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LOWER PROTEROZOIC BASIC INTRUSIVE ROCKS OF THE KATHERINE - DARWIN AREA, NORTHERN TERRITORY.

by

Robert Bryan.

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SUMMARY

The basic rocks of the Katherine - Darwin region have been divided into eight geographical groups and the field relationships and petrology of the rocks from each group are discussed. The general conclusions are :-

1. The rocks were intruded principally as sills or sub-horizontal sheets, prior to the folding of the sediments.

2. The rocks were predominantly dolerites and formed from tholeiitic magma.

3. Dolerite sills were intruded on two separate occasions during the Lower Proterozoic, but there is no geographic overlap between the sills of the two ages.

4. The dolerites were affected by deuteric alteration and low-grade regional metamorphism - the maximum alteration is in the Rum Jungle and Brocks Creek areas, the least in the South Alligator area.

5. In the main trough of the Pine Creek Geosyncline the dolerites were certainly intruded before the folding of the Lower Proterozoic sediments and possibly before the deposition of the Finniss River Group. In the South Alligator basin, the intrusives are younger than the equivalents of the Finniss River Group, and the form of some of the intrusions may have been controlled by the pattern of regional deformation.

6. All the dolerites are older than the granite.

7. No genetic link exists between the Lower Proterozoic granites and dolerite.

8. There is no connexion between the dolerite and the uranium, gold, silver, copper, tin, or lead mineralization of the region.

INTRODUCTION

The term "Katherine - Darwin Area" as used in the title of this paper, covers that portion of the Northern Territory lying between latitude 12°S. and 15°S., and between longitude 130°E. and 133°30'E.; this is the area covered by the 10 mile to 1 inch "Geological Map of the Katherine - Darwin Area" compiled by the Bureau of Mineral Resources (see Map1).

Most of the basic intrusive rocks within the region are clearly Lower Proterozoic. Upper Proterozoic dolerites are common only in the extreme south-east of the region, where they form the westerly extensions of a pattern of sills that have been mapped on the adjoining Urapunga Sheet. The petrography of these sills has been described in detail by the Australian Mineral Development Laboratories (1960). The Lower Proterozoic intrusive rocks are widespread throughout the areas of Lower Proterozoic sediments, and are especially common in the central part of the region.

The rocks have been treated as a whole only by J.R. Stewart, in an unpublished thesis. Apart from this, some basic rocks have been described in detail, but these have been from isolated localities, and few general conclusions have been drawn. Their descriptions will all be referred to below.

PETROGRAPHY AND FIELD RELATIONSHIPS OF THE BASIC ROCKS

Geological mapping of the Katherine - Darwin region has shown that the Lower Proterozoic basic intrusive rocks occur in eight principal areas (see Map 1):-

Oenpelli Mission Area
Jim Jim Creek Area
South Alligator River - Gerowie Creek - Coirwong Creek Area.
Mt Masson Area.
Burrundie Area.
Brocks Creek Area.
Daly River Area.
Rum Jungle Area.

During the present investigation, specimens were collected and described from the five most important areas; the remaining areas - Oenpelli Mission, Jim Jim Creek, and Daly River - were not sampled, but will be considered briefly, making use of existing information.

Oenpelli Mission Area

This area lies in the extreme north-east of the region (see Map 1), and the only work done there is mapping by Dunn (1960) at 4 miles to 1 inch.

The basic rocks form several irregularly shaped masses up to 10 miles in length and 1 mile across, intruding the Archaean Myra Falls Metamorphics, but intruded and thermally altered by the Nimbuwah Granite of Lower Proterozoic age. The basic rocks are unconformably overlain by Upper Proterozoic sediments. They form discordant plutons of porphyritic gabbro, consisting of ophitically intergrown labradorite and augite, with accessory amounts of biotite, olivine, apatite, and magnetite (Dunn, 1960).

The gabbro plutons were intruded after the folding of the enclosing sediments, but before the intrusion of the Nimbuwah Granite.

Jim Jim Creek Area.

This area lies south-south-west of Oenpelli, and 20 miles east-north-east of El Sharana Mine (see Map 1). Once again, very little is known about the basic rocks.

The intrusions are of a comparable size to those at Oenpelli, but are more elongated and follow the Lower Proterozoic trends. The rocks intruded the Mt Partridge Formation and the South Alligator Group, both of Lower Proterozoic age, probably before they were folded. Some fine-grained unsheared basic dykes cut across the sheared and folded Mt Partridge Formation at Mt Basedow, but their relationship to the larger concordant intrusives is unknown. The latter have been described in the field as dolerite, but no detailed work has been done.

South Alligator River - Gerowie Creek - Coirwong Creek Area.

This area comprises a strip of country 70 miles long and up to 10 miles wide, running north-west roughly parallel to the South Alligator River (see Map 1). This is also the direction of all major fold axes and faults in the area.

Basic intrusive rocks occur throughout the length of this zone, as a series of discontinuous, very elongate bodies, parallel to the regional trend of the area (see Fig. 1). Only in the Rockhole Mine - El Sharana Mine strip are the basic rocks missing; there, they appear to have been down-faulted to the north-east, and so concealed beneath the Upper Proterozoic sediments.

In the south-eastern half of the zone, the basic rocks intrude the Fisher Creek Siltstone, and to the north-west the Koolpin Formation and the Gerowie Formation. These three units make up the whole of the South Alligator Group, which is thought to have formed during the closing stages of Lower Proterozoic sedimentation in the region.

The only previous petrological work done on this large zone of basic rocks was by Stewart (loc. cit., pp. 21, 93) who gave a generalized description based on specimens from the Zamu Creek area in the south-east. He called the rock uralitized dolerite. As the previous sampling was too restricted to be at all representative of such a large area, a new collection was made late in 1959. Specimens were collected systematically across two large bodies of dolerite in the Zamu Creek area to the south-east, and also near Gerowie Creek and Coirwong Creek in the north-west. Core from the diamond drill hole Mundogie Hill No.1, located 4 miles east-north-east of Coirwong Gorge, was also sampled. This hole was sunk by Broken Hill Proprietary Co. Ltd during 1959; it passed through 140 feet of material logged as 'dolerite and amphibolite'.

There seems little doubt that this great belt of basic rocks was formed during one phase of intrusive igneous activity. The very constant lithologies, together with the form and the constant direction of elongation of the outcrops, suggest that throughout the belt, the rocks were formed in a very similar geological setting.

The intrusions closely follow the strike of the strongly folded Lower Proterozoic sediments, and over distances of up to several miles are strictly concordant with the bedding. Yet in some places, the intrusions bifurcate (and anastomose), forming an interlaced pattern; north-east of Goodparla Homestead, two parallel bodies with an outcrop thickness of over a mile break up into six parallel masses within a strike distance of three miles.

The low relief, and the poor outcrops of the adjacent sediments, make it impossible to say whether the apparent concordance of the igneous masses is maintained down dip as well as along strike. Thus the intrusions could be either pre-folding sills and sub-horizontal sheets, or post-folding dykes parallel to the tectonic trend of the area. Walpole (1959) has noted that most of the basic rocks of the Katherine - Darwin region clearly ante-date the folding of the Lower Proterozoic sediments; but in this zone, no conclusive evidence of relative age has been found.

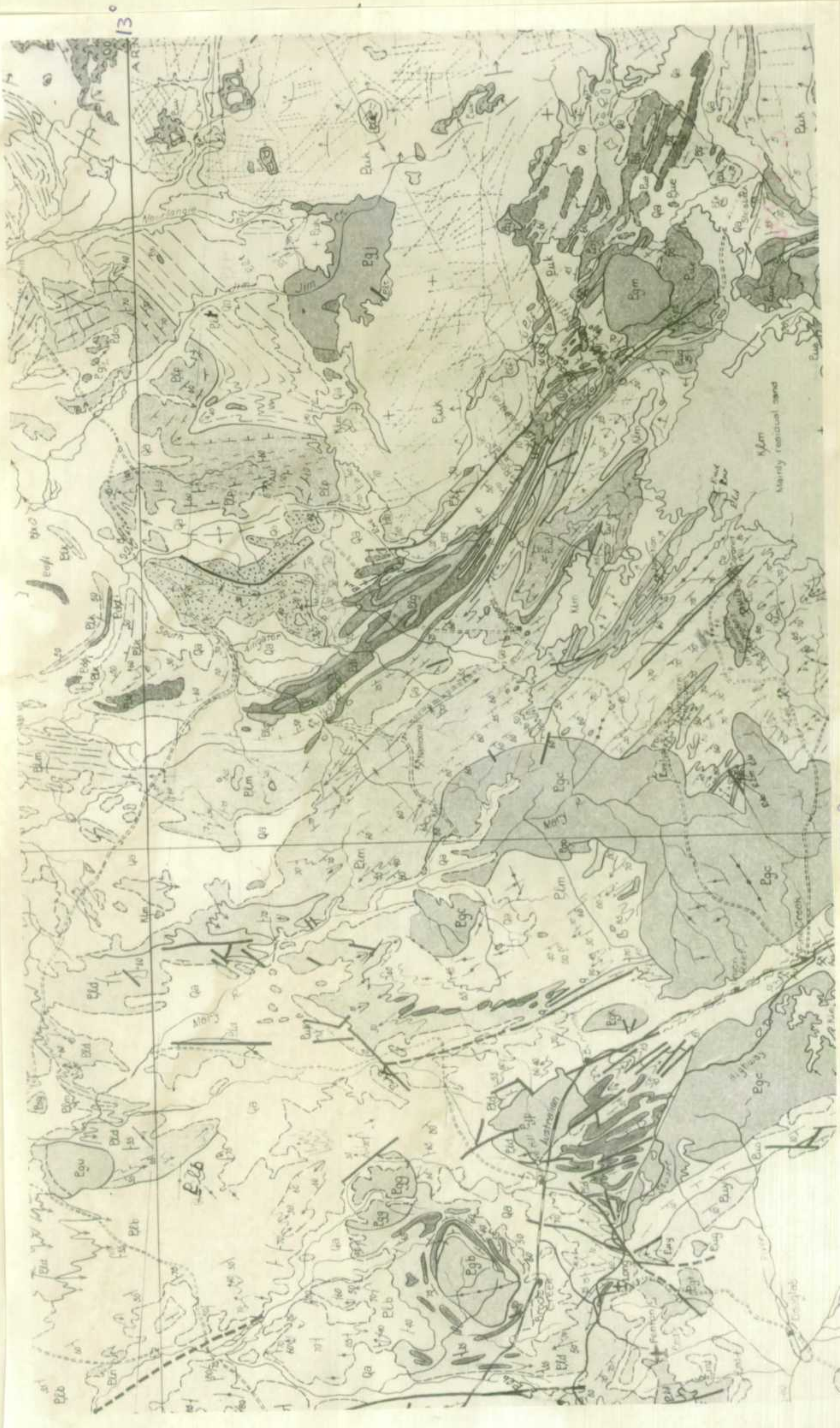

Figure 1. Portion of the Geological Map of the Katherine - Darwin area, N.T.: Present scale 11 miles to 1 inch. (Dolerite (Pdi) coloured very dark grey.)

Figure 2. Portion of the Geological Map of the Mt Evelyn 1:250,000 Sheet.
Present scale: $4\frac{3}{4}$ miles to 1 inch.
(Dolerite (Pdi) coloured dark grey, and marked by random-line hachuring.)

As mentioned earlier, new collections of basic rocks were made from several widely scattered localities within the zone, and the petrography of the intrusives from each general area will be considered separately. The areas are :-

Mundogie Hill No.1 (drill core)
Gerowie Creek - Coirwong Creek (surface samples)
Zamu Creek (surface samples)

Mundogie Hill No.1 Diamond Drill Hole

This drill hole was sunk by Broken Hill Proprietary Co. Ltd at a site 4 miles east-north-east of Coirwong Gorge, at the extreme north-west end of the zone of intrusives (see Fig.2). The drill intersected 110 feet of dolerite, then passed into 100 feet of pyritic siltstone and chert before bottoming in a second mass of dolerite; 30 feet of this lower dolerite was cored before drilling was halted.

The dolerite is, throughout, severely saussuritized, uralitized, and sericitized. Its original constituents were plagioclase, clinopyroxene with a little orthopyroxene, and possibly olivine. Secondary hornblende, iron oxide, chlorite, epidote, and carbonate are common.

The rocks are fine-grained, massive, and grey to grey-black in colour; seen in thin section they show intergranular and intersertal textures, and the minerals have no preferred orientation. There are marked differences in the proportion of crystals to matrix across the masses, and also within a single thin section; some areas up to 5 mm. across may be virtually free from crystals, and they impart a very patchy appearance to the thin section (T.S.5605). (If the specimens were surface samples rather than drill core, this patchiness might have been visible in the hand specimen.) The matrix is very fine-grained, and commonly altered beyond recognition (see Fig.3).

Figure 3. Augite dolerite, Mundogie Hill D.D.H. No.1, 113 feet.
T.S.5605, plane polarized light, diam. 4 mm..
Typical of main (upper) dolerite; laths of zoned plagioclase (showing altered cores), (?)orthopyroxene cores encased in augite (centre of field), magnetite, fine, buff-coloured matrix.

Plagioclase is the most common mineral; only relicts of twinning are seen, and accurate determinations are very difficult. Several combined carlsbad and albite twins fell within the calc-andesine/labradorite range. Zoning of the feldspar is common. The maximum size of the feldspar laths is consistently about 0.8 mm., both in the dolerite proper and in the chilled margin. Smaller laths which make up the bulk of the feldspar within the dolerite are absent from the chilled margin of the mass. This indicates two generations of feldspar, the larger laths having formed before emplacement and the finer laths during the cooling of the intrusion, but after the initial chilling of the margin (T.S.5603).

Clinopyroxene is the principal mafic mineral; commonly it has been altered to chlorite, secondary amphibole, and much fine unidentifiable material. The cores of the pyroxenes have been much more affected by the alteration than the margins - suggesting the possibility of original differences between the central and marginal portions of the pyroxene crystal (T.S.5605). Abundant leucoxene is commonly associated with the pyroxene.

Near the top of the main body of dolerite, subhedra of serpentine are possibly pseudomorphing orthopyroxene and olivine (T.S.5604). Positive identification was not possible, but similar pseudomorphs were not seen in any other part of the dolerite; hence there is a possibility that olivine and orthopyroxene formed very locally, but not in such quantities as to require a special concentrating mechanism.

Chlorite, epidote, and carbonate minerals are all common as disseminations, veins, and patches. Quartz has a similar distribution, but is almost wholly restricted to the lower dolerite. Biotite occurs in accessory amounts in the lower dolerite.

The matrix of the main (upper) dolerite mass is very distinctive, and quite different from that of the lower mass. In the main dolerite the matrix is pale brown and makes up 20 - 30% of the rock, but is very irregularly distributed, patches up to 5 mm. across being composed entirely of matrix (T.S.5605). In some thin sections (T.S.5607) the matrix is variolitic, consisting of fine slender feldspar laths. In one slide (T.S.5608) the matrix consists - at least in part - of an unknown mineral, with a refractive index that ranges from slightly below to slightly above canada balsam, low birefringence, positive sign, and medium 2V. The brown colouring in both kinds of matrix is probably due to finely divided iron oxide.

In the lower dolerite, the matrix consists of meedle-like feldspar laths - in part chloritized - embedded in quartz (see Fig. 4). In some places this resembles granophyric intergrowth except for the predominance of quartz over feldspar. There is no brown colouring in this matrix (T.S.5949).

At the top of the main mass of dolerite variolitic dolerite occurs, representing the chilled margin of the intrusion (T.S.5603). It consists of subhedra of labradorite, pyroxene, and (?)olivine, all extensively altered, set in a groundmass of feldspar variolites, crystallites and palagonite. A transition between the devitrified glass at the margin and the normal dolerite can be seen; an intermediate stage is a finely porphyritic dolerite (T.S.5611) found 5 feet in from the margin.

