one inch or more in diameter at the base to sand grade and finer at the top.

Limestone generally predominates over shale, but near the base of the formation there may be as much as 16 to 20 feet of highly fossiliferous shale, with only one or two thin limestone bands through it.

Brill (in Banks 1957), measured a section through the limestone in the Elephant Pass area and considered it to be 144 feet thick. The thickest individual limestone bed is approximately six feet thick, and the thickest mudstone bed is five feet thick.

Bryozoans and brachiopods are probably the most abundant fossils and include *Strophalosia, Dielasma, Fenestella, Polypora, Stenopora tasmaniensis, Stenopora sp.,* and *Lyroporella.* Foraminifera, *Calcitornella* (Banks 1957), and large pectens up to eight inches across are common throughout the formation. Corals occur in certain horizons, (*Euryphyllum*) and sponge spicules are abundant. At 023,705 crinoid remains are so numerous that the limestone could be called a crinoidal limestone. Many additional genera and species are recorded by Voisey (1938).

The Berriedale Limestone is about 140 feet thick in the Elephant Pass area, thickens rapidly to the south and thins to the north and west (Fig. 1).

Correlate of Risdon Sandstone

The correlate of the Risdon Sandstone (Banks and Hale 1957) conformably overlies the Berriedale Limestone, and conformably underlies the Ferntree Mudstone. Between the uppermost limestone beds, and the first sandstone bed, there is 12 to 18 inches of mudstone exposed at 023,704 and 042,708. This mudstone is in the same stratigraphical position as the Malbina Siltstone and Sandstone in the Hobart area. Brill (Brill and Hale 1955) identified glauconite in the sandstone beds and correlated these beds with the Risdon Sandstone member of the Ferntree Mudstone at a locality between Mt. Peter and Mt. Paul near Friendly Beaches. On Maria Island (Brill and Hale 1955, Banks 1958) and at Friendly Beaches, the Risdon Sandstone contains a small amount of glauconite.

The sandstone is pebbly throughout and several distinct bands of conglomerate are present. The pebbles vary in size, and range from ½ an inch or less to approximately 12 inches in diameter. At 040,753, the formation is extremely pebbly, the pebbles consisting mainly of metamorphic rocks including banded quartzites, muscovite schists, and conglomerate (similar to the Owen Conglomerate). One specimen shows small scale folding, of a type which is not present in the Mathinna sediments. The nearest place where metamorphic rocks of the type just mentioned outcrop is Beaconsfield.

The sandstones are poorly sorted, and consist of quartz, glauconite, rock fragments, and plagioclase in a fine silt or clay matrix. The percentage of glauconite varies from 15 to 40 per cent. A specimen from 055,720, consisted of quartz 18%, rock fragments and feldspar 6%, glauconite 34%, and fine silt and clay grade material 52%. In other specimens the percentage of fine grained matrix is higher, probably 60-70%. Angular quartz particles, usually with undulose extinction, average 0.2 to 0.3 mm. in diameter, the largest measured being 0.8 mm. and the smallest less than 0.05 mm. The glauconite grains are rounded, and average about 0.15 to 0.2 mm. in diameter. The rock fragments are sub-angular to sub-rounded, consist mainly of chert and slate, and average 0.35 mm. in diameter. The fine matrix consists of quartz and clay with subordinate flakes of muscovite and biotite.

Fossils are not abundant, and are represented by rare brachiopod shells. However, at 061,720, the sandstone contains pectens, brachiopods and gastropods in large numbers, while at 001,720, fenestellids and stenoporids are present.

The base of the sandstone is exposed in several places, but no scouring was observed.

The formation is very irregular in thickness varying from three feet at the Elephant Pass to 60 feet at the northern end of Mt. Elephant. The comparatively large thickness of glauconite rock at the northern end of Mt. Elephant is probably partly equivalent to the Ferntree Mudstone or Malbina Formation.

Ferntree Mudstone

The Ferntree Mudstone (Banks and Hale 1957), conformably overlies the Risdon Sandstone correlate and is overlain, probably disconformably by subgreywacke or quartz sandstone of Triassic age. Voisey (1938) considered the Ferntree Mudstone as part of the Gray Stage. It is 90 feet thick at Elephant Pass, and consists of an alternation of fissile and non-fissile siltstones and mudstones. Hale and Brill (1955) recorded a one inch bed of white montmorillonite bearing clay in the Ferntree Mudstone at Elephant Pass.

In hand specimen the rock is light to dark grey in colour, usually fissile, and appears fine grained, with numerous sand grade and a few larger particles scattered through it. Beds average 9 to 12 inches thick. A thin section showed that the rock consists of mineral and rock fragments up to 0.25 mm. long, in a groundmass of very fine silt and clay. The rock is poorly sorted as all intermediate grades are present, and approximately 10% of the particles are between 0.04, and 0.25 mm. in diameter. Quartz is the dominant mineral, with subordinate rock fragments, feldspar, muscovite, and glauconite. Sericite is well developed in the clay.

Fossils are rare, and consist of poorly preserved brachiopods.

Depositional Environment of the Permian Sediments

Fossils indicate that all sediments except the Mt. Elephant Sandstone, and possibly the Wardlaw Conglomerate are marine. The Mt. Elephant Sandstone contains plant fragments and very rare marine fossils and may be deltaic, the Wardlaw Conglomerate contains no marine fossils, and may be non-marine.

The basal sandstone of the Mt. Elephant Sandstone are coarse grained and are characterised by coarse cross bedding which indicates a very shallow water environment, possibly a beach or shore line. Above the coarse sandstones, there is abundant shale, mudstone and carbonaceous matter associated with the sandstone, and the environment was lacustrine, lagoonal, or deltaic. Marine beds occur in an equivalent position to these a few miles to the north-west. The average grainsize from the Wardlaw Conglomerate through to the top of the Mt. Elephant Sandstone gradually decreases, indicating that the source was being worn down, or the depth of water increasing.

Above the clean sandstones of the Mt. Elephant Sandstone, are the greywacke sandstones and siltstones of the Gray Siltstone and Sandstone. These sediments are extremely poorly sorted, although sorting does improve towards the top of the formation. Graded bedding is suggested in several places, pebbles are common, and fossils are fragmentary and small. The pebbles could be explained by assuming that they were dropped from a floating ice-sheet or ice-bergs on melting, but no striated pebbles were found, and the writer suggests that these sediments are at least in part turbidity current deposits.

The limestones of the Berriedale Limestone are of clastic origin, and usually contain a relatively high percentage of non-calcic material. Graded bedding is present in some limestone bands. Shale beds, rich in fenestellids, stenoporids and brachiopods occur throughout the Berriedale Limestone. The fossils in the shale beds are unbroken, indicating that the shales were deposited in relatively quiet conditions.

The Risdon Sandstone correlate is extremely pebbly, poorly sorted, and contains pebbles of Precambrian rocks and silicified conglomerates, similar to the Owen Conglomerate. No such sediments occur nearby, and the nearest place that the pebbles could have been derived from is Beaconsfield about 80 miles to the west-north west. Glauconite occurs in the Risdon Sandstone and the thickness of glauconite bearing sediment increases to the northeast. Although previously described as a near shore deposit the writer suggests that the Risdon Sandstone marks a period of instability, and is possibly of turbidity current origin.

The Ferntree Mudstone contains few pebbles, but has a sub-greywacke character in that it contains up to 20% silt and sand grade particles in a clay matrix.

The only evidence to indicate the source area are cross beds in the Mt. Elephant Sandstone, which indicate currents from the west-northwest, or north-west, and the presence of Precambrian pebbles in the Risdon Sandstone.

TRIASSIC SYSTEM

Overlying the Permian System, probably disconformably, are a series of flat lying subgreywacke sandstones, (Pettijohn 1957), with interbedded shales, mudstones, allochthonous coal, and rare conglomerates. Sub-bituminous coal occurs in composite seams with shale or mudstone, the seams ranging from about 1 foot or less to 16 feet thick. Plant remains and silicified wood are commonly associated with the shales (e.g. *Dicroidium, Cladophlebis australis, Johnstonia* &c.), and indicate a Triassic age, Banks 1952). All the rocks within this system have been mapped as one unit (New Town Coal Measures of Carey and Hills 1949, Feldspathic Sandstone of Banks (1962), and will be referred to as Feldspathic Sandstone. The sandstones usually outcrop as small discontinuous cliffs about 30 to 50 feet high. Dips are always shallow (between 0 and 4 degrees), and Keid (Hills *et al* 1922), reported that the coal seams in the Dalmayne Colliery dip in a southerly direction at a low angle. The total thickness of sediment varies between 500 and 750 feet, depending on the position in which the Jurassic dolerite was intruded.

At the base of the Triassic System around Mt. Elephant and just south of Gray, there is a granule conglomerate similar to the Sister's Granule Conglomerate at Ray's Hill (Walker 1957). This granule conglomerate is discontinuous and varies rapidly in thickness, e.g., may vary from 40 feet thick to zero in less than 100 yards. It does not appear to be present in the Piccaninny Point square. Graded bedding is common, the graded beds varying from granule conglomerate at the base, to medium coarse sand at the top. The graded beds are never more than 6 inches thick, and are extremely limited in lateral extent. No medium or coarse conglomerates are associated with the basal beds.

The so-called feldspathic sandstones consist of a regular series of subgreywacke sandstone, interbedded with variously coloured shales. Up to seven coal seams are represented, the lowest one occurring within 20 feet of the base of the system at 684,027. Bedding is not well developed, and on weathering, the sandstone becomes grey to buff coloured, and numerous horizontal partings, (about 1 cm. apart) giving it a laminated appearance, tend to become developed. Thinly bedded alterations of sandstone, shale, or carbonaceous matter are quite common.

The rocks are moderately even grained, of fine to medium sand grade, and consist essentially of rock fragments and quartz. Feldspar occurs as twinned plagioclase approximately 0.15 to 0.2 mm. in diameter, (probably andesine). Biotite and muscovite (1 to 2%) occur as long flakes up to 1 mm. long. Quartz particles (15 to 20%, including quartzite and chert) are usually angular to sub-angular, and average 0.2 mm. in diameter. Quartzite particles frequently show evidence of strong deformation, and the quartz fragments exhibit undulose extinction. Rock fragments, excluding quartzite and chert, comprise about 70 to 80% of the rock, and include mudstone, shale, slate, schist, and igneous rock fragments. Some of the fragments have been extensively sericitised. The pieces of fine grained igneous rock consist of interlocking laths of plagioclase (about 0.25 to 0.3 mm.).

