ON SOME METAMORPHOSED DOLERITES FROM BROKEN HILL.

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(With Plate XIII.)

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Introduction.

In a petrological appendix to the Geological Survey Memoir on the Broken Hill Lode the writer has given a description of the Archaean rocks forming the Willyama Series. The terrain, in the immediate neighbourhood of Broken Hill, consists largely of a series of highly metamorphosed sedimentary rocks, now represented mainly by garnet-sillimanite-cordierite gneisses; these are invaded by primary gneisses of a general granitic character, and by gabbros and gabbro-gneisses, the basic rocks forming sills and sheets which pass through the granite-gneisses in many cases. These latter are also intersected by dykes of aplite and gabbro.

There is ample evidence that the main metamorphism of the sediments was accomplished before the intrusion of the gneisses, but subsequent shearing has resulted in a certain amount of superimposed low-grade dynamic metamorphism, locally intensified. This, however, has to a large extent failed to obliterate pre-existing structures, although in places its effects are visible to a greater or less degree.

It was thought at first that all the basic rocks of the neighbourhood were of later age than the granite-gneisses; since the publication of the Broken Hill Memoir, however, it has become evident that there are basic rocks occurring
quite close to the city, of which some clearly and others possibly represent crystallizations antedating the intrusion of the granite-gneisses. It is with the former division of these that the present paper is concerned.

The rocks in question are all contained within the limits of the outcrop of what is known as the Alma Augen-Gneiss, a coarse porphyritic gneiss forming what Mr. Andrews has called the Mack Plateau, to the east of the township of Alma. This mass is intersected by a number of dykes of gabbroic nature, very comparable in all respects with the gabbro of the sills, intimately associated with aplite in some cases, and clearly intrusive through the gneiss. Some of these basic rocks are coarse, others fine in grain. In certain of the latter the original pyroxene has been wholly or partly altered into green hornblende by shearing, but their affinities with the unaltered gabbros are quite clear.

In addition to these there are a series of small outcrops of fine-grained dark rocks, as well as some dyke-like masses with similar texture, which on the field-evidence and by analogy with the other occurrences were regarded as intrusions. One of these dyke-like masses lies near the eastern end of the Alma rifle-range, runs slightly obliquely to the foliation of the augen-gneiss, and even appears to cut through an aplitic dyke which is clearly satellitic to the gneiss. Microscopic examination of specimens of the basic rock having strongly suggested that it had suffered thermal metamorphism, it was thought that possibly some mistake had been made in labelling the specimens. For this reason no mention of the occurrence was made in the generalised description of the basic rocks given in the Broken Hill Memoir, but when later the opportunity presented itself, further check-specimens were collected and a field-examination of the occurrence was made, by which the previous observations as to the apparent relations of the mass were completely confirmed.
At least four outcrops of rock of this type are represented in the specimens examined.

**Petrographic Description.**

In hand-specimen the rocks are dark, heavy, compact and massive, without any traces of directional structures. Tiny, dark hornblende grains are conspicuous by reason of their lustre. The different specimens, while having most points in common, show minor variations.

Specimen B120 (Plate XITI, Figs. 1 and 2), from the hill east of the rifle-range, contains plagioclase, augite, brown hornblende, hypersthene and magnetite. Felspar forms about half, and pyroxene and hornblende each about a quarter, of the rock-section, the dark minerals showing clear evidences of a former ophitic relation towards the felspar. The grainsize varies from point to point, this being shown particularly by the columnar felspars, which in some places attain a length of 3 mm., while elsewhere they average about .5 mm. Locally the blastophitic texture is lost through recrystallization, and a granular or granoblastic appearance is produced.