Figure 4. Uralitized dolerite, Mundogie Hill D.D.H. No.1, 271 feet. T.S.5616, plane-polarized light, diam. 3.2 mm. Typical of lower dolerite; elongate laths of actinolite (lower, right), and aggregates of chlorite (upper, left), both after pyroxene, surrounded by partly altered pyroxene; sericitized plagioclase (lower, centre), intergranular texture.

The principal differences between the main mass of dolerite and the lower mass are in the matrix - as noted above - and in the form of the principal minerals. In the main mass, the crystals are all stout, and the texture is intersertal. In the lower mass the clinopyroxene forms very slender laths up to 5 mm. long, and the feldspar laths reach 2 mm. in length. Also, the apatite in the lower mass forms much larger crystals, though it is still fine-grained.

It is difficult to judge the effect the dolerite has had on the adjacent shale, as the latter now consists predominantly of chlorite, but the grain-size is still very fine. Products of the regional metamorphism may have obscured any new minerals. The shale now consists predominantly of chlorite, with some muscovite, quartz, and pyrite. It is cut by veins of carbonate, chlorite, and quartz, all of which can be attributed to the intrusion of dolerite (T.S.5611).

Gerowie Creek - Coirwong Creek Area

This area covers a length of 20 miles and a breadth of 2 to 5 miles. Over this breadth the dolerite forms 2 to 6 parallel, discontinuous masses (see Fig. 2). The specimens were collected at random from several localities within the area. Three types of rock were found : medium-grained dolerite; fine-grained granophyre; a variolitic dolerite.

Medium-grained dolerite makes up the great bulk of the intrusives and originally consisted of plagioclase, augite (in places diallage), and hypersthene, together with accessory amounts of biotite, magnetite, ilmenite, sphene, and apatite. The quartz and hornblende now present may be primary. The matrix is of fine-grained quartz and feldspar.

The plagioclase has been severely sericitized, and other secondary minerals include actinolite, chlorite, epidote, calcite, serpentine, and quartz. The rocks are medium-grained, and strongly porphyritic. The texture is commonly ophitic, though some rocks show intergranular texture, and others show both textures (T.S.5624). The minerals show no preferred orientation. Plagioclase laths range up to 2 mm. in length and show relics of multiple twinning. Zoning is prominent in the less altered grains. The few determinations on the twinning (T.S.5624) gave a range in composition from An 45 to An 60 - calc-andesine to labradorite.

Augite and diallage, in about equal amounts, form the dominant mafic mineral; in some places they are surrounded by a thin fringe of green hornblende. Hypersthene is less common and forms smaller subhedra than the augite (T.S.5624); the hypersthene is never intergrown with the plagioclase. Biotite is also present and forms small irregular books. Iron oxide is not common. The matrix of the rock consists principally of a fine mesh of quartz and feldspar, in some cases granophyrically intergrown. In some sections the matrix is partly obscured by secondary minerals.

The fine-grained granophyre is a leucocratic, fine-grained, massive rock consisting of albite with subordinate quartz, set in a very fine micrographic matrix. Some very slender prisms of hornblende are also present. Accessory amounts of biotite, apatite, prehnite, chlorite, and possibly pumpellyite are present (see Fig. 5).

The albite forms subhedral stout prisms with square cross-sections, is usually untwinned, but shows some zoning. The quartz forms very irregular anhedra up to 7 mm. across. Hornblende is the only common mafic mineral, making up 15 - 20% of the rock. It forms very slender prisms up to 5 mm. long; the margins of some are fringed by biotite. The matrix of the rock consists of minutely intergrown quartz and potash feldspar, making up 30% of the rock. Some of the matrix is micro-granophyric (T.S.5628). The weathered surface of the granophyre is a distinctive brown colour, and is criss-crossed by dark grooves left by the less-resistant hornblende laths.

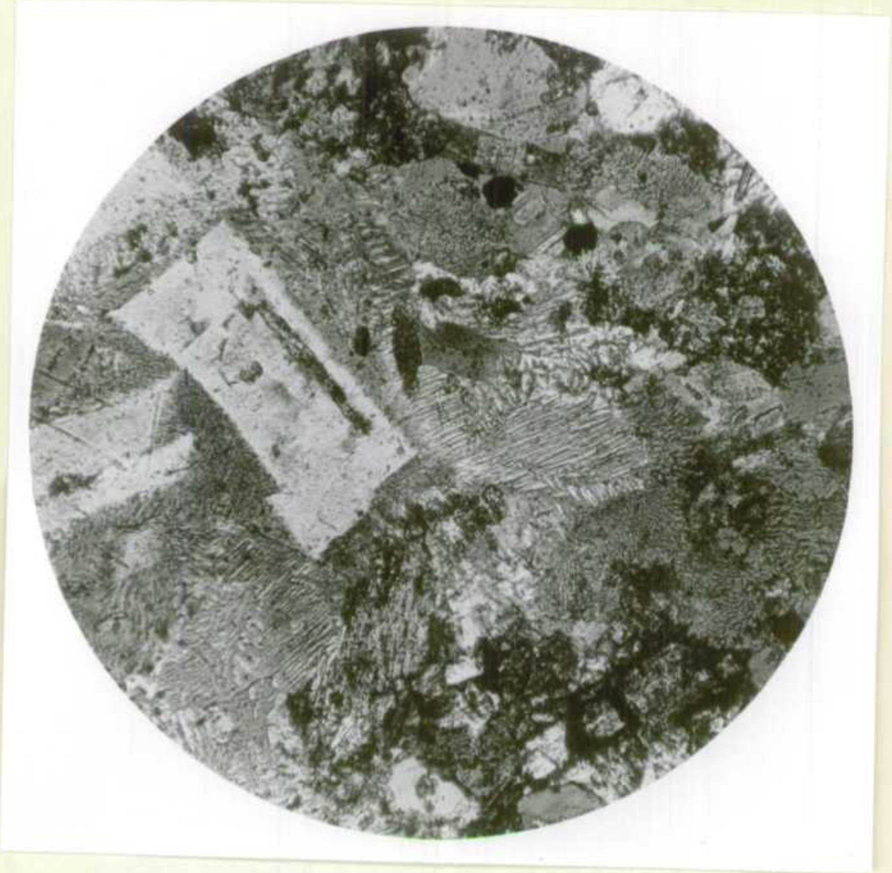

Figure 5. Hornblende granophyre, Coirwong Creek, T.S.5628, crossed nicols, diam. 1.2 mm.
Subhedral prisms of albite, anhedral quartz (upper, central), hornblende (lower, central), and allanite (lower, right), set in micrographically intergrown quartz and potassic feldspar.

In the field, the granophyre forms isolated outcrops, though normal dolerite invariably crops out nearby. There can be no doubt that the granophyre is an acid differentiate of the doleritic magma, and was intruded either within or close by the sheets of dolerite. W.B. Dallwitz (pers. comm.) has reported albitized sediments adjacent to the granophyre in the Coirwong Creek area. The original sediments were probably limestone.

Variolitic dolerite. Small outcrops which are quite common adjacent to sills of normal dolerite, in the Gerowie Creek - Coirwong Creek area, have also been reported (Stewart loc. cit.) from the Zamu Creek area, south-east of El Sharana.

In the hand specimen the rock is dull, grey, massive, homogeneous and glassy-looking, except for dull black patches, up to 3 mm. across, which are found in some specimens. These patches are commonly shaped like glass shards.

In thin section (T.S.5829) the rock is indistinquishable from the glassy selvage found in Mundogie Hill D.D.H. No.1 (T.S.5603). It consists of subhedral laths of sericitized feldspar up to 1 mm. long, and a few subhedral grains of serpentinized (?)olivine, up to 0.5 mm. across. These microphenocrysts make up 10% of the rock; the remainder consists of very fine varioles and crystallites of monoclinic pyroxene, set in a mass of brown palagonite (Fig. 6).

Figure 6. Variolitic dolerite, Gerowie Creek, T.S.5625, plane polarized light, diam. 2 mm. Sericitized plagioclase laths, and serpentine after euhedral (?)olivine, set in a matrix of brown glass containing varioles and crystallites of monoclinic pyroxene.

The irregular black patches, when seen in thin section, appear to be identical in texture to the surrounding material (T.S.5625). At the centre of the patch, the crystallites have been bleached to pale green, and the surrounding palagonite is a much deeper brown than the normal palagonite of the rock. This suggests that the iron from these centres has migrated to the surrounding material, but the reason why this has taken place is unknown.

The outcrops of variolitic dolerite are surprisingly large - up to 60 feet across in one place. They appear to follow the trend of the adjacent normal dolerite, but the relationship between the two is quite uncertain. The outcrops - when compared with the 1-foot thickness of glassy selvage in the Mundogie Hill No.1 drill hole - appear to be far too large to be simply a chilled margin. An alternative explanation would be that the variolitic dolerite represents a segregation of the magma that was intruded separately as a series of very small masses that chilled quickly.

Zamu Creek Area

This area is at the south-eastern end of the South Alligator dolerite belt; the rocks occur as a series of discontinuous and converging elongate masses cropping out over a length of 25 miles and extending over a maximum width of 12 miles, on the Mt Evelyn 1-Mile Sheet (Fig. 7).

Two parallel dolerite masses were sampled, at right angles to their lengths; each sample represented over half a mile of continuous outcrop. The sampling was carried out near Zamu Creek Prospect, about one mile north of the Malone Creek Granite.

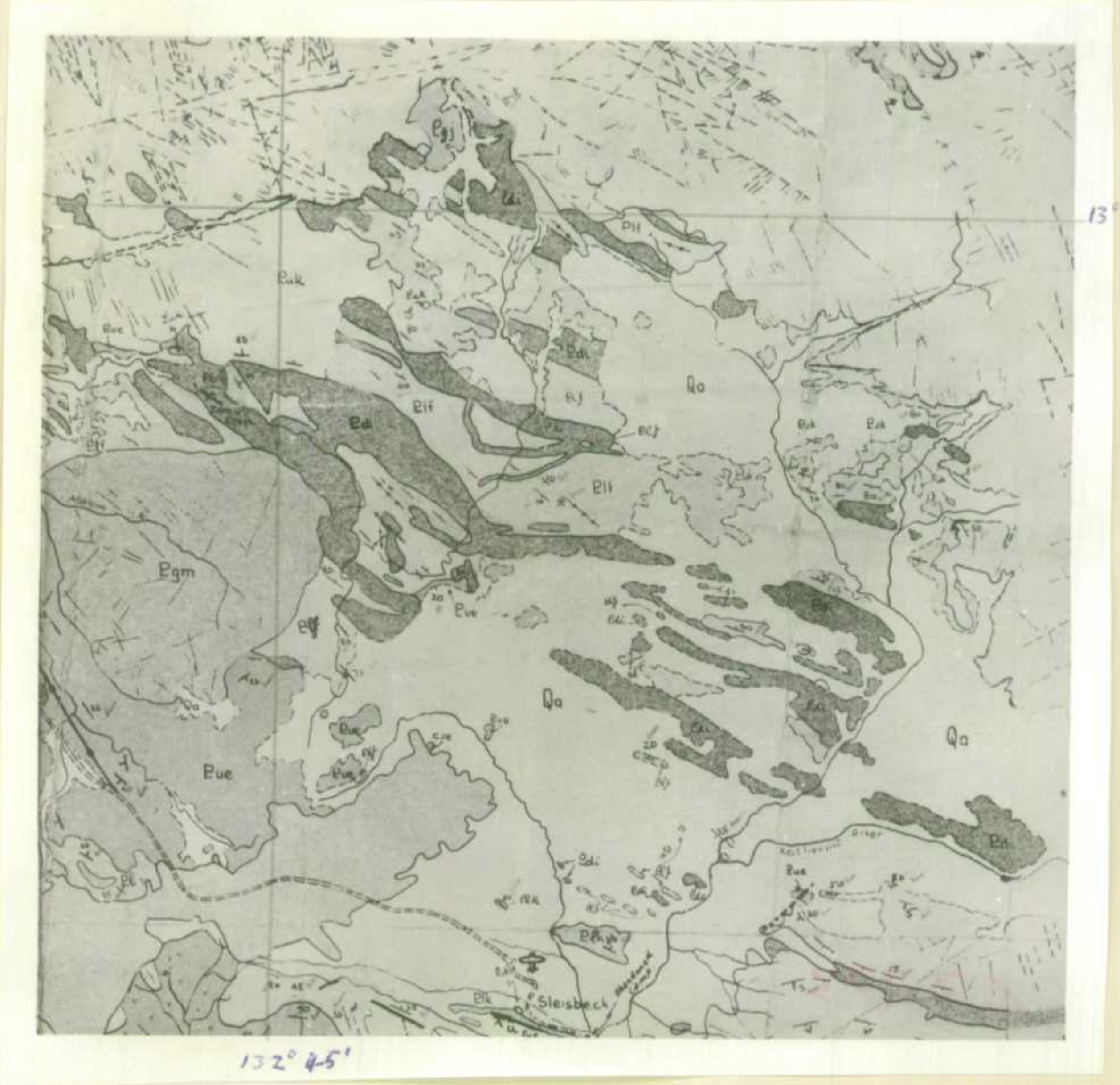

Figure 7. Portion of the Geological Map of the Mt Evelyn 1:250,000 Sheet, N.T., scale 4 miles to 1 inch. (Dolerite (Ɇdi) coloured dark grey.)

Two principal types of rock were recognized:-

Uralitized dolerite and,

Biotite-hornblende-diallage pegmatite.

Uralitized dolerite makes up the great bulk of the intrusion, and appears to have been very constant in its original composition; but with varying degrees of alteration - probably deuteric - a variety of secondary products has been developed. The original rock consisted predominantly of diallage, hypersthene, and plagioclase, together with some hornblende, and accessory amounts of biotite, quartz, magnetite, ilmenite, and apatite. The hypersthene and the diallage occur in approximately equal amounts, but in individual thin sections one or other may predominate.

The first stage of alteration has been marked by the change of hypersthene to bastite (T.S.5663); this is followed by the conversion of the bastite and the primary diallage to tremolite-actinolite (T.S.5651). This progressive alteration has been accompanied by increasing saussuritization of the plagioclase (Fig. 8).

