# Geology and Petrology of the Enoggera Granite and the Allied Intrusives.

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## PART II.—PETROLOGY.

(Plates I.-III.)

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## I. INTRODUCTORY.

In November, 1914, the author had the privilege of reading before this Society the first part of a paper entitled "Geology and Petrology of the Enoggera Granite and the Allied Intrusives."[1] This dealt with the general geology of the area, and it was the author's hope that it would be followed, after a short interval, by the second part of the paper, which was to deal more particularly with the Petrology. Much of the work required for this part of the paper had been done, but its publication has been very much delayed, chiefly as the result of the author's absence abroad with the Australian Imperial Forces.

[1] Proc. Royal Soc. Qld. Vol. XXVI. p. 141.

## II. GENERAL PETROLOGY.

The rocks dealt with fall into two main groups—viz., the granitic and granodioritic rocks forming the outcrops at Enoggera, Green Hill, and Kedron Brook, and intrusives of a rhyolitic and porphyritic nature which are intimately associated with the former series, and which are believed to be genetically related to them.

The former group is called locally the "Enoggera Granite," and is best known from the building stone which has been very largely used in and about the city of Brisbane, and which is obtained from a quarry on the left bank of the Enoggera Creek. This rock has been dealt with by Professor H. C. Richards, D.Sc., mainly from the economic aspect.[2] This particular variety cannot, however, be regarded as typical either of the group of granitic rocks as a whole, or even of those forming the outcrop of the principal Enoggera area.

The most marked feature of the granitic group petrologically is the wide variation of type to be met with for such a restricted area of outcrop. This variability is both chemical and textural. Mineralogically the variation is not so marked, the different rock types resulting rather from differences in the proportion of the minerals present than in actual differences in character and appearance of the minerals themselves.

In the face of such wide differences in the field it is at first difficult to generalise, but it seems to the writer that this variability can be revolved into—

(1.) Two main phases, which for convenience we may term the Pink and the Grey, which differ chemically as shown by a comparison of the Rock Analyses E1 and E4, and mineralogically in the proportions of the minerals present.

[These were referred to in the earlier part of this paper (p. 150) as the "adamellite type" and "granodiorite type" respectively. While the author has every reason still to regard the "Grey Phase" as being essentially granodioritic, he now doubts the wisdom of referring to the "Pink Phase" as an adamellite type. If one

[2] Proc. Royal Soc. Qld. Vol. XXX. p. 101, and Plate X., fig. 13.

uses Hatch's simple criterion[3] then since the Orthoclase and Plagioclase felspars are present in approximately equal amount the rock is an adamellite. Further, the analysis of the Pink Phase (Analysis I.) is remarkably close in all its essentials to that quoted by Hatch p. 179, as "iv. Adamellite, Shap."[4] However, these analyses also agree in differing somewhat sharply, both in amount and proportion of the alkalies, from Analyses I., II., and III., which are presumably more typical adamellites.]

(2.) A wide variability within both the light and dark phases, which, however, is textural merely and not chemical, as is seen by a comparison of the mineral contents of specimens very dissimilar texturally, which show plagioclases of the same chemical composition and in which the other minerals are identical.

(3.) In addition to the former varieties we occasionally get others which depart rather widely from the more typical rocks in the proportion of the minerals present. Of these, only one forms outcrops of any importance, and this is remarkable in that it appears to have some important characteristics in common with each of the phases. It is not so much a mineralogical average of the Pink and Grey Phases as a mineralogical mixture. At first sight it appears to represent a connecting link between the phases, but the discussion of this question is deferred. The rock in question is to be seen outcropping at the Quarry on Enoggera Creek.

One might reasonably expect that such marked chemical differences as those shown in the analyses (E1 and E4) of the two phases would be reflected in their distribution in space or in time.

With regard to distribution in space, rocks representative of the Pink Phase cover roughly three-quarters of the main Enoggera area of outcrop and all of the Green

[3] Hatch, "Petrology of Igneous Rocks," p. 164.

[4] Op. cit. p. 171.

Hill area, while the Grey Phase occupies one-quarter of the Enoggera area and the whole of the two outcrops at the Kedron Brook area. Further, the latter phase is usually restricted to the more deeply dissected or more central portions of the Enoggera area, the highest points and peripheral portions being almost invariably occupied by the aplitic, fine-grained and "sandy" granites which form a distinct type of the Pink Phase. The vertical section in the central part of the Enoggera area, obtained by descending into the valley of the Enoggera Creek from the heights lying to the north, gives in descending order the following sequence:—

$\left.\begin{array}{l}\text{Aplitic and ``sandy'' granites}\\ \text{Typical Pink Phase}\end{array}\right\}\text{Pink Phase.}$

Pink Phase with included fragments of Grey Phase.

Typical Grey Phase.

A similar sequence is often, but not always, found in passing from the periphery towards the centre of the area.

This arrangement of the dark and light phases seems at first glance to suggest a differentiation into two main types as the result of gravitative separation, but a closer study of the relationship of the phases does not support such an hypothesis.

The only indications which have been noted which suggest any difference in the time of intrusion of the two phases appear at first sight to be contradictory.

In some sections the Grey appears to intrude the Pink Phase as dykes, but in many other sections it is definitely surrounded by the Pink Phase and forms irregular inclusions or "segregations" of very variable size. While some of the smaller of these are undoubtedly segregations in the strict sense of the word, the vast majority of the larger ones appear to be fragments caught up by the enclosing magma.

There is thus some evidence that part at least of the Grey Phase is later in age than the Pink, but the weight of evidence points to the Pink as being the later phase. These two groups of evidence, though apparently contradictory, may perhaps be reconciled in the following way:—The Pink appears to have broken through the Grey rock, carrying fragments of varying size with it. Later the underlying dark rock may, as the result of heat or pressure changes, have become molten again and have been forced up into the cooler overlying Pink Phase as intrusions.

The field evidence thus appears to indicate that the two phases are not the result of differentiation in place, either by gravitative or other methods, and that the Pink Phase is younger than the Grey, and that, further, the aplitic and sandy granites are later than the more normal type of the Pink Phase. Thus we see that the order of succession is Grey Phase followed by typical Pink Phase, which in turn is followed by the aplitic and "sandy" granite types of this phase, with finally a reversion to the basic or Grey Phase. This is the order of primary differentiation of Brögger, who, to quote Harker, believes in "an order of increasing acidity with in many instances a final reversion to basic types."[5]

It is interesting to note that this relationship is strictly analogous with the sequence of intrusions in New England, the Moreton district of Southern Queensland, and that of Charters Towers of Northern Queensland, but more detailed comparisons with these areas are made later in the paper.

The following rock analyses give a general idea as to the chemical relationships of the two phases. Analysis E1 is that of a rock selected as typical of the Pink Phase, while Analysis E4 is that of a rock typical of the hornblendic type of the Grey Phase. Analysis E2 is the only other analysis from the area and is that of the "Enoggera Granite" used largely as a building stone, and which mineralogically presents important points of similarity with both phases. Analysis E3 is that of the Mountain Camp rock, a few miles to the north of Enoggera.

The precise position of E2 and its relationship to the Pink or to the Grey Phases is a question about which the author has long been in doubt. In appearance it resembles neither a typical granite nor a typical granodiorite. The grey colour, the relative basicity of the plagioclases, the absence of pink orthoclase and the abundant pyrites were all points in common with the Grey Phase, but the high acidity of the rock and the marked

[5] Eruptivgesteine des Kristianiagebietes," II. (1895), pp. 165-181.

preponderance of biotite and the specific gravity were factors in common with the Pink Phase.

TABLE 1.

| —— | Pink Phase. E 1. | Grey Phase. E 4. | (?) Hybrid. E 2. | Calculated Rock. A. | Mountain Camp Rock. E 3. |
|---|---|---|---|---|---|
| $SiO_2$ | 73·52 | 61·10 | 71·50 | 70·41 | 61·54 |
| $Al_2O_3$ | 11·05 | 19·24 | 14·13 | 13·10 | 19·03 |
| $Fe_2O_3$ | Nil | 4·66 | 0·60 | 3·53 | Nil |
| FeO | 3·15 | | 3·23 | | 5·04 |
| MgO | 1·03 | 2·56 | 1·17 | 1·41 | 2·97 |
| CaO | 1·70 | 5·25 | 2·70 | 2·59 | 4·90 |
| $Na_2O$ | 4·08 | 3·82 | 2·97 | 4·01 | 2·84 |
| $K_2O$ | 3·99 | 1·68 | 2·86 | 3·41 | 2·76 |
| $H_2O$ + | 0·44 | 1·31 | 0·32 | 0·66 | 0·35 |
| $H_2O$ − | 0·16 | 0·64 | 0·10 | 0·28 | 0·10 |
| $CO_2$ | .. | .. | .. | .. | .. |
| $TiO_2$ | 0·20 | .. | 0·41 | .. | 0·72 |
| $P_2O_5$ | 0·15 | .. | 0·35 | .. | 0·08 |
| Total | 99·48 | 100·26 | 100·34 | 99·40 | 100·33 |
| Sp. Gr. | 2·58 | 2·71 | 2·59 | .. | .. |
| NORM | | | | | |
| Quartz | 30·24 | 14·82 | 34·32 | .. | 15·00 |
| Orthoclase | 23·35 | 10·01 | 16·24 | .. | 16·68 |
| Albite | 34·58 | 32·49 | 25·15 | .. | 24·10 |
| Anorthite | .. | 26·13 | 11·40 | .. | 24·46 |
| Diopside | 6·34 | .. | .. | .. | .. |
| Corundum | .. | 1·43 | 1·84 | .. | 2·24 |
| Hypersthene | 4·67 | 11·55 | 8·52 | .. | 16·64 |
| Magnetite | .. | 1·86 | 0·93 | .. | .. |
| Ilmenite | 0·46 | .. | 0·76 | .. | 1·37 |
| Apatite | 0·34 | .. | 0·67 | .. | .. |
| Symbol | I. 3.1.3.(4) Alaskose | II. 4.3.4 Tonalose | I. 3.2.3 Tehamose | .. | II. 4.3.3(4) Harzose |

This rock, as the result of the opening of new quarries, has proved to be considerably more extensive than the author first thought. If, as its mineralogical contents and chemical composition both suggest, it is related to *both* phases, there are only three possible modes of origin—

(1.) That it is the parent magma from which both the Pink and Grey Phases sprang;

(2.) That it is an intermediate member of a series E1-E2-E4, thus linking the two phases; or

(3.) That it is the result of admixture of the Pink and the Grey Phases.

The first idea that it may represent part of the parent magma or undifferentiated portion is refuted by the evidence as to the two main magmatic series in Southern Queensland, to be discussed more fully later in the paper. Further, in the light of modern petrology we can hardly postulate the splitting of such a magma as that represented by Analysis E2 into two parts such as those we see in analyses E1 and E2. Such an hypothesis as the second might explain the intermediate chemical composition, but does *not* explain the mixed mineralogical nature of the rock.

The only alternative remaining is that this curious rock is produced by admixture of two distinct rock types. It seems to be what Harker terms "a hybrid."

By weighting the Analyses E1 and E4 in the proportion 3:1 (a ratio already mentioned as that of the outcrops of the two phases in the somewhat deeply dissected Enoggera area) we obtain the hypothetical rock which would be produced by the admixture of the Pink and Grey Phases in the proportions in which we believe them to exist. The chemical composition of such a rock is represented by Analysis A, which is seen to agree quite closely in many respects with Analysis E2.

In comparing the calculated Analysis A with the actual Rock Analysis E2, it is seen that while the value of the calculated CaO is somewhat less than the actual, both the alkalies are considerably in excess, although the proportion $K_2O$ : $Na_2O$ is much the same. This is not unexpected, for Harker[6] in discussing the calculation of the chemical composition of hybrid rocks points out that while in bulk the hybrid rock must be a linear variation of the two unmixed rocks, differences may be expected in the chemical composition of the rock specimens analysed. The example quoted by this eminent authority resembles the present case in that the CaO found in the hybrid rock is less than the calculated, the difference being that in Harker's case the discrepancy is considerably greater. This is explained by Harker as probably due to difference in the rate of diffusion of CaO on the one hand and of the alkalies on the other. Hence the divergences to be expected are precisely those found to exist in the present case. The calculated value of CaO will be less than that of the actual, while that of the alkalies will be greater and further as the rates of diffusion of the potash and soda molecules are very nearly identical, the proportion $K_2O$ : $Na_2O$ as calculated should agree very nearly with the proportion found by actual rock analysis.

[6] "The Natural History of Igneous Rocks," p. 358.

If, then, the rock is a hybrid, we might expect it to betray its mixed origin more directly in its chemical composition. The most remarkable feature of the Analysis E2 is the practical equality and low values of CaO, $Na_2O$, and $K_2O$. In this combination the analysis differs markedly from all the analyses of average acid plutonic rocks compiled by Clarke, Daly, and Osann, to which the author has access. Further, a search was made through the ninety-six analyses of rocks placed in the same subrang (Tehamose) in Washington's "Superior Analyses of Fresh Rocks" for similar types.