The plagioclase, which is very basic (about Ab26An74), is twinned on the albite, Carlsbad and pericline laws: zoning is absent. The habit is mostly sub-columnar, the original outlines having been modified and indented through the recrystallization of the pyroxene. The longer columns are sometimes slightly bent and fractured. A fairly constant characteristic of the felspar crystals is the presence, in their central parts particularly, of tiny inclusions. These are often fairly well-defined crystals, and augite, hypersthene and occasional brown hornblende can be recognised. In suitably-oriented sections strings of little prisms may be seen with their long axes arranged along the pinacoidal cleavage.
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Pyroxene is in part primary and in part secondary. The primary augite is in the usual irregular grains or patches up to about 2 mm. in diameter, indented and intersected by felspar prisms. It is light-grey in colour, but was probably darker originally, as the grains are now for the most part heavily schillerized, plates and rods of iron-ore being arranged not merely parallel to (100), but also parallel to the base, and in a direction inclined at about 60° to the vertical axis in sections parallel to (010). Cross-sections show, in addition to the black rods along the dialagie parting, rows of little square dots parallel to (010); these are probably cross-sections of rods. The surface of an augite section is often quite darkened by black magnetite (or ilmenite) dust and rods. The optic axial angle is variable, being sometimes quite low, though no values approaching 0° were observed; the mineral is therefore, in part at least, of the magnesia-rich variety known as enstatite-augite.

Most of the primary augite has been reecrystallized into granular aggregates of brown hornblende, augite, and hypersthene, the individual grains averaging about .25 mm. in diameter. The distribution of the hornblende is quite irregular; from some of the replacing aggregates it is quite absent, elsewhere it is the predominating constituent, and sometimes in larger grains it envelopes a felspar, being wholly or partially pseudomorphous after original augite. The pleochroic scheme is: X = yellowish-brown, Y and Z = brown, with extinction in the principal zone up to 20°.

The granular augite is light grey coloured and shows no peculiarities. Hypersthene, though subordinate to the other dark minerals, is present in notable proportion: it is faintly but noticeably pleochroic, and has weak negative birefringence. Where it forms the principal constituent of the granular aggregates, these may represent the re-ecrystallization of a former primary hypersthene.
A little magnetite in tiny granules is included in the secondary hornblende and pyroxene, evidently representing schiller-material not used up by these minerals. The absence of signs of primary magnetite and apatite is noteworthy, likewise the absence of any quartz.

Another specimen, B1320 (Plate XIII, Fig. 3), from the dyke-like mass east of the rifle-range, shows a further stage towards complete reconstitution. The proportion of original pyroxene is smaller than in the first specimen, and while there are many columnar felspars, there is an increase in the proportion of granular felspar. This latter is noticeably free from inclusions, and in many cases shows little or no twinning. Some portions of the thin section have the structure of a typical pyroxene-granulite.

Specimen B1321 (Plate XIII, Fig. 4), from the same mass, shows many of the same characters as those described above. The abundant hornblende is of a greenish-brown colour, and occurs both as a granular mosaic encroaching on the primary augite, and as a replacement to the augite along cracks and cleavage-planes. A feature fairly conspicuous in this slide, but not very prominent in the others, is the occasional inverse zoning of the felspar. As a rule, the small, less basic nucleus is not centrally placed and is irregular or rounded in shape, and it passes outwards by a fairly narrow transition zone into the outer more basic portion. Inverse zoning is a feature noted by Becke² and others as characteristic of metamorphic rocks, though it may also be produced under conditions of igneous crystallization.

This specimen has suffered further metamorphism of a regressive nature, which is probably to be ascribed to the period of dynamic metamorphism referred to above. The brown hornblende passes into a colourless type which frays out into a fringe of parallel needles, while the pyroxenes
have been changed partly or wholly into aggregates of brightly-polarising colourless or very pale green needles of amphibole with parallel arrangement. So much of this has straight extinction that one is tempted to regard it as anthophyllite, though much is undoubtedly monoclinic amphibole. Where these aggregates impinge on felspars, they pass over into a narrow border of more distinctly coloured amphibole, pleochroic in yellow-green, green and bluish-green tints.

The amphibole has replaced practically all of the hypersthene; augite has been attacked also, though to a much less extent, while the brown hornblende has suffered least of all. Here and there patches of magnetite-dust testify that the pale amphibole has a smaller iron-content than the mineral it replaces.

The amphibolisation just described is exactly similar to that observed affecting the gabbros of the Broken Hill area in places, and is due apparently to the sensitiveness of pyroxene, and particularly the rhombic variety, to minor crustal stresses.