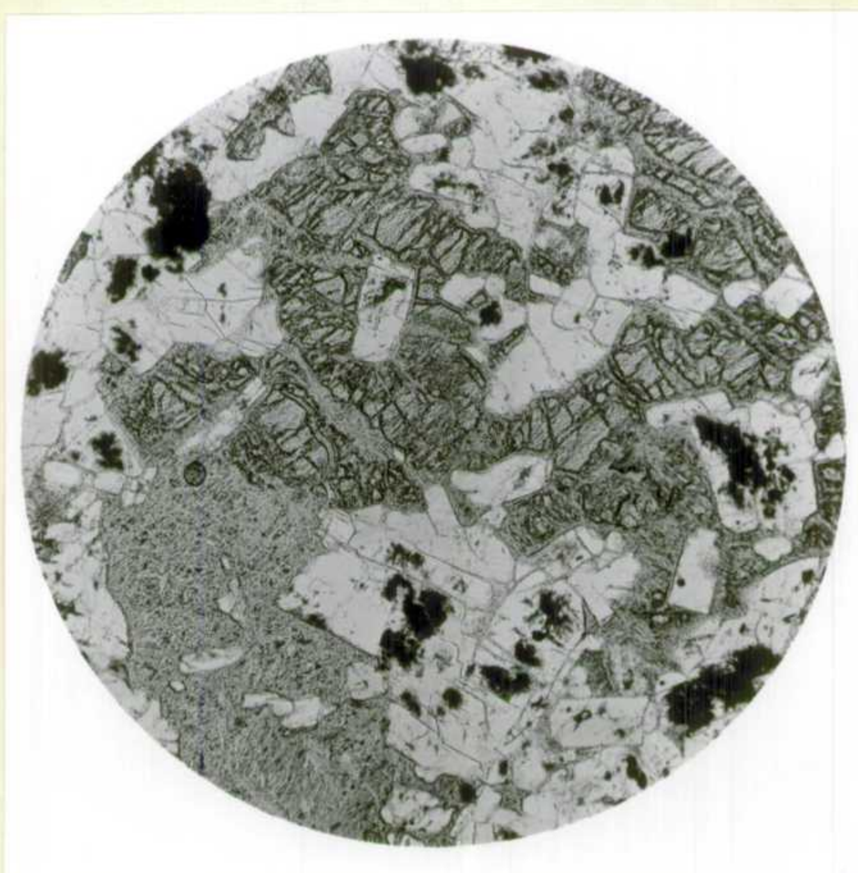

Figure 8. Altered hypersthene-diallage dolerite, Zamu Creek area; T.S.5663., plane polarized light, diam.3.5 mm. Large, irregular grain of hypersthene enclosing labradorite subhedra; hypersthene is partly altered to bastite (upper field); diallage is wholly altered to actinolite (lower, left). Labradorite is partly saussuritized (black patches).

All the hand specimens have a greenish tinge due to the uralitization of the mafic minerals. The rocks are medium-grained and the minerals show no preferred orientation. Commonly the pryoxenes form phenocrysts which are ophitically intergrown with the plagioclase (T.S.5661). A few of the rocks are finer-grained, and more even-grained; in these cases the pyroxenes are not intergrown, and the texture is intergranular (T.S.5659) (Fig. 9).

Diallage may form either stout subhedral prisms up to 3 mm. long, or anhedra up to 5 mm. across, which are riddled with small plagioclase laths (T.S.5667). Twinning is very common. Reaction rims of green hornblende surround many diallage crystals and also the tremolite-actinolite derived from the diallage. Plagioclase makes up 50% of the rock, but is commonly too saussuritized to identify; in several thin sections the composition fell within the calc-labradorite range. Zoning is very pronounced. Hypersthene is common, forming large ophitically intergrown anhedra, up to 4 mm. across. It is generally altered to bastite along very irregular fractures, producing a pattern similar to that shown by altered olivine. Hornblende is commonly present as individual crystals, in addition to forming reaction rims around the diallage. Biotite is usually interleaved with (?)prehnite,

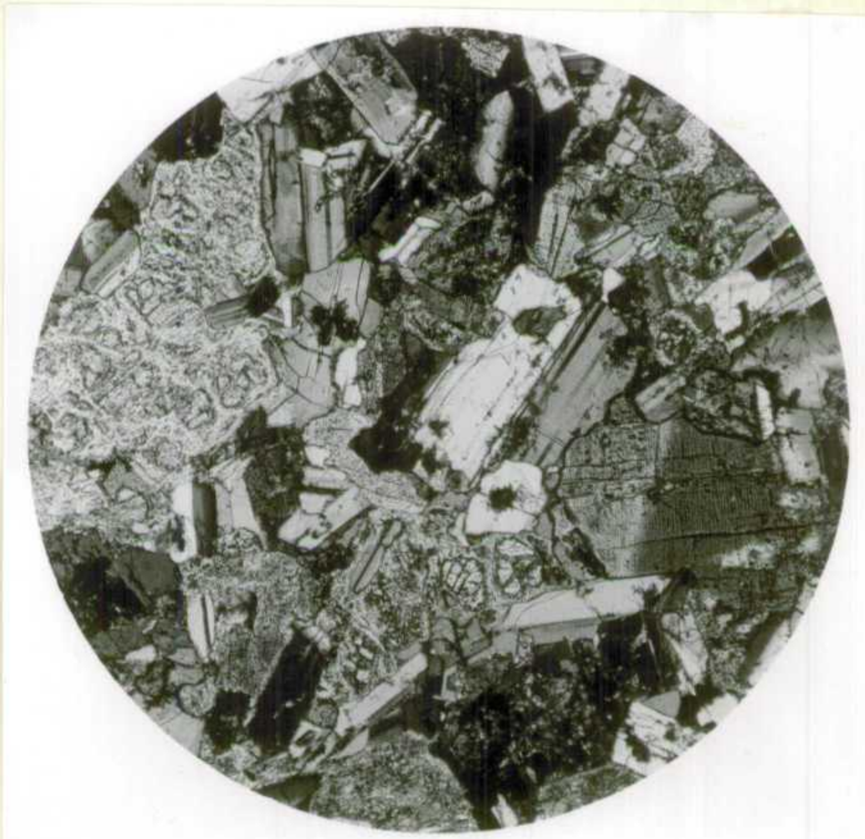

Figure 9. Altered hypersthene-diallage dolerite. Zamu Creek area, T.S.5663, crossed nicols, diam. 3.5 mm. Subhedra of labradorite (centre), diallage (central, right), hypersthene (upper left) partly altered to bastite, interstitial quartz, hornblende (centre, mid-left), biotite (centre, left).

forming irregularly shaped books. All the rocks are noticeably free from iron oxide. Quartz is constantly present, but in very variable amounts - up to 10% of the rock in an extreme case. Some of the finer interstitial quartz is certainly primary, but whether the remainder is primary or secondary is quite uncertain.

In most of the rocks, very little matrix is present, the spaces between the larger crystals being filled by finer - though similar - minerals. The last mineral to crystallize was quartz, which filled the fine interstices.

In a few rocks, a distinctly granophyric or micrographic texture has developed (T.S.5660). The overall appearance of these rocks is very similar to the normal matrix-free dolerite described above, and the presence of an intergrown matrix is probably not important. It would develop by relatively minor enrichment in potash and silica during the final stages of differentiation and solidification of the rock.

No consistent variation was observed in the rocks towards the margins of the intrusions, though the actual contacts were hidden by scree.

Biotite-hornblende-diallage pegmatite occurred as veins and irregular patches enclosed by uralitized dolerite, over an area of 20 yards by 40 yards near the margin of one of the intrusions. In most cases the pegmatite clearly post-dates the enclosing dolerite. In the hand specimen the rock appears as a deep-green and cream patchwork, due to the large crystals of uralitized diallage and altered feldspar.

Seen in thin section the rock consists of plagioclase, diallage, hornblende, biotite, quartz, and accessory amounts of sphene, apatite, ilmenite, and rutile, set in a matrix of intergrown quartz and anorthoclase. Alteration has been very marked, leading to the formation of sericite, tremolite-actinolite, chlorite, clinozoisite, and, less commonly, carbonate. The rocks are coarse to medium-grained, and massive. Matrix makes up 10-20% of the rock (Fig.10).

Plagioclase makes up 40% of the rock, occurring as well-formed laths up to 8 mm. in length. Some poorly preserved albite twinning gave a composition $Ab_{90}An_{10}$. The alteration of the albite - and possibly oligoclase - has produced sericite and lesser amounts of clinozoisite and chlorite (T.S.5656).

Diallage is the predominant mafic mineral, making up 30% of the rock. It forms stout subhedral prisms, commonly twinned, and surrounded by reaction rims of hornblende. Alteration to tremolite-actinolite is very common, especially along margins of crystals, and along twin planes (T.S.5653).

Hornblende and biotite make up 10% of the rock. The hornblende forms reaction rims around the diallage, and also individual anhedra; the mineral is invariably only slightly pleochroic from pale green to pale brown. Biotite is present in much smaller amounts than the hornblende, and forms small books containing lenticular aggregates of prehnite. In one specimen (T.S.5653), the biotite has been replaced by black iron oxide and leucoxene.

Figure 10. Saussuritized biotite-hornblende-diallage pegmatite, Zamu Creek area; T.S.5656, crossed nicols, diam. 6 mm. Saussuritized feldspar (upper and lower, left), diallage (centre) altered to chlorite and carbonate and surrounded by actinolite (right, in extinction) and hornblende (lower end); biotite containing lenses of prehnite (lower, right, in extinction); quartz anhedra, micropegmatitic matrix.

Quartz makes up 10% of the rock, excluding the quartz in the matrix. It commonly forms smooth-edged anhedra containing inclusions of apatite, rutile, and fine dust-like material. Apatite is a very common accessory mineral, and some of the anhedral slender prisms are over 2 mm. long (T.S.5656).

The matrix consists of intergrown quartz and anorthoclase; the patches of intergrowth are up to 5 mm. across (T.S.5656), and individual filaments range from very fine-grained up to 0.8 mm. across. Some of the feldspar has been replaced by aggregates of clinozoisite and, in one case, chlorite. Close to the south-eastern contact of one of the dolerite masses, where it abuts against the younger Malone Creek Granite, the doleritic rocks show a pronounced lineation that has resulted from shearing. Considerable recrystallization has resulted, the final assemblage being tremolite-actinolite, saussuritized feldspar, and quartz, together with some hornblende, biotite, and iron oxide; some quartz and feldspar are intergrown to form micropegmatite (T.S.5668).

These changes appear to have been brought about by shearing alone, and the main result - apart from the actual crushing of material - has been an accelerated rate of alteration along the same lines as in the uncrushed doleritic material.

Conclusions

There seems little reason to doubt that all the dolerites from the Coirwong Creek - Gerowie Creek - Zamu Creek areas belonged to the same phase of igneous activity. The granophyres and pegmatites represent late-stage differentiates of the doleritic magma; they were probably intruded during, or very soon after, the consolidation of the dolerite.

The actual composition of the magma is not certain, but to judge from the almost complete lack of olivine, and the plentiful quartz both as separate anhedra and in the fine matrix, it was probably tholeiitic.

The dolerites were probably for the greater part injected before the folding, as sills and sheets. As the present outcrop of dolerite in this belt exceeds 130 square miles, and all the adjacent sediments dip very steeply, a very considerable amount of magma was involved.

Mount Masson Area

Mount Masson lies in the Ban Ban 1-Mile Sheet area, (see Map 1), and approximately 23 miles east-north-east of Grove Hill siding.

The basic rocks of the area crop out discontinuously along a 15-mile north-south belt, immediately west of the Mount Harris - Mount Masson - Mount George tin field. The intrusives occur along the boundary of the arenaceous Masson Formation and the overlying silts and shales of the Golden Dyke Formation; some also occur wholly within the lower horizons of the Golden Dyke Formation (Fig. 11).

Frequently the contact between the two formations is marked by faults arranged en echelon; these faults have also affected the intrusives. The majority of the intrusives are undoubtedly older than the folding, and form stratigraphically controlled sills and sub-horizontal sheets.

As an outcome of the detailed mapping of the Mount Harris tin field, Hays (1960) has suggested that some of these igneous rocks may be sub-aqueous flows; but in the absence of pillow lava and other criteria of such an environment, little support can be given to the suggestion.

The only petrography carried out on the basic rocks has been by Morgan and Oldershaw (see Hays, 1960). The rocks had all been uralitized to such an extent that few original constituents remained.

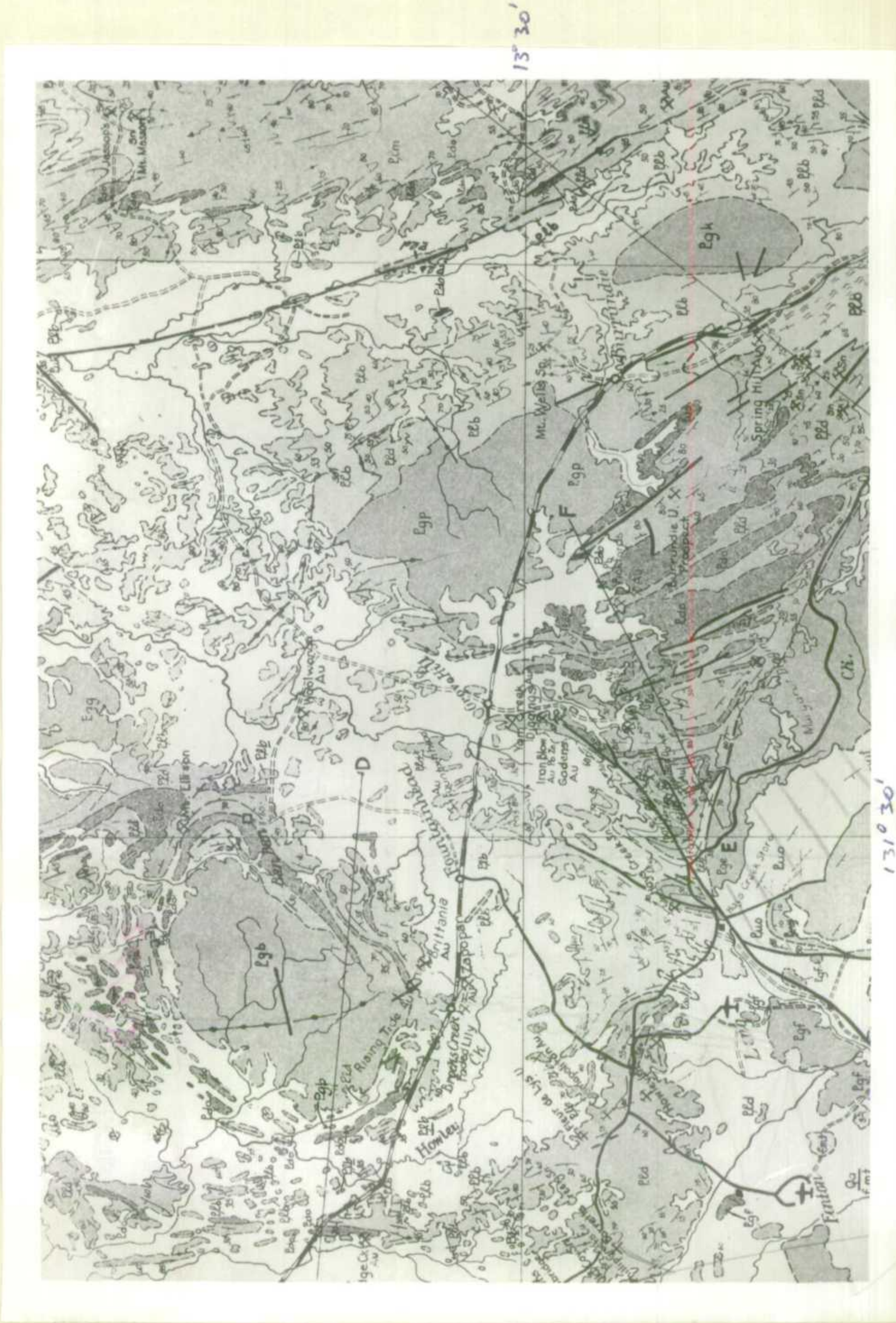

Figure 11. Portion of the Geological Map of the Pine Creek 1:250,000 Sheet; scale 4 miles to 1 inch. (Doleritic rocks (Bdo) coloured dark grey.)