A noticeable feature of the analyses was the wide range in the absolute and relative values of CaO, $Na_2O$, and $K_2O$, a point to which the author naturally gave much attention. One analysis was found which is remarkably close to E2, especially in the alkalies and alkaline earths; but—and this the author considers very significant—it is not strictly an igneous but a metamorphic rock. It is No. 9 in Washington's list for the subrang, and is described as a granite gneiss from Virginia, U.S.A.[7]

The analysis next most like that in question is No. 2, a Hypersthene Adamellite from Havnefjord, Ellesmere Land, and is patently not a normal granitic type. No. 61, Tonalite Porphyrite, from the Tyrol, and No. 65, Adamellite from Switzerland, approach the Enoggera hybrid in some respects, and a curious series of rocks from Japan, notably the "Granite" No. 79, seems to provide a somewhat similar rock.

The evidence, on the whole, seems to uphold a hybrid origin for the Enoggera building-stone.

It is interesting to note here that Jensen suggests that the Cooroy Monzonite and the Pt. Arkwright Porphyrite, both some 75 miles to the north of Enoggera, are "made up of a mixture of a dioritic magma with the aplitic differentiation product . . . ."[8]

Further consideration of this important question of hybridism in the Enoggera area will be given in that portion of the paper dealing with comparisons of the local granitic rocks with those of other areas.

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[7] "A Description of the Quantitative Classification of Igneous Rocks," 1918, p. 81.

[8] "Geology of the Volcanic Area of the East Moreton and Wide Bay Districts, Queensland." Proc. Linn. Soc. N.S.W. 1906, p. 132.

## (III.) PETROGRAPHY.

### (*a*) The Pink Phase.

This phase is characterised by its high acidity and the consequent presence of quartz in considerable amount; by its pink orthoclase, which is usually slightly in excess of a white soda rich plagioclase, and which gives the rock its typical colour; and by biotite, which is usually present though not in any great amount. Hornblende is either absent or rare. Pyrites is absent. Associated with the Pink Phase proper are modifications of it of an aplitic and granophyric nature, which occur generally near the margins of the granite and capping the higher hills, and sometimes as distinct intrusions through the Pink Phases. These modifications are slightly later in time of intrusion than the typical pink rocks, and are almost certainly the equivalents of the "Euritic" series of Andrews and the "Aplites and Sandy Granites" of Saint-Smith in New England and Stanthorpe respectively (*see* Table II.). In the Enoggera area they are so intimately associated with the Pink Phase proper that it does not seem advisable to treat them as a separate group.

The following descriptions give some idea of the rock types found in this phase.

The bracketed numbers refer to the special "Enoggera" collection of rocks, while the other numbers are those of the collection of Microslides. Both are the property of the Geology Department, University of Queensland.

(*G. 1*) 141. (*See* Micro-photograph Pl. II., No. 1, and analysis E1.)

Specimen from southern part of main Enoggera mass.

*Megascopic.*—A pink holocrystalline, porphyritic rock, composed of medium-sized phenocrysts of quartz, pink orthoclase, white plagioclase and black mica set in a fine-grained flesh-coloured ground mass.

*Microscopic.*—The porphyritic character of the rock is marked and the proportion of phenocrysts to ground mass somewhat variable (Sempatic to Dopatic of Iddings). The *ground mass* is made up for the most part of quartz and felspar, sometimes irregularly intergrown, with occasional small crystals of green biotite. The *quartz phenocrysts* are from 1-3 mm. in diameter and occur as allotriomorphic and rounded crystals, frequently fractured and containing numerous dust-like inclusions. In addition to these there are other small inclusions of biotite and larger ones of orthoclase and plagioclase. In one quartz crystal is enclosed an aggregate of quartz and felspar closely resembling the ground mass, but this may be the infilling of a deep embayment. *Orthoclase* occurs as hypidiomorphic phenocrysts which are considerably altered. These often include patches of another felspar intergrown in perthitic fashion. The *plagioclase phenocrysts* prove to be Albite-Oligoclases, and occur as large hypidiomorphic crystals which exhibit twinning on both the Carlsbad and Albite laws. *Biotite* occurs as brownish-green phenocrysts which become reddish-brown on alteration, and which show the characteristic strong absorption and perfect cleavage. Inclusions of zircon and apatite are sometimes found. *Magnetite* occurs in idiomorphic crystals and a few needles of *Apatite* are present. *Zircon* is present in small amount.

Order of consolidation of phenocrysts.—Normal.

In the ground mass quartz and orthoclase solidified at approximately the same time.

*Name.*—Granite Porphyry.

*Note.*—Among the many recommendations embodied in the "Report of the Committee on British Petrographic Nomenclature" is one that "The name granite-porphyry is ambiguous, and should not be used." This name has found considerable use in Australian petrographic literature, where it has a quite-definite meaning. The rock described above is so like many other Australian so-called "Granite-porphyries" that, principally for purposes of correlation, the author has deemed it wise to retain the term.

(*G.2*) 150. (*G.4*) 152.

These two specimens also come from the southern part of the Enoggera area. They are very like the rock described above in most respects, but there is seen in these slides a definite tendency for the felspar phenocrysts to be closely grouped together.

(*G. 8*) 156.

This specimen comes from the N.N.E. portion of the main Enoggera outcrop.

*Megascopic.*—A pink medium-grained rock made up of colourless quartz, pink orthoclase and white plagioclase, together with a little green mica.

*Microscopic.*—Holocrystalline rock of medium and fairly even grain. *Quartz* occurs in allotriomorphic crystals from 1-4 mm. in diameter. It is fresh, shows radiating fractures, and contains numerous large inclusions of felspar and many dust-like inclusions. *Orthoclase* is present generally in somewhat altered crystals, from 2-4 mm., showing Carlsbad twinning. Inclusions of both plagioclase and biotite occur. The *Plagioclase* felspar is a somewhat acid andesine. It occurs in smaller crystals than the orthoclase, and shows both Carlsbad and Albite twinning. Microcline is also present showing the characteristic combination of Albite and Pericline twinning. *Biotite* occurs as a few comparatively small dark green crystals which are partly altered to chlorite and contain a few inclusions of apatite. *Magnetite* is present in small amount and shows in places alteration to Limonite.

Order of consolidation.—Normal.

*Name.*—Biotite Granite.

(*G. 9*) 157.

This specimen comes from N.N.W. part of the Enoggera area.

*Megascopic.*—A medium-grained pink rock made up of colourless quartz, pink orthoclase, cream plagioclases, and a dark mica.

*Microscopic.*—Holocrystalline, medium grained. *Quartz* occurs as numerous allotriomorphic and interstital crystals from 1-3 mm. in diameter, considerably fractured, with inclusions of plagioclase, orthoclase, biotite, and apatite, and numerous small dust-like inclusions. Quartz also occurs intergrown with orthoclase and rarely as inclusions in orthoclase crystals. *Orthoclase* occurs in hypidiomorphic and allotriomorphic crystals from 1-3 mm. in diameter. It usually shows some alteration to sericite or other micaceous products. It is sometimes intergrown with quartz and often shows inclusions of plagioclase, biotite, and quartz. The principal *Plagioclase* present is an albite-oligoclase, but an acid andesine is also present; and further, a zonal structure is sometimes seen. These felspars vary from 1-3 mm. in diameter and show Albite twinning commonly and Pericline twinning occasionally. They contain as inclusions crystals of biotite. *Biotite* occurs as brown and light green crystals strongly pleochroic, with inclusions of *Apatite*.

Order of crystallisation.—Normal.

*Name.*—Biotite Granite.

(*G. 26*) 422.

This is typical of the outcrop of the Pink Phase forming the Green Hill area to the south of the main Enoggera area. (*See* Microphotograph Plate II., No. 2.)

*Megascopic.*—This is a holocrystalline, porphyritic rock made up of phenocrysts of colourless quartz, white felspar and black mica set in a fine-grained pink ground mass. The rock is somewhat darker in appearance than the specimens from the principal area described above, and differs from them in the almost complete absence of phenocrysts of pink orthoclase.

*Microscopic.*—Holocrystalline, porphyritic. The medium size of the felspar phenocrysts, the fine-grained ground mass and the general arrangement, including the tendency of the felspar phenocrysts to form clusters, are all characters in which this rock approaches very nearly the rocks from the southern part of the main Enoggera area. (Compare Nos. 1 and 2 of Plate I.) The ground mass is made up of a microcrystalline mosaic of quartz and altered felspars, which, judging by the pink colour of the ground mass as seen in the hand specimen, are mostly orthoclase.

*Quartz* occurs as comparatively small rounded crystals usually from ½-1 mm. in diameter. Further, this mineral is not so abundant as in the specimens described above. *Orthoclase* phenocrysts are rare. The *Plagioclases* present are all strongly zoned, so that it is difficult to calculate from them the proportion of lime to soda in this rock. *Biotite* of the usual type is present. *Magnetite* and *Apatite* are present in very small amount.

*Name.*—Granite (Granodiorite?) Porphyry.

Associated with the Pink Phase, but a little later as regards time of intrusion, are aplitic and granophyric rocks which, however, do not merit detailed descriptions, since they are quite normal in most respects. In the former, however, flakes of molybdenite are occasionally found, while the latter sometimes show very beautiful micrographic intergrowths of quartz and orthoclase. (*See* Plate II., No. 3.)

### (*b*) The Grey Phase.

Under this heading are included a number of rock types which, though they differ in some respects, have in common several characteristics which mark them off clearly from the "Pink Phase." In general the rocks of this phase are of a grey colour. Quartz is not so abundant as in the other phase (pink orthoclase is absent), and the plagioclases are more calcic, the phenocrysts usually being acid andesine and the felspars in the ground mass an intermediate andesine. Hornblende is usually present, sometimes in great abundance. Pyrites is invariably present, sometimes in considerable amount.

The rocks of this phase vary between two types. Of these the first is characterised by the very strong development of numerous long prismatic and acicular crystals of hornblende, which give the type quite a distinctive appearance. This rock occurs as inclusions, and larger masses set in and surrounded by the Pink Phase. They are evidently the remnants of an older rock. Although they are marked off from the enclosing mass by a well defined boundary, there is evidence that the hornblendic rock has been in some cases somewhat modified by the enclosing acid magma. In particular, one very interesting rock has resulted from a partial mixing of the two types. In the hand specimen it suggests mechanical mixing rather than chemical intermingling, although evidence of chemical interaction is seen on a closer inspection. The specimen examined was obtained from Portion 373, parish of Enoggera, and presents a curious appearance, irregular pink patches being scattered through the dark hornblendic rock. Numerous rounded quartz blebs occur sporadically throughout the rock, and each is surrounded by a very distinct corona of ferro-magnesian minerals. This suggests that at least some chemical interaction took place.

The second type of Grey Phase is not nearly so conspicuous as the first, but is probably present in greater amount, occupying as it does a considerable portion of the western and north-western portions of the Enoggera area. This type is finer grained, of a grey colour, has considerably more biotite present (usually in small crystals), and often has present quartz and felspar intergrown to give a rudimentary granophyric structure. The plagioclases are again andesines, and pyrites is always present. This type is sometimes found as inclusions in the Pink Phase and occurs as small zenoliths in the Enoggera (?) Hybrid. (*See* Microphotograph Plate III. No. 8.)

(*G. 44*) 416.—Specimen from Portion 374, parish of Enoggera.

This is representative of the hornblende rich type of the Grey Phase. (*See* Microphotograph Plate II. No. 4, and Analysis E4.)

*Megascopic.*—This rock has a remarkable appearance in the hand specimen. Numerous long slender crystals of hornblende, ranging up to 8 mm. in length and averaging about 4 mm. are set in a fine-grained light-coloured base and give the rock a pseudoporphyritic character. Pyrites is present in small amount.

*Microscopic.*—Fine-grained holocrystalline for the most part, but with large crystals of hornblende. *Quartz* is present but not very conspicuous, occurring as small allotriomorphic crystals and irregular patches. The felspars are for the most part clouded with decomposition products, but seem to consist for the most part of plagioclases. Some of the altered felspathic material shows a tendency for vague intergrowth with the quartz, and this is presumably *Orthoclase.* The plagioclases still show indistinctly traces of Albite twinning, very few of them being determinate. Those sections capable of determination by the Michel-Levy method show a variation from *intermediate to basic andesines.* *Hornblende* occurs in numerous elongated, relatively large crystals, which give an apparently prophyritic character to the rock. This impression is contradicted by two facts—first, there is no sign that the hornblende is present in two generations; and second, that the small plagioclases are idiomorphic to these large hornblende crystals, showing clearly that at least the latter part of the growth of the hornblendes was subsequent to the consolidation of the plagioclases. This is, of course, seen best in prismatic sections of the hornblende, transverse sections often showing beautifully idiomorphic outlines with both sets of cleavages well developed. The mineral is light-green in colour, strongly pleochroic, and shows alteration to Chlorite. *Biotite* is very rare, but those few small crystals present are definitely idiomorphic to the hornblende. *Augite* is present in three very small crystals. *Magnetite* is present in considerable amount, but is largely pseudomorphous after *Pyrites*. *Sphene* and *Apatite* are present, but in very small amount.

Order of consolidation.—Biotite, Andesine, Hornblende, Orthoclase, Quartz.

*Name.*—Hornblende Quartz Diorite.

(*G. 41*) 345.—Specimen from near "The Summit," Taylor Range.

This forms a connecting link between the more typical hornblendic rock (G. 44) on the one hand and the biotitic rock (G. 14) on the other.