The most important fact arising from this description is that these sandstones are not feldspathic sandstones according to any modern classification. Pettijohn (1957), classifies these rocks as lithic sandstones, within the subgreywacke subdivision.

Clay pellets, a few inches in length, and clay lenses up to several feet in length, are extremely common throughout the sandstone. Similar lenses and streaks of carbonaceous matter are also common. Just south of this area at Seymour, four bores have been drilled through the Triassic beds (Hills *et al* 1922), and the ratio of shale to sandstone in the cores is approximately 0.65.

Several thin beds of pebble conglomerate one to three feet thick occur south of Gray. No pebbles of definite Permian age occur in these conglomerates. Cross bedding occurs in a few localities, but is poorly exposed, and no reliable current directions were obtained.

QUATERNARY SYSTEM

Dolerite Talus

Dolerite talus is extensive around St. Patrick's Head, Mt. Elephant, and on the slopes of the hills flanking the coast south of Gray. The scree is up to 200 feet thick, and consists of dolerite pebbles, cobbles, and boulders up to 15 feet in diameter, in a clay matrix. Fragments of feldspathic sandstone are rare.

Around Mt. Elephant, the scree cover extends down to 1300 feet above sea level, i.e., to the top of the Permian or just below it. The cover is not complete, and several large areas of Triassic sediment outcrop within it, often as small cliffs. The talus has been interpreted by Everard (in Hughes 1957), as small sills, but this seems unlikely as wherever the underlying rock is exposed (e.g. in creeks), it consists of Triassic sediment. At the present, with only 200 feet of dolerite on the top of Mt. Elephant there is very little scree forming, and the talus slopes are being dissected and eroded.

South of Gray, the dolerite talus is very extensive, particularly in the Dalmayne area. At 057,677, the talus is only 200 feet above sea level, and extends for 1400 to 1500 feet to the dolerite in situ at approximately 1600 feet above sea level. South of Piccaninny Point, the talus extends to sea level, but here the dolerite occurs at less than 1000 feet above sea level. The talus slopes are now fairly stable and have a thick cover of vegetation.

IGNEOUS GEOLOGY

ST. MARYS PORPHYRY

The St. Marys Porphyry has been described by W. N. Benson for Twelvetrees (1911), and by Walker (1957). Twelvetrees referred to it as a granitic porphyry, but Walter rejected this name in favour of porphyrite. The writer considers the rock to be a biotite, hypersthene, adamellite porphyry.

The St. Marys Porphyry is hard, brittle, blue-grey to light-grey, and varies from strongly to weakly porphyritic. Phenocrysts of plagioclase, quartz and ferromagnesian minerals are usually visible in the hand specimen. The porphyry produced only low grade thermal metamorphism in the Mathinna Beds.

The porphyry is a shallowly dipping intrusion, and underlies an area of at least 33 square miles, including the northern and eastern parts of the Mt. Elephant square. The base of the intrusion is exposed west of Falmouth, and has been described by Walker (1957), who considered that the floor of the mass dipped south at an angle of approximately 15 degrees. In the Mt. Elephant square the top of the intrusion is exposed at 002,792, and 004,777. At 002,792 the top of the porphyry dips to 210 degrees at 10 to 15 degrees, and at 004,777, dips in a south-westerly direction at 25 to 30 degrees.

The thickness of the St. Marys Porphyry is difficult to estimate, but is at least 800 feet (equivalent to a volume of 5 cubic miles), and may be as much as 5000 feet (which would give a volume of at least 32 cubic miles). There is no evidence of multiple intrusion. The most probable thickness is 4000 feet. This figure is obtained after allowing for faulting, by assuming that the base of the intrusion near Falmouth (Walker 1957), and the top at St. Marys both dip in a southerly or south-westerly direction at 15 degrees.

The porphyry was intruded after the folding of the Mathinna Beds, but the structure of the sediments did not influence the form of the intrusion. The porphyry is older than, (not younger, as Walker suggested) and has been intruded and metamorphosed by adamellite east of Mt. Elephant.

Careful examination of the main rock mass has not revealed any preferred orientation, although microscopic flow structures are present at the margins.

A chemical analysis of the St. Marys Porphyry has been published in Spry and Banks (1962).

Rocks similar to the St. Marys Porphyry have been described from Victoria and New South Wales. David (1950) refers to a large mass of hypersthene bearing porphyrite in the Strathbogie area of Victoria, but later writers (White 1953), have considered this rock as a dacite. A similar hypersthene dacite has been described by Edwards (1955), from the Dandenong Ranges, and a quartz, biotite, hypersthene rhyodacite has been described by Thomas (1947), from the Cerberean Ranges. This last rock contains rare phenocrysts of orthoclase, and appears to be very similar to the St. Marys Porphyry.

Petrology

The St. Marys Porphyry is remarkably homogeneous and is always porphyritic, although where the groundmass is coarse the porphyritic character tends to be obscured to some degree. The grainsize of the groundmass varies systematically throughout the intrusion from cryptocrystalline, in and near the chilled border region, to fine grained (0.1 mm.) in the centre. Where the groundmass is relatively coarse, it is difficult to assign an upper limit in size to it, because there is a complete range between the groundmass and the phenocrysts.

No evidence for differentiation was found from a study of thin sections from various parts of the intrusion, or from a traverse up the road from Four Mile Creek to Irish Town, through approximately 1000 feet of porphyry (from 048,761 to 073,768). The data obtained from these thin sections is summarised in Table 1. Specimen A came from 1200 feet above sea level and within 200 feet of the top of the intrusion. The average grainsize of the groundmass increases downwards to a point 800 to 900 feet below the top, where it begins to decrease again. This may mean that specimen D is from near the middle of the intrusion.

Modal analyses were carried out on 24 thin sections, using an intergrating stage, and the average mineralogical composition calculated. Quartz (21.4%), plagioclase (25.6%), potash feldspar (about 1%), biotite (8.4%), and hypersthene (5.8%) occur as phenocrysts in a crystalline groundmass which comprises 37.9% of the rock.

Several slides in which the groundmass is comparatively coarse, were stained with sodium cobaltinitrite (Chayes 1952), to enable potash feldspar to be readily distinguished. Modal analyses showed that about 57% of the groundmass is potash feldspar, 38% quartz, and 5% plagioclase. Thus the approximate mineralogical composition of the rock is—

	Phenocrysts	Groundmass	Total
Quartz	21%	14%	35%
Plagioclase	26%	2%	28%
Potash Feldspar	1%	22%	23%
Biotite	8%	....	8%
Hypersthene	6%	....	6%

Quartz phenocrysts occur as clear, irregular grains, often extremely corroded and poikilitic with pseudo-inclusions or inclusions of groundmass. The largest quartz phenocroyst measured was 6 mm. by 4 mm., but generally the maximum size is approximately 3 to 4 mm., and the average size about 1.5 mm.

Plagioclase phenocrysts are euhedral or subhedral, often slightly corroded, and sometimes appear to have been derived from larger phenocrysts by shattering. They are smaller than the quartz phenocrysts and average less than 1 mm. in diameter. The average composition of the plagioclase (from carlsbad-albite and albite laws) is Ab50, andesine-labradorite, and in zoned crystals the compositional variation is usually from Ab45 to Ab60. The fragments of plagioclase of groundmass size, (i.e., about 0.1 mm.), are more acid and vary from acid-andesine to andesine.

Potash Feldspar phenocrysts are comparatively rare, and are generally clear, undecomposed, and slightly rounded by corrosion. They are free from twinning, average about 0.4 to 0.6 mm. long, and are rarely greater than 1 mm. long. The phenocrysts differ in composition from the potash feldspar of the groundmass. Whereas the feldspar of the groundmass is probably orthoclase, the phenocrysts are sanidine and anorthoclase. The optic angle (2V), of the potash feldspar phenocrysts varied from 28 to 62 degrees.

Hypersthene, light olive grey in colour, forms euhedral to anhedral crystals averaging 0.6 to 0.7 mm. in diameter. The grains are cracked and in-inclusions of groundmass and plagioclase occur. Reaction rims of amphibole are common but the characteristic green-pink pleochroism is not always present. Hypersthene varies from 3 to 9.5% of the rock, and there is a tendency for the percentage to decrease towards the middle of the intrusion. Where hypersthene is lacking, quartz is generally relatively abundant, and vice versa.

Biotite forms between 5.5 and 12% of the rock and occurs in fresh euhedral to subhedral flakes. The flakes are variable in size, ranging from approximately 2 mm. to 0.1 mm. in length. In places the cleavage lamellae have been forced apart by the groundmass. Zircon crystals are present in the biotite.

The groundmass consists of quartz, potash feldspar (probably orthoclase), and plagioclase, in the proportion 7:12:1. It varies in grainsize from 0.009 mm. in the contact zone to 0.1 mm. in the central part of the intrusion.

The plagioclase of the groundmass is acid andesine to andesine, and is generally present in zoned, euhedral crystals. The quartz grains are colourless, and the potash feldspar fills the interstices and was the last mineral to crystallise.

Magnetite, apatite, zircon and topaz occur as accessory minerals.

Contact Zone.

At the contact, quartz phenocrysts comprise 18% plagioclase phenocrysts 11%, ferromagnesian minerals and chlorite 4%, and the groundmass 67% of the porphyry. There are abundant small quartz particles about 0.1 mm. in diameter, which are derived from the greywacke sandstones of the Mathinna Beds. The larger phenocrysts of quartz are well formed with fairly round edges, and are up to 4 mm. long. Plagioclase is not abundant, and is confined to small crystals less than 1 mm. long. The groundmass is very fine grained (about 0.009 mm.), and contains abundant chlorite which is aligned to give a flow structure. This microscopic flow structure is generally sub-parallel to the contact but diverges around and encircles the larger phenocrysts.