Morgan has described five specimens from minor intrusions in the Mount Harris area; three of the rocks were called 'albitized and uralitized quartz dolerite' (Fig. 12) with an average composition of :

Albite	35%
Actinolite with ripidolite (probably after pyroxene)	48%
Quartz	7%
Epidote	5%
Apatite, calcite, pyrites, leucoxene	5%

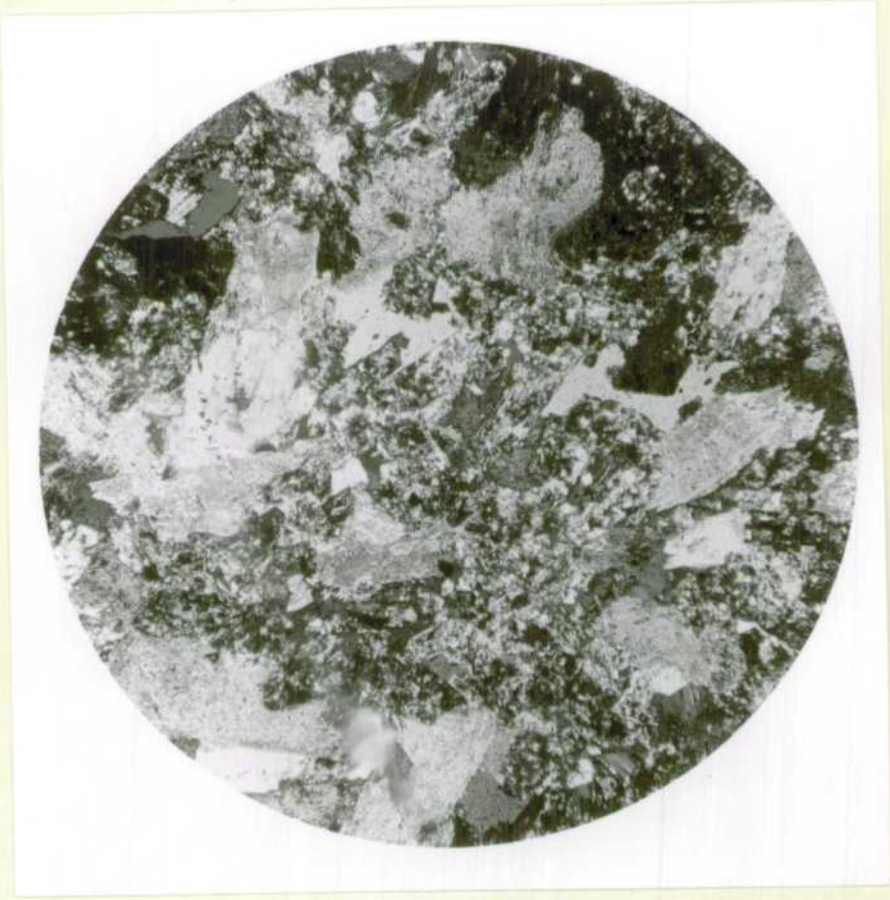

Figure 12. Saussuritized and uralitized quartz dolerite, Mount Masson area, T.S.4234, plane polarized light, diam. 4 mm.
Poikiloblastic actinolite (central, left, grey anhedra), very irregular quartz grains (clear anhedra), leucoxene (after ilmenite) (upper, right, almost opaque), fine-grained albite, and clinozoisite (both indistinguishable, in fine-grained material).
(Rock first described by Morgan - see Hays, 1960).

A fourth specimen had a similar composition, except that the feldspar was labradorite-bytownite, not albite. The fifth specimen described by Morgan was 'an actinolite spilite, or an albitized - basaltic dyke rock'.

I have re-examined the thin sections and feel that in the average mode of the 'albitized and uralitized quartz dolerite' - listed above - the amount of epidote (principally clinozoisite) is nearer to 20% than 5%. This fact, combined with the absence of primary feldspar, indicates that the rock has been saussuritized rather than enriched in soda. In other words, there are probably enough secondary minerals in the rocks to account for all the lime originally contained in the primary feldspar ((?)labradorite), while the sodic fraction is represented by albite. Thus no special magma type, or special conditions at the point of emplacement, are necessary to account for the presence of albite.

Hays considers that these rocks are spilitic, and has summarized the evidence as follows : 'The association of albitization with sediments rich in iron and manganese oxides and silica, in an area in which arkose and greywacke-type sediments are abundant ...... (suggests) that the sill is spilitic and was intruded into, or extruded sub-aqueously upon, unconsolidated sediment'.

This evidence is circumstantial, relying in part on the sedimentary environment at the time of intrusion - or possibly extrusion. But the igneous environment of the area at this time and during the subsequent history of the geosyncline should also be considered. At most places in the world where spilitic rocks are found there is a close association - in the geographical sense - between spilites and ultrabasic intrusive rocks. At no place within the Katherine - Darwin region have any deep-seated peridotites, serpentinites, or other ultrabasic rocks been observed, despite the fact that the sedimentary environment noted by Hays has been observed at many places.

It has been pointed out by many writers that once a normal basic rock has been subjected to low-grade regional metamorphism it will tend to develop a mineral assemblage of albite, actinolite, and epidote; the same applies to basic intrusive rocks subjected to deuteric alteration.

In the case of the Mount Masson rocks, either - or more probably both - of the above processes appears to have operated, and produced rocks that are now both texturally and mineralogically different from their parent rocks. In the absence of any evidence to show that the albite is either primary or derived by metasomatism associated with sea water, I consider that the rocks probably formed part of normal tholeiitic dolerite sills that have suffered deuteric alteration and low-grade regional metamorphism.

Burrundie Area

The basic rocks of this area crop out over a large part of the Burrundie 1-mile Sheet, south-west of the Mount Masson intrusives (Map 1).

The basic rocks occur as conformable sheets that vary in thickness from 5000 feet down to 1000 feet over distances of several miles. They intrude pyritic shales and siltstones of the Golden Dyke Formation. The basic rocks are clearly older than the folding and have been affected by the Cullen Granite (Fig. 11).

Apart from the mapping of the intrusive bodies, no previous work has been carried out on them. The samples for this investigation were collected from an area close to the track from 'The Banyans' Homestead westward to Saunder's Creek, about five miles west of Burrundie Siding. The basic rocks of this area show marked differences from those previously dealt with; the textures and mineralogy are clearly metamorphic, but there can be no doubt about their igneous origin.

Seen in the hand specimen, the rock is typically fine to medium-grained, massive, uniform, and steel grey to greenish grey in colour. In one place, the rock is cut by veins of calcite and of mafic material; a segregation of pink granitic rock is also found.

In thin section three broad groups and sub-groups can be distinguished :

Quartz-feldspar-actinolite rock
(i) fine to medium-grained phase
(ii) fine-grained phase

Granophyric dolerite

Dolerite aplite

Quartz-feldspar-actinolite rock makes up the great bulk of the intrusives; the constituent minerals are almost wholly metamorphic, though some corroded laths of twinned plagioclase and remnants of doleritic texture clearly show that the rocks were originally fine to medium-grained basic intrusives.

The fine to medium-grained phase is even-grained, and the minerals are all xenoblastic, commonly ragged, and sieved with inclusions. The rock consists of actinolite, feldspar, quartz, sphene, phlogopite, pyrrhotite, pyrite, and iron oxide (Fig. 13). Actinolite makes up half the rock, and occurs as very ragged anhedra, sieved with inclusions of phlogopite, feldspar, quartz, pyrite, and pyrrhotite. Most of the grains are randomly oriented, and show moderate strain effects (T.S.5632). Both twinned and untwinned feldspar are present; the former is generally severely saussuritized, but several sections had a composition of andesine (T.S.5632). Commonly fine needles of actinolite have extensively replaced plagioclase (T.S.5634). Quartz is quite common, some at least being primary. Sphene is the commonest accessory mineral; it forms subhedral crystals and also granular aggregates enclosing magnetite or ilmenite. It is markedly pleochroic from wine red to pale buff (T.S.5632). Pyrrhotite and a little pyrite form up to 5% of the whole rock in extreme cases, but are absent in other sections; some of this sulphide could be related to the later intrusion of granite. Some secondary carbonate is also present.

The principal differences between the fine-grained phase and the preceding phase are in the grainsize and degree of crystallinity of the actinolite. The components are actinolite, feldspar, sphene, and a little magnetite or ilmenite (Fig. 14).

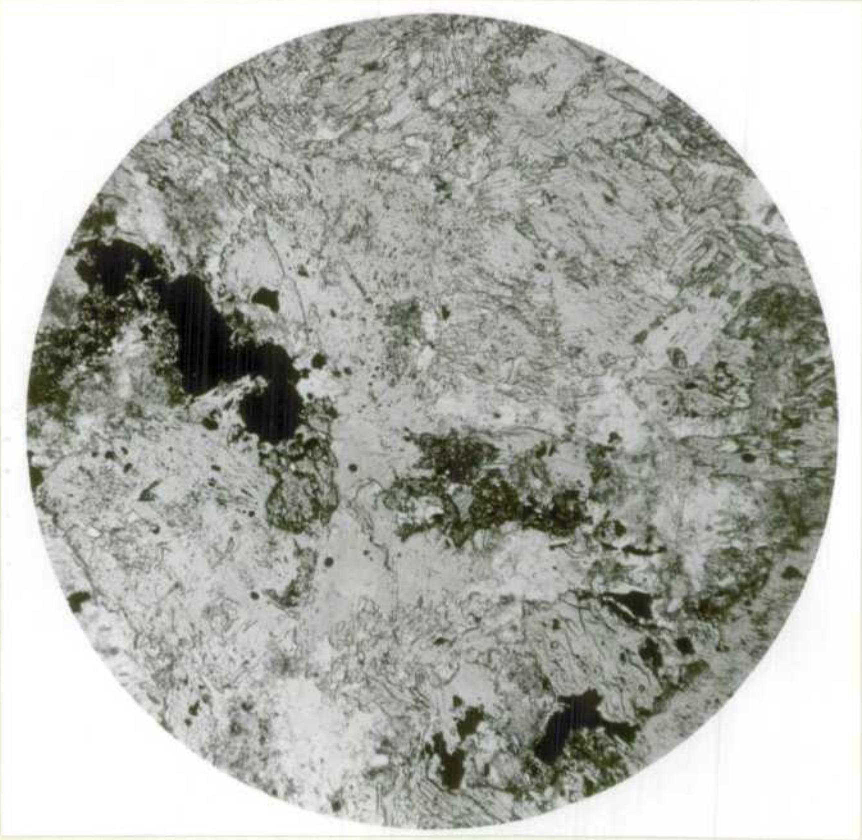

Figure 13. Quartz-andesine-actinolite rock (fine- to medium-grained phase), Burrundie area T.S. 5632, plane polarized light; diam. 4 mm. Poikiloblastic actinolite (large grey anhedra), recrystallized sodic andesine (centre, mid-right, grey white), quartz (extreme lower, white), sphene (central), and pyrrhotite (centre, left, black).

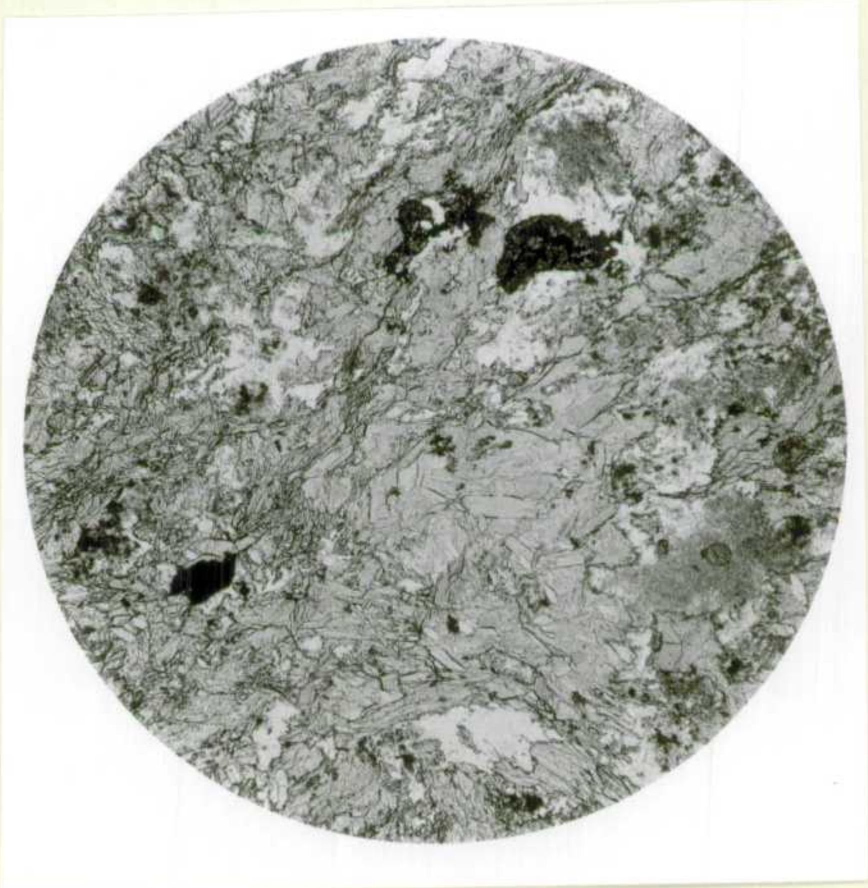

Figure 14. Oligoclase-actinolite rock (fine-grained phase) Burrundie area. T.S.5629, plane polarized light; diam. 4 mm. Clumps of fine subhedral and euhedral actinolite (grey, bulk of slide), pools of oligoclase (clear patches), sphene surrounding ilmenite (upper centre), pyrite (black).

The actinolite is very fine-grained, usually euhedral or subhedral, and occurs in elongate clumps up to 1 mm. across; these clumps are sub-parallel and give the rock a distinct lineation in thin section, though not in the hand specimen (T.S.5629). The spaces between the clumps of actinolite are filled with a fine mosaic of untwinned feldspar and possibly some quartz. Some corroded labradorite laths are found, and represent remnants of the original igneous rock. Sphene is a common accessory mineral and usually encloses cores of magnetite or ilmenite, from which the sphene has been derived. The sphene forms very irregularly shaped, fine-grained aggregates. Little iron sulphide occurs in this rock. This fine phase is cut by numerous veins of varying composition, close to the contact of the dolerite and limestone. The types of veins are : augite-prehnite-calcite; actinolite-feldspar; calcite; and aplite.

The vein of augite examined was 2 cm. wide and consisted of coarse, interlocking, twinned, unaltered grains of augite. This vein was cut by cross veins, 2 mm. thick, of very fine white material consisting of prehnite and subordinate calcite (T.S.5642). The explanation of the unaltered augite vein, enclosed in a host rock of actinolite (after pyroxene) is probably that the vein was injected after the host rock had cooled, and after the mafic material had been altered to actinolite. (A similar explanation is required to account for the unaltered augite in the dolerite aplite from Burrundie and illustrated in Fig. 15). The cross-cutting veins of prehnite and calcite probably resulted from the filling of cracks in the augite vein.

One actinolite-feldspar vein 6 cm. across has a bulk composition very similar to that of the enclosing rock; yet within the vein the rock is strikingly segregated (T.S.5631). Actinolite forms sub-parallel bifurcating layers, 2-4 mm. thick; in these layers, very little felsic material occurs. The actinolite layers are separated by areas 5-10 mm. thick of predominantly felsic material. Labradorite, commonly twinned, forms an inter-locking mesh; very fine actinolite is disseminated through the plagioclase and forms up to 30% of the layer. Little quartz was observed. These layers run across the vein and end abruptly at its contact with the enclosing rock - the fine-grained phase. The vein was presumably injected before the host rock had been altered, but the explanation of the cross-banding of the vein is quite unknown.

Both calcite and aplite veins were commonly found near the margins of the dolerite; but as no detailed petrography has been carried out on them, there is no way of knowing if they are associated with the intrusion of the basic rocks, or with the later granite.

The causes of the differences between the fine-grained and the medium- to fine-grained phases are not clear. In each case relict minerals and textures clearly indicate an igneous origin, and each group of rocks has been either partly or wholly reconstituted. Yet the actinolite - the most conspicuous product of the reconstitution - forms both very fine-grained euhedral crystals, and much larger, irregular, sieved anhedra. In the field the two types cannot be satisfactorily distinguished - probably because the very fine actinolite commonly forms medium-sized aggregates, superficially similar to the larger anhedral actinolite.