*Megascopic.*—A grey holocrystalline fine-grained rock, made up for the most part of white plagioclase and dark hornblende, together with very small flakes of biotite and numerous small crystals of pyrites.

*Microscopic.*—Holocrystalline, fine-grained. *Quartz* occurs as interstital growths, which (since the other minerals are strongly idiomorphic) are bounded by numerous short straight lines running at various angles, thus giving a curious graphic appearance to the mineral. Other somewhat larger plates are seen enclosing smaller crystals of all the other minerals. *Orthoclase* occurs as a few comparatively large, irregular crystals (up to 3 mm.), idiomorphic only to the quartz and showing perthitic intergrowths with another felspar. *Plagioclase* is present as numerous, mostly small, idiomorphic crystals, showing fine Albite twinning, but with a zonal extinction pointing to a considerable variation in chemical composition in each individual. In addition to these felspars is a large irregularly rounded crystal of plagioclase. The round outer edge of this is optically discontinuous with the remainder, and is evidently a "reaction rim." The crystal proper shows both Carlsbad and Albite twinning and is considerably larger and quite different in appearance from the plagioclases of the enclosing rock. It is evidently a xenocryst. Unfortunately the section is in such a direction that the plagioclase is indeterminate. *Hornblende* occurs as numerous acicular crystals showing marked pleochroism and in some stouter crystals, these latter showing intergrowths with biotite. *Biotite* is present in small amount, generally in irregular patches associated with the hornblende. *Pyrites* occurs as numerous small crystals scattered throughout the slide. *Apatite* is present as abundant minute crystals.

Order of consolidation.—Normal.

*Name.*—Hornblende Microgranodiorite.

(*G. 14*) 418.—Specimen from western part of area.

This is representative of the second or biotitic type of the Grey Phase.

*Megascopic.*—A grey fine-grained holocrystalline rock composed of occasional phenocrysts of quartz and white felspar set in a grey even-grained ground mass. Some small veins of pyrites are apparent.

*Microscopic.*—Only one undoubted phenocryst (an altered felspar) was seen in the slide examined, the rock being made up of a fine-grained but somewhat variable aggregate of quartz felspar hornblende and biotite. The quartz occurs in very irregular crystals moulded about and enclosing all the other minerals. Occasionally, however, the quartz crystals have moulded about them a discontinuous ring of small ferro-magnesian minerals. *Orthoclase* is present as hypidiomorphic crystals which sometimes show simple Carlsbad twinning. *Plagioclases* are numerous and seem to be divisible into two groups, the first a medium oligoclase and the second an oligoclase-andesine. A felspathic xenocryst with similar outline and reaction phenomena to that described above in No. 345 is present in this slide. It shows no twinning, however, and resembles anorthoclase in general appearance. *Hornblende* occurs in comparatively large elongated green crystals which are largely altered into chlorite. *Biotite* is present as numerous flesh flakes of a brown colour. The ferro-magnesian minerals show a distinct tendency towards segregation into definite groups. *Magnetite* occurs as fairly numerous crystals. *Apatite* is present as very small needles generally included in the other minerals. *Sphene* and *Zircon* are also present, but in much smaller amounts.

Order of consolidation.—The order of consolidation is not normal, and the various minerals "overlap" very much more than is usually the case. Some of the plagioclases are definitely earlier than some of the hornblendes, while others are just as definitely later. The same overlapping is noticeable with hornblende and biotite. Even some of the quartz crystals appear to be earlier than the small flakes of biotite which partly surround them. The ferro-magnesian minerals often appear as clusters illustrating the "together-swimming structure or synneusis struktur" of Vogt[9], which is characteristic of those minerals segregated from the magma at an early stage. But in this case they were certainly preceded by some at least of the plagioclases.

*Name.*—Granodiorite.

(*G. 18*) 421.—Specimen of Grey Phase from the southern of the two Kedron Brook outcrops.

*Megascopic.*—A grey rock made up of small phenocrysts of felspar and a ferro-magnesian mineral set in a very fine ground mass.

*Microscopic.*—Holocrystalline, porphyritic with small to medium phenocrysts set in a very fine-grained microcrystalline ground mass of quartz and felspar. *Quartz* occurs as rounded and embayed phenocrysts from ·5-1 mm. in diameter. *Orthoclase* is present as medium-sized phenocrysts very much altered by weathering. *Plagioclase* is present as medium-sized phenocrysts of Andesine very much altered, *Biotite* is present as ragged crystals, and *Hornblende* as long prisms both considerably altered.

*Name.*—Granodiorite Porphyry.

[9] "Magmatic Differentiation of Igneous Rocks," Journal of Geology, Vol. xxix. p. 321.

### (c) The (?) Hybrid Rock.

This occurs as a patch a few acres in extent on the left bank of Enoggera Creek and about one-third of a mile from the eastern edge of the granitic mass. It is entirely surrounded by rocks typical of the Pink Phase. This rock has been quarried and used to some extent in public buildings in Brisbane and for kerbing purposes. It is known commercially as the "Enoggera Granite." (*See* analysis E. 2 and microphotograph Plate III., No. 7.)

(*G. 6*) 154.—From the Quarry, Enoggera Creek.

*Megascopic.*—In the hand specimen the preponderance of the light-coloured "salic" minerals over the dark-coloured "femic" minerals and the small size of individuals, and especially those of the latter group, give to the rock a somewhat curious "pepper and salt appearance,"[10] and a general absence of relief.

*Microscopic.*—Holocrystalline, medium-grained, the grain size, however, being somewhat variable, the resulting texture resembling the "seriate porphyroid fabric" of Iddings. *Quartz* occurs as allotriomorphic crystals from 1-3 mm. in diameter, fresh, generally unbroken, enclosing numerous large crystals of felspar. It also occurs commonly with orthoclase in micrographic intergrowths. *Orthoclase* occurs as hypidiomorphic crystals of varying size, sometimes as inclusions in quartz and sometimes in micrographic intergrowths. Carlsbad twinning is seen and inclusions of another felspar tend to give a rudely perthitic structure. It is usually considerably darkened and altered. The *Plagioclases* present are mostly intermediate andesine. A few crystals of oligoclase-andesine are present, and in addition there are a number of zoned plagioclases. Albite twinning is common, and Pericline twinning combined with Albite is not infrequent. All these felspars are darkened as a result of decomposition, and while some crystals are hypidiomorphic, the majority of them, and particularly the more basic, show irregular embayed and corroded outlines. *Biotite* occurs as rather small brown and green crystals, sometimes considerably bleached and altered into chloritic material and usually strongly pleochroic. *Hornblende* occurs very sparingly as green idiomorphic pleochroic crystals. *Pyrites* occurs commonly, generally in

[10] H. C. Richards, Op. cit. p. 102.

association with the ferro-magnesian minerals, both as well-shaped individual crystals and somewhat irregular clusters. *Magnetite* and *Apatite* are also present in small amount.

Order of consolidation.—Normal.

*Name.*—Biotite Granodiorite.

It is difficult to reconcile this rock mineralogically with either the Pink Phase or the Grey Phase. The abundance of quartz and the great excess of biotite over hornblende are points in comon with the former, while the absence of pink orthoclase, the nature of the plagioclases, and the abundant pyrites are more like the latter.

A comparison of the soda and lime content in analyses E. 1, E. 2, and E. 4 would lead us to expect in this rock plagioclases intermediate in character between those of the Pink and Grey Phases, and the calculated norms also predict such a result. However, measurements of the extinction analyses of suitable sections of felspars (Michel-Levy's method) in many specimens, actually give the following result:—

*Pink Phase*—Phenocrysts, 5 degrees; ground mass, 10 degrees.

*Grey Phase*—Phenocrysts, 9 degrees; ground mass, 15 degrees.

(?) *Hybrid*—Mostly 14 degrees; a few 9 degrees; some zoned.

The plagioclases in this rock, and particularly the more basic, frequently show corrosion, which suggests that they are xenocrysts from the Grey Phase.

This rock has, in addition, other features of special interest. The most remarkable of these is the abundance of primary pyrites, which occurs as individual crystals, sometimes of comparatively large size, and clusters of crystals scattered sporadically through the rock. Pyrites occurs, too, in the "vughs" to be described below. The pyrites is present in such amount and oxidises so rapidly on exposure to the air, producing dirty brown stains on the face of the rock, that the value of the rock as a building stone is very greatly lowered. Indeed it has of late been superseded by other granites brought from greater distances. In describing this rock Professor Richards states:

—"The occurrence of crystals of pyrites throughout the rock, and of cavities or 'vughs' containing calcite pyrites, &c., is a great disadvantage to this stone."[11].

These "vughs" or "druses" are peculiar to this rock and this particular outcrop, the writer never having observed them anywhere else in the area. They are of various size and occur in perfectly fresh rocks, having been found in the heart of the building-stone quarries. The minerals associated with these vughs are mostly calcite and pyrites, though quartz and prehnite are also found. These minerals are certainly not secondary in the sense that they are weathering products, but they are probably primary in origin and result from the action of mineralisers at a late stage of consolidation. They would thus be secondary only in the sense that many of the zeolites of the Tertiary basalts of Queensland are secondary. To use Sederholm's term, they are "deuteric."[11a]

Professor Richards points out that "a noteworthy feature of the stone is the comparative absence of segregations."[12] The present writer discovered small patches of fine-grained more-basic material which he at first regarded as segregations, but which microsections proved to be small zenoliths of the Grey Phase. A comparison of Plate II. No. 6 (a zenolith) with No. 5, which is described in the writer's field notes as "typical of the Grey Phase in the west and north-west of the Enoggera area," gives some idea of the close resemblance which is seen between these rocks when placed side by side on the stage of a petrographical microscope.

Of especial interest is the occurrence in both slides of rounded crystals of quartz, free from inclusions and surrounded by a rim of idiomorphic crystals of biotite arranged parallel to the outline of the quartz.

Towards the edges of the (?) Hybrid mass one finds irregular and vaguely defined patches of pink material of varying size. This zone forms in the field a connecting link between the Enoggera (?) Hybrid and the Pink Phase.

### (*d*) The Rhyolitic Intrusives.

The intrusive rocks surrounding and associated with the granitic rocks fall naturally into two distinct types,

[11] Op. cit. p. 102.

[11a] Bull. de la Comm. Geol. de Finlande No. 48, 1916, p. 142.

[12] Op. cit. p. 102.

although an occasional dyke is seen which has some points in common with each of these types. The types the author considered in Part I. of this paper under the headings "The Rhyolitic Intrusives" and "The Porphyries." More recently Mr. L. C. Ball, B.A., in his report dealing with the geology of the silver-lead deposits near Indooroopilly, included both these groups under the term "Felsites."

With his "Notes on Indooroopilly"[13] Mr. L. C. Ball, Deputy Chief Government Geologist, publishes a map of the Indooroopilly area on a considerably larger scale than that which accompanies Part I. of this paper, and showing the network of outcrops which the Rhyolitic Series form in this area in much greater detail than was done by the author. The author would like here to digress from the purely petrological point of view to discuss a structural matter of some importance.

Although Mr. Ball states that "attempts to distinguish laccolites and sills among the dykes are not warranted on the exposures," the author finds in Mr. Ball's descriptions and map several points which appear to uphold his published opinion that the intrusions of the southern area are largely laccolitic, the present outcrops being partial exposures of irregular laccolites. The author never intended to convey the idea that these laccolites were of the ideal type, which rarely has been found in the field. The closest approach to this ideal are the laccolites described by Gilbert from the Henry Mountains, Utah.[14] Gilbert himself, however, figures as an "ideal cross section of a laccolith with accompanying sheets and dykes," a series of intrusions which, on partial exposure by weathering, might very well give a quite similar outcrop to that in the neighbourhood of Indooroopilly. But the types of laccolite most closely approached in the Indooroopilly area are, in the author's opinion, those of the El Late Mountains, Colorado, described by Cross, and the so-called "Cedar-tree" compound laccolite described by Holmes from the La Plata Mountains of Colorado.[15] A good example of the less regular type of laccolite, and one which the author has had the opportunity of studying in the field, is the Gabbro

[13] Qld. Govt. Min. Journal, vol. xxi. p. 266.

[14] Report on the Geology of the Henry Mts. 1879.

[15] Harker, "Natural History of Igneous Rocks," p. 66, fig. 10.

laccolite of the Cuillins, Isle of Skye, described and figured by Harker.[16]

A glance at Mr. Ball's map shows a network of outcrops which at first are difficult to reconcile with the conception of a laccolite. This network is not, however, the outcrop of vertical and steeply dipping dykes striking in every direction. It is the result of mapping more or less continuous intrusions generally with a slight dip in a hilly locality. Mr. Ball recognises this fact and writes:—"In many of the exposures the dyke walls dip at comparatively low angles. In fact, most of the mapped loops are in reality not due to branching of the dyke mass, but to partial covering by schist islands or inliers."[17]

Away from the effect of the intrusions the Brisbane schists strike N.N.W. and dip quite steeply to the E.N.E. In discussing the Brisbane schists in the locality in question, Mr. Ball states:—"The strata have been much disturbed, notwithstanding that steep dips are exceptional here about. Even on the flat arches there has been much crenulation and puckering."

The expression "flat arches" fits in precisely with the author's view as to the laccolitic origin of these low dips.