The rocks above described are all olivine-free, but a number of olivine-bearing types have been collected, some of them from the dyke-like mass at the rifle-range. In B1322 (Plate XIII, Fig. 5), the original ophitic fabric of the rock is clearly recognisable, and the columnar felspars are in places very thickly crowded with tiny inclusions. Traces of original hypersthene are seen, and the segregation or clustering of brown hornblende grains is very marked, these clusters in places enclosing magnetite now coalesced into definite grains.

Olivine probably formed under 5 per cent. of the original rock. It still retains some traces of idiomorphism, but is much cracked, and scored and rimmed with trails of magnetite-dust. Much of the original olivine-substance still
survives, but much has been reconstituted, and is now represented largely by pyroxene. A few traces of a kind of rude centric structure appear, where olivine grains are partially rimmed with pyroxene granules, mostly hypersthene, but nothing in the way of a definite corona-structure exists. The olivine is altering in places to aggregates of colourless amphibole fibres, and elsewhere to ill-defined little patches of talcose (?) material.

The olivine in specimen B141, from a little neck-like mass at the narrowest part of the long southerly projection of the Alma gneiss, just near the municipal tip, is rather more altered. In most cases the site of the mineral is now occupied partly by hornblende and pyroxene granules, but mostly by anthophyllite fibres and hazy talc-like aggregates, and only the strings of magnetite-dust deposited along cracks remain to form a kind of ghost of the original olivine. It is not clear whether these changes are the result of a second metamorphism.

Re-crystallization of the pyroxene has not proceeded so far in this specimen as in the others, and the rock has a rather coarser grain. The surface of the augite sections is partially covered with a fine brown dust and with aggregates of tiny brown transparent and translucent brown rods and dots: this discharged material is generally arranged in more or less definite patterns, sometimes approximating to hour-glass shapes.

From the small outcrop just at the southerly tip of the long southerly projection of the gneiss comes a specimen (B147) which shows a number of interesting features (Plate XIII, Fig. 6). Olivine is more abundant, and felspar less abundant, than in the others. The olivine is fairly fresh, but with the usual magnetite along cracks, and this has a marked micro-dendritic or mossy arrangement. In
the felspar, almost entirely prismatic, the tiny inclusions are so abundant as to impart quite a grey colour to the mineral.

A little hypersthene appears among the primary pyroxene, but by far the greater part of the ferro-magnesian material forms a recrystallized granular mosaic, and at a rough estimate 65 to 70% of this is brown hornblende, while of the pyroxene hypersthene forms a greater proportion than usual.

Another noteworthy feature of this rock, and one found only to a very slight extent in the other olivine-bearing specimens, is the presence of a dark greenish-brown mineral in very tiny granules without definite shape, in some places occurring in little open clusters, but elsewhere aggregated into a solid mass, opaque in the centre, but translucent at the edges, where the dark mineral thins out on top of another transparent one. The properties of this mineral, in so far as they are determinable, agree best with those of the spinel picotite.

*Summary of Petrographical Characters.*

What appear to be the significant petrographical facts and deductions in regard to the rocks may now be summarised.

The unaltered rocks consisted mainly of columnar basic felspar and pyroxene, including enstatite-augite and hypersthene: magnetite and apatite were scarce or absent. Some of the rocks contained olivine and others were olivine-free. Alteration of the augite has produced heavy schillerization, and then by recrystallization augite, hypersthene and brown hornblende. The last is always plentiful and sometimes predominant: it varies in colour from greenish-brown in some specimens, through golden brown in others, to a reddish-brown, almost like the colour of biotite. It shows
a tendency to form mosaic-aggregates whose individuals are larger than those of the granular pyroxenes and have straight-line boundaries.

The very basic felspar has recrystallized, mostly with the original columnar habit, former impurities or enclosures due to decomposition being now represented by tiny crystals of augite, etc.; in some cases recrystallization has been to clear granular felspar. Inverse zoning has been observed in a number of slides. The felspar content of the rocks is usually fairly high, but declines notably in the rock containing the greatest proportion of olivine. The olivine-bearing rocks contain a small to negligible proportion of what is probably picotite.