Because of the relatively simple history of the basic rocks since emplacement, it is hard to account for all the textural differences as due to metamorphism alone. Apart from autometamorphic effects, the dolerite has suffered only low-grade regional metamorphism and possibly some thermal alteration due to the intrusion of granite.

Granophyric dolerite is seen in only one specimen; the doleritic texture is preserved, and only the augite has been altered. The rock consists of actinolite, labradorite, quartz, with a little black iron oxide, and phlogopite (T.S.5633). Actinolite makes up half the rock, and forms ragged, fine- to medium-grained anhedra containing numerous inclusions of iron oxide, feldspar, and some phlogopite. The feldspar is zoned labradorite, forming twinned fine- to medium-grained laths. Quartz is quite common, amounting to 5-10% of the rock. A small amount of granophyrically intergrown quartz and anorthoclase makes up the only matrix in the rock. With further alteration of plagioclase this rock would probably produce an actinolite-feldspar rock similar to the fine- to medium-grained phase.

Dolerite aplite forms an area less than 20 yards across within the dolerite, close to its contact with marble. Granite crops out less than one quarter of a mile away. In the hand specimen, the rock looks like a pink, medium-grained aplite.

In thin section, it shows a granitic texture, and consists of microcline, placioclase, quartz, augite, sphene prehnite, and black iron oxide (T.S.5630). (Fig. 15).

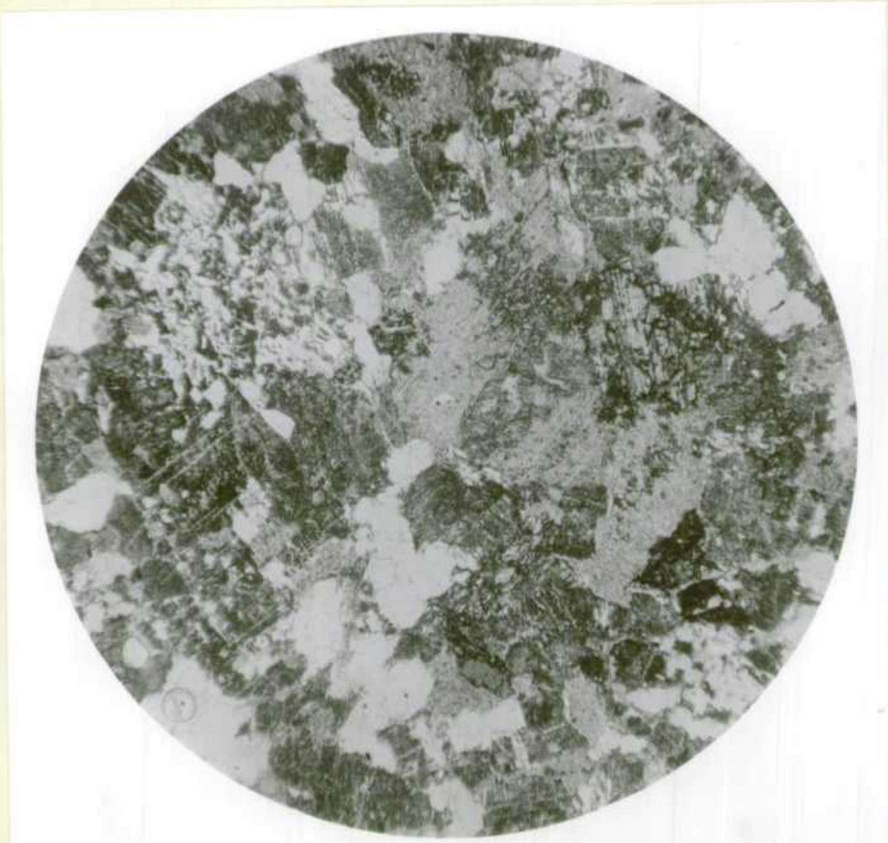

Figure 15. Kaolinized dolerite aplite, Burrundie area, T.S.5630, crossed nicols; diam. 6 mm. Kaolinized microcline (central, mid-left, grey-black anhedra), oligoclase (centre, light-grey anhedra), quartz (white), augite (central, mid-right), micrographically intergrown quartz and microcline (upper, left) and sphene (lower, central).

Microcline makes up over 40% of the rock; it forms medium to fine-grained anhedra, some with granulated margins. Oligoclase, mostly fine-grained, comprises 30% of the rock. It forms anhedral to subhedral grains and also occurs as a patchwork type of replacement within some of the larger microcline crystals. Fine to medium-grained quartz forms 20% of the rock; all grains show shadow-extinction, and a few have granulated margins. Some patches of quartz and microcline are intergrown in a granophyric texture; some of the potash feldspar within these intergrowths has also been replaced by plagioclase.

Augite is the only mafic mineral present, but forms only a few percent of the rock. It occurs in fine to medium-grained anhedra, usually associated with black iron oxide and sphene. Once again, the sphene is noticeably pleochroic from brownish buff to very pale buff. Prehnite has commonly in part replaced plagioclase, and also occurs as veinlets cutting the feldspars and the quartz. There appears to be very little doubt that the rock is related to the dolerite; the presence of augite, prehnite, and the pleochroic sphene, suggests that the rock is an acid differentiate of the dolerite rather than related to the adjacent biotite granite. It is for this reason that the rock has been called dolerite aplite, rather than augite granite, which is the correct name on the basis of composition.

Dolerite-Limestone Relationship.

In the Burrundie and Brocks Creek areas, a number of long narrow bands of marble occur along the margins of dolerite masses. These bands may reach a length of half a mile and a width of 40 yards. At several places where the marble has been quarried, beautiful faces of the rock have been preserved. The rock contains many parallel dark bands, up to several centimetres in thickness, that are invariably highly contorted. These bands appear to be sedimentary layers contorted by slumping - a feature very common in calcareous muds. (Fig. 16).

Figure 16: Marble with contorted diopside-rich bands.
Burrundie - Brocks Creek area.

Despite a statement by Campbell (1956), the carbonate rock has been completely recrystallized to a marble. In thin section it is seen to consist of fine- to medium-sized interlocking grains of calcite, and possibly a little dolomite; sparsely scattered very fine grains of diopside, (?)oligoclase, and pyrite also occur. The dark bands in the rock consist of fine-grained dolomite, calcite, and diopside, with subsidiary hornblende, (?)grossularite, pyrite, and grains and veinlets of (?)oligoclase (T.S.5828).

At no place within the Burrundie and Brocks Creek areas has marble been found except close to dolerite. Because of this, it has been suggested that the marble-dolerite association may be genetic, and that the marble is a carbonatite (Mackay - verbal communication). But carbonatites are invariably associated with either undersaturated alkaline rocks or else undersaturated gabbros, peridotites, and anorthosites. As the Burrundie dolerite is markedly oversaturated - averaging 10% quartz as crystals and in the matrix - this interpretation cannot be supported.

There seems little doubt that the marble was formed from almost pure limestone, containing bands of dolomitic, feldspathic siltstone, and has been recrystallized by the dolerite. The most likely explanation of its association with the dolerite is that the upstanding dolerite ridges have helped to preserve the limestone occurring along their flanks; also it is quite likely that the recrystallization to marble - attributable to the dolerite - assisted its preservation. The Golden Dyke Formation, which encloses the marble and the dolerite, is very poorly exposed in both the Brocks Creek and Burrundie areas, and many limestone lenses could occur within the siltstone, but fail to crop out except where they have been shielded from the weathering processes.

Conclusions: There is little doubt that all the basic rocks of the Burrundie area belong to the same phase of igneous activity, and were intruded as tholeiitic sills and sub-horizontal sheets, into the unfolded Golden Dyke Formation. The dolerite aplite is a late stage acid differentiate of the basic magma. No explanation has been put forward to account for the textural variations within the altered dolerite.

Brocks Creek Area

The basic rocks of this area cover much of the eastern half of the Burnside 1-mile Sheet, and also the western fringe of the adjoining Ban Ban Sheet (Map 1). They form a series of parallel, very elongate masses that conform to the bedding of the enclosing Golden Dyke Formation. The sediments and the sills have been domed up by the intrusion of the Burnside Granite (Fig. 11).

Noakes (1949), Sullivan & Iten (1952), and most subsequent workers consider that the basic rocks were sills or sub-horizontal sheets intruded into pyritic siltstone of the Golden Dyke Formation, before folding. Campbell (1956) thought they consisted of a series of lava flows, but this interpretation has received little support.

No petrographic work of general application has been carried out on the basic intrusions; Langley (1954) has described a small collection of very atypical specimens from the area, but because these specimens were problematical rather than typical, the information gained from the work appears to be of local importance only. For the present examination, surface samples were collected from 1 mile north of "Ban Ban Springs" Homestead, and also from several masses about 2 miles south-west of the homestead. Core from the following diamond drill holes was also sampled :-

E.E.P. Brocks Creek No.1 - ½ mile N.E. of Howley Siding.
" " " No.2 - near "Ban Ban Springs" Homestead.
" " " No.3 - 2½ miles N.N.W. of Howley Siding.
(For locations of these drill holes, see Map 2)

B.M.R. Cosmopolitan - Howley No.1 - 5 miles S.S.W. of Brocks Creek Siding
" " " No.2b - " " " " "
" " " No.3 - " " " " "
(For exact locations of these drill holes, see Plate 2, McQueen, 1959)

The basic intrusives consist predominantly of fine to medium-grained actinolite-feldspar rock, together with patches of much coarser-grained rock of similar composition; there can be little doubt that, prior to the uralitization of the pyroxene, the rocks were fine to medium-grained dolerites containing coarse-grained segregations richer in pyroxene. The two types will be considered separately :-

(a) Fine to medium-grained phase of feldspar-actinolite rock.
(b) Coarse-grained phase of actinolite-feldspar rock.

Fine to medium-grained phase : This is the predominant rock type of the area, but in most places it is very poorly exposed. Because of this, the petrography is based on thin sections from drill core at Brocks Creek No.2, and Cosmopolitan-Howley No.2b. diamond drill holes. In hand specimen, the rock is steel grey and massive; owing to alteration, it appears much finer-grained than it actually is. Seen in thin section, the rock consists of actinolite, feldspar, phlogopite, chlorite, quartz, pyrite, and sphene. The texture is granoblastic, and all minerals are randomly oriented (Fig. 17).

Green, weakly pleochroic actinolite is the predominant mafic mineral; it forms very irregular anhedra, sieved with inclusions of phlogopite and quartz (T.S.5590). In some rocks, especially from the Cosmopolitan-Howley drill hole, the actinolite forms medium-sized sheaths of fine sub-parallel fibres (T.S.5598). These fibres were probably formed from the medium-sized anhedra of actinolite, in response to changing physical - and possibly chemical - conditions; for the basic rocks of Cosmopolitan-Howley have been far more strongly uralitized and saussuritized than those at any other place in the Brocks Creek area.

Very little of the original feldspar has remained, the bulk of it having been broken down to sericite and albite; veinlets of albite also occur. Some very fine intergrowths of quartz and feldspar, as well as individual anhedra of quartz, are quite common (T.S.5592). One result of the alteration of the rocks has been the development of much "matrix" material - extremely fine-grained products of the decomposition of feldspar and pyroxene - that make up to one third of the rock (T.S.5598).

Though few of the original constituents remain, there can be no doubt that this rock type was igneous and intrusive, as thermally altered sediments were found at both top and bottom contacts in the Brocks Creek No. 2 Hole.

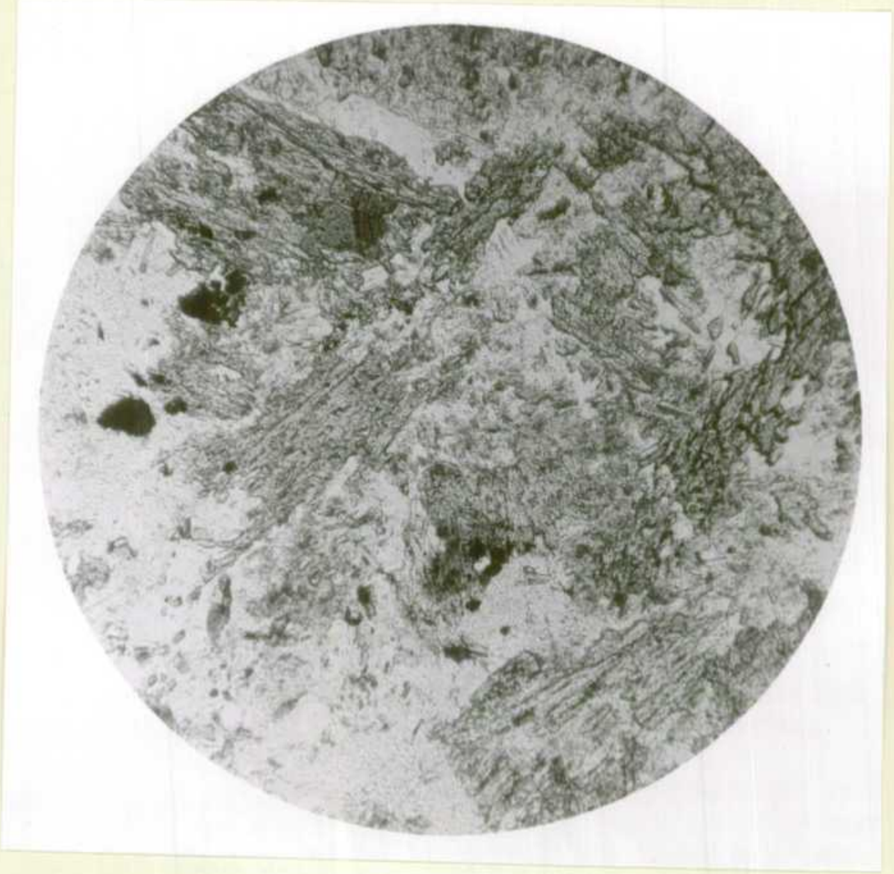

Figure 17: Feldspar-actinolite rock (fine to medium-grained phase) Brocks Creek E.E.P., D.D.H. No.2, 171 feet; T.S.5590, plane polarized light, diam. 2 mm. Poikiloblastic actinolite (plentiful dark grey anhedra), fine untwinned feldspar (pale grey areas), quartz, biotite (upper, mid left), pyrite (upper, left, black).

In each case the sediment had been modified for a distance exceeding 15 feet from the intrusion. The result has been that the sediment has developed an assemblage of minerals similar to that of the uralitized intrusion, but the testures are quite distinct (T.S.5596). The mineralogical similarities between the altered sediment and the altered igneous rock are especially interesting in view of the work Walker et al. (1960) have done towards distinguishing calc-silicate rocks from metamorphosed dolerites.

The unaltered sediment was pyritic carbonaceous siltstone, in part dolomitic, belonging to the Golden Dyke Formation; this suffered low-grade regional metamorphism, after the intrusion of the dolerite.

At both top and bottom contacts, the sediment has been recrystallized to a fine-grained patchwork of actinolite, biotite, and quartz, with some sodic feldspar, and pyrite (T.S.5593). Though much of the original lineation has been lost, the various minerals still tend to form elongate sub-parallel clumps that probably represent differences in composition within the sediment (Fig. 18).

Figure 18: Biotite-sericite-quartz-actinolite schist, Brocks Creek R.E.P., D.D.H. No.2, 160 feet;T.S.5588, plane polarized light, diam. 3.5 mm. Xenoblastic actinolite (upper, mid-right, light grey), sub-parallel biotite flakes (deep grey), sericite and quartz after plagioclase (dark, fine-grained areas), anhedral quartz (white patches), pyrite and iron oxide (both black).