To quote Mr. Ball further:—"The brecciation of the schists along the faults on Finney's Hill is a puzzling feature. The structure is certainly not due to compressive forces. To explain it we must assume an arching of the strata above a plutonic or hypabyssal intrusion sufficient to cause a breaking-down of the beds under the tensile stresses induced. Alternatively these stresses may have been induced in the sedimentaries by a partial retrograde movement (a sucking back, as it were) of the molten magma." The author feels sure the great majority of geologists would favour the former as being the more probable hypothesis. The arching of the strata which Mr. Ball "must assume" is the arching which I firmly believe to exist.

We have, then, found all the essential features of irregular laccolitic intrusion, with the exception of the flat bases. No evidence is available either way on this point at

[16] "The Tertiary Ingeous Rocks of Skye," Mem. Geol. Surv. U.K. 1904, 85 *et seq.*, fig. 15.

[17] Op. cit. p. 266.

the present time, but future mining operations in the area may furnish data on this matter.

To return to a consideration of the Petrology of the Rhyolitic Intrusives. The naming of the fine-grained acid intrusives was a matter to which the author gave considerable attention. In spite of their definitely intrusive character and the fact that many of them have been considerably altered by the addition of secondary silica, they appear to be petrologically more closely related to the Rhyolites than to any other rock group. Mr. Ball, in referring to rocks of this series, uses the terms ''felsite'' and ''felsitic,'' which certainly reflect the mode of occurrence better than the author's term ''Rhyolite'' unless one is careful to qualify it by the word intrusive, but the absence of felsitic textures in the rocks examined under the microscope and, further, the fact that they can be closely correlated with the intrusive ''Rhyolites'' (so-called by Andrews and Saint-Smith) of New England (*see* Table II.), has led the author to retain the term ''Rhyolitic Intrusives.''

(*D. 12*) 171.—Dyke near junction of creeks in Portion 681, Parish of Indooroopilly. (*See* Microphotograph Plate III., No. 9.)

*Megascopic.*—A fine-grained greyish rock showing very small yellowish-brown felspars and small patches of pyrites set in a fine-grained grey base. A vein of quartz from 1-2 mm. across is to be seen traversing the specimen.

*Microscopic.*—Very fine-grained holocrystalline rock, with small vaguely defined decomposed phenocrysts of felspar (orthoclase ?) set in a ground mass made up entirely of *Quartz* and *Orthoclase*. Only part of the former mineral seems to be primary, as there is considerable evidence of secondary silicification. Pyrites occurs as fresh individual crystals of very small size and as larger aggregates.

*Name.*—Intrusive Rhyolite.

(*D. 64*) 415.

This specimen is of particular interest from the economic point of view. It was obtained by Mr. L. C. Ball at a depth of 130 feet in the main vertical shaft of the Finney's Hill United Silver Mines Ltd., near Indooroopilly, and supports in a very decided manner his hypothesis that the silver-lead and other ores of this area are closely associated with rhyolitic ("felsitic") intrusions. (*See* Microphotograph Plate III., No. 10.)

*Megascopic.*—A fine-grained light-coloured rock evidently made up for the most part of felspathic material and quartz, and traversed by numerous veins of quartz. Part of the surface of the specimen is coated with galena, accompanied by well-shaped quartz crystals.

*Microscopic.*—In order to preserve the appearance of this specimen a slice was cut not through the metalliferous part, but from a chip of the rock within one centimetre of it. Curiously enough this section shows no trace whatever of any metals except a few very small crystals of pyrites. The rock is similar in all its essentials to that described above (*D. 12*), but has numerous quartz veins through it and clusters of crystals of secondary quartz.

*Name.*—Intrusive Rhyolite.

### (*e*) The Porphyritic Series.

The members of this series are usually easily separated from those of the Rhyolitic Series, but as pointed out by the author in Part I. of this paper, one occasionally meets with dykes that appear to be intermediate between these. This is, of course, only to be expected, as the two series are almost certainly genetically related. The evidence as to the relative time of intrusion of the Rhyolitic and Porphyritic Series is, so far, not conclusive, but points to the latter series as being later than the former.

(*D. 7*) 166.

Dyke across West Ithaca Creek in eastern part of Portion 678, parish of Enoggera. (*See* Microphotograph Plate III., No. 11.)

*Megascopic.*—A white prophyryritic rock made up of rounded colourless phenocrysts of quartz (in which can be seen numerous inclusions of a white mineral), with smaller phenocrysts of a white felspar set in a fine-grained light-coloured ground mass.

*Microscopic.*—Holocrystalline, porphyritic, the proportion of phenocrysts to ground mass corresponds to the "dopatic fabric" of Iddings. The ground mass is finely microcrystalline, and made up almost entirely of quartz and felspar, often intergrown. *Quartz* occurs in two distinct generations. The phenocrysts of this mineral are all rounded and embayed. They vary from 2-5 mm. in diameter, are more or less fractured, bear signs of corrosion, and show very definite "reaction rims" just outside the crystals themselves. Comparatively large rounded inclusions (or cross-sections of very deep embayments) made up of quartz-felspar aggregates similar to that of the ground mass is a feature of these quartz phenocrysts. The felspar phenocrysts are considerably altered to muscovite and other micaceous products, with the result that some of them are indeterminate, but in some cases enough remains of the original minerals to show that both *Orthoclase* and *Plagioclase* are present. The latter shows traces of Albite twinning and appears, from measurements of extinction angles, to be an intermediate andesine. Zoning is fairly definite in some of these phenocrysts. Inclusions of apatite were observed. Ferro-magnesian minerals are but poorly developed, but fragments of *Biotite* largely altered into colourless secondary minerals and magnetite were observed. Magnetite occurs in irregular patches and idiomorphic crystals, and seems to be pseudomorphus after *Pyrites*, as some remnants of this mineral are present in the interior of the magnetite crystals. Further alteration has resulted in patches of Limonite. Other minerals present in small amount are *Apatite* and *Zircon*.

*Name.*—Quartz Porphyry (Granodiorite Porphyry).

(*D. 4*) 163.

Dyke on road, Constitution Hill, Taylor Range. (*See* Microphotograph Plate III., No. 12.)

*Megascopic.*—A holocrystalline porphyritic rock made up of numerous phenocrysts of brown felspars, showing zoning and fewer smaller phenocrysts of quartz and a dark ferro-magnesian mineral set in a fine brown ground mass.

*Microscopic.*—Rock very decomposed. Holocrystalline, porphyritic (sempatic fabric of Iddings). The ground mass is a very fine-grained confused aggregate of felspathic material, quartz, and secondary minerals, resulting from the alteration of the felspars. Small patches of limonite are scattered throughout the rock. The felspar phenocrysts, which vary from 2-7 mm. in length, occur in very altered crystals, and are really pseudomorphous aggregates of muscovite and other secondary minerals. In spite of this the felspars still show idiomorphic outlines, and zoning is still recognisable (indeed the zoning is apparent in the hand specimen), and points to the felspars as *Plagioclases*, although no more exact determination is possible. In some cases these phenocrysts partly enclose chloritic clusters, which are secondary after some ferro-magnesian mineral. *Quartz* occurs as a few phenocrysts up to 2 mm. in diameter, which are very similar to those described in (*D. 7*). The ferro-magnesian constituents are represented by patches of chloritic material.

*Name.*—Quartz Porphyry (Granodiorite Porphyry).

## IV. COMPARISON WITH ROCKS OF OTHER AREAS.

(*a*) *New England and Stanthorpe*—

In Part I. of this paper the author pointed out that the granitic and allied rocks of the Enoggera district were closely comparable with those of New England in northern New South Wales, and the contiguous masses of the Stanthorpe district in the southern part of Queensland. The age of these great intrusions was seen to be much about the same, *i.e.*, very late Palæozoic; structurally they followed the same trends, while mineralogically they were very similar.

Even more striking resemblances are discovered if the sequence of events in the different areas be compared. Table II. has been drawn up for this purpose. The order of intrusion in the New England district is that found by Andrews, while in the adjacent Stanthorpe area the sequence adopted is that of Saint-Smith. These two areas are practically continuous, so that they can be very definitely correlated. If these two columns be compared it will be found that, although the grouping and naming differ somewhat, the rock types and their order of intrusion are identical, with but one exception. The "Sphene" granite is considered by Andrews to be definitely earlier than the

"Acid" granite, and probably earlier than the "Basic Granites," while Saint-Smith thinks it is much more closely related to the "Stanthorpe" (Acid) granite, and, indeed "may possibly be a modification of the 'Stanthorpe' granite."[18] The Enoggera sequence shown in the third column agrees more closely with Andrews's interpretation on this point, but otherwise the local sequence is remarkably close to both the New England and Stanthorpe records.

TABLE II.

| New England (Andrews)[19]. | Stanthorpe (Saint-Smith)[20] | Enoggera (Bryan). |
|---|---|---|
| Intermediate to basic dykes | Basic dykes often associated with Au., Ag., Pb. Zn., Cu. | .. |
| Rhyolites, Q. porphyries, porphyries | Rhyolites, Q. porphyries, porphyries, also | Rhyolites with Ag., Pb., Zn., Q. porphyries, porphyries |
| " The Euritic Period " .. | Aplites, greisens and pegmatites; sandy granite with Sn. Wo., and Mo. | Aplites with little Mo, granophyres and pegmatites |
| " Coarse acid granites " .. | Coarse acid " Stanthorpe granite closely associated with porphyritic sphene granite | Pink phase proper (= Mountain Camp quartz mica diorite) |
| " Hornblendic, dioritic, and other basic granites " | Maryland adamellite (= Greymare granite) | Grey phase |
| " Blue granite " .. .. | " Blue granite " .. .. | .. |
| "Blue and black porphyries" | .. | .. |
| "Grey felspar porphyry " .. | "Acid grey felspar porphyry" | .. |
| | Altered dioritic rocks .. | .. |

*Note.*—The " sphene-diorite porphyry " of Andrews and the " porphyritic sphen granite " of Saint-Smith are one and the same rock. The difference in position reflect a difference of opinion of these authors.

Although the Pink Phase, the Aplitic, and the Rhyolitic and Porphyritic Intrusives had their obvious counterparts in the Stanthorpe and New England Series, the "Grey Phase" was not so easily placed, and the author did not (in the earlier part of this work) care to venture an opinion as to the precise position it occupied in these series. Since the publication of Part I., definite evidence

[18] Op. Cit., p. 18.

[19] " New England Geology " Part IV. Petrology. Rec. Geol. Surv. N.S.W., Vol. VIII. pt. 3, p. 196 *et. seq.*

[20] " Geology and Mineral Resources of the Stanthorpe, Ballandean, and Wallangarra Districts." Qld. Geol. Surv. Pub. No. 243.

of a chemical nature has become available as the result of analyses of the "Grey Phase" and the Greymare rock. The first of these (E4) was found to resemble certain analyses of the "basic granites" very closely, and did not resemble those of any other of the Phases.

Of these "basic granites," Andrews writes:—"Striking dissimilarities in appearance is a marked feature."[21] The analyses which accompany his descriptions emphasise this feature. Of the four quoted, two are comparatively acid and have alkalies in moderate amount, the $K_2O$ being in excess of the $Na_2O$. These obviously have little in common with the "Grey Phase." They seem, indeed, to be more closely related to the coarse-acid granite that immediately followed them, for Andrews remarks that the more-basic types were somewhat earlier and the remaining two analyses are of this earlier more-basic type. They are of very different rock types from the others, and possess the essential characteristics of the Grey Phase, as can be seen by their positions (N.7 and N.8) on the variation diagrams.

No analysis exists as yet of the "Maryland" granite, which, however, is considered by Mr. Card[22] to be an Adamellite. It is "a fine to medium-grained greyish-blue rock." Saint-Smith,[23] in his chapter on the "Maryland" granite refers to one other rock which he says "resembles the Maryland granite to such a marked degree in hand-specimens that it may ultimately prove to represent an outcrop of this rock." This is the "Greymare" granite which has since been analysed (S.4.) This analysis, while considerably more acid, resembles those of the "Grey Phase" on the one hand and "Basic Granites" on the other in several important particulars, particularly in the preponderance of $Na_2O$ over $K_2O$.

The Grey Phase seems then to be connected indirectly (through the Greymare granites) with the Maryland Adamellite and directly with the "Basic Granites" of New England.

If chemical tests be applied it will be found that the results confirm very strongly the above correlations.

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[21] Op. Cit., p. 212.

[22] Min. Res. N.S.W. No. 14, p. 91.

[23] Op. Cit., p. 61.

Variation diagrams, Plate I., Figures 1 and 2, have been carefully prepared, which show a very definite chemical relationship between the "Pink Phase" and "Acid" granites on the one hand, and the "Gray Phase" and "Basic" granites on the other.