A specimen 18 inches from the contact consisted of phenocrysts of plagioclase (19%), quartz (10%), anorthoclase (7%), and ferromagnesian minerals (6%), in a cryptocrystalline groundmass (58%). Anorthoclase occurs as anhedral to rounded crystals which are often slightly cloudy. The largest crystal measured was 4 mm. by 2.5 mm. No sanidine was identified in the contact zone. The plagioclase and quartz grains are badly cracked, and the plagioclase is commonly partly sericitised, particularly in the cores. The quartz grains are up to 2 mm. long, have rounded edges, and show undulose extinction. Some of the grains are composed of a mosaic of quartz particles, resembling strongly deformed quartzite. Biotite is not abundantly developed as phenocrysts, but it does occur in small crystals up to 0.8 mm. long. Generally the ferromagnesian minerals have been altered to chlorite.

A little further from the contact the phenocrysts of quartz and plagioclase begin to break up. A specimen 20 feet from the contact shows quartz phenocrysts shattered into several pieces with groundmass filling the cracks and pushing the pieces apart. This rock is composed of phenocrysts of quartz (19%), plagioclase (27%), chlorite (18%) in a cryptocrystalline groundmass. The groundmass varies from 0.005 to 0.01 mm. in diameter, and there is a poorly developed flow structure present.

TABLE 1.

	A	B	C	D	E	F
Height above sea level	1200	980	840	640	380	180
Locality	004, 761	652, 761	057, 762	061, 762	066, 762	072, 768
Plagioclase (%)	23.4	28.8	25.6	22.1	27.8	20.6
Composition	Ab46-Ab64	Ab44-Ab66	Ab50-Ab60	Ab44-Ab56	Ab40-Ab66	Ab50-Ab66
Maximum Size (mm.)	2.3	2.5	2.0	2.0	13.0	2.0
Average Size (mm.)	0.9	1.0	0.9	0.8	0.8	1.0
Quartz (%)	19.8	22.8	21.1	19.5	23.8	19.2
Maximum Size (mm.)	2.7	5.0	6.0	2.0	4.0	4.5
Average Size (mm.)	1.0	1.0	1.5-2.0	0.9	1.0	1.5
Biotite (%)	11.0	6.1	10.7	11.9	8.2	7.4
Maximum Size (mm.)	1.0	1.0	2.2	2.0	2.0	1.5
Average Size (mm.)	0.6	0.55	0.5	0.6	0.7	0.6
Hypersthene (%)	6.2	4.1	6.5	7.0	3.0	9.3
Maximum Size (mm.)	1.3	1.0	2.0	1.3	1.6	2.3
Average Size (mm.)	0.8	0.5	0.65	0.7	....	0.8
Groundmass (%)	40.5	38.3	36.1	39.5	37.4	43.5
Maximum Size (mm.)	0.3	0.3	0.35	0.4	0.3	0.45
Average Size (mm.)	0.045	0.06	0.07	0.08	0.06	0.065
Potash Feldspar Phenocrysts	Present	Present	Present	Present	Present	Present
Maximum Size (mm.)	0.85	0.50	0.65	0.95	0.65	0.8

Discussion

From the above petrological evidence, there is no doubt that the magma was partly crystallised (about 30%) at depth, before it was emplaced in the Mathinna Beds. The fractured and fragmentary nature of many phenocrysts, especially plagioclase and quartz, and the ruptured twin lamellae and bent biotite flakes, all indicate that strains were imposed on these mineral grains during the process of magma emplacement.

The corroded nature of the feldspar, and the presence of corrosion embayments in the quartz phenocrysts, indicates that the phenocrysts were metastable after intrusion. Rapid cooling forestalled complete reabsorbtion of any mineral, although the relatively high concentration of anorthoclase phenocrysts in the contact zone indicates that most of the potash feldspar phenocrysts were absorbed in the main mass of porphyry. The fact that the potash feldspar phenocrysts are much larger in the contact zone (about 3 mm. in diameter), than in the more central parts of the intrusion, (always less than 1 mm. in diameter), also supports this conclusion.

The presence of sanidine and anorthoclase indicates that the magma was at a high temperature when these phenocrysts were formed. The unaltered state of the anorthoclase in the contact zones indicates that the magma was probably still at a high temperature when intruded.

Walker's original name of porphyrite has been discarded in favour of porphyry. Porphyrite is commonly used for acid rocks rich in plagioclase, but deficient in potash feldspar. Porphyry (Johannsen, p. 276, 1939), is generally used for rocks showing larger crystals in a finer groundmass. Thus as the St. Marys Porphyry contains approximately equal amounts of potash and plagioclase feldspar and is porphyritic, adamellite porphyry is considered a more suitable name than porphyrite.

PICCANINNY CREEK ADAMELLITE

The adamellite and associated granitic rocks (Middle or Upper Devonian) form an elongated stock, the axis of which trends 353 degrees. It outcrops over an area of slightly more than 9 square miles, and is partly obscured by Permian sediments to the north-west, and by alluvium and the sea to the south-east. It intrudes the Mathinna Beds and St. Marys Porphyry with sharp transgressive contacts. South of Wardlaw Creek the contact dips 60 degrees west. The best exposed contacts with the Mathinna Beds occur at Piccaninny Point, and in the lower part of the Elephant Pass section of the Tasman Highway.

The main mass is an adamellite, but granodioritic variations occur along the northern boundary of the mass and at Piccaninny Point. No porphyritic, or muscovite bearing varieties occur. Exposure is poor in the southern part of the stock, where the adamellite forms low hills and the coastal plain, but improves to the north where it rises to over 1000 feet above sea level and has been deeply dissected by small streams.

Walker (1957), mapped a similar granitic rock in the Scamander-St. Helens area, but named it a quartz monzonite. The similarity in appearance, grainsize, texture and mineralogy of the quartz monzonite and adamellite indicates that they are probably equivalent, and part of the same batholith which plunges beneath the St. Marys Porphyry from the north and south. Outcrop to the south of Piccaninny Point is poor, but a granodiorite similar to that at Piccaninny Point occurs on Long Point at Seymour. Further south, around Bicheno, a porphyritic granitic rock, with large phenocrysts of feldspar, averaging 2 to 3 inches long crops out.

Aplitic rocks (quartz 35%, orthoclase 60%, plagioclase 5%), are very common, and occur as small dykes cutting both the adamellite and surrounding Mathinna Beds. They are confined to the border regions of the adamellite, and strike in an east-west direction. Pegmatites are present as dykes in the quarry at 069,674, and as irregularly shaped bodies north of there in a road cutting on the Tasman Highway.

A basic dyke occurs in a road cutting on the Tasman Highway at 057,679. It is about 3 feet wide, dark coloured, vertical, and strikes approximately east-west. The rock is badly weathered, has an intergranular to slightly micro-porphyritic texture and consists of plagioclase (75%), clino-pyroxene (5%), and mesostasis (20%). The plagioclase (Ab50) occurs in laths averaging 0.4 mm. long, and is often corroded and slightly zoned. One or two euhedral phenocrysts greater than 2 mm. long are present. Clino-pyroxene forms small grains averaging 0.1 to 0.2 mm., with some larger crystals up to 0.4 to 0.6 mm. long. The mesostasis consists of fine pyroxene and untwinned feldspar together with abundant iron oxide. Apatite is comparatively abundant (approximately 1% of the rock) and forms euhedral crystals up to 0.6 mm. long.

Contact metamorphism is of low grade, except in one or two places that will be discussed later, (Piccaninny Point, and part of the adamellite—St. Marys Porphyry Contact). Generally the only metamorphic effect that the adamellite had on the Mathinna Beds was a slight recrystallisation and induration and the development of minor biotite.

Petrology

The main mass of granitic rock is an adamellite with approximately equal amounts of potash and plagioclase feldspar. In hand specimen it is a light coloured, medium even grained rock, with visible quartz, feldspar and biotite. It is mineralogically uniform, and there are no porphyritic, or microgranitic variations.

The mineralogical composition of the rock was determined by modal analyses of both thin and polished sections. Both methods yielded approximately the same percentage, and all counts were averaged to find the mineralogical composition to the nearest percent :- quartz 34%, potash feldspar 33%, plagioclase 28%, biotite 4%, hornblende 1%.

Quartz anhedra are often intergrown with potash feldspar, or form sutured mosaics, the component grains of which are characterised by undulose extinction. Undulose extinction is fairly common among the normal ragged anhedra, and the quartz content of the rock varies from 29% to 39%. The average grain size varies from 1 to 1.5 mm., with grains up to 5 or 6 mm. across.

Potash feldspar was the last mineral to crystallise and form anhedra which enclose all other minerals. It forms between 30 and 36% of the rock, and is untwinned orthoclase, or more rarely microperthite. The grains are unaltered, and average 2 to 3 mm. in diameter, ranging up to 6 to 8 mm. long.

Plagioclase occurs in slightly altered, euhedral to subhedral grains and comprises between 24 and 36% of the rock. Slight sericitisation is common, particularly in the cores of zoned crystals. The composition is andesine (approximately Ab60), varying to oligoclase (approximately Ab80) in zoned crystals. The average grain size of the plagioclase is 1.2 mm., and the largest crystal measured was 4.5 by 4.0 mm.

Biotite is the only mafic mineral of any importance in the adamellite, although rare crystals of hornblende are present. It constitutes approximately 4% of the rock, and is generally unaltered although chloritisation has been noted in places. The flakes are small and less than 1 mm. in diameter. Hornblende occurs in aggregates of small crystals each less than 1 mm. long; however, the size of the aggregate may reach several millimetres long.

Small grains of sphene, zircon, apatite and magnetite are present, but muscovite is completely absent.

A more basic, or biotite-hornblende-adamellite, apparently formed by contamination of the magma with Mathinna sediments, occurs along the western boundary of the stock. A specimen from 058,676, consists of quartz 33%, potash feldspar 24%, plagioclase 29%, biotite 9%, hornblende 5%. The biotite and hornblende are present mainly at the expense of orthoclase. The grain size and the quartz and orthoclase are similar to that of the main adamellite. The composition of plagioclase is andesine and in zoned crystals varies from Ab55 to Ab70. Biotite is present in relatively large crystals up to 2 mm. long, and hornblende occurs in large crystals up to 4 mm. long. The contaminated zone is approximately 50 yards wide.