At a distance of 10 feet from the upper contact the sediment has been only partly recrystallized to a fine biotite hornfels, with a little muscovite, actinolite, and pyrite. Biotite flakes parallel the original layering of the rock, which is still apparent, At a distance of 14 feet from the upper contact, the rock appears to be only slightly affected (T.S.5586).

One rather anomalous alteration affect was seen in a rock 6 feet from the contact; the rock consisted mainly of clinopyroxene (probably diopside), with subordinate quartz, actinolite, sodic feldspar, and accessory clino-zoisite, epidote, pumpellyite, tourmaline, and pyrite (T.S.5587). Over 50% of the rock consists of xenoblastic clinopyroxene, with the remainder principally of quartz. The rock probably formed from dolomitic siltstone. The tourmaline is almost certainly derived from sedimentary boron; according to Williams, Turner & Gilbert (1954, p.183) there is usually enough boron in marine shales to account for disseminated tourmaline in slates and hornfelses, without invoking a magmatic source. Another unusual feature of this pyroxene hornfels is that the clinopyroxene has remained unaltered, whereas all the pyroxene of the dolerite has been converted to actinolite. The most likely explanation of this is that the alteration of the igneous pyroxene was due to uralitization - the action of late magmatic fluids on the cooling rock. The sediment has apparently been shielded from these fluids so that only the rise in temperature has been effective in changing the mineral assemblage of the sediment.

Coarse-grained phase: This rock type is quite conspicuous in the Brocks Creek area, because it is particularly well exposed; but probably it makes up only a small part of the total volume of the basic rocks in the area.

In hand specimen, the rock is greenish-grey, massive and medium to coarse-grained. Seen in thin section, it consists of actinolite, calc-andesine, hornblende, and accessory sphene, pyrrhotite and phlogopite. The minerals are randomly oriented, and predominantly coarse-grained (T.S.5637). As in the case of the "medium to fine-grained phase" from Burrundie, some of the actinolite anhedra are bent and cracked and may assume distinctly curved shapes (T.S.5639).

Amphibole makes up 60% of the rock; two thirds of this is actinolite, and the remainder hornblende. Pale green, poorly pleochroic actinolite forms anhedra up to 4 mm. long. It shows well developed cleavages and also remnants of ophitic texture, indicating that the actinolite has pseudomorphed pyroxene (T.S.5636). The cores of many of the pseudomorphs consist of aggregates of fine, almost colourless, tremolite-actinolite fibres (Fig. 19), which may reflect a compositional variation in the original pyroxene - for instance, the core may have been orthopyroxene, or a core of augite may have been surrounded by pigeonite. Alternatively the fibres of tremolite-actinolite may have developed from the actinolite pseudomorphs in response to changing conditions - but then the change would be expected at the outside rim rather than at the centre of the pseudomorph.

The rims of the actinolite pseudomorphs are commonly pleochroic from blue-green to pale green to pale straw brown, and could be a soda-rich, alumina-poor hornblende (c.f Fig.20). This material is almost certainly formed from the actinolite by the addition of a small quantity of alumina and soda derived from the plagioclase.

Scattered throughout the feldspar are many fibres apparently identical in composition to the hornblende rims described above. These have been derived from scattered actinolite fibres - a common feature in uralitized basic rocks - by the addition of soda and alumina from plagioclase.

Figure 19: Coarse uralitized dolerite, Brocks Creek area. T.S.5637, crossed nicols, diam. 6 mm.
Fibrous aggregates of almost colourless tremolite-actinolite (centre, mid-left), in the core of the actinolite pseudomorph of pyroxene (upper and lower, left).

(At Cosmopolitan-Howley a rather different trend is seen. The actinolite pseudomorphs probably formed, but no enrichment in soda and alumina followed; instead, the processes of uralitization and saussuritization continued, broke down all the original feldspar, and produced large bundles of actinolite fibres in place of the actinolite pseudomorphs (T.S.5599)).

In the coarse-grained phase from Brocks Creek plagioclase occurs as fine to medium-grained, well twinned, strongly corroded laths of calc-andesine. Some feldspar has also been recrystallized to clear, untwinned anhedra, but there does not appear to have been any noticeable enrichment of soda in the new plagioclase. Phlogopite forms irregularly arranged groups of books, commonly in the cores of the large actinolite pseudomorphs. Sphene forms very irregular patches enclosing remnants of the parent ilmenite or magnetite. Some very fine intergrowths of quartz and feldspar make up part of the interstitial filling.

Conclusions

The textural and mineralogical similarities, combined with the close field relationship, suggest that the "fine to medium-grained phase" and the "coarse-grained phase" are genetically related. The coarse phase may represent material that crystallized early, and from which the felsic liquor has been removed either by crystal settling or filter press action.

The only counterparts of these very coarse-grained gabbroic rocks found elsewhere in the Katherine - Darwin region, are some coarse, very altered basic rock from a drill hole at Rum Jungle Creek South. In that case also, the coarse rock was associated with finer material, and probably represented a segregation within the dolerite intrusion.

In the Brocks Creek area the sediment and the dolerites have been domed up by the Burnside Granite. At one contact between the dolerite and a tongue of granite, W.B. Dallwitz (verbal communication) states that the dolerite has been converted to a fine-grained plagioclase-pyroxene granulite.

At a number of places next to the dolerite near the southern margin of the granite, very elongate lenses of pure marble are found. These lenses are identical with those described earlier in this report from the Burrundie area, both in character and in their relationship to the dolerite and granite.

Langley (1954) is the only other petrologist to have described these rocks in any detail. She suggested the following sequence of events :-

injection of gabbro (associated with scapolitization)
low-grade regional metamorphism
injection of diorite
intrusion of granite.

In my opinion, the alteration of the basic rocks was due to the combined effects of autometamorphism and regional metamorphism. I have found little evidence of a later intrusion of diorite; this rock may represent a variant of the dolerite that escaped the uralitization and sericitization - possibly due to its different composition. The bulk of the basic rocks, also, were doleritic rather than gabbroic or dioritic.

The order of events in the Brocks Creek area appears to have been as follows : The dolerite was intruded in a semi-solid state at moderate temperature, into unfolded pyritic carbonaceous and dolomitic siltstone containing some bands of limestone. The intrusion took the form of sills and sub-horizontal sheets. The sediments were thermally altered for at least 14 feet from the contact, and actinolite biotite hornfels, diopside hornfels, and marble were formed. The dolerite was sericitized and uralitized at a late stage in its cooling. The siltstone and the uralitized dolerite were later extensively folded, faulted, and intruded by the Burnside Granite.

There is no indication that the dolerite was in any way related to the mineralization of the area; the only sulphides contained within the dolerite are very variable - though small - amounts of pyrite and a little pyrrhotite.

Daly River Area

In the Daly River area, doleritic rocks form two quite large masses, but little is known about them (see Map 1). Because they are 30 miles apart, the two masses will be treated separately. The masses are :-

Daly River dolerite
Chilling Creek dolerite

Daly River dolerite is a tongue-shaped mass that extends from close to the Daly River Copper Mine northward for 5 miles, where it almost abuts on the Litchfield Granite. The basic rocks are surrounded by alluvium, but probably occur in a position towards the base of, or immediately below, the Burrell Creek Formation. Searl (1955) suggested that the dolerite was younger than the regional folding and the Litchfield Granite, but no evidence was cited to support this conclusion. A more likely interpretation is that the dolerite is, like most other dolerites in the Katherine - Darwin region, older than both folding and granite.

Copper mineralization, together with a little silver and lead, is found in shears within slate, close to the southern edge of the Daly River dolerite (Searl, 1955). Searl thought that the mineralization might be related to the dolerite but has presented no data to support this conclusion.

Chilling Creek dolerite. This mass occurs 25 miles south-south-west of the Daly River Police Station, and west of the headwaters of Chilling Creek. It intrudes the Hermit Hill Metamorphics (Archaean) to the west, and the Berinka Volcanics (Lower Proterozoic) to the east. No petrological work has been done on the basic rocks.

Rum Jungle Area

The Rum Jungle area is about 40 miles south-south-east of Darwin (see Map 1) and is covered by a geological map at 1 mile to 1 inch. (Rum Jungle Area, B.M.R., 1960).

On this map, basic intrusions are shown immediately east of Mount Deane close to the Stuart Highway, and at Dolerite Ridge two miles north-west of Rum Jungle Siding. Basic rocks have been intersected in a drill-hole at Rum Jungle Creek South, which is two miles south of Rum Jungle Siding; at Browns Prospect, one mile south-west of White's Open Cut, and at Waterhouse No.2 Prospect which is six miles south of Batchelor.

In the Mount Deane Area the basic rocks crop out along a narrow strip almost two miles long, following the contact between the Acacia Gap Tongue of the Masson Formation and the overlying Golden Dyke Formation. Broadly, this is a contact between silicified sandstone and greywacke and the overlying pyritic carbonaceous siltstone. In all outcrops the rocks are extremely altered and commonly look more like iron-rich gossans than igneous rocks. Stevens (1955) did some petrological work on the rock, describing it as "highly altered rock of probable basic igneous origin, consisting of medium-grained calcite, quartz, amorphous chlorite, magnetite, hydrated iron oxides, and a little sphene". Malone (1955) considers it to be a sill-rock that has been subjected to extreme uralitization, but in my view the alteration has advanced to the stage of propylitization.

Dolerite Ridge is a small isolated feature, surrounded by alluvium and elongated north-west. Three surface samples from Dolerite Ridge were described by the South Australian Mines Department Laboratory during 1959. These were called "melanocratic microdiorite, sheared altered meladiorite, and sheared fine-grained amphibolite". The rocks are clearly igneous and originally either dioritic or gabbroic; probably they represent dolerites that have been uralitized and regionally metamorphosed to epidiorite.

Rum Jungle Creek South Area. At this uranium prospect a diamond drill hole intersected more than 900 feet of what has been logged as amphibolite, spotted and sheared amphibolite, and chloritic schist. Close sampling of the core of this hole - T.E.P. Diamond Drill Hole 337 - has shown that both igneous and sedimentary amphibolite * occur. A rough distinction can be made in the hand specimen as the sedimentary material is banded and the igneous rock is massive; but as shearing effects are superimposed on this, the differences are commonly not easy to pick.

The igneous amphibolite occurs from 373 feet to 772 feet, and from 1286 feet to 1342 feet. In the hand specimen it is massive, dark grey, fine to medium-grained, and shows little variation along the length of the core. Seen in thin section it consists predominantly of alumina-poor hornblende, actinolite, oligoclase-andesine, and quartz, with accessory amounts of sphene, ilmenite, leucoxene, and biotite. In one section (T.S.6894), amphibole has been completely replaced by chlorite.

The texture is clearly metamorphic, many of the minerals showing xenoblastic outlines; but corroded laths of plagioclase and relics of ophitic intergrowth between pyroxene (now pseudomorphed by hornblende) and feldspar, place the rocks' igneous origin beyond doubt. Amphibole makes up 60% of the rocks examined. It shows a wide variation in colour from non-pleochroic pale green tremolite-actinolite, to strongly pleochroic blue green to green to straw yellow hornblende. This indicates a variation in composition from tremolite-actinolite to alumina-poor soda rich hornblende. Commonly the centres of the hornblende

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* None of the amphibolite from the Rum Jungle area falls within the amphibolite facies of metamorphism, but rather within the albite epidote facies (Turner and Verhoogen, 1951). This problem is discussed in more detail elsewhere (Bryan, 1960).

crystals are filled with bundles of fine tremolite-actinolite fibres; it has been suggested by Oldershaw (1960) that the fibres are the products of uralitization of the original pyroxene and that the surrounding hornblende was produced by reaction with plagioclase (Fig.20). Corroded twinned unzoned oligoclase-andesine laths are very common; some fine-grained untwinned plagioclase is also present. Ilmenite forms a triangular lattice work around cores of leucoxene; as Oldershaw noted, this effect is probably due to lamellae of ilmenite that have exsolved from the original titaniferous magnetite, which has subsequently been converted to leucoxene. Oldershaw has also reported pyrite, arsenopyrite, and chalcopyrite, but in this study pyrite was the only sulphide observed.

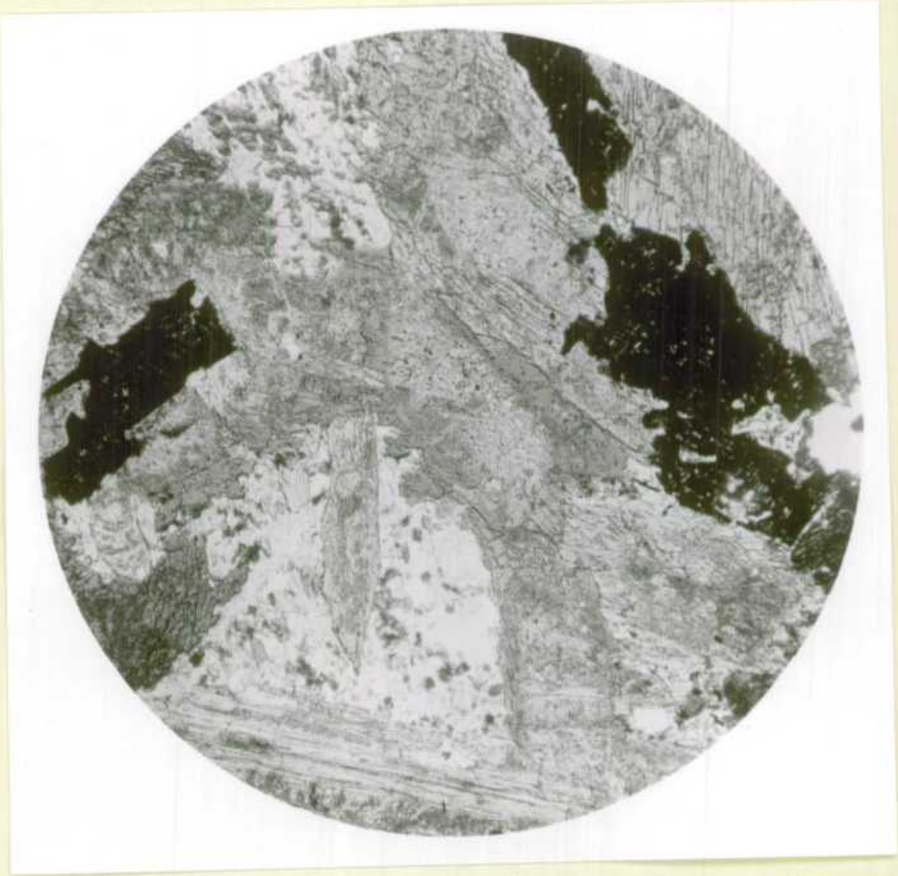

Figure 20. Coarse uralitized dolerite, Rum Jungle Creek South Prospect, D.D.H. 337, T.S.5202B, plane polarized light, diam. 4 mm. Blue-green hornblende rims surrounding pale alumina-poor centres, containing residual aggregates of fibrous tremolite-actinolite (centre). Similar looking fibres in the plagioclase (white patches), are of blue-green hornblende.
(Slide first described by Oldershaw.)

The explanation of the coarse hornblende and included tremolite-actinolite from the Brocks Creek area given in a previous section of this report, may be applicable to the Rum Jungle Creek South rocks as well. This would imply that the original pyroxene altered progressively to actinolite, then to a pale green alumina-poor hornblende which was enriched in soda - especially along the margins of the pseudomorphs - by reaction with plagioclase. The very fine tremolite-actinolite fibres within the hornblende appear to be residual.

Oldershaw (op. cit. 1960) suggests that the Rum Jungle Creek South rock was "probably a medium to coarse-grained gabbro, containing andesine or labradorite, probably pyroxene, and magnetite". The close similarity of this specimen to the "coarse phase" from Brocks Creek suggests that the Rum Jungle Creek South rock described by Oldershaw may also be a coarse segregation of a typically doleritic intrusion.