If reference be made to Figure 1, in which the percentage weights of $K_2O$ and $Na_2O$ have been plotted against that of $SiO_2$, it will be noticed that the "Grey Phase" of the Enoggera granite (E.4) is connected with the "Greymare" granite (S.4) on the one hand and the "Basic Granites" of New England (N.7 and N.8) on the other by variation lines which show that $Na_2O$ is present in considerable excess of $K_2O$ in each case. While at first glance these lines seem parallel, a closer inspection shows that there is a gradual convergence as one proceeds from the more basic to the more acid rocks. In other words, the ratio $Na_2O : K_2O$ varies inversely with the acidity. The Ballandean granite (S.3) has been linked up with these curves for obvious reasons, although Saint-Smith refers to the specimen from which the analysis was made as one type of the "Stanthorpe" granite—"a medium-grained variety from Ballandean."[24]

If these "curves" be compared with the corresponding curves joining the "Pink Phase" and the "Stanthorpe" and "Sandy" granites, some very decided differences will be observed. A very close approximation in the values of $K_2O$ and $Na_2O$ is apparent, the curves for these oxides interweaving and remaining close together. One would naturally expect that the "Acid" granites and "Eurites" of New England, which have been so definitely correlated with the "Stanthorpe" and "Sandy" granites respectively, would approach them so closely in chemical composition as to be readily reconciled to one variation curve for the two series. In the $K_2O$ and $Na_2O$ values such is not the case. The $K_2O$ is somewhat higher in the New England rocks and the $Na_2O$ correspondingly lower. Consequently the ratio $K_2O : Na_2O$ is very much greater than in the Stanthorpe rocks. Curiously enough, in the chain of chemical evidence connecting the Pink Phase, the acid Stanthorpe granites, and the acid granites of New England, the latter is the weaker link in spite of the fact that the former connects outcrops which are separated by approximately 100 miles.

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[24] Op. Cit., p. 43.

The values of the alkalies of these New England rocks have, then, been linked up to form curves independent of the main "Pink Phase"—"Stanthorpe" curve.

Three analyses are shown in which the $K_2O$ and $Na_2O$ values do not readily fall on either curve. These are the "Acid" granites from Tingha, New South Wales (N.2), the "Sandy" granite of Stanthorpe (S.1), and the Enoggera Hybrid. It may be argued that any attempt to fit this "Sandy" granite into the variation diagrams was unwarranted in the first place, as it represents a later phase than the "Acid" granite. However, these two acid phases are very closely associated in the field, and the position of the New England "Euritic" granite (N.4) on the diagram partly justifies the assumption of their close relationship. However, if both the Sandy and Euritic granite be ignored there remains one rock (N.2) in a somewhat anomalous position.

In Figure 2 the values of CaO and MgO have been plotted in the same manner as the alkalies in Figure 1. In this case the same sets of curves have been drawn, but the natural grouping along three different sets is not nearly so well displayed. Indeed, one might draw one set of generalised curves to which all the values plotted might be referred.

In both figures it will be noted that the values for the Enoggera (?) Hybrid do not fall on either curve. Any attempt to include them with the Pink Phase or the Grey Phase will seriously derange either curve.

TABLE III.

THE PINK PHASE AND THE EQUIVALENT ROCKS IN STANTHORPE AND NEW ENGLAND.

| — | E. 1. | S. 1. | S. 2. | S. 5. | N. 1. | N. 2. | N. 3. | N. 5. | N. 6. |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 73·52 | 77·15 | 76·19 | 67·24 | 78·14 | 76·28 | 75·78 | 73·98 | 71·27 |
| $Al_2O_3$ | 11·05 | 13·45 | 11·53 | 14·20 | 11·89 | 11·41 | 12·42 | 13·47 | 13·40 |
| $Fe_2O_3$ | Nil | 0·40 | 0·84 | 1·50 | 0·60 | 1·60 | 0·55 | 0·72 | 1·11 |
| FeO | 3·15 | 1·26 | 1·25 | 2·88 | 0·27 | 0·72 | 1·08 | 0·97 | 1·89 |
| MgO | 1·03 | 0·72 | 0·60 | 1·39 | 0·15 | 0·15 | 0·50 | 0·36 | 0·79 |
| CaO | 1·70 | 1·22 | 1·14 | 3·24 | 0·44 | 0·62 | 1·06 | 0·90 | 2·46 |
| $Na_2O$ | 4·08 | 2·72 | 3·80 | 3·98 | 3·51 | 3·97 | 3·20 | 3·39 | 3·08 |
| $K_2O$ | 3·99 | 3·76 | 4·14 | 4·07 | 4·62 | 4·54 | 4·60 | 4·88 | 4·91 |
| $H_2O$ + | 0·44 | 0·20 | 0·28 | 0·50 | 0·32 | 0·40 | 0·44 | 0·32 | 0·32 |
| $H_2O$ − | 0·16 | 0·08 | Nil | 0·12 | 0·28 | 0·16 | 0·14 | 0·12 | 0·18 |
| $CO_2$ | n.d. | .. | .. | 0·06 | .. | .. | 0·01 | 0·04 | 0·03 |
| $TiO_2$ | 0·20 | .. | 0·09 | 0·65 | 0·06 | 0·20 | 0·29 | 0·54 | 0·24 |
| $P_2O_5$ | 0·15 | 0·10 | 0·25 | 0·11 | 0 02 | 0·17 | 0·10 | 0·05 | 0·10 |
| MnO | n.d. | 0·32 | 0·16 | 0·06 | .. | .. | 0·07 | 0·03 | .. |
| Etc. | .. | .. | .. | 0·07 | .. | .. | 0·11 | 0·06 | .. |
| Total | 99·47 | 101·38 | 100·27 | 100·07 | .. | .. | 100·35 | 99·83 | .. |
| Sp. Gr. | 2·58 | .. | .. | 2·711 | .. | .. | 2·626 | 2·030 | .. |
| Symbol | I. 3.1.3 (4) | I. 4.2.3 | I. 3(4).1.3 | II. 4.2.3 (4) | I. 3(4).1.3 | I. 3(4).1.3 | I. 3.2.3 | I. 3.1.3 | I. 4.2.3 |
| Name | Alaskose | Toscanose | Alaskose | Adamellose | Alaskose | Alaskose | Tehamose | Alaskose | Toscanose |

TABLE IV.

THE GREY PHASE AND THE EQUIVALENT ROCKS IN STANTHORPE AND NEW ENGLAND.

| —— | E. 4. | S. 3. | S. 4. | N. 7. | N. 8. |
|---|---|---|---|---|---|
| $SiO_2$ | 61·10 | 74·89 | 69·70 | 55·05 | 50·04 |
| $Al_2O_3$ | 19·24 | 15·11 | 17·70 | 14·15 | 18·68 |
| $Fe_2O_3$ | 4·66 | 1·06 | 1·94 | 1·80 | 0·80 |
| FeO |  | 2·26 | 1·40 | 5·31 | 6·91 |
| MgO | 2·56 | 0·82 | 1·19 | 8·07 | 7·79 |
| CaO | 5·25 | 1·67 | 2·29 | 9·36 | 9·88 |
| $Na_2O$ | 3·82 | 2·06 | 3·12 | 2·82 | 2·35 |
| $K_2O$ | 1·68 | 0·73 | 1·36 | 0·72 | 0·12 |
| $H_2O +$ | 1·31 | 0·50 | 0·47 | 1·46 | 1·74 |
| $H_2O -$ | 0·64 | 0·31 | 0·25 | 0·22 | 0·28 |
| $CO_2$ | .. | .. | Nil | 0·02 | 0·27 |
| $TiO_2$ | Det. with $Al_2O_3$ | .. | 0·19 | 0·57 | 0·80 |
| $P_2O_5$ | .. | 0·27 | tr. | 0·06 | 0·16 |
| MnO | .. | 0·22 | tr. | 0·22 | 0·14 |
| Etc. | .. | .. | .. | 0·06 | 0·62 |
| Total | 100·26 | 99·90 | 99·61 | 99·89 | 100·58 |
| Sp. Gr. | 2·71 | .. | 2·66 | 2·814 | 2·977 |
| Symbol | II. 4.3.4 | I. 2.2.4 | I. 3.3(2).4 | III. 5.3.4 | III. 5.4.3 |
| Name | Tonalose | .. | Near Alsbachose | Camptonose | Auvergnose |

TABLE V.

ANALYSES USED IN TABLES III. AND IV. AND PLATE I, FIGURES 1 AND 2.

| No. | Type. | Locality. | Reference. | Analyst. | Laboratory. |
|---|---|---|---|---|---|
| N. 1 | Acid .. .. | Butchart's Reef, Tingha, New England | Ann. Rpt. Dept. Mines, N.S.W., 1907, p. 185 | Not stated .. | Department of Mines, N.S.W. |
| N. 2 | Acid .. .. | Middle Creek, Tingha, New England .. | Min. Res. N.S.W., No. 14, p. 63 .. .. | H. P. White .. | Department of Mines N.S.W. |
| N. 3 | Acid average .. | Bolivia, New England .. .. .. | Rec. Geol. Surv. N.S.W., vol. viii., pt. 3, p. 220 | J. C. H. Mingaye | Department of Mines, N.S.W. |
| N. 4 | Euritic .. .. | Two miles east of Tenterfield, New England | Rec. Geol. Surv., N.S.W., vol. viii., pt 3, p. 225 | J. C. H. Mingaye | Department of Mines, N.S.W. |
| N. 5 | Acid .. .. | 21-mile peg, Deepwater to Bolivia, New England | Rec. Geol. Surv., N.S.W., vol. viii, pt. 3, p. 220 | J. C. H. Mingaye | Department of Mines, N.S.W. |
| N. 6 | Tingha .. .. | Tingha, New England .. .. .. | Min. Res., N.S.W., No. 14, p. 64 .. .. | W. A. Grieg .. | Department of Mines N.S.W. |
| N. 7 | Diorite .. .. | Near Junction Baker's Creek, Hillgrove, New England | Rec. Geol. Surv., N.S.W., vol. viii, pt. 3, p. 214 | J. C. H. Mingaye | Department of Mines, N.S.W. |
| N. 8 | Diorite .. .. | Near Murgatroyd's Tunnel, Hillgrove, New England | Rec. Geol. Surv., N.S.W., vol. viii, pt. 3, p. 216 | J. C. H. Mingaye | Department of Mines, N.S.W. |
| S. 1 | Sandy .. .. | Stanthorpe, Southern Queensland .. | Qld. Geol. Surv. Pub. 243* p. 38 .. | G. R. Patten .. | Queensland Agricultural Department. |
| S. 2 | Stanthorpe .. | Quarry, near Stanthorpe, Southern Queensland | Qld. Geol. Surv. Pub. 243, p. 43 .. | G. R. Patten .. | Queensland Agricultural Department. |
| S. 3 | Stanthorpe .. | Ballandean, Southern Queensland .. | Qld. Geol. Surv. Pub. 243, p. 43 .. | G. R. Patten .. | Queensland Agricultural Department |
| S. 4 | Greymare .. | Greymare, near Warwick, Southern Queensland | Proc. Roy. Soc. Qld., vol. xxx, p. 150 .. | Miss I. Sterne .. | Geological Department, University of Queensland |
| S. 5 | Stanthorpe .. | Amosfield, near Stanthorpe, Southern Queensland | Min. Res., N.S.W., No. 14, p. 84 .. | H. P. White .. | Department of Mines, N.S.W. |
| E. 1 | Pink Phase .. | Portion 823-824, parish of Enoggera, near Brisbane | Ann. Rep. Ag. Chem. Qld., 1915, p 20 .. | G. R. Patten .. | Queensland Agricultural Department |
| E. 2 | Hybrid .. | Quarry, Enoggera Creek, near Brisbane.. | Proc. Roy. Soc. Q d., vol. xxx, p. 150 .. | N. H. Christensen | Queensland Agricultural Department |
| E. 3 | Pink Phase .. | Quarry, Mountain Camp, near Brisbane.. | Now first published .. .. .. | G. R. Patten .. | Queensland Agricultural Department |
| E. 4 | Grey Phase .. | Included mass in Pink Phase, Enoggera, near Brisbane | Now first publ shed .. .. .. | Miss E. W. Muir.. | Geological Department, University of Queensland |

* This analysis has evidently been confused with that on page 43 (S. 2). The correct analysis appears under S. 1.

## (b) Other Queensland Areas.

The division of the granitic rocks of the Enoggera district into two phases—the earlier typically granodioritic (the Grey Phase) and the later somewhat more alkaline (the Pink Phase)—seems to be reflected in all those granitic rocks of Queensland of which analyses are available. Not only is this twofold development widespread geographically; in time, too, it appears to be wonderfully persistent. As far north as Charters Towers and as far back as Early Devonian, these two distinct phases are met with.

The plutonic rock nearest to the Enoggera area, of which a chemical analysis exists, is the Mountain Camp Quartz Mica Hornblende Diorite, which lies within 3 or 4 miles of the main Enoggera outcrop (*see* analysis E.3). This rock has a handsome appearance and makes an excellent building stone. It was selected by Professor H. C. Richards as the most suitable granitic rock available for the construction of the base of the new Brisbane Town Hall. Mineralogically this rock most closely resembles the Pink Phase, although it is, of course, considerably less acid and does not carry enough pink orthoclase to give the characteristic colour. The chemical analysis gives added weight to the mineralogical evidence, for though it is remarkably like that of the Grey Phase (E.4) in most respects, in the all-important matter of the alkalies it shows its true relationship to the Pink Phase, the $Na_2O$ being slightly in excess of the $K_2O$. The variation diagrams, too, point clearly to its relationship to the Pink Phase.

The remaining comparisons must necessarily be general in their nature. So little has been done in the study of the plutonic rocks of Queensland that little in the way of detailed correlation is possible.