A fine grained porphyritic adamellite sill is exposed in a road cutting on the Tasman Highway at 056,679. The mineralogical composition is: quartz 34%, orthoclase 31%, plagioclase 31%, biotite 4%. The plagioclase phenocrysts are andesine, are slightly sericitised, and occasionally contain small inclusions of quartz. Quartz phenocrysts are not as abundant, and average 1 mm. in diameter varying to a maximum of 4.5 mm. The groundmass consists of small rounded quartz particles (0.1 to 0.3 mm. in diameter), set in orthoclase " cement ".

Granodiorite (at contact with the St. Marys Porphyry)

A small area of granodiorite occurs at the contact of the granitic rocks with the St. Marys Porphyry (087,720). The granodiorite is even-grained and much darker than the adamellite. It consists of anhedral quartz (26%), euhedral to subhedral plagioclase 47.5%, biotite 13%, hornblende 9%, and a little orthoclase 4.5%. Thus the rock approaches a trondhjemite, or tonalite (depending on classification) in composition. The texture is slightly micro-porphyritic, with large phenocrysts of plagioclase up to 5 mm. long. The quartz is generally unstrained, and averages 1 mm. in diameter. The plagioclase crystals average 1.5 mm. in diameter, and vary from 5 mm. to 0.1 mm. Zoning is common, especially in the larger crystals. The composition of the plagioclase except for the few large crystals which are more sodic, (basic oligoclase, Ab70) is andesine Ab56. Sericitisation is common in the large crystals, particularly in the more basic cores. Biotite and hornblende both form euhedral to subhedral crystals that average about 1 mm. in length. Apatite is an important accessory, and is much more abundant than in the adamellite.

At the boundary of the granodiorite and the adamellite, the rock contains approximately 30% ferrogmanesian minerals, (biotite and hornblende). Orthoclase is more abundant, and forms 10 to 20% of the rock. Plagioclase occurs in two distinct sizes; anhedral crystals greater than 1 mm. in diameter, and small lath shaped crystals which are scattered haphazardly throughout all the other minerals, except the hornblende, (i.e., quartz, orthoclase, and biotite). This gives the rock a very distinctive texture. The composition of both large and small crystals of plagioclase is Ab 56. The quartz is clear and unstrained, and twinning is common in the hornblende. The biotite flakes are irregular, and have a sub-ophitic relationship with the plagioclase. The unusual texture and relatively large amount of orthoclase, may indicate that this rock is an adamellite that has been metamorphosed by the granodiorite.

Contact Metamorphism of the St. Marys Porphyry.

The granitic stock is a later body than the St. Marys Porphyry, and has intruded and metamorphosed the porphyry. The contact and metamorphosed porphyry are well exposed in a small creek at 087,721 where numerous xenoliths of porphyry are present in the granitic rock. The porphyry near the contact shows a weak schistosity, a lightening in colour, and a marked increase in the amount of visible biotite. The metamorphosed porphyry is fine, even-grained, and consists of quartz, plagioclase, biotite, clinopyroxene, hornblende, and a little orthoclase. Mineral percentages and sizes vary considerably.

Quartz is present in clear, anhedral grains which are very variable in size. In some cases the quartz has a poikilitic appearance with inclusions of subhedral or euhedral plagioclase, pyroxene and biotite. Some of the quartz grains have recrystallised in optical continuity, forming large areas of granular quartz up to 10 mm. across.

Plagioclase occurs in euhedral to subhedral or lath shaped crystals that vary in size from less than 0.1 mm. to large crystals 5 mm. in width. Frequently the larger grains are composite, consisting of several plagioclase crystals, each of which are about 2 mm. in diameter. They have corroded and irregular edges, but presumably their large size has prevented them from being altered. The composition of the large plagioclase crystals is Ab48, but the smaller lath shaped crystals are more calcic with a composition of Ab42.

Orthoclase is present interstitially, but only in small amounts, and never exceeds 10%. It is generally clear and undecomposed, and is most easily recognised by using staining techniques (Chayes 1952).

Hypersthene and a clinopyroxene (diopside?) are present. The clinopyroxene occurs in small granules, which average 0.1 to 0.2 mm. in diameter, and is much more abundant than the hypersthene. The clinopyroxene is particularly abundant right at the contact, and in some specimens it comprises 10 to 20% of the rock. The amount of clinopyroxene decreases rapidly away from the contact. The hypersthene, which occurred in the original rock as phenocrysts, has been partly or completely altered to hornblende and biotite. In some cases hypersthene is comparatively abundant, and occurs as residual cores up to 0.8 mm. long, in hornblende.

Apatite is present, often in relatively large amounts, (up to 1 to 2%).

During contact metamorphism the first effect of heating was to stimulate a reaction between the hypersthene phenocrysts and the orthoclase of the groundmass, to yield biotite. With more intense heating CaO became available from the plagioclase, and reacted with the biotite to form hornblende (Edwards 1955). The presence of regenerated pyroxene in the contact zone indicates that metamorphism is high grade, and the rocks belong to the Pyroxene Hornfels facies. Of the original rock the quartz, and most of the plagioclase has been recrystallised, only the larger phenocrysts of plagioclase persisting.

A xenolith several feet wide, with a high lime content, was found in the granodiorite near the St. Marys Porphyry contact. The rock is light-grey to blue-grey in colour, and consists of wollastonite, quartz, diopside and a little potash feldspar.

PICCANINNY POINT CONTACT

The contact between the Mathinna Beds and granodiorite is well exposed at Piccaninny Point. The sediments are extremely indurated and veined, and locally, high grade metamorphic temperatures were reached (pyroxene hornfels facies). The contact is partly concordant and dips west at approximately 80 degrees.

Small veins of quartz, aplite, pegmatite and granodiorite 3 to 4 inches thick, are common, and some contain tourmaline. Ptygmatic folding is present, and was noted particularly where a vein cuts across the bedding of the sediments. Veins which are parallel to the bedding are usually straight, although some show a tendency to develop pinch and swell structure. The veins have clear cut boundaries, and appear to have been intruded in a liquid or semi-liquid state. Little granitisation has taken place at the boundaries of the veins (about 1 to 2 mm.) and some have been extensively sheared. A possible explanation of the ptygmatic structures might be sought in a local internal movement of the sediment parallel to the bedding before complete consolidation of the vein material. Such movement would deform the veins cutting across the bedding, but would retain the linear nature, although causing some pinch and swell, of the parallel veins. The sheared nature of some veins also supports this idea.

A well marked parallelism of ferromagnesian minerals and xenoliths, trending between 165 and 175 degrees, occurs within the granitic rocks at Piccaninny Point. Petrofabric analyses have been carried out on several specimens (see page 41). Xenoliths are abundant, and are elongated parallel to the lineation in the granodiorite. They are usually rounded and occur in all stages of assimilation.

Small transcurrent faults, cutting both sediments and granodiorite are common and show horizontal movements of a few inches, to three feet. Fourteen trends were measured, and can be divided into two groups. Those with dextral movement trend between 112 and 125 degrees, and those with sinistral movement trend between 65 and 100 degrees. It can be demonstrated in at least one case that they are conjugate shears. Similar transcurrent faults occur at Long Point, Seymour, about four miles south of Piccaninny Point.

Several aplite dykes approximately one foot thick and trending 100 degrees, cut both the sediments and granodiorite at the southern end of Piccaninny Point.

Petrology

The main mass of granitic rock at Piccaninny Point is biotite, hornblende granodiorite, which has an average composition of : quartz 33%, potash feldspar 20%, plagioclase, 32%, biotite 8.5%, hornblende 6.5%.

In hand specimen the rock appears slightly platy, and is considerably darker than the normal adamellite. The texture is sometimes slightly microporphyritic.

Quartz varies from 28 to 40% of the rock. The quartz grains make up streaky, sutured mosaics, the component grains of which are all characterised by undulose extinction. Individual grains are small (average 0.3 mm.), and are never more than 1 mm. long, although the mosaic patches of sheared quartz are up to 4 or 5 mm. long i.e., about the same maximum size of the undeformed quartz particles in the adamellite.

Plagioclase varies from 27 to 36% of the rock, and occurs in euhedral to subhedral grains averaging 1 to 2 mm. in diameter. The composition is andesine, but in zoned crystals, the outer layers are acid andesine or basic oligoclase.

Orthoclase varies from 11 to 25% of the rock, It is always anhedral, clear and unaltered, and was the last mineral to finish crystallising.

Biotite varies from 6 to 13% of the rock. The maximum grain size is about 2 mm., and the average grainsize 0.7 mm. A few flakes are bent.

Hornblende occurs in euhedral to subhedral twinned crystals or aggregates of crystals, and varies from 4 to 9% of the rock. The average length of the crystals is about 1 mm., with some up to 3 or 4 mm.

In addition to the parallelism in the granodiorite, there is a well marked compositional banding along some parts of the contact. The bands are best exposed in a sill, a few yards away from the main intrusion. The mineralogical composition of the bands sampled are as follows:—

	(1)	(2)	(3)
Quartz	30.8%	34.4%	34.5%
Potash Feldspar	14.7%	22.9%	minor
Plagioclase	30.6%	33.1%	34.7%
Biotite	14.6%	6.6%	22.0%
Hornblende	9.4%	2.9%	8.8%

The bands trend approximately north-south, parallel to the contact, specimen one being nearest the contact, specimen two next, and specimen three farthest away. Each band is 2 to 3 feet thick. The percentages of quartz and plagioclase are fairly constant, but both the ferromagnesian minerals and orthoclase vary considerably. The first two bands could be classified as biotite-hornblende-granodiorite and biotite-granodiorite respectively, but the third band is a biotite-hornblende-tonalite (quartz-diorite), or a biotite-hornblende trondhjemite. The individual minerals are very similar to those already described for the main granodiorite. The textures however, are usually micro-porphyritic, with large phenocrysts of plagioclase up to 6 mm. long. The plagioclase is andesine and the quartz particles are always strained and shattered.

Thermal Metamorphism

The sediments at Piccaninny Point are more highly metamorphosed than the Mathinna Beds at the adamellite contact. Elsewhere the Mathinna Beds have been recrystallised, deformed and extensively veined, but generally the metamorphism is not high grade, and most of the sediments can be classified within the albite-epidote hornfels facies (Turner and Verhoogen 1951).