Another specimen of "very altered basic or intermediate rock such as dolerite, trachyte, or andesite", has been described by Oldershaw (1960a); the core was from D.D.H. 363, also in the Rum Jungle Creek South area. Though the rock was very altered, it probably represents part of a basic intrusive that could be equated to the "fine to medium-grained phase" from Brocks Creek.

The sedimentary amphibolite from D.D.H.337 at Rum Jungle Creek South is very similar to material from a diamond drill hole at Mount Burton, five miles to the north-west, and is typical calc-silicate rock (Bryan, 1960).

Brown's Prospect. Core from D.D.H. 60B 49 has been thoroughly sampled, and though it is predominantly sedimentary, some altered igneous rock does occur. Igneous amphibolite occurs between 340 feet and 352 feet, probably between 367 feet and 490 feet, and probably between 1491 feet and 1512 feet.

The intervening sediments are of slate, spotted slate, and amphibolite, all derived from shale and calcareous shale, by low-grade regional metamorphism. They are commonly rich in pyrite and pyrrhotite, and contain some chalcopyrite. Most of the sulphide is concentrated along the bedding planes, and in one case it outlines a minor slump structure.

The igneous amphibolite is a fine to medium-grained massive grey rock; seen in thin section its texture is almost wholly metamorphic. The rock consists of xenoblastic alumina-poor hornblende, oligoclase-andesine, iron oxide, pyrite, and accessory amounts of apatite, epidote, prehnite and carbonate. The amphibole makes up over 50% of the rock; it is only slightly pleochroic (T.S.6934), but its other optical properties indicate that it is probably an alumina-poor variety of hornblende. The plagioclase makes up 30% to 40% of the rock, and in most cases forms untwinned pools; several corroded laths of oligoclase-andesine occur. Black iron oxide forms 5%, and pyrite 1%.

The original igneous rock was basic, and the corroded laths of plagioclase were medium-grained; it is possible that the rock is related to the altered dolerite or gabbro from Rum Jungle Creek South.

Waterhouse No.2 Prospect. This uranium prospect is located six miles south of Batchelor, and occurs in slates and siltstones of the Golden Dyke Formation. The Bureau of Mineral Resources D.D.H. No.4 passed through sediments and into 140 feet of amphibolite (Ruxton, 1961); this rock has been examined in detail and is igneous in origin (Bryan, 1961).

Variations in composition and texture of the rock can be best explained in terms of original differences in the rock; an approximate log can be drawn up in the following way :

112 to 117 feet: In the hand specimen the rock is dark grey and consists of euhedral and subhedral hornblende crystals, set in a white or pale grey groundmass. In thin section, the hornblende crystals are found to average .5 mm. across and 1.0 mm. in length (T.S.6870). Hornblende makes up about 30% of the rock - though in one case it has been partly replaced by chlorite (T.S.6878). Albite forms about 60% of the rock and occupies most of the space between the hornblende crystals. It forms untwinned anhedra averaging .02 mm. across. Apatite is unusually common, forming prisms up to .5 mm. long, as well as very fine needles scattered evenly through the feldspar. A partial analysis of a sample from 113 feet gave 8.62% P_2O_5 (Baker, 1962). This is at least eighteen times the amount normally found in amphibolites. Iron oxide and lesser amounts of pyrite and pyrrhotite occur in accessory amounts (Fig. 21). The igneous origin of the rock is confirmed by the indurated nature of the sediment within 5 feet of the contact, and also by the presence of the long apatite crystals in the amphibolite.

124 to 134 feet: In the hand specimen, this rock is grey, massive, and fine- to medium-grained. Seen in thin section it consists of fine- to medium-grained aggregates of actinolite and chlorite, together with an equal amount of albite. Leucoxene, sphene, iron oxide, biotite, and augite occur in accessory amounts (T.S.6872). The texture of the rock is metamorphic in character, and is typical of basic rocks that have been reconstituted through low-grade regional metamorphism.

144 to 154 feet: This rock is grey, massive, medium- to fine-grained, and is cut by calcite veins. In thin section it is seen to consist of actinolite, brown hornblende, carbonate, black iron oxide, and accessory amounts of leucoxene, sphene, biotite, muscovite, and pyrite. Very little feldspar is present. Green actinolite makes up about 80% of the rock, forming medium-grained, moderately pleochroic anhedra; commonly it encloses very irregular anhedra of strongly pleochroic brown hornblende, which are undoubtedly original constituents of the rock (T.S.6875). The hornblende makes up 5% of the rock, and carbonate - probably all calcite - makes up about 10%.

The rock is probably derived from an ultrabasic pyroxenite that contained some hornblende.

174 to 250 feet: This rock is pale grey to greenish-grey, fine-grained, massive, and cut by calcite veins. Seen in thin section it consists of tremolite-actinolite, black iron oxide, brown hornblende, and accessory apatite. Tremolite-actinolite makes up about 85% of the whole, and is pale green, weakly pleochroic, and forms masses of fine-grained, randomly-oriented fibres (T.S.6878). Strongly pleochroic brown hornblende makes up 5% of the rock, and is encased in anhedra of tremolite-actinolite, rather than in the fibrous aggregates. Black iron oxide forms 5-10% of the rock (Fig.22).

Figure 21. Apatite-rich hornblende-albite amphibolite, Waterhouse No.2 Prospect, D.D.H. No.4, 112'8", T.S.6869, plane polarized light, diam. 4 mm. Fine anhedral albite (white area), subhedral and euhedral hornblende (large dark crystals), euhedral apatite (fine colourless crystals and needles), and black iron oxide (centre of field).

Figure 22. Hornblende-actinolite amphibolite, Waterhouse No.2 Prospect, D.D.H. No.4, 239'4", T.S.6880, crossed nicols, diam.4mm. Tremolite-actinolite (groundmass of fibres), hornblende (large irregular crystals) which is dissected by iron oxide veins (centre). Iron oxide also forms large anhedra (right side of field).

This rock was probably derived from an ultrabasic pyroxenite containing some hornblende, by low-grade regional metamorphism.

All the amphibolite of this drill hole is igneous, and was probably derived from a basic magma. The composition of this magma may be close to that of the material found between 124 and 134 feet. The narrowness of this zone when compared with the total thickness of "amphibolite", can possibly be explained by a fault at 140 feet postulated by Ruxton (1961), cutting off the greater part of this material.

The ultrabasic rocks occurring between 144 and 154 feet, and between 174 and 250 feet, differ from each other only in that the latter apparently contain a higher proportion of Mg to Fe. Both types probably formed as differentiates from the basic magma.

The apatite-rich amphibolite found between 112 and 117 feet was probably formed by the later intrusion of a more felsic differentiate. The green hornblende crystals were probably original constituents. The very high percentage of P_2O_5 over this zone has not been satisfactorily explained.

Conclusions on the Rum Jungle area

The order of events in the Rum Jungle area appears to have been similar to that in most of the other areas considered in this report, except that regional faulting here plays a major role. The basic rocks were probably sills, injected into unfolded sediments, and uralitized late in their cooling history. Both basic rocks and sediments were subsequently "recrystallized at the same time in response to low-grade regional metamorphism, and due in particular to moderate stress conditions" (Bryan, 1960). At this time, the Rum Jungle and Waterhouse granites were intruded and domed up the sediments. A major transcurrent fault that cuts the area - the Giants Reef Fault - has offset ~~the~~ Rum Jungle Granite three miles; it seems probable that this fault was active in pre-granite times also.

A small quantity of pyrite is the only sulphide mineral found in the basic rocks; there has never been any real support for the suggestion that the uranium, lead, copper or cobalt mineralization in the Rum Jungle area was in any way related to, or localized by, the basic sills.

GENERAL CONCLUSIONS

Throughout the Katherine - Darwin region the doleritic rocks maintain very constant relationships to the adjacent sediments and to the granitic intrusions; the conclusions reached can be considered under the following headings :

Comparison between the areas of basic rocks

- Time of intrusion
- Mode of intrusion
- Temperature of intrusion
- Composition of the basic rocks
- Degree of metamorphism of the basic rocks

Relationship between basic rocks and granites

Relationship between basic rocks and mineralization

Relationship between basic rocks and aeromagnetic anomalies.

Comparison between the areas of basic rocks.

Time of Intrusion. Throughout the main trough of the Pine Creek Geosyncline, i.e., west of longitude 132°E. the great bulk of the basic rocks intrude the Golden Dyke Formation, yet are almost entirely absent from the overlying Burrell Creek Formation - despite the enormous areas of this formation that are exposed. Exceptions are found in the Burrundie area, where several very small masses of dolerite have been mapped within the lower part of the Burrell Creek Formation. These exceptions may not be very significant, bearing in mind the somewhat gradational boundary between the two formations. A more important case is the Daly River dolerite which occurs close to the western margin of the geosyncline. The dolerite is now overlapped by Cambrian sediments and Recent alluvium, but it is quite possible that these are underlain by a veneer of Burrell Creek Formation.

This restriction of the dolerite to the lower formations within the trough may have a bearing on the time of emplacement of the dolerite. There are three possible explanations but none appears to fully account for the distribution of the dolerite :

1. The magma had an insufficient head to intrude the overlying formation.
2. The rising magma encountered a stratigraphic barrier at the base of the Burrell Creek Formation, and spread out beneath it.
3. The dolerite may have been emplaced before the Burrell Creek Formation had been deposited.

If the absence of dolerite from the Burrell Creek Formation was caused by insufficient magma pressure, then it would be expected that the upper limit to the intrusions would be along a plane of equal pressure; that such a plane should almost coincide with the boundary between the Golden Dyke and Burrell Creek Formations throughout a large part of the trough is most surprising, as it would imply that the thickness of both formations were constant throughout this area.

The differences in lithologies between the two formations are not marked, and the change from one formation to the other is gradual. The Golden Dyke Formation is predominantly carbonaceous dolomitic siltstone, whereas the Burrell Creek Formation is mainly siltstone and greywacke.

The possibility that the dolerites were intruded before the Burrell Creek Formation was laid down has some drawbacks, the chief one being that the intrusives must have almost reached the sea floor, and yet no submarine lavas have been recognised. Nevertheless, this explanation seems to be the most likely of the three. (The absence of volcanic equivalents of the dolerites would readily be explained by a disconformity between the Golden Dyke Formation and the Burrell Creek Formation; but field mapping has been sufficiently detailed to virtually rule out this possibility.)

The intrusives can, with certainty, only be placed as prior to the folding, and the intrusion of granite.

To the east of the main trough a subsidiary basin developed approximately along the alignment of the present South Alligator valley. Sedimentation in this area began towards the end of the period of "infilling" of the main trough, and continued well after that time (Walpole, 1959). In this eastern basin, dolerites intrude all the Lower Proterozoic sediments - the South Alligator Group - and were probably emplaced in the early stages of their deformation. To the south-east of El Sharana (Mount Evelyn 1-mile Sheet) the stratigraphic control of the dolerite is not at all marked, and Walpole (op. cit.) has suggested that some of the masses may be dykes controlled by the marked north-west zone of folding and faulting.

If the correlations between the sediments of the main trough and those of the South Alligator basin are accepted, there is a strong possibility that the South Alligator dolerites were intruded later than those of the main trough. For, if it is assumed that the Lower Proterozoic folding in the main trough and in the eastern basin took place at the same time, the intrusions of basic rocks in these two areas are separated by a tectonic event - even if the dolerites of the main trough are younger than the Burrell Creek Formation. In the main trough the basic intrusions are conformable and have invaded unfolded strata; but in the eastern basin many of the dolerite masses are discordant and commonly appear to be controlled by the regional north-west line of folding and faulting.

Mode of Intrusion. In most places the dolerite has clearly been intruded as sills or sub-horizontal sheets into the unfolded sediments. Only in the South Alligator Valley - and particularly in the Zamu Creek area - is there a real possibility that the dolerite has been injected as dykes which have risen up fault-lines in the folded rock. All the contacts of the dolerites are sharp.

At no place in the region are there any indications that the dolerite has reached the surface and formed lava flows or pyroclastic outpourings.

Temperature of Intrusion. The country rock appears to have been affected by a rise in temperature due to the intrusions, but there are no signs of any significant interchange of material between the sediment and the dolerite. The thermally altered sediments form a zone less than 20 feet wide; originally carbonaceous and dolomitic siltstones, they have reached their maximum alteration with the development of a diopside-actinolite-epidote assemblage. This assemblage is characteristic of the albite-epidote-amphibolite facies of Turner & Verhoogen (1951), which forms at low to moderate temperatures and under low stress conditions.

Composition of the basic rocks. All the basic rocks of the region are extensively altered due to the combined effects of deuteric alteration and low-grade regional metamorphism. This has resulted in the conversion of most of the pyroxene to actinolite and commonly the plagioclase has been sericitized and/or saussuritized; the changes have commonly resulted in the formation of sodic plagioclase and quartz as byproducts, but in the South Alligator area in particular, some of the plentiful quartz may have been introduced.

All these changes have tended to obliterate any differences in composition that may have been present in the original intrusions; but all the rocks look as if they were originally tholeiitic dolerites that gave rise to segregations of gabbro, dolerite pegmatite, dolerite aplite, and granophyre.

Degree of metamorphism of the basic rocks. Very little direct information has been gained on the grade of metamorphism achieved by the basic rocks, because of the extensive saussuritization and uralitization that was apparently associated with the cooling of the dolerite. In the Rum Jungle and Brocks Creek areas in particular, some of the changes can certainly be attributed to low-grade regional metamorphism. Far more accurate results can be obtained by studying the alteration produced in the sediments (Bryan, 1960). There seems little doubt that the grade of metamorphism was consistently low - seldom above the greenschist facies - throughout the geosyncline.

Relationship between the basic rocks and the granites.

In a geographic sense the dolerite sills and granite are very closely associated. This can partly be explained on a purely structural basis - that the granite has domed up the sediments and, after erosion, exposed the sills in cross-section; but this is only part of the reason.

There seems little basis for postulating a genetic link between the granite and dolerite. Throughout the central part of the geosyncline, the sills were pre-granite, and possibly intruded before the main sedimentation commenced. In the South Alligator basin the dolerite is pre-granite, but the two are probably separated by only a relatively short interval.

It is in the main trough of the geosyncline that the granite - dolerite relationship is closest. Probably the reason for this is stratigraphic rather than genetic. From Burrundie northwards, the granite does not intrude sediments occurring stratigraphically above the Golden Dyke Formation - apart from several masses close to the western edge of the trough - and this is also the upper limit of the dolerite sills.

Also, the Golden Dyke Formation commonly crops out best where the sediments have been domed up by the granite; as the Golden Dyke Formation contains most of the basic sills, it is not surprising that the granite and dolerite often crop out in the same areas.

In the South Alligator basin, the situation is rather different; the dolerites have riddled all the Lower Proterozoic sediments, and the dolerite outcrop is largely controlled by the folding and faulting of the area. The later granite appears to have had little effect in localizing the outcrop of dolerite. This is a good illustration of the relationship to be expected if the dolerites intrude all the formations, rather than being restricted to only the lower horizons - assuming that no genetic link exists between the granite and the dolerite. It lends weight to the idea of a "stratigraphic" rather than a genetic relationship between the two groups of igneous rocks.

Relationship between basic rocks and mineralization.

In a number of places base metal, silver, gold, uranium, and tin mineralization is found in the vicinity of dolerite sills, but there is very little apart from this geographical proximity to suggest that the mineralization is genetically related to the dolerite. The sill-rock usually contains either pyrite or pyrrhotite in small but very variable quantities, in addition to the opaque black oxides of iron. No other sulphides have been positively identified from within the sills.