The structure of the rocks is blastophitic to granoblastic. Regressive metamorphism is indicated in a few instances, chiefly in the form of amphibolisation, which has affected all the ferro-magnesian minerals, and particularly the hypersthene.

Chemical Changes during Metamorphism.

It is sufficiently evident that the rocks under consideration are metamorphosed dolerites. The original rocks apparently belonged to the quartz-dolerite suite or kindred, which includes olivine-bearing types, and which is characterised by the presence in its members of enstatite-augite, often with rhombic pyroxene, and sometimes with the inter-growth known as pyroxene-perthite, an obscure example of which was detected in one of the slides examined.

The extreme metamorphism of such rocks has been shown to result in the breaking-up of the pyroxenes, with separation of rhombic and monoclinic pyroxenes as distinct grains, the reaction being expressed thus:

\[
\begin{align*}
\{ m\text{CaMgSi}_2\text{O}_6 \} \\
\text{MgAl}_2\text{SiO}_6 \\
\{ n\text{MgSiO}_3 \} \\
\end{align*}
\]

\[
\begin{align*}
= \{ m\text{CaMgSi}_2\text{O}_6 \} + n\text{MgSiO}_3 \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)
\end{align*}
\]
A notable feature of some of these rocks is the inverse zoning of some of the plagioclase. This does not appear to have been noted in rocks of similar origin and composition, and it calls for explanation. It really implies that there has been in the process of metamorphism an enrichment of the original felspar in the anorthite molecule, and the lime for this could only be made available by the breaking-down of augite. A reaction such as

\[
\begin{align*}
\left\{ m \text{CaMgSiO}_6 \right\} + \text{SiO}_2 &= (m - 1) \text{CaMgSi}_2\text{O}_6 + (n + 1) \text{MgSiO}_3 \\
\text{Diopside} + \text{Hypersthene} &= \text{Enstatite-augite} + \text{CaAl}_2\text{Si}_2\text{O}_8
\end{align*}
\]

would provide a means for the production of anorthite in addition to hypersthene and a diposidic pyroxene. For an ordinary aluminous pyroxene a similar reaction would hold, but the resultant hypersthene would be much smaller in amount. The silica necessary for this reaction might be got from the quartz in an original quartz-dolerite, and it may or may not be significant in this connection that, among the rocks studied, inverse zoning of the felspars has been noticed only in the olivine-free types, some or all of which may originally have contained quartz.

Of course, a more basic plagioclase might also be expected to result from the change of augite into hornblende, since in general this involves a release of lime and a taking-up of soda.

The absence of garnet from these rocks is noteworthy. In the various explanations which have been given to account for metamorphic garnet, there has been assumed a reaction between original augite and felspar, with the removal of some anorthite from the latter, or else simply a chemical disintegration of the original augite, involving no interaction with felspar. In the Broken Hill rocks
the absence of garnet may be due to the presence of sufficient free silica to enable reaction (2) to take place, in which case there is a causal relationship between the absence of garnet and the presence of a plagioclase more basic than the original one. But the absence of garnet from the olivine-bearing types shows that some inhibitive factor other than availability of silica must be at work, and this factor may be a physical rather than a chemical one.

Mention has been made of the presence of tiny granules of greenish-brown spinel in certain of the rocks; for this two possible explanations may be suggested. In the first place the spinel may have existed in solid solution in the augite, and during the process of metamorphism may have been forced, like the hypersthene, to take up a separate existence. The spinel should then be expected to appear in any of the rocks, but, as a matter of fact, careful search has failed to reveal it in any but the olivine-bearing types—that is, those in which no quartz could have been present originally. This suggests the second alternative, that there has been desilication of the Tschermak molecule of the original augite, either to provide the silica necessary for the conversion of some of the olivine into hypersthene, or else to enable the reaction expressed by equation (2) to be carried out, thus:

\[
\begin{align*}
\frac{m}{n}\text{CaMgSi}_2\text{O}_6 & = m\text{CaMgSi}_2\text{O}_6 + n\text{MgSiO}_3 + \text{MgAl}_2\text{O}_4 + \text{SiO}_2 \\
\text{MgAl}_2\text{Si}_6\text{O}_{16} & \quad \text{Diopside} \\
\text{nMgSiO}_3 & \quad \text{Hypersthene} \\
\text{nMgSiO}_3 & \quad \text{Spinel}
\end{align*}
\]