At Piccaninny Point the metamorphosed sediments are medium to fine grained, and contain biotite, quartz, microcline, cordierite and lesser amounts of muscovite, epidote, albite and chlorite. Biotite flakes are very variable in size, quartz particles are strained, and the potash feldspar and cordierite are usually slightly turbid. Within one slide the grainsize may change abruptly from medium grain, with a mineralogical composition of quartz, microcline, cordierite and biotite, to very fine grained with a mineralogical composition of quartz, biotite, muscovite and chlorite.

In several places a small zone at the contact, less than one inch thick, contains sillimanite and corundum. Abundant biotite and microcline and lesser amounts of quartz, cordierite, and muscovite also occur. Sillimanite is relatively abundant, and occurs as slender prismatic crystals which generally form a felted mass of fibres. Corundum forms 3 to 5% of the rock and occurs in large crystals up to 2 mm. in diameter. Microcline occurs as large xenoblastic crystals up to 3 or 4 mm. long and biotite as flakes averaging 0.5 to 0.7 mm. long.

At the contacts of several small granite veins small crystals of a green spinel are developed, usually surrounded by a reaction ring of muscovite, chlorite, and zoisite. Rare crystals of epidote are also present.

The thermal metamorphism at Piccaninny Point, and the lack of metamorphism elsewhere indicates that the Piccaninny Point area was probably a " high spot " near the roof of the adamellite stock, in which the vapours and fluids of the magma were concentrated.

Petrofabric Analysis

A pronounced megascopic lineation, trending 165 to 175 degrees is present throughout the granodiorite at Piccaninny Point.

Petrofabric analyses were carried out on selected, oriented specimens from the main mass of granodiorite, compositional bands near the sediment-granodiorite contact and a granodiorite sill. Sections were cut perpendicular and parallel to the lineation and the poles to biotite cleavage flakes (001 cleavage) and the optic axes of quartz crystals were plotted on an equal area net (using the lower hemisphere) and contoured.

The analysis of the main granodiorite mass using biotite cleavage flakes is shown in figure 3A. The

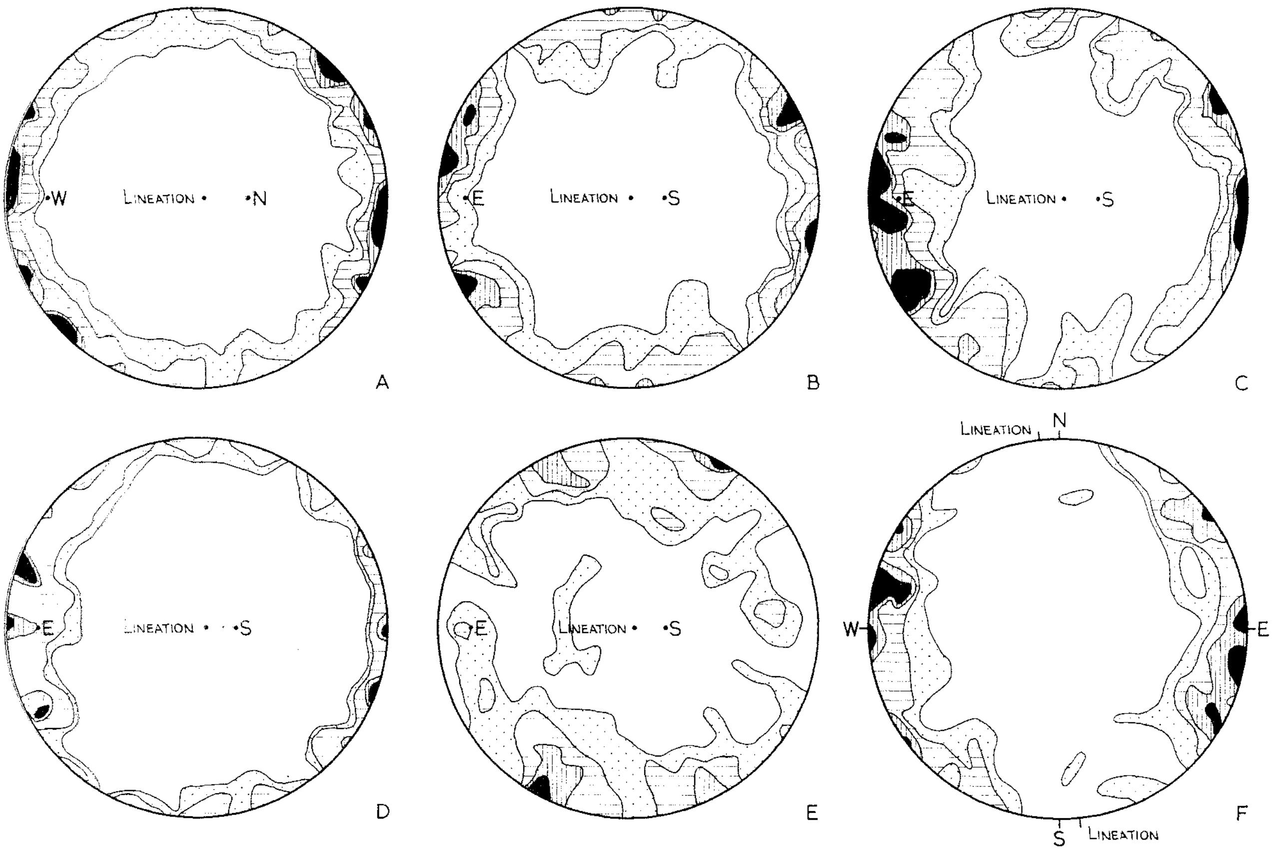


FIG. 3.—Biotite and quartz orientation diagrams (equal area projections). Contour interval—6%, 5%, 3%, and 1%.
3A Poles to 250 biotite flakes, main granodiorite mass, Piccaninny Point.
3B Poles to 160 biotite flakes, band two (see page 40) Piccaninny Point.
3C Poles to 250 biotite flakes, band one (see page 40) Piccaninny Point.
3D Poles to 160 biotite flakes, band one (see page 40) Piccaninny Point. Diagrams 3C, and 3D represent serial sections taken from the same specimen.
3E Optic axes of 250 quartz grains, band one (see page 40) Piccaninny Point.
3F Poles to 200 biotite flakes, band one (see page 40) Piccaninny Point.

plane of the projection is vertical, and two serial sections were used to obtain sufficient biotite flakes. There is a complete girdle of poles with four maxima. If the maxima are grouped together, to give two main maxima, the symmetry is almost orthorhombic. However, the maxima are slightly asymmetric and there is a tendency towards monoclinic symmetry.

The two compositional bands (see page 40) and the granodiorite sill gave similar results, (figures 3B, C. D. E and F).

The mineralogy of the granodiorite indicates that the magma was at least partly crystalline when intruded. The biotite flakes were easily oriented, but the quartz particles were shattered and strained by the orienting forces. If it is assumed that the symmetry of fabric reflects the symmetry of deforming movements, it is apparent that the fabric is due to a combination of both monoclinic and orthorhombic movements. Further, the monoclinic movement appears to have been greatest at the contact, and least near the centre of the granodiorite. This could be explained by assuming that the monoclinic fabric at the contact is due to the drag of the magma against the wall or movement of the magma relative to the wall. This would decrease with distance from the contact. The tendency to form an orthorhombic fabric is due to confining pressure on the magma when intruded, the axis of maximum stress being near horizontal, and striking east-north east, and the axis of minimum stress vertical. This corresponds to the maximum and minimum stress directions at the time of the folding of the Mathinna Beds and probably indicates that the magma was intruded while folding was still active.

JURASSIC DOLERITE

Dolerite occupies almost a quarter of the area, and invariably caps the main hills, including St. Patrick's Head, Mt. Elephant, and the low plateau area south, and south-west of Gray. It is intrusive into the Triassic sediments where it appears to form slightly transgressive sheets. No intrusive contacts with Permian sediments have been mapped.

At St. Patrick's Head there are three possible forms of intrusion to be considered: the intrusion may be sill like, or slightly transgressive; it may be part of a sheet dipping to the west or north-west at 40 to 45 degrees; or it may be a neck of dolerite, cylindrical in plan with steeply dipping or vertical contacts on all sides.

The peak is elliptical in plan, elongated approximately east-west, and above the 1600 foot contour rises very steeply to the summit. This gives the impression in the field that there is dolerite in situ above this level, but definite outcrop does not occur until the 1800 foot contour is reached. All the dolerite is fine grained and can be classified within the lower zone of Spry (1958). If the intrusion was sill like, there must be a lower zone of fine grained dolerite at least 600 feet thick. This is much greater than the figure given by Spry (1958). If it is assumed that the dolerite was intruded as a sheet, dipping west at 30-45 degrees, the apparent thickness of the lower zone would be reduced considerably but would still be in excess of 400 feet. However, there is no evidence for this structure and the writer considers it an unlikely solution.

On the present evidence the last possibility appears to be the most favourable, i.e., the dolerite is in the form of a neck which is approximately 1 mile by half a mile.

South of St. Patrick's Head, Mt. Elephant is capped with 50 to 300 feet of dolerite, in the form of a slightly transgressive sheet.

The south-western and western parts of the Piccaninny Point square are covered by dolerite, but little is known of the form of intrusion. The eastern boundary of the dolerite with the Triassic System appears to be sill like or slightly transgressive in the northern half of the Piccaninny Point square and is repeatedly stepped down to the south by Tertiary faults. In the southern half of this square it may become more transgressive. The maximum thickness is difficult to estimate, but in the south-west corner it probably reaches 800 to 1000 feet. The thickness north-west of Dalmayne and south-west of Gray is rarely more than 200 to 300 feet.

Petrology

The dolerite at the southern end of Mt. Elephant and south of Gray can be classified within Spry's (1958) Lower Zone and consists of plagioclase 46%, pyroxene 45%, and mesostasis 9%. The texture is ophitic to intergranular, and the rock is clear and unaltered. The plagioclase is always labradorite and occurs as small laths averaging 0.3 to 0.4 mm. in length. Augite and pigeonite occur in approximately equal proportions and twinning is common in the pigeonites. The average size of the clino-pyroxene is approximately 0.8 mm. and rare orthopyroxene, possibly enstatite, occurs in well formed crystals up to 2 mm. long. A small amount of intersertal mesostasis is present, and consists of alkali feldspar, a little iron oxide and rare quartz needles.