Mr. Reid[25] has described from the Charters Towers goldfield a series of granodiorites and associated rocks of Lower Devonian or pre-Devonian age, all of which show rather low alkalies with a decided excess of $Na_2O$ over $K_2O$, and which are followed by an aplitic granite which "is intrusive in the granodiorite" and the analysis of which shows high alkalies with the potash in excess of the soda.

[25] "The Charters Towers Goldfield," Qld. Geol. Surv. Pub. No. 256, p. 66.

This seems to have been followed by a reversion to a series of dykes of a dioritic and porphyritic nature, all of which show a preponderance of $Na_2O$ over $K_2O$ with comparatively high values for CaO.

In the East Moreton and Wide Bay districts to the north of the Enoggera area are a number of plutonic and hypabyssal rocks which have been described by Dr. H. I. Jensen,[26] and which petrologically and chemically seem to have many points in common with the Enoggera rocks. Of these the "Neurum" granite of the Woodford area seems to most nearly approach the Enoggera granites in age, since Jensen considers it to be "post-Carboniferous, probably Permian."[27] It is described as "a bluish, tonalitic granite." Referring to this granite he says further:—"The graphic granite aplites of the Delaney's Creek and Fife's Range mountains are probably the last differentiation products of this mass." This seems a fairly close parallel both of types and events with the Enoggera area.

Further, Jensen, in summarising the history of this East Moreton and Wide Bay area, refers to an original quartz dioritic rock which was closely followed by an aplitic phase, one result being the formation of "mixed" rocks referred to earlier in this paper.

## V. ECONOMIC.

The decision at which the author arrived, that the Enoggera granite was probably related to the Stanthorpe and New England "acid" granites, held an economic interest in addition to its geological significance, as both these granites are stanniferous. However, so far as the author can discover, no find of tin has ever been made on this area. As noted on p. 152, Part I., of this paper, flakes of molybdenite were discovered while the field work was being carried out, and since that time molybdenite in small quantities has been found in several parts of the area.

This sparse occurrence of molybdenite and the local tourmalinisation of the granite on its north-eastern edge are the only points which suggest the possible existence of tin

[26] "Geology of Parts of the East Moreton and Wide Bay Districts. Proc. Linn. Soc. N.S.W. Part I. 1906, p. 73.

[27] Op. Cit., p. 92.

within this area, although mining for arsenic, gold, silver, copper, lead, and bismuth[28] has been carried out at the neighbouring Samford massif some few miles away.

On p. 161, Part I., Rands was quoted as having described "very minute specks of gold" in one of the dykes which form the extensive system of intrusions between the south-eastern edge of the Enoggera granite and the Brisbane River at Indooroopilly. Up to that time (November, 1914) no other minerals of economic value had been found associated with these intrusions, but in the year 1918, a discovery of silver-bearing galena was made at Finney's Hill, near Indooroopilly, associated with the "Rhyolitic" intrusions. Up to the present some 280 tons of lead and 45,753 oz. of silver have been produced from the area, while the presence of copper, zinc, and bismuth in smaller amounts has been proved. Ball has mapped the intrusives in this area in great detail, as he considers them the "sole guides in searching for new shoots of ore."[29] He states further that "a clear case is presented at Indooroopilly in favour of a magmatic derivation, the metalliferous solutions being an extreme differentiate of the plutonic igneous mass from which the felsitic dyke rocks arose—the presence of $\frac{1}{4}$ to $\frac{1}{2}$ per cent. bismuth is, in my opinion, decisive evidence."

A specimen of the rhyolite ("felsite"), which actually contained silver-bearing galena, was kindly supplied by Mr. Ball, sliced and microphotographed. (*See* Plate III., No. 8.) The rock is in all respects like the other intrusive rhyolites of the neighbourhood, except that veins of secondary quartz are even more pronounced than usual.

The value of the Hybrid rock (commercially known as the "Enoggera Granite") as a building stone, and for purposes of "pitching," "kerbing," and road-making has been very fully dealt with by Professor Richards in a paper read before this Society in July, 1918.[30]

## CONCLUSION.

In conclusion, I wish to thank Professor H. C. Richards, D.Sc., for the interest he has shown in this work (which was originated at his suggestion) and for his helpful advice on many points.

[28] L. C. Ball, Qld. Govt. Min. Journ., Vol. XXI. p. 266.

[29] L. C. Ball, Qld. Govt. Min. Journ., Vol. XXI. p. 267.

[30] "The Building Stones of Queensland," Proc. Roy. Soc. Vol. xxx., p. 101 *et seq.*

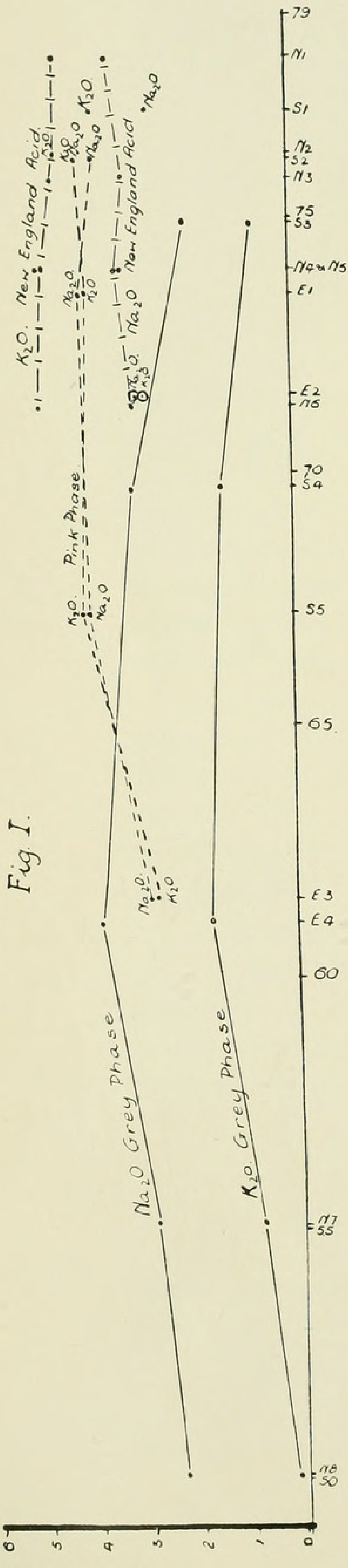

K2O. New England Acid
Na2O New England Acid
Pink Phase
Na2O Grey Phase
K2O. Grey Phase
79
N1
S1
N2
S2
N3
75
S3
N4 & N5
E1
E2
N6
70
S4
S5
65
E3
E4
60
N7
55
N8
50
0
1
2
3
4
5
6

Fig. I.

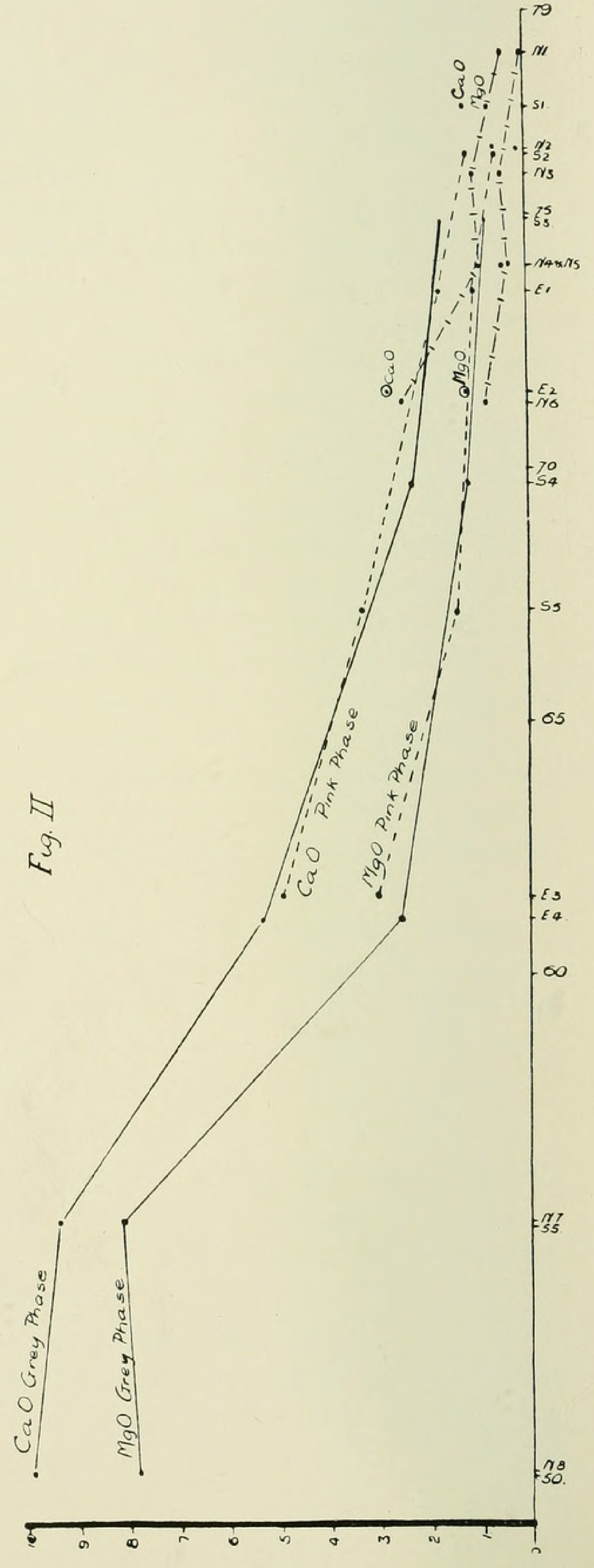
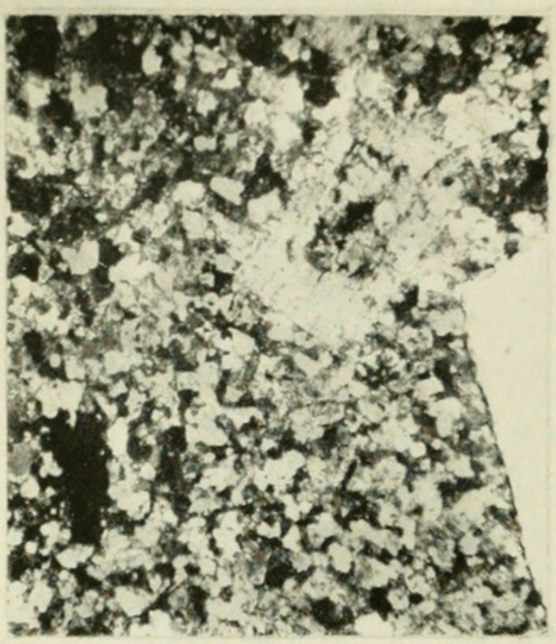
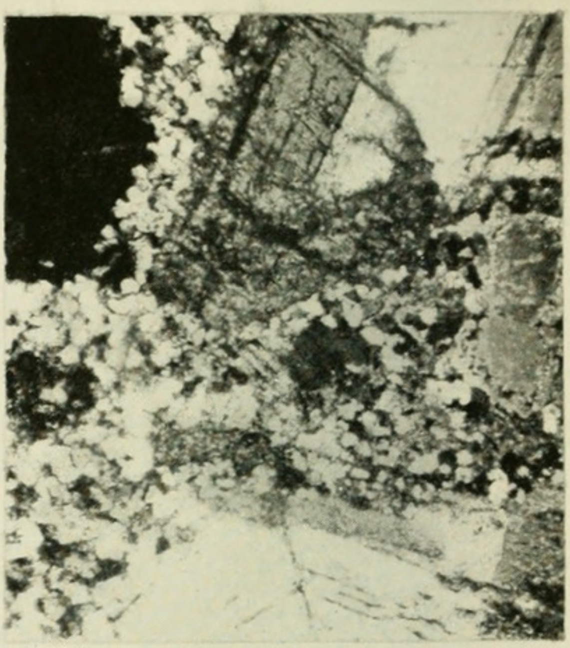

CaO
MgO
CaO Pink Phase
MgO Pink Phase
CaO Grey Phase
MgO Grey Phase
79
N1
S1
N2
S2
N3
75
S3
N4 & N5
E1
E2
N6
70
S4
S5
65
E3
E4
60
N7
55
N8
50.
0
1
2
3
4
5
6
7
8
9
10

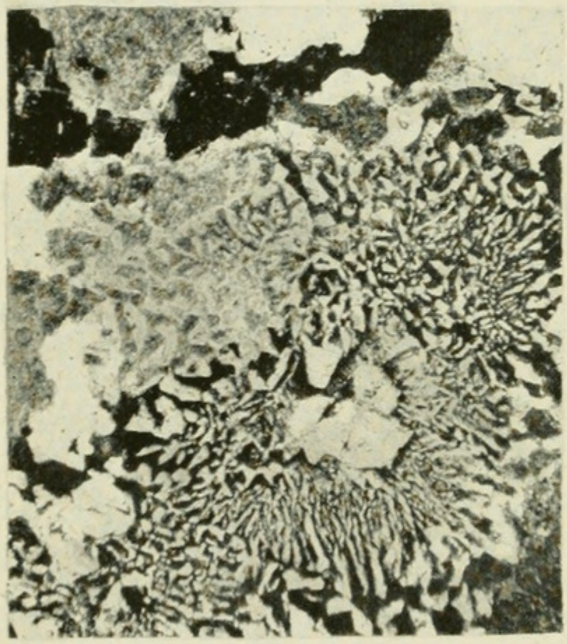
Fig. II



1.