Enstatite-augite

The time and manner of formation of the brown hornblende are not known with certainty. It may have developed concurrently with the granular augite and hypersthene, but there is a possibility, discussed below, that it belongs to a later period of further partial recrystallization of the rocks under somewhat changed conditions.
Quite a wide range of chemical composition appears to be possible in brown hornblendes: in the present instance the colour probably betokens a special richness in one or other of the iron oxides, and perhaps in titania. These could easily have been supplied by the primary augite, which, if one may judge from its present heavy schillerization, must have been quite highly ferriferous.

The simultaneous recrystallization of hornblende, augite and hypersthene from enstatite-augite may be expressed by the equation:

\[
\begin{align*}
\{m \text{CaMgSi}_2\text{O}_6\} \\
\{\text{MgAl}_2\text{SiO}_6\} \\
\{n \text{MgSiO}_3\} \\
= \text{CaMgSi}_2\text{O}_6 + (n - 1)\text{MgSiO}_3 + \{\text{CaMg}_4(\text{SiO}_8)\} \\
\{\text{MgAl}_2\text{SiO}_6\} \\
\text{Diopside} \\
\text{Hypersthene} \\
\text{Hornblende}
\end{align*}
\]

By this reaction, however, the quantity of hornblende produced would be very small in comparison with the pyroxene, which does not accord with what is observed in the rocks. Indeed, there is no constancy in the ratio of hornblende to pyroxene in the recrystallized portions of the rocks, and this and other circumstances, such as the pseudomorphing of original augite by brown hornblende, the occasional marginal conversion of pyroxene into hornblende, and the frequent segregation of hornblende grains into clusters whose individuals are markedly larger than the pyroxene grains, make one feel that the hornblende may really be the product of a subsequent high-grade thermal metamorphism, in the presence of the water or other volatile mineralizers which are necessary for the formation of this mineral.

The inspection of a series of chemical analyses of enstatite-augites reveals the fact that many approach closely some of the hornblendes in composition, owing to the fact that the incorporation of the enstatite molecule lowers the CaO/MgO ratio in the augite to a value comparable with that obtaining in the amphiboles. The change from
pyroxene to brown hornblende would then be little more than a paramorphic one, and this is indeed suggested by the absence of rejected constituents where the hornblende is seen partially replacing original pyroxene.

It is conceivable, too, that some hornblende might arise in a subsequent metamorphism from the recombination of the molecules of the granular augite and hypersthene.

No vestige of biotite has been detected in any of the rocks examined, a rather surprising thing in view of the very common occurrence of biotite and orthoclase in rocks of the quartz-dolerite suite; the absence of secondary sphene, too, is somewhat unusual. It may be that potash and titania were both low in the original rocks, and that they were taken up during metamorphism into plagioclase and pyroxene or amphibole.

**Comparison with Analogous Occurrences elsewhere.**

Transformations similar to many of those recorded above have been observed in several other areas as the result of high-grade thermal metamorphism of basic igneous rocks.

Sir J. Flett mentions the occurrence of augite in the hornblende-schists of the Lizard, ascribing it either to contact-alteration or to folding and regional metamorphism at high temperatures. The same author, describing the diabase-hornfelses at Land’s End, due to alteration by intrusive granites, mentions the very common occurrence, in the extreme stages of alteration, of a pale brown or brownish-green hornblende, with less abundant colourless or pale green augite.

The alteration of diabase round the Dartmoor granite is also of interest in this connection. The first change is the production of much new green or bluish-green hornblende, and this mineral is scattered in enormous quantities in tiny grains through the felspar. Nearer the granite the original
augite is completely replaced by clear brown hornblende quite distinct from the green, iron oxides decrease, and the felspar, originally albite, becomes more basic.