Modal analyses of specimens from (A) the top of St. Patrick's Head (B) 350 feet, (C) 600 feet below the top, gave the following results:—

	(A)	(B)	(C)
Plagioclase	38.6%	39.9%	39.9%
Pyroxene	44.8%	40.9%	36.6%
Mesostasis	16.6%	19.1%	23.4%

The dolerite is always fine grained, both clino and orthopyroxene are present, and in B orthopyroxene is comparatively abundant. The mesostasis of some specimens appears to have been altered, and is quite dark and turbid, with abundant chlorite and iron oxide.

TERTIARY BASALT

A small exposure of basalt occurs on the north-western slopes of St. Patrick's Head at the 1600 foot contour. It is less than 10 feet thick, and is very limited in area. In thin section it has a microporphyritic texture with phenocroysts of pyroxene set in a groundmass of fine plagioclase laths and intersertal mesostasis. The plagioclase is labradorite and occurs as small lath shaped crystals averaging 0.15 mm. in diameter. The pyroxene (augite and pigeonite) averages 0.4 to 0.5 mm. in diameter and frequently has a sub-ophitic relationship to the plagioclase. The mesostasis is opaque and has abundant iron ore granules scattered throughout it.

STRUCTURAL GEOLOGY

TABBERABBERAN FOLDING

The only major folding of the area occurred in post-Silurian and pre-Permian times, and is considered to be due to the Devonian Tabberabberan

Orogeny. This folding involved only the Mathinna Beds, which were folded about axes that trend north-north-west.

Minor folds are well developed, but in only a few localities can they be studied in detail—notably the Elephant Pass region of the Mt. Elephant square. Several good sections at an angle to the strike occur in road cuttings and creek beds, and all observations on the folding of the area have been based on these outcrops. Forty measurements of minor fold axes have been plotted as figure 4. The figure shows two maxima, and the axis of the regional fold is assumed to be somewhere between them, i.e., about 335 to 340 degrees.

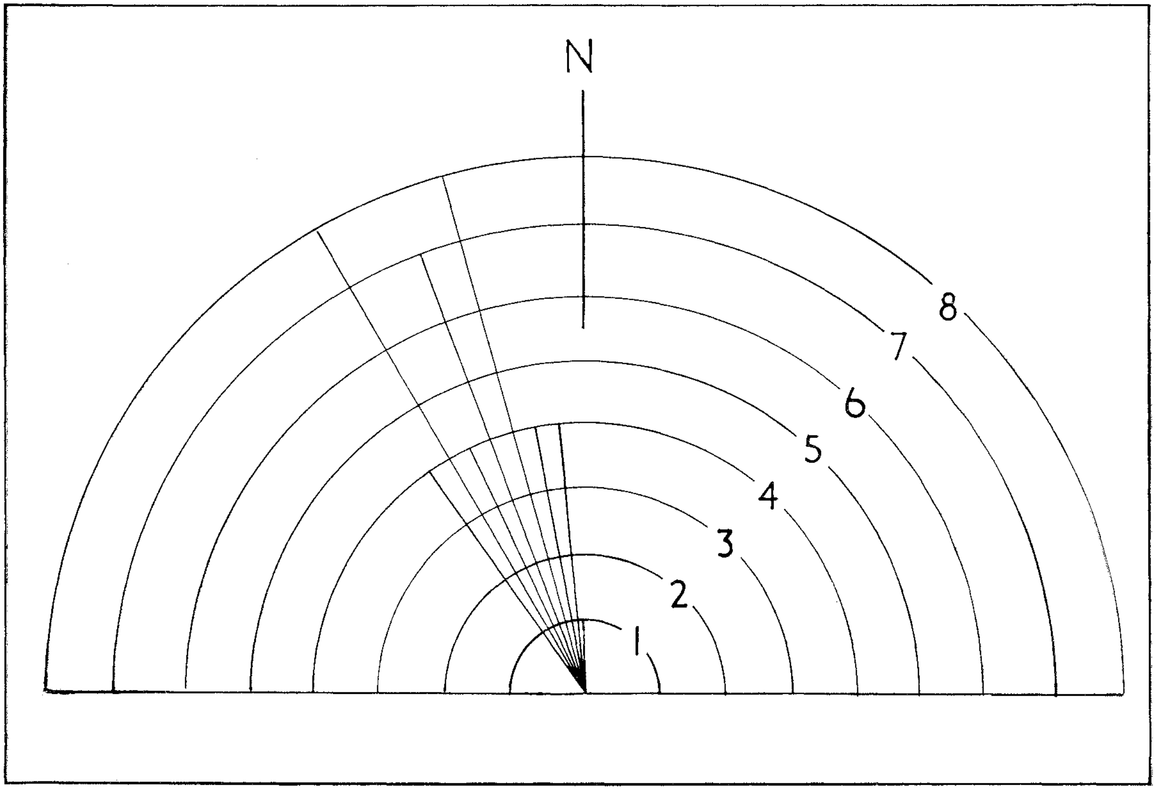


FIG. 4.—Rose diagram showing plunge directions of minor folds in the Mathinna Beds in the Elephant Pass area. Forty minor folds were measured and maxima are at 330 and 345 degrees.

The structure of the Mathinna Beds in the vicinity of the Elephant Pass was analysed by traversing road cuttings on the Tasman Highway, and the neighbouring creeks, including Wardlaw Creek, (figure 5). The fold axes in the Elephant Pass section vary between 340 and 350 degrees, whereas the axes exposed in the creeks, which are 400 feet lower, vary between 320 and 340 degrees. Thus, the minor fold axes swing slightly towards north as they ascend through the structure, (indicating a north pitching anticline or anticliorium to the east). In addition all minor folds plunge towards the north at angles varying between 3 and 30 degrees. Wavelengths vary from 10 to 100 feet.

Section B-B[1] (figure 5) indicates that the dominant dip is towards the west between B and C, a distance of 2700 feet, and that the axial planes of the minor folds dip steeply to the west. Between C and D, the area is more intensely folded, and the axial planes of the folds dip steeply to the east. Between D and E the sediments are still closely folded, but the axial planes of the folds dip east. Section A-A' (figure 5) is parallel to, but about 2000 feet south of, the main section. Although it is not possible to trace individual folds between these sections, the fold at B' of section B-B' is found at A' in section A-A' exactly where it would be predicted.

The whole section appears to correspond to one limb of a major anticlinorium centered east of point B.

A further section of Mathinna Beds is exposed on the coast just south of Piccaninny Point. Here the sediments are very closely folded, generally with axial planes which dip steeply to the west. All the minor folds plunge to the south at angles between 5 and 55 degrees, (average 15 degrees), and it is assumed that the major fold also plunges to the south.

The main structure in the Mathinna Beds appears to be a dome over the adamellite, the regional fold, (anticlinorium) plunging north in the Elephant Pass area and south at Piccininny Point. At this stage it is not possible to determine whether the adamellite occupied a previously formed dome or whether the intrusion actually caused the formation of the dome.