2.



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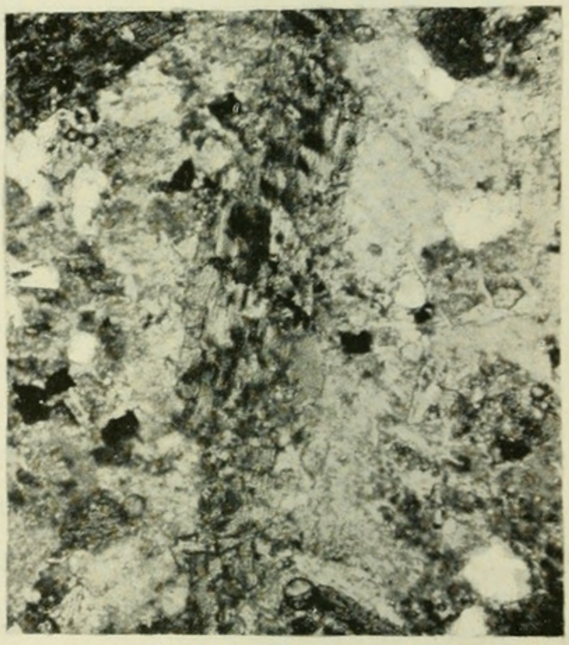


4.

5.

6.

## Plate I.

## VARIATION DIAGRAMS.

These have been constructed by plotting the silica percentage (on the horizontal axis) against the other oxides in percentages (on the vertical axis). The scales are the same for each axis and for each figure.

Lines joining members of the Grey Phase are shown thus:——————

Lines joining members of the Pink Phase are shown thus:- - - - - - - -

Lines joining members of the New England Area are shown thus:—|—|—|—|—|

The position of the Enoggera Hydrid is shown thus :◎

The letter-numbers (E.1, S.3, N.4, &c.) refer to the analyses of Tables III., IV., and V.

*Figure* 1 shows the curves obtained by plotting $K_2O$ and $Na_2O$ against $SiO_2$.

*Figure* 2 shows the curves obtained by plotting CaO and MgO against $SiO_2$.

## Plates II. and III.

## MICROPHOTOGRAPHS.

All the microphotographs are magnified 25 diameters. No. 4, Plate II., was taken in ordinary light. All the other microphotographs were taken with crossed nicols.

## Plate II.

*No. 1* (G.1) 141.—Pink Phase. Specimen from southern part of main Enoggera mass, × 25, crossed nicols.

*No. 2* (G.26) 422.—Pink Phase. Specimens from Green Hill area, × 25, crossed nicols.

*No. 3* (G.43) 351.—Micrographic structure in Aplite, × 25, crossed nicols.

*No. 4* (G.44) 416.—Grey Phase. Hornblendic type. Portion 374, parish of Enoggera, × 25, ordinary light.

*No. 5* (G.41) 345.—Grey Phase. Intermediate between Hornblendic type (*see* No. 4) and Biotitic type (*see* No. 6). From near "The Summit," Taylor Range, × 25, crossed nicols.

*No. 6* (G.14) 418.—Grey Phase. Biotitic type from western part of the main Enoggera area, × 25, crossed nicols.

## Plate III.

*No. 7* (G.6) 154.—(?) Hybrid Granodiorite from Quarry, Enoggera Creek, × 25, crossed nicols.

*No. 8* (G.6) 154.—Zenolith of Biotitic type of Grey Phase in (?) Hybrid. Compare with Plate II., No. 6, × 25, crossed nicols.

*No. 9* (D.12) 171.—Intrusive Rhyolite near junction of creeks in portion 681, parish of Indooroopilly, × 25, crossed nicols.

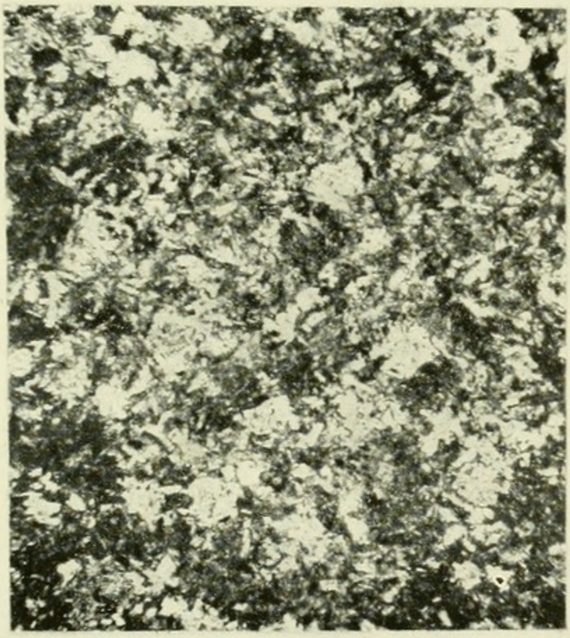
*No. 10* (D.64) 415.—Intrusive Rhyolite associated with silver-lead ores, Indooroopilly, × 25, crossed nicols.

*No. 11* (D.7) 166.—Porphyritic dyke across west Ithaca Creek, × 25, crossed nicols.

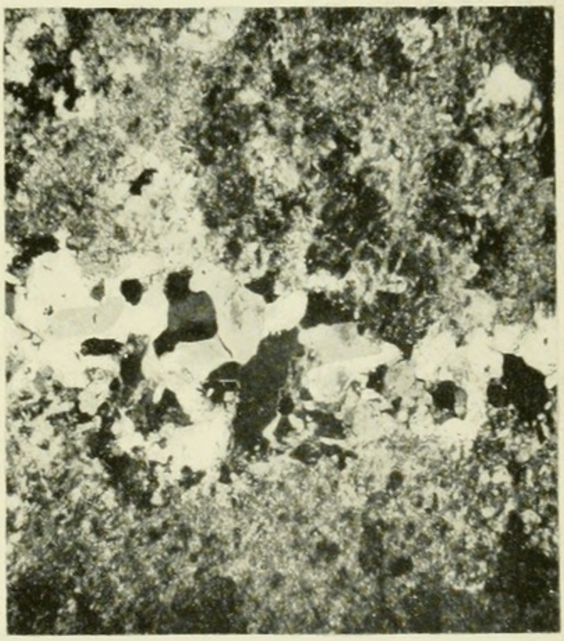
*No. 12* (D.4) 163.—Porphyritic dyke on road, Constitution Hill, Taylor Range, × 25, crossed nicols.

7.

8.



9.



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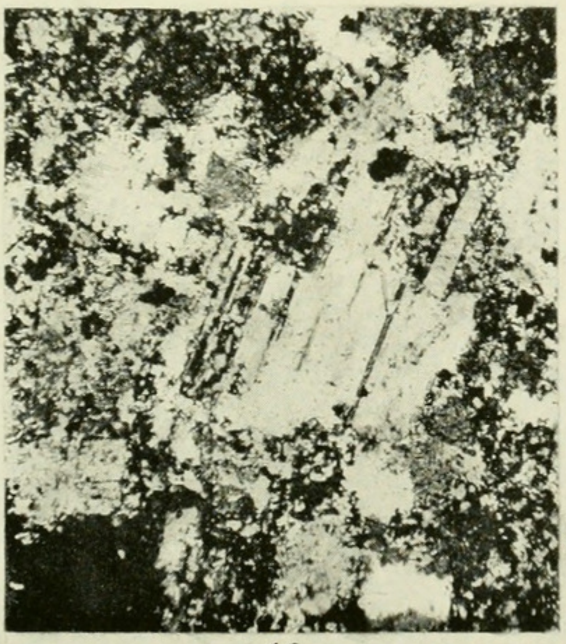


11.

12.

# Anorthoclase Basalt from Mapleton, Blackall Range, South-Eastern Queensland.

By H. C. Richards, D.Sc., Professor of Geology and Mineralogy, University of Queensland.

(Plate IV.)

(*Read before the Royal Society of Queensland, 31st August*, 1922.)

Some time ago, while investigating the volcanic rocks of the Blackall Range some 60 or 70 miles north of Brisbane, in the Mapleton area, the author was attracted by a basaltic flow which contained numerous lozenge-shaped phenocrysts of felspar. Subsequent microscopic examination bore out the prediction that they were crystals of anorthoclase felspar.

Mr. G. J. Saunders, B.E., M.Sc., who was completing his honours course in Geology at the University in 1918, kindly undertook the complete chemical analysis of the rock; and an inspection of this shows the presence of 7·02 per cent. of alkalies—an excess of nearly 3 per cent. over the combined alkalies in the average analysis of basalt as given by Daly.[1]

Although many rhyolitic and trachytic rocks with very decided alkaline characters have been described from Southern and Central Queensland by Dr. H. I. Jensen and the author, up to the present there has not been any record of a sub-basic or basic alkaline rock containing anorthoclase.

This paper, therefore, constitutes the first record in Queensland of a basic alkaline lava containing anorthoclase.

## FIELD OCCURRENCE.

About 2 miles to the south-west of the township of Mapleton, in the proximity of the Mapleton Falls, where the road leaves the top of the range to descend into the

[1] R. A. Daly, "Origin of Igneous Rocks."

valley, one finds the flow in question outcropping on the road and in the paddocks on either side. The extent of the outcrop has not been determined, but it covers a considerable acreage, while the thickness is probably something more than 20 feet.

The flow forms one of the most recent of a large number which rest approximately horizontally upon the denuded surface of the Bundamba Sandstones of Upper Triassic age, and in all probability the flow was poured out in Upper Kainozoic times.

About one-half mile nearer to Mapleton than this anorthoclase basalt one finds rhyolitic rocks outcropping in a very weathered condition. In other parts of the Blackall Range, *e.g.*, near Montville and Flaxton, the upper basalts have been poured out over the rhyolite, and this is probably the relation of the different rocks at Mapleton. Immediately underlying the anorthoclase basalt flow is a considerable thickness of olivine basalt, which is well shown in the section over which passes the water at Baroon or Mapleton Falls.

The height above sea-level is approximately 1,400 feet, and both to the south and west the range falls away steeply.

Generally speaking the basalts of the Blackall Range are very much weathered, and considerable depths of soil are accumulated on the surface. This rock yields a very rich red soil, and the weathered surface has a distinctive dark-brown colour which serves as a useful indication of its weathered outcrop.

In collecting specimens, the extreme toughness of the rock is evident and in marked contrast to most of the basalts of the area. For purposes of road construction this toughness should result in a resistance to abrasion superior to that of the other basalts in the neighbourhood, and as such it has a special value.

## MEGASCOPIC CHARACTERS.

In general grain-size and colour the basalt is quite normal, but the presence of numerous phenocrysts of more or less lozenge-shaped anorthoclase felspars is a characteristic feature. An occasional phenocryst, lath-shaped and showing lamellar twinning, is seen, but anorthoclase much predominates.

The cleavage surfaces of the latter show an interference in the reflection, owing to the abundant inclusions of augite and magnetite, which are seen to better effect under the microscope.

The specific gravity is 2·725 and is rather lower than usual in the basalts of this area.

## MICROSCOPIC CHARACTERS.

### SECTION No. 266.[2]

The rock is holocrystalline, with phenocrysts of anorthoclase up to 5 mm. in length.

The ground-mass is composed of plagioclase laths up to 0·35 mm. long, augite granules averaging 0·1 mm. in diameter, and abundant small octahedral crystals of magnetite about ·03 mm. in diameter.

The fabric is porphyritic and perpatic.[3] The minerals present are anorthoclase as phenocrysts, plagioclase (acid andesine to medium andesine), augite, olivine, magnetite, and a greenish alteration product.

*The anorthoclase phenocrysts,* like many of the phenocrysts of plagioclase in the basalts and andesites of Upper Kainozoic age in Southern Queensland, have been much affected by the ground-mass, as the corners are rounded and a definite reaction rim has developed.

The abundance of augite and magnetite inclusions in these anorthoclase phenocrysts is a marked feature. In all cases the reaction rim is free from inclusions. (*See* Fig. 1, Plate IV.)

A definite net-like arrangement of considerable regularity characterises the inclusions, and many instances suggesting micrographic intergrowth of the augite "inclusions" and the phenocryst may be seen.

Simple twinning is common in the crystals, and in one or two cases very fine microcline twinning occurs.

*The plagioclase crystals* in the ground-mass furnish lath-shaped and rectangular sections.

[2] The number refers to the slide in the University of Queensland collection.

[3] J. P. Iddings, "Igneous Rocks," Vol. I., 1909, p. 199.

From the extinction angles the felspar varies from acid to medium andesine.

*The augite* is highly titaniferous, as it has a distinct violet tinge. The habit of the crystals varies. It may be in compact granules showing ophitic structure with the plagioclase and containing inclusions of magnetite, or else it may occur as long narrow wisps up to 1·75 mm. but still showing ophitic structure.

The most interesting occurrence of augite, however, is in the form of inclusions in the anorthoclase phenocrysts when several granules in close proximity are optically continuous, and in this way micrographic intergrowth of the felspar and augite is indicated.

*Olivine* in the form of clear rounded granules occurs abundantly, and it is usually associated with a greenish alteration product—possibly serpentine.