In most places the mineralized areas are also close to granite, and it is much more likely that the mineralization is genetically related to the granite. If this is so, then the nearness of the mineralization to the dolerite could readily be explained, as it has been shown that in most of the granite - dolerite areas within the region, the outcrops of dolerite are controlled largely by the location of the later intrusion of granite.

Relationship between basic rocks and aeromagnetic anomalies.

Extensive airborne magnetic surveys carried out by the Bureau of Mineral Resources over much of the Katherine - Darwin area, have shown widely differing effects over large areas of basic igneous rocks. Throughout the South Alligator dolerite belt no high readings were registered over the dolerite, but in the Burrundie, Brocks Creek, and Rum Jungle areas very high readings were associated with dolerite intrusions.

In normal basic igneous rocks, magnetite is responsible for over 80% of the magnetic reading, and there can be little doubt that the anomalies associated with dolerites at Burrundie, Brocks Creek, and Rum Jungle, are caused by additional magnetite in those rocks, as compared with the South Alligator dolerite. This has been confirmed, in general, by thin section examination.

Two factors have been mainly responsible for this variation in magnetite content - differences in original composition, and in the degree of alteration. It has been suggested that the dolerite from the Burrundie, Brocks Creek and Rum Jungle areas are somewhat older than the South Alligator dolerite, and could have been derived from a magma richer in iron

Also, the deuteric and low-grade metamorphic alteration of the dolerite in the main trough is much more pronounced than in the South Alligator belt, and one result of such alteration is an increase in the magnetite content of the rock.

Insufficient field and laboratory work has been done to explain local variations in magnetic results associated with the dolerite; but it seems probable that the two factors dealt with above, along with sudden changes in the attitude and thickness of the dolerite, are capable of explaining most of the apparently quite unpredictable local variations.

The possibility that some of the variation could be accounted for by fluctuations in the amount of ilmenite and pyrrhotite has also been considered. Pyrrhotite occurs in very variable amounts in the rocks, but everywhere the percentage is too low to appreciably offset the overall magnetisation, as the mineral is only weakly magnetic relative to magnetite. Ilmenite is even less magnetic than pyrrhotite, but the exact amount of ilmenite present in the rocks is not known, as no general polished section work was undertaken. However, the deuteric alteration and low-grade regional metamorphism of basic rocks produces magnetite and not ilmenite, and the magnetic highs are, in general, found in the more altered rock; therefore, it would appear that the ilmenite does not play a major role.

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REFERENCES

AUST. MIN. DEV. LAB., 1960 - Basic intrusives of the Chambers River - Maiwok Creek area. Bur.Min. Resour.Aust. File note 166, dated 31.10.60 (unpubl.)

BAKER, S. 1962 - Phosphate analysis of sample from Waterhouse No.2 Prospect, D.D.H. No.4, 113 feet. Bur.Min.Resour.Aust. File note 84/NT/10R dated 3.1.62 (unpubl.)

BRYAN, R., 1960 - "Amphibolites" from the Rum Jungle area, N.T. Bur.Min.Resour.Aust. File note 84/NT/4A, dated 13.12.60 (unpubl.)

" " 1961 - Notes on the amphibolite from D.D.H. No.4, Waterhouse No.2 Prospect, Rum Jungle area, N.T. Bur.Min.Resour.Aust. File note 84/NT/4A, dated 13.12.61 (unpubl.)

CAMPBELL, F.A., 1956 - Report on gossan formations of Brocks Creek, Northern Territory. Report for Enterprise Exploration Pty Ltd (unpubl.) Copy for Resident Geologist's office, Darwin filed under Rep. N1-27 (unpubl.)

DUNN, P.R., 1961 - 1:250,000 geological series: explanatory notes. Alligator River, N.T. Bur.Min. Resour.Aust.Explan.Notes D/53-1.

HAYS, J., 1960 - The geology of the Mt. Harris Tinfield, Northern Territory. Bur.Min.Resour. Aust. Rec. 1960/2 (unpubl.)

LANGLEY, J.M., 1954 - Diorites from Brocks Creek, Northern Territory. Bur.Min.Resour.Aust. File note 120/NT/2, dated 5.10.54 (unpubl.)

McQUEEN, W.F., 1959 - Report on Diamond Drilling at Cosmopolitan Howley Mine, Brocks Creek, N.T. Bur.Min.Resour.Aust. Rec. 1959/145 (unpubl.)

MALONE, E.J., 1958 - The geology of the Darwin- Adelaide River area, Northern Territory. Bur.Min. Resour. Aust. Rec. 1958/96 (unpubl.)

NOAKES, L.C., 1949 - A geological reconnaissance of the Katherine - Darwin region, Northern Territory. Bur.Min.Resour.Aust.Bull. 16

OLDERSHAW, W., 1960 - T.E.P., D.D.H. 337, Rum Jungle Creek South. Bur. Min. Resour. Aust. File note 120/NT/4A (unpubl.)

" " 1960a- Specimen from D.D.H. 363, depth 120 feet, Rum Jungle, T.E.P. Ltd. Bur.Min.Resour. Aust. File note 120/NT/4A (unpubl.)

SEARL, R.A., 1955 - Report on investigations in Authority to Prospect No. 79 N.T. (Stapleton - Daly River area). Rio Tinto (Aust.) Explor. Pty Ltd Report (unpubl.) Copy on Bur.Min.Resour.Aust.File note 120/NT/2/3

REFERENCES contd.

STEVENS, R.D., 1956 - Rocks collected by the Marrakai Party. Bur. Min. Resour. Aust. File note 120/NT/2/4/ dated 11.7.56 (unpubl.)

STEWART, J.R., (undated) - Proterozoic igneous rocks in the Katherine - Darwin region, Northern Territory. Thesis submitted for M.Sc. Univ. of New England (unpubl.)

SULLIVAN, C.J. and ITEN, K.W.B., 1952 - The geology and mineral resources of the Brocks Creek district, Northern Territory. Bur.Min.Resour. Aust. Bull. 12.

TURNER, F.J. and VERHOOGEN, J., 1951 - IGNEOUS AND METAMORPHIC PETROLOGY. N.Y., McGraw-Hill.

RUXTON, B.P., 1961 - The testing of electromagnetic anomalies by diamond drilling at Waterhouse No.2 Uranium Prospect, N.T. Bur.Min.Resour.Aust.Rec. 1961/161 (unpubl.)

WALKER, K.R., JOPLIN, Germaine A., LOVERING, K.F. and GREEN, R., 1960 - Metamorphic and metasomatic convergence of basic igneous rocks and lime-magnesium sediments of the Precambrian of North Western Queensland. J. Geol. Soc. Aust., 6(2), 149-177.

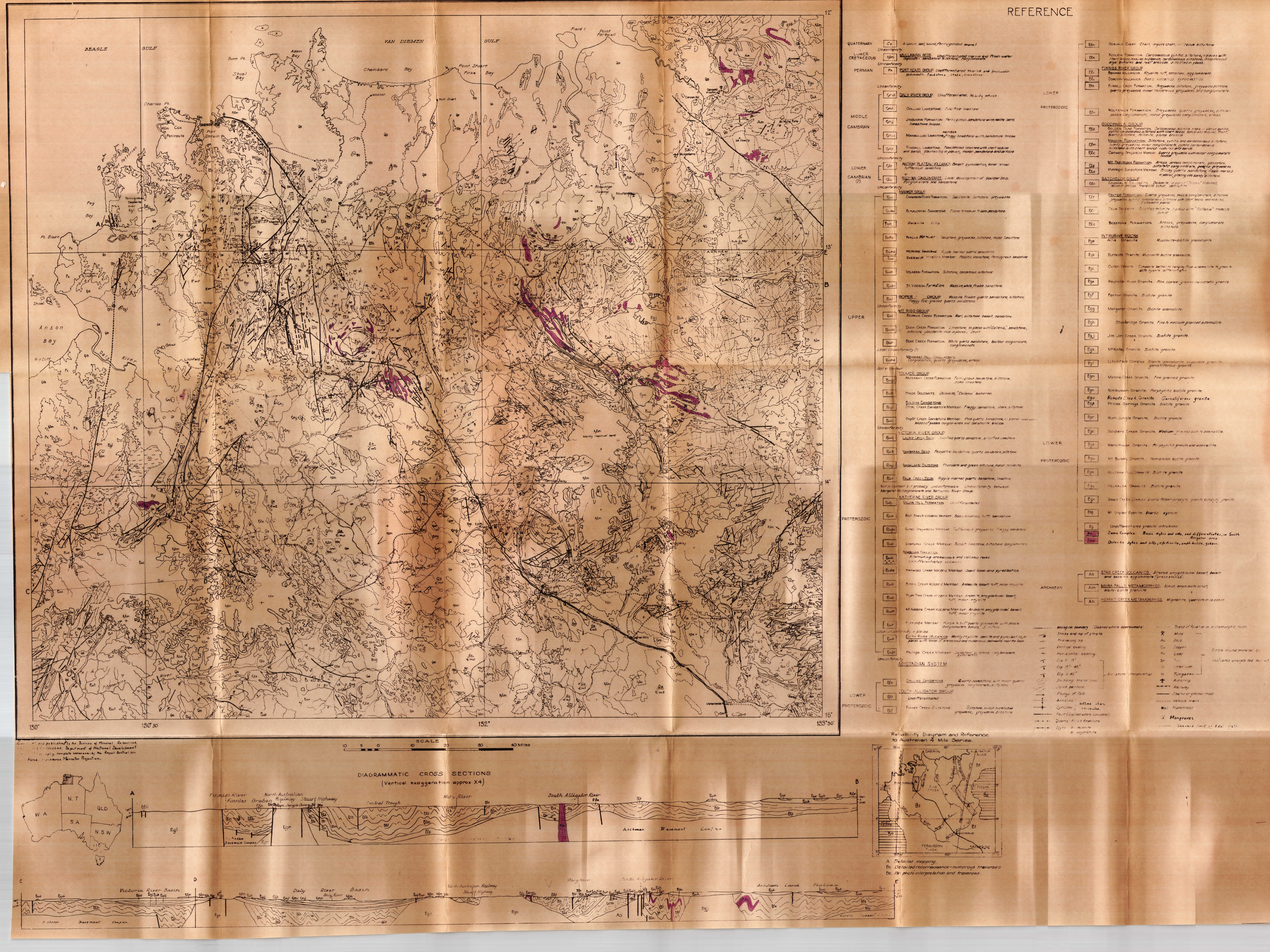
WALPOLE, B.P., 1959 - The evolution of the Pine Creek Geosyncline and its relationship to the structural framework of North West Australia. PhD. Thesis. Aust. Nat. Univ. (unpubl.)

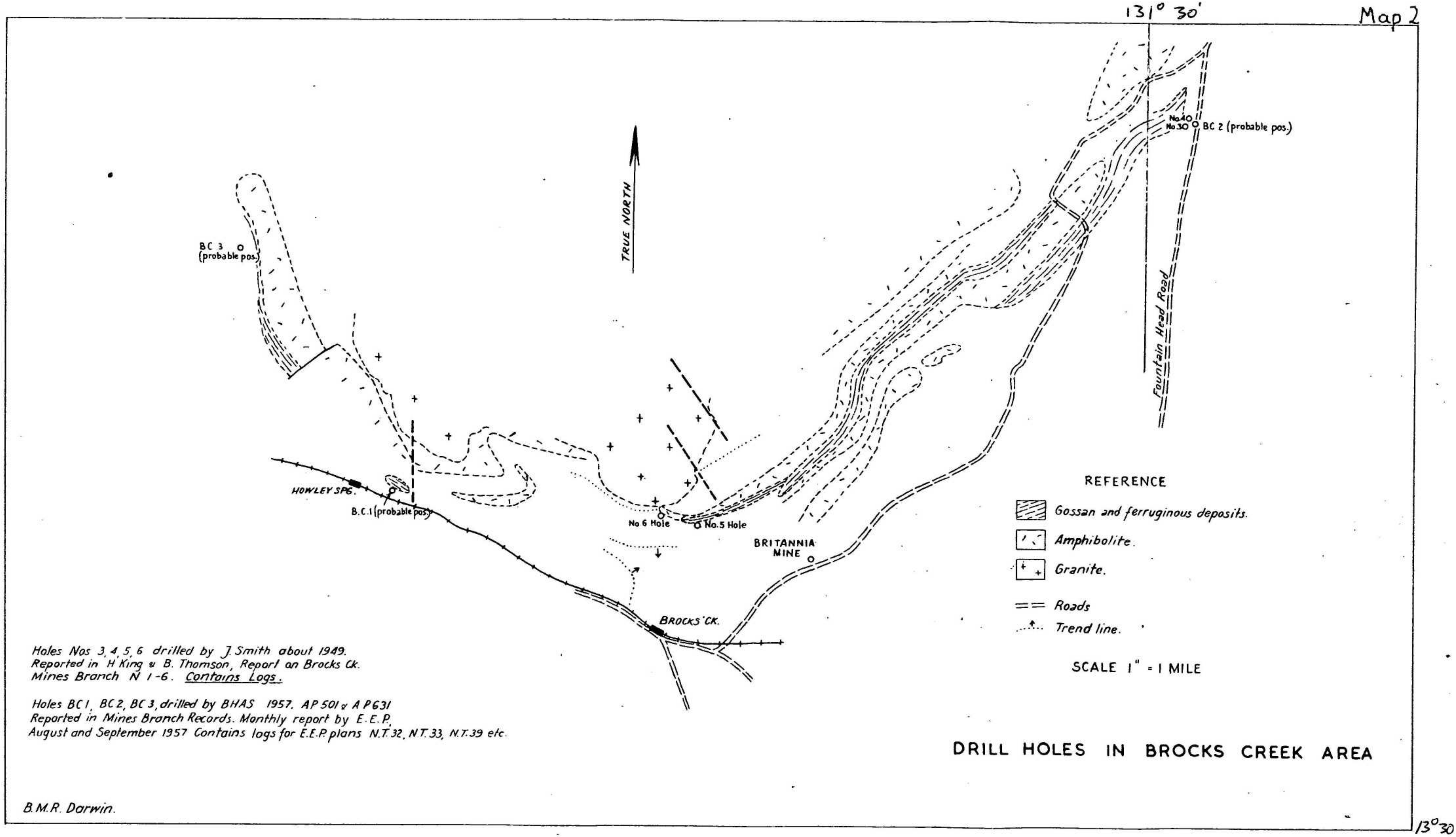
WILLIAMS, H., TURNER, F.J. and GILBERT, C.M., 1954 - PETROGRAPHY. San Francisco, Freeman.

GEOLOGICAL MAP
KATHERINE - DARWIN AREA
NORTHERN TERRITORY

DRAFT COMPILATION ONLY

MAP I





131° 30'
Map 2
13° 30
TRUE NORTH
BC 3 (probable pos.)
No.4 O
No.3 O
BC 2 (probable pos.)
Fountain Head Road
HOWLEY SPG.
B.C.1 (probable pos.)
No 6 Hole
No.5 Hole
BRITANNIA MINE
BROCKS' CK.
REFERENCE
Gossan and ferruginous deposits.
Amphibolite.
Granite.
Roads
Trend line.
SCALE 1" = 1 MILE
Holes Nos 3, 4, 5, 6 drilled by J. Smith about 1949.
Reported in H King & B. Thomson, Report on Brocks Ck.
Mines Branch N 1-6. Contains Logs.
Holes BC1, BC2, BC3, drilled by BHAS 1957. AP 501 & AP 631
Reported in Mines Branch Records. Monthly report by E.E.P.
August and September 1957 Contains logs for E.E.P. plans N.T. 32, N.T. 33, N.T. 39 etc.
DRILL HOLES IN BROCKS CREEK AREA
B.M.R. Darwin.