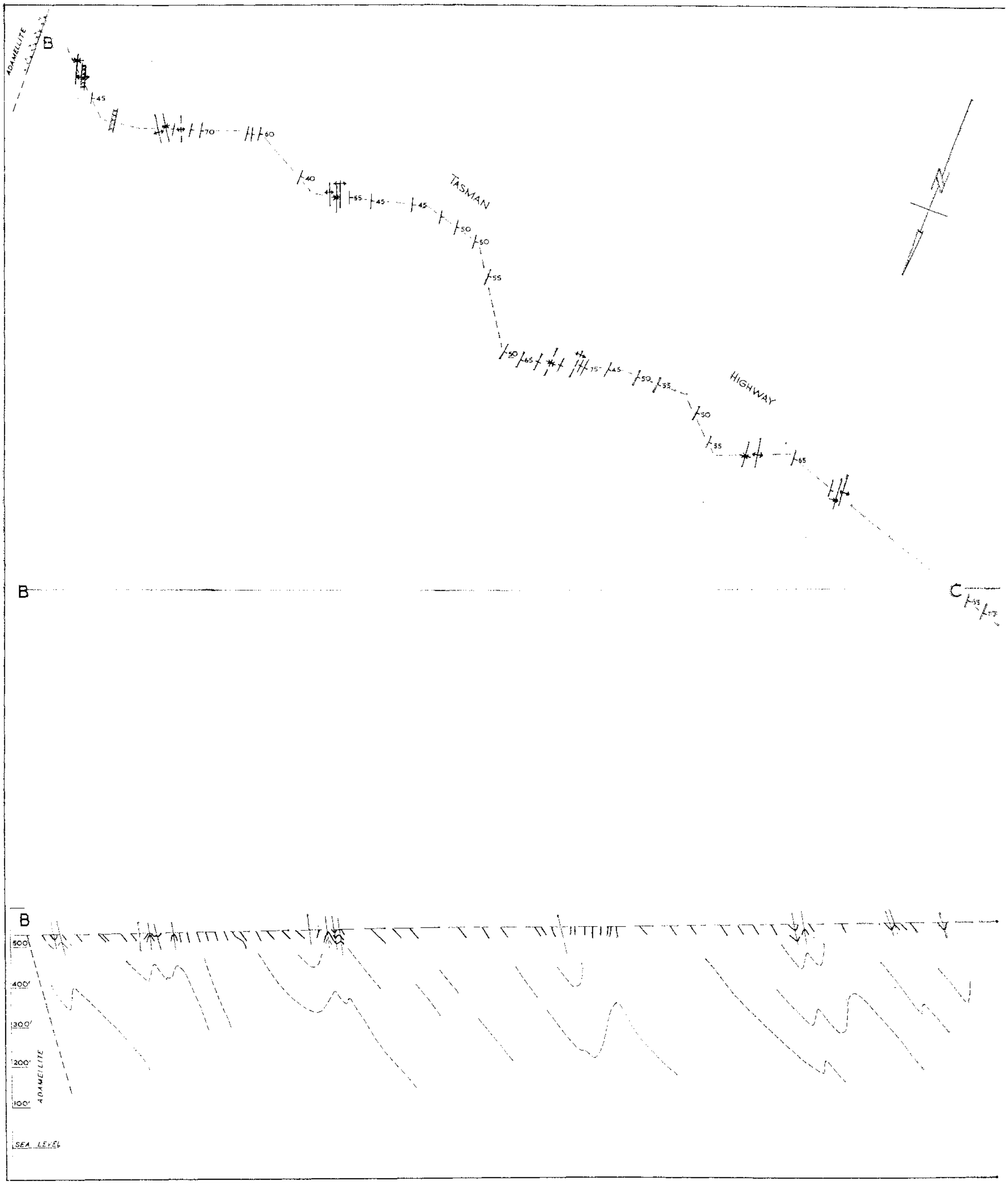
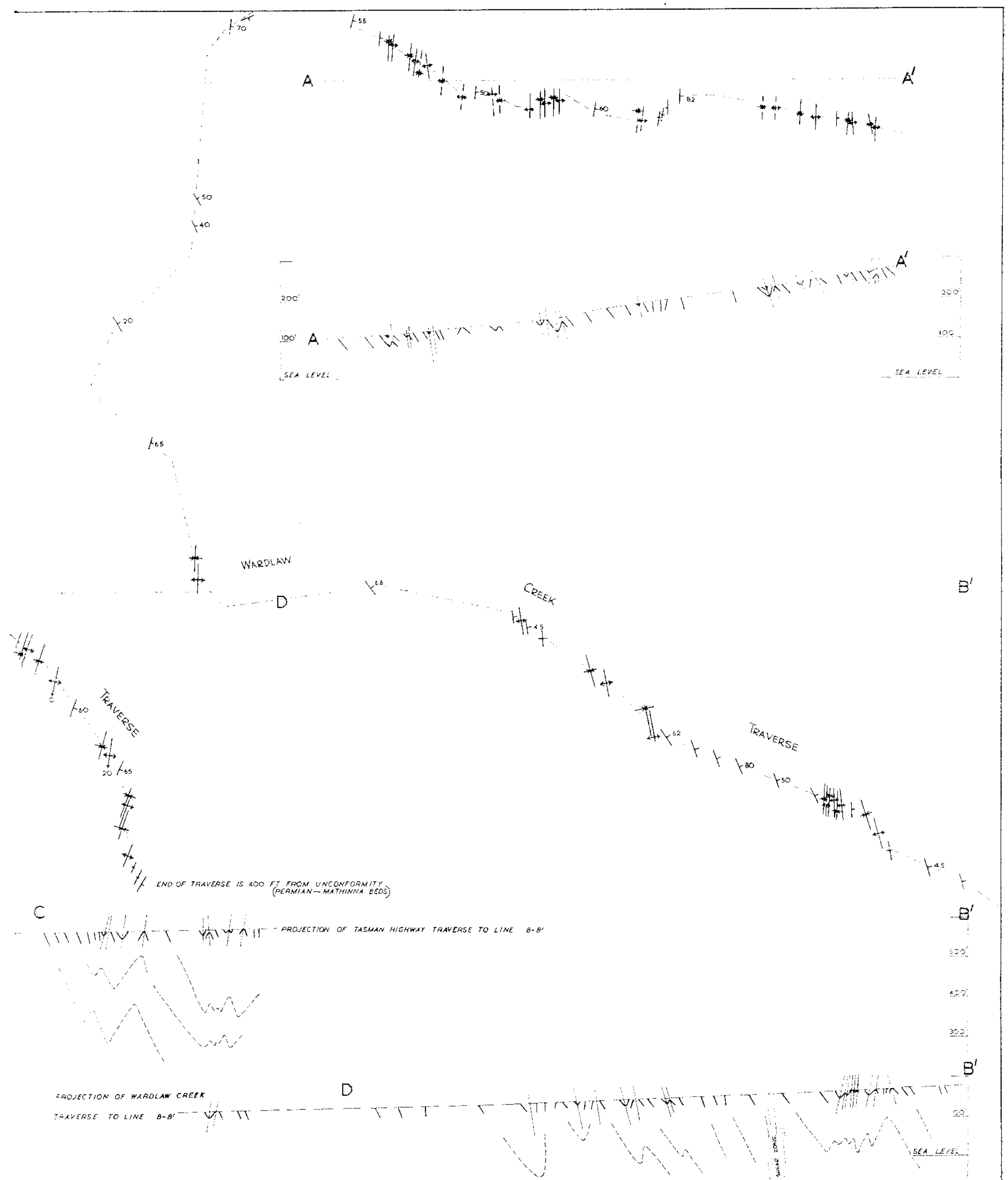


FIG. 5.—Plan and Cross Sections showing structure of Mathinna Beds in the Elephant Pass area.

TERTIARY FAULTING

Normal faulting, which is considered to be Early Tertiary in age (Hills and Carey 1949), has been of moderate magnitude, particularly in the south-western part of the Mt. Elephant square, and in the Piccaninny Point square. Keid's (Hills et al 1922) structural interpretation of the area has been revised, and although the Cornwall Fault exists in the south-west of, and to the west of the Mt. Elehpant square, it is not in the position shown by Keid. The down faulted trough shown on Keid's map in the Dalmayne area does not exist. Figure 6 is a diagrammatic map of the fault system.

The major structure of the region is a graben and horst, the Cornwall Graben occupying the upper part of the Break O' Day Valley between the Silkstone and Cornwall Faults, and the St. Marys Horst occupying most of the Mt. Elephant square between the Cornwall and associated faults, and north-west trending faults in the Falmouth square which have been inferred by Walker (1957). The



Silkstone Fault crosses the Break O' Day Valley in a north-westerly direction, just west of the Mt. Nicholas railway station, and is not shown on the accompanying maps. The position of the faults in the Falmouth square is uncertain, but they must exist as the Berriedale Limestone occurs at Enstone Park, and 1200 to 1500 feet higher on Ray's Hill near St. Marys.

Minor faults (throw of between 0 and 50 feet) are very common and were often encountered during the operation of the Dalmayne Colliery. Minor faults also caused several small mines around Mt. Elephant to be abandoned many years ago.

A marked linear occurs in the St. Marys

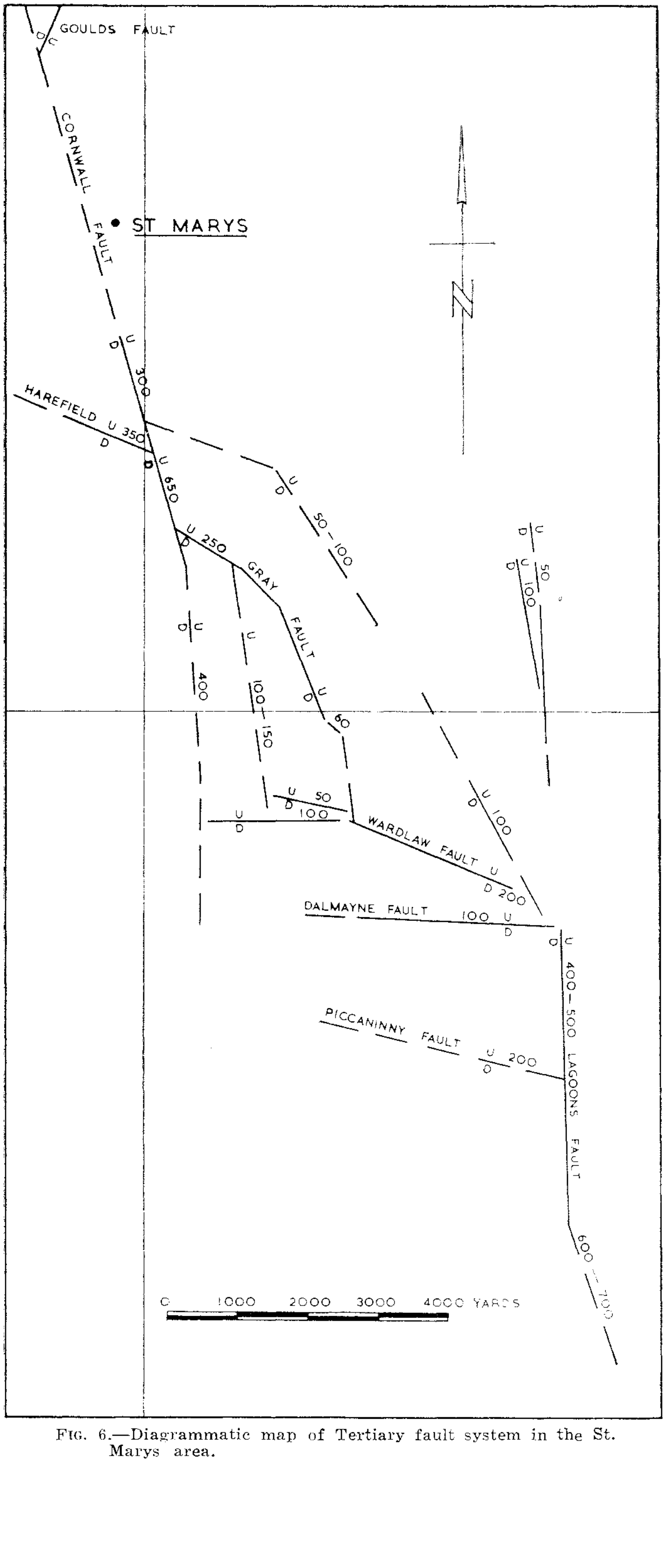


FIG. 6.—Diagrammatic map of Tertiary fault system in the St. Marys area.