*Magnetite* in small octahedral crystals occurs abundantly throughout the ground-mass and as inclusions in the phenocrysts and in the augite granules.

## CHEMICAL CHARACTERS.

For the purposes of comparison four other analyses are given in addition to that of the anorthoclase basalt.

The second one—that of a flow of oligoclase basalt from the summit of Spicer's Peak in the Main Range, near Cunningham's Gap—bears a striking similarity to the analysis under consideration.

The third analysis of an olivine basalt from Mount Lindsay is also of interest for comparison.

The fourth analysis carried out by Miss Rose Scott, M.Sc., in 1918, indicates the chemical character of the normal basalt which occurs along the top of the Blackall Range.

The fifth analysis is that given by R. A. Daly as the average analysis of a basalt.

It will be noted that the anorthoclase basalt has lower alumina, more iron oxides, less magnesia, considerably less lime, more soda, and twice as much potash as the ordinary sub-alkaline basalt from Montville, which is characteristic of the Blackall Range as a whole.

In comparison with the average basalt analysis, the marked deficiencies in magnesia and lime and equally marked excesses of soda and potash are the outstanding features of the anorthoclase basalt.

An examination of the norms shows a very close resemblance, especially in the felspathic content of the Mapleton and Spicer's Peak basalts. The modes of the two rocks differ considerably, also there is much difference in their textures and crystallinity.

The felspathic content of the norm of the Montville basalt is in sharp contrast with that of the Mapleton basalt. The deficiency in potash and the excess in lime of the former is made very pronounced.

CHEMICAL ANALYSES.

| Rock. | Anorthoclase Basalt. Mapelton. | Oligoclase, Basalt. Spicer's Peak. | Basalt. Mount Lindsay.[4] | Basalt. Montville. | Average Basalt (R. A. Daly.) |
|---|---|---|---|---|---|
| Analyst | G. J. Saunders, B.E., M.Sc. | G. R. Patten. | G. R. Patten. | Rose Scott, M.Sc. | |
| $SiO_2$ .. | 53·33 | 52·95 | 47·50 | 52·00 | 49·06 |
| $Al_2O_3$ .. | 14·57 | 15·56 | 14·19 | 18·76 | 15·70 |
| $Fe_2O_3$ .. | 4·47 | 2·62 | 1·78 | 1·86 | 5·38 |
| FeO .. | 6·67 | 7·29 | 12·15 | 5·84 | 6·37 |
| MgO .. | 3·24 | 2·89 | 5·06 | 4·15 | 6·17 |
| CaO .. | 5·76 | 4·92 | 7·47 | 7·31 | 8·95 |
| $Na_2O$ .. | 4·40 | 4·46 | 3·85 | 3·75 | 3·11 |
| $K_2O$ .. | 2·62 | 2·94 | 1·58 | 1·27 | 1·52 |
| $H_2O+$ .. | 2·09 | 2·18 | 1·59 | 1·06 } | 1·62 |
| $H_2O-$ .. | 0·98 | 0·75 | 0·33 | 0·80 } | |
| $TiO_2$ .. | 1·71 | 1·84 | 3·08 | 1·85 | 1·36 |
| $P_2O_5$ .. | 0·83 | 1·15 | 0·79 | 1·24 | 0·45 |
| MnO .. | n.d. | 0·14 | 0·20 | .. | 0·31 |
| Total .. | 100·67 | 99·69 | 99·57 | 99·89 | 100·00 |
| Sp. Gr. | 2·725 | 2·74 | 2·79 | .. | .. |

Norms.

| | | | | | |
|---|---|---|---|---|---|
| Quartz .. | 2·46 | 0·90 | .. | 3·90 | .. |
| Orthoclase .. | 15·46 | 17·24 | 9·45 | 7·78 | .. |
| Albite .. | 37·20 | 37·73 | 30·39 | 31·44 | .. |
| Anorthite .. | 12·23 | 13·90 | 16·68 | 28·91 | .. |
| Nepheline .. | .. | .. | 1·14 | .. | .. |
| Corundum .. | .. | .. | .. | 0·61 | .. |
| Diopside .. | 9·34 | 3·00 | 13·24 | .. | .. |
| Hypersthene | 9·33 | 14·16 | .. | 16·47 | .. |
| Olivine .. | .. | .. | 17·43 | .. | .. |
| Magnetite .. | 6·50 | 3·71 | 2·55 | 2·78 | .. |
| Ilmenite .. | 3·19 | 3·50 | 4·41 | 3·50 | .. |
| Apatite .. | 2·02 | 2·69 | 1·68 | 2·69 | .. |
| Water, etc. .. | 3·07 | 2·93 | 1·92 | 1·86 | .. |
| Total .. | 100·91 | 99·76 | 98·89 | 99·94 | .. |
| American Class | II. 5.2.4 Akerose | II. 5.2.4 Akerose | III. 5.3.4 Camptonose | II. 5.3.4 Andose | .. .. |

[4] Volc. Rocks, S.E., Qld., p. 177.

## DESCRIPTION OF PLATE IV.

This shows six microphotographs of the anorthoclase basalt and of the various basalts with which it has been compared. The first four microphotographs have been taken with crossed nicols, and the last two in ordinary light. In all cases the magnification was 17 times.

No. 1.—*Anorthoclase Basalt* from Mapleton, Blackall Range. Microslide No. 266. In the centre of the field there is a phenocryst of anorthoclase showing simple twinning, inclusions of augite granules, &c., and a clear zone around the margin. The groundmass is composed of plagioclase, augite, olivine, and magnetite. Crossed nicols; magnified 17 times.

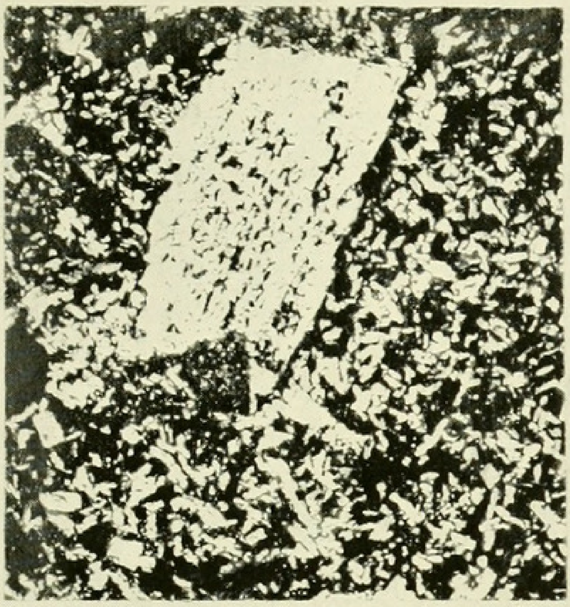
No. 2.—*Anorthoclase Basalt* from Mapleton. This is another portion of the same slide, as used for No. 1, and shows much the same features. Crossed nicols; magnified 17 times.

No. 3.—*Olivine Basalt,* Mapleton Falls, Mapleton, Blackall Range. Microslide 260. This rock immediately underlies the anorthoclase basalt. It contains phenocrysts of olivine set in a groundmass of plagioclase, augite, olivine, magnetite, and a greenish glass. Crossed nicols; magnified 17 times.

No. 4.—*Basalt* from road cutting near State School, Montville, Blackall Range. Microslide 262. This slide is representative of the basalts of Blackall Range, and is composed of plagioclase, augite showing ophitic structure, olivine, magnetite, ilmenite, and a greenish-brown glass. Crossed nicols; magnified 17 times.

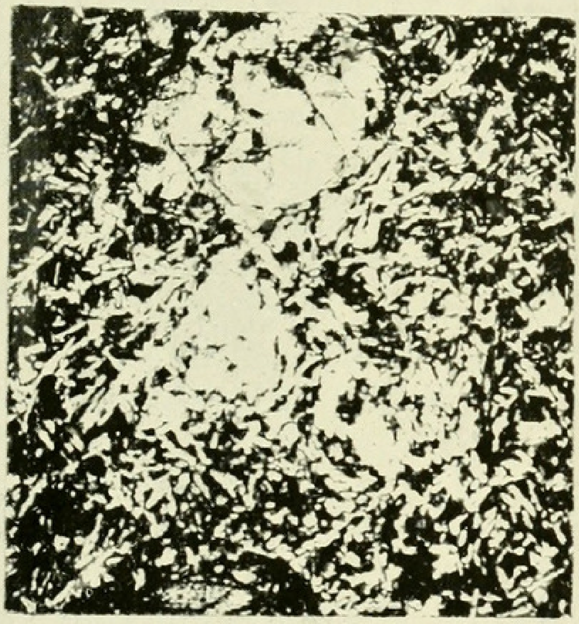
No. 5.—*Basalt* from 3,000-ft. level. Eastern slope of Mt. Lindsay, MacPherson Range. Microslide 221. Occasional lath-shaped crystals of plagioclase occur in the hypohyaline groundmass, which is streaked parallel to direction of flow. Ordinary light; magnified 17 times.

No. 6.—*Oligoclase Basalt* from Spicer's Peak, Main Range. Microside 116. This slide shows the very fine-grained nature of the rock. The dark patch in the centre represents a crystal of olivine. Ordinary light; magnified 17 times.



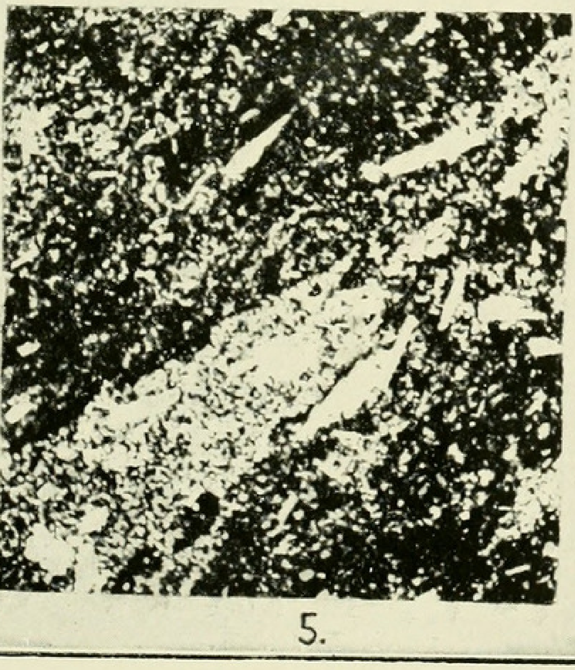
1.

2.

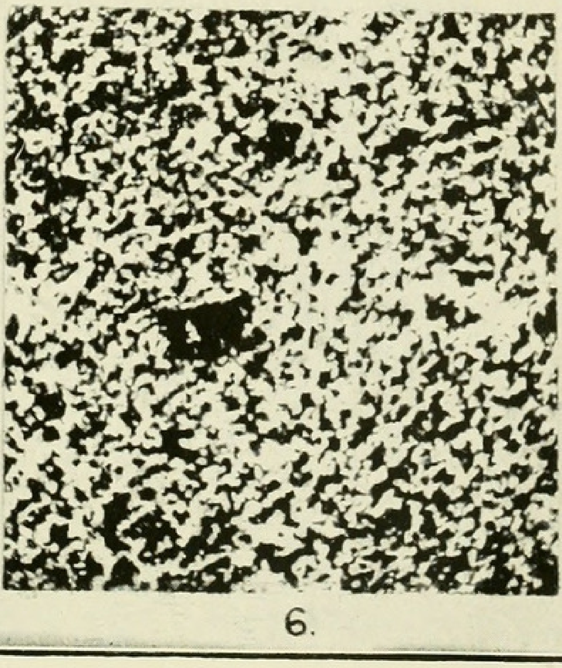


3.

4.



5.



6.

## PETROGENIC SIGNIFICANCE.

In a previous publication[5] the author, in describing the Spicer's Peak oligoclase basalt, fully recognised its chemical difference from the ordinary sub-alkaline flows of Southern Queensland, and showed the close chemical relationship with that of the mugearites described by Harker[6] from Skye. Similar chemical characters were noted in the oligoclase basalt and the olivine basalt from Mount Lindsay, both of which terminated phases of effusion of lavas, the lower and upper basaltic series respectively, and the author wrote[7]: "Whether the occurrence of these rocks at the termination of two periods of activity during which basic rocks have been poured out is a mere coincidence or not, is a question." It is a matter of very considerable interest to find that this alkaline basalt from Mapleton, which has the same peculiar chemical characters as the basalts from Spicer's Peak and from Mount Lindsay, like them also represents the concluding effusion of a volcanic phase—the Upper Basaltic one.

One would expect the concluding effusions of each of these phases to be more differentiated than the earlier flows, owing to the law of increasing divergence, but the alkaline character of the last flow in each case has a particular interest and certainly does not support Daly's assimilation hypothesis as to the origin of alkaline rocks.

In conclusion, I extend to Miss Rose Scott, M.Sc., and Mr. G. J. Saunders, B.E., M.Sc., my thanks for carrying out, when advanced students at the University, the two analyses which have hitherto been unpublished, and which have been of the greatest help in the points considered in this paper.

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[5] "Volcanic Rocks of South-Eastern Queensland," Pr. Roy. Soc. Qld., xxvii., 1916, p. 172, p. 176.

[6] Harker, "Tertiary Igneous Rocks of Skye," p. 263.

[7] Op. Cit., p. 192.