Dr. W. F. Smeeth describes how the Kolar hornblende-schists of Mysore, themselves derived from basic lavas, have been recrystallized into augite-granulites, and in places hornblende-granulites near their contact with an igneous intrusion; and Dr. C. E. Tilley has recorded a somewhat similar case at Carn Chois, Perthshire, where epidiorite-sills and sheets involved in the contact-aureole of a diorite intrusion have been converted into granular augite-hyperssthene hornfelses.

Rocks having certain resemblances to those under discussion have been recorded from Adélie Land by Dr. F. L. Stillwell. In these rocks, which are olivine-free, the place of the original columnar felspars has been taken by granular aggregates of secondary felspar, garnet is present, and green, but not brown, hornblende is found. The rocks occur as dykes through garnet-cordierite gneisses, and their characters are attributed apparently to deep-seated regional metamorphism, though the reported occurrence of a pegmatite-dyke in the neighbourhood might suggest the close proximity of a granite-bathylith.

The nearest and most striking analogues to the Broken Hill rocks, both in mode of occurrence and in general characters, are the metadolerites of Southern Eyre Peninsula, described by Dr. C. E. Tilley. The original rocks belonged to the quartz-dolerite group, and some contained olivine. The most noteworthy differences manifested by these when compared with the Broken Hill examples are the presence of garnet and of green instead of brown hornblende, and the greater acidity of, and absence of inverse zoning in, the plagioclase. Tilley interprets the present characters of the rocks as resulting from engulf-
metamorphosed dolerites.

ment of portions of a mass of dolerite in, and their thermal metamorphism by, an acid igneous magna. It is noteworthy that in the occurrences cited by Tilley and Stillwell both hypersthene and augite result from the breaking-up of the original pyroxene.

*Origin of the Rocks.*

From the evidence of the examples just cited it may be inferred that augite and hornblende may be produced as the result of high-grade thermal alteration of basic rocks. Augite may apparently result from regional and contact-metamorphism, and brown hornblende from contact-metamorphism, but in this connexion it is to be noted that Grubenmann has considered the probability that the brown hornblende found in the altered basic rocks of his "kata-zone" has formed under the same deep-seated conditions as the augite, in contrast with the green hornblende which is characteristic of the "meso-zone".

From the internal evidence of texture it may be inferred that the Broken Hill rocks crystallized originally as intrusives, though not necessarily in their present surroundings; the grainsize and the ophitic fabric indicate clearly hypabyssal conditions of consolidation. The alteration shows that they have subsequently suffered a high degree of thermal metamorphism. There remain, then, to be discussed the time of intrusion and the time and circumstances of the metamorphism. The sedimentary rocks among which the augen granite-gneiss is injected had, previously to its intrusion, been converted into garnet-sillimanite-cordierite gneisses with "kata-zone" characters and a fairly pronounced schistosity. At a later date, and during the continuance of the folding, the granite-gneiss was injected, and had impressed on it during crystallization a primary gneissic foliation. Subsequent local shearing superinduced a further low-grade metamorphism
which, however, did not obliterare, though it modified, the primary gneisses structure.

However, the point to be emphasised is that there is no evidence of high-grade metamorphism having affected the granite-gneiss subsequently to its cooling, and the masses of altered dolerite within its borders must therefore, in spite of the dyke-like appearance of some of them, be interpreted as inclusions of pre-existing rock-masses, engulfed in the gneiss magna at the time of its injection. This being so, there are two possible alternatives as to the time of formation of the dolerites:

(1) they were injected after the metamorphism of the sedimentary series and immediately before the injection of the augen-gneiss; or

(2) they were injected into the sediments before the metamorphism of the latter.