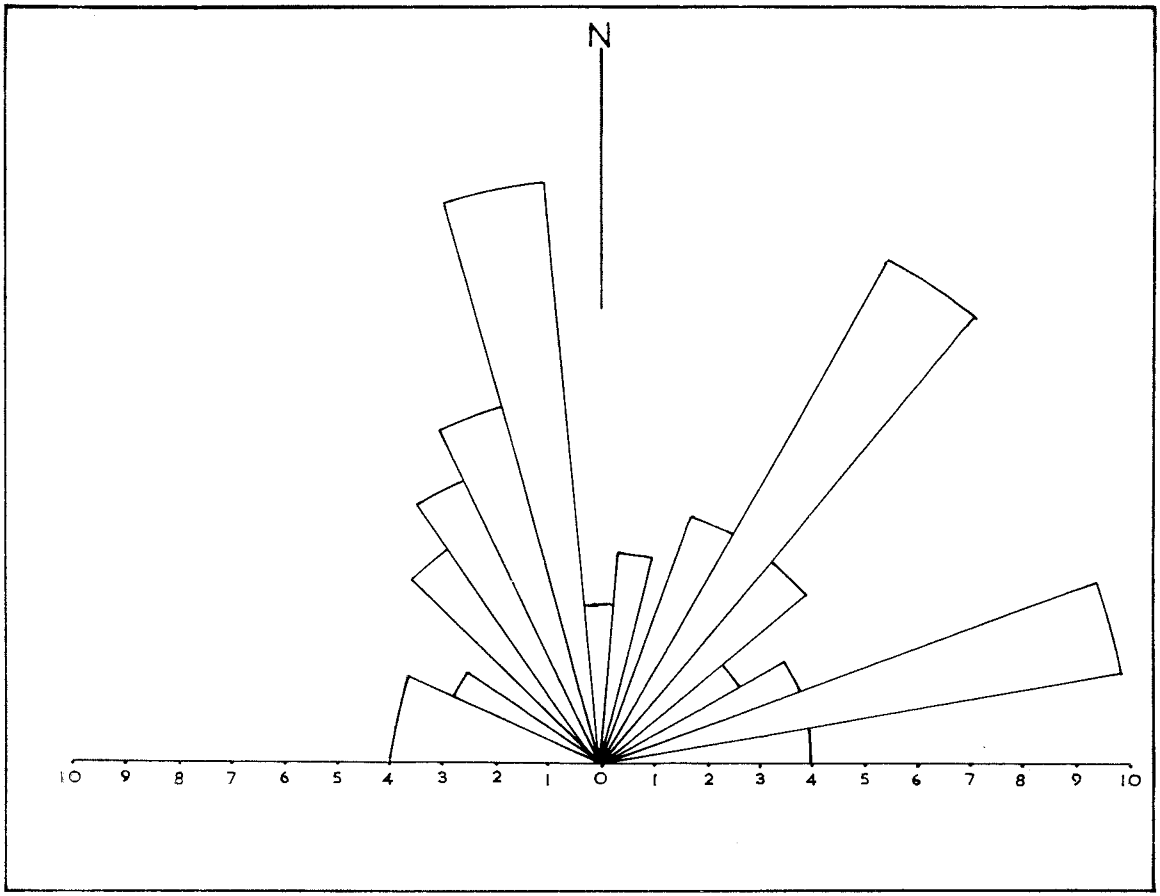


FIG. 7.—Rose diagram showing joint directions in the Permian and Triassic sediments in the Gray-Dalmayne area. Maxima are at 350, 35 and 75 degrees.

Porphyry to the north-east of Mt. Elephant. It strikes north-east and follows the valley of Four Mile Creek, but does not cut the overlying Permian beds. and is probably a pre-Permian fault.

JOINTS

Joints were measured in the Permian and Triassic sediments. The majority of joints are cnetrated along the following trends: 350, 35 and 75 degrees (figure 7).

Joints in the St. Marys Porphyry were measured at widely scattered outcrops over the whole intrusion and the poles to the joints were plotted on a stereogram (figure 8). Major maxima (8%), occur at 350 and 40 degrees, corresponding to two sets of vertical joints striking at 80 and 310 degrees respectively. Minor maxima (6%) occur at 85 and 310 degrees, corresponding to two sets of vertical joints striking 355 and 40 degrees respectively.

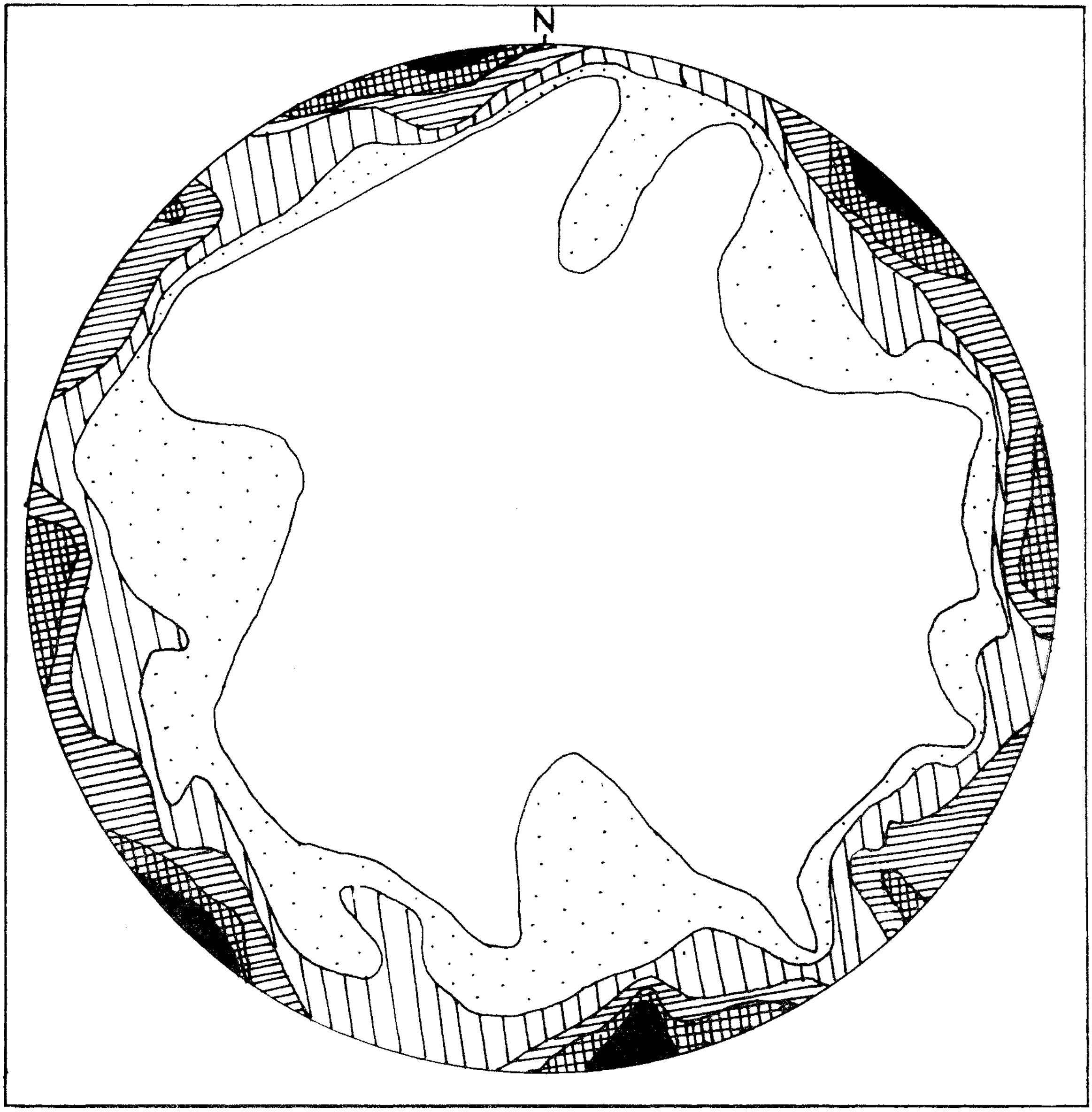
The 350, 35 and 75 degree trends in the sediments are probably equivalent to the 355, 40 and 80 degree trends in the St. Marys Porphyry.

SUMMARY AND CONCLUSIONS

The oldest rocks exposed are Upper Silurian and, or, Lower Devonian in age, and consist of monotonous, well bedded greywacke sandstones, greywacke siltstones, and mudstones. The sediments are mainly turbidity current deposits, the currents originating to the south-west and west.

The Middle Devonian Tabberabberan Orogeny caused shallow folding of the Mathinna Beds, with very little accompanying metamorphism. The main fold structure postulated is an anticlinorium, which trends N.N.W. east of the Elephant Pass.

At or near the end of the folding, the St. Marys Porphyry was intruded in the form of a thick sheet or lens shaped intrusion, approximately 4000 feet thick. The porphyry was partly crystalline and at a relatively high temperature (sanidine and anorthoclase are present) when intruded. The St. Marys Porphyry was followed by an intrusion of adamellite which metamorphosed the porphyry along its southern boundary. The adamellite was intruded along the axis of an anticlinorium



POLES TO 185 JOINT PLANES IN THE ST MARYS PORPHYRY.

EQUAL AREA PROJECTION. CONTOUR INTERVAL 8,6,4,2 & 1%

(Carey's Ringarooma Anticlinorium). The intrusion may have domed up the Mathinna Beds slightly. Contact metamorphism is generally slight, but at Piccaninny Point the granitic fluids and gases were concentrated and high temperature thermal metamorphic rocks which contain sillimanite, corundum, cordierite, microline and andalusite were developed.

Peneplanation, which followed the Tabberabberan Orogeny, appears to have been fairly complete, except to the east, where the resistant St. Marys Porphyry formed low hills at the beginning of Permian sedimentation.

Permian sedimentation (with marked unconformity to the Mathinna Beds), probably began in the Lower Artinskian, and continued through to the Kungurian or later. The sediments are dominantly marine, and consist of sandstones, greywacke sandstones, greywacke siltstones, limestones and mudstones.

Above the Permian System were deposited at least 700 feet of sandstone, granule conglomerate, and subgreywacke sandstone of Triassic age. Disconformity is indicated by the presence of basal sandstones and granule conglomerates, which thicken and thin rapidly and are probably infillings of former valleys; and by the variable thickness of the Ferntree Mudstone which was probably partly eroded before the deposition of the Triassic sequence. The Triassic sediments were deposited in a series of large shallow lakes. The climate was probably hot and humid and there was sufficient vegetation to allow the formation of allochthonous coal seams up to 16 feet thick.

Triassic sedimentation was probably terminated by the intrusion of dolerite during the Jurassic. Peneplanation after the intrusion of dolerite and tensional faulting in the early Tertiary, followed by normal weathering and erosion has produced the present day topography.

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