Under the first assumption the present condition of the rocks is entirely due to contact-metamorphism and engulfment in the granite-magma. As opposed to this first view and more in harmony with the second is the ophitic fabric of the original rocks. The granular and gabbroic textures are usually regarded as belonging to large deep-seated basic intrusions, and the ophitic as being characteristic rather of smaller hypabyssal injections and of surface-flows. It is therefore more natural to associate ophitic dolerites with dykes or sills through a series of unaltered sediments than to imagine them as heralding deep-seated granite-gneiss injections through a terrain still undergoing metamorphism under conditions of mountain-building and deep burial. It seems preferable, then, to ascribe these rocks to a period antedating the metamorphism of the sedimentary rocks. This implies that they received their first and probably their main metamorphic impress under regional conditions. Whether brown hornblende as well as pyroxene was formed
then it is impossible to say. But the hornblende is very variable in its proportions and very uneven in its distribution through the rocks within the limits of a single occurrence, and we know that this mineral requires the existence of “wet” rather than “dry” metamorphic conditions, and has been recorded as a contact-mineral; perhaps, therefore, it is most reasonable to ascribe the secondary pyroxene to the first or regional metamorphism, and the brown hornblende to the subsequent high-temperature, “wet” alteration of both primary and recrystallized pyroxene during and as a result of engulfment in the granite-gneiss magma.

Summary.

Petrographical descriptions are given of a series of basic rocks enclosed within the outcrop of a granitic augen-gneiss at Broken Hill. These have been originally ophitic dolerites belonging to the quartz-dolerite kindred, and have suffered high-grade thermal metamorphism, with the production of augite, hypersthene, brown hornblende, very basic plagioclase, and in some cases a little spinel, with partial or complete obliteration of original textures.

An attempt is made to indicate the general nature of the probable chemical reactions taking place during metamorphism, and the time and manner of alteration are discussed. It is considered most probable that the rocks first suffered extreme regional metamorphism and subsequently underwent contact-metamorphism with engulfment at the time of the injection of the granite-gneiss.

REFERENCES.

FOUR NEW SPECIES OF BORONIA.

DESCRIPTIONS OF FOUR NEW SPECIES OF BORONIA, WITH NOTES ON CERTAIN OTHER SPECIES.

By Edwin Cheel, Curator of the Notional Herbarium, Sydney, (Read before the Royal Society of New South Wales, Dec. 7, 1927.)

In working over the large collection of specimens of the genus Boronia contained in the National Herbarium, one cannot but notice the extreme variation of the material representing the various species. In a previous paper published in the Journal and Proceedings of this Society (11) I endeavoured to show that at least two species were worthy of separate entity from the pinnate-leaved series, and in continuation of my investigations I now submit descriptions of four species which do not appear to have been previously described, together with notes on certain other species which have been incorporated as synonyms, and composite descriptions drawn up to cover the supposed variations.

The following is a synopsis of the species dealt with in the present paper:—

B. suhulifolia sp. nov. Previously included under B. pilosa but the latter and its forms are confined to Tasmania and South Australia.

B. hispida sp. nov. Previously included under B. polygalifolia as a variety.

B. Ruppii sp. nov. Somewhat related to B. Fraseri.

B. Whitei sp. nov. Affinities with B. granitica.

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EXPLANATION OF PLATE XIII.

Fig. 1.—Slide B120. Ordinary light. × 33. Note hornblende (dark grey), primary augite with schiller-inclusions, and plagioclase. Traces of ophitic fabric still visible.

Fig. 2.—Same as Fig. 1. Crossed nicols. Shows modified columnar habit of plagioclase.

Fig. 3.—Slide B1320. Ordinary light. × 173. Recrystallization has produced an approach to granoblastic structure.

Fig. 4.—Slide B1321. Crossed nicols. × 45. In the centre is a grain of plagioclase with inverse zoning, the more basic shell being at extinction: the grain also shows traces of albite and pericline twinning. Above and to the right are relatively large grains of brown hornblende.

Fig. 5.—Slide B1322. Ordinary light. × 173. Ophitic fabric is plainly evident. Note cluster of hornblende grains at right top, granular pyroxene elsewhere, and felspars crowded with tiny inclusions.

Fig. 6.—Slide B147. Ordinary light. × 173. Note olivine grains at top left and bottom right, between them a little felspar with hornblende inclusions, and at top left a cluster of spinel. Rest of field consists mostly of little hornblende and pyroxene grains.

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