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Probable Carbonatites in the Strangways Range Area, Alice Springs 1:250,000 Sheet Area SF 53/14: Petrography and Geochemistry

by

D.C. Gellatly

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ALICE SPRINGS 1:250,000 SHEET AREA SF 53/14:
PETROGRAPHY AND GEOCHEMISTRY

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CONTENTS

SUMMARY

Crystalline carbonate rocks from the Mud Tank apatite prospect in the Precambrian Arunta Complex near Alice Springs consist mainly of dolomite and calcite, and contain bands rich in apatite and magnetite, along with minor zircon, phlogopite, amphibole, chlorite, and possible columbite (or ?fersmite) pseudomorphs after pyrochlore. The mineralogy and textures of the rocks, especially the peripheral arrangement of inclusions of magnetite and apatite in dolomite, the growth forms of both apatite and zircon, the reversed pleochroism of the phlogopite, the presence of possible pyrochlore pseudomorphs, and the association with albite-aegirine pegmatites are consistent with a suggested carbonatitic origin. Trace element contents, particularly of Nb, Ba, Sr, La, and Y, are appreciably higher than those of sedimentary carbonates, and fall within the range of those of known carbonatites.

Petrographic descriptions of both carbonatites and adjacent country rocks are given as an appendix.

INTRODUCTION

The presence of crystalline carbonate rocks containing apatite associated with zircon and magnetite in the Strangways Range area, Alice Springs district, has been known since 1940 and probably considerably earlier (collection in Geology Department Museum, University of Adelaide). The assumed origin of the carbonates as metamorphosed sedimentary limestones has not been questioned until recently. P.W. Crohn, who first visited the area in 1965, suggested a possible carbonatite origin for these rocks after seeing the Canadian Oka and Firesand carbonatite complexes in 1966. Subsequently he obtained a number of drill core samples of the crystalline carbonate rocks from Geopeko Ltd, who had tested the prospect in 1966 as a possible source of apatite for fertiliser manufacture. The writer became associated with this project when he undertook a petrological examination of this material and of surface specimens collected by Crohn.

A preliminary note of the occurrence has recently been published (Crohn and Gellatly, 1969). The present report presents in greater detail the petrological and geochemical results which were summarised in the preliminary note. Further work on the occurrence is in progress.

LOCATION

The specimens described in this report come from deposits situated near the northern margin of the Strangways Range, close to the northern margin of the Alice Springs 1:250,000 Sheet area, and about 57 miles north-northeast of Alice Springs, and 5 miles southwest of Mud Tank, Alcoota Station. The locality is some 90 miles distant by road from Alice Springs. Parts of the outcrop are crossed by a track that leads from Mud Tank on the principal track to Alcoota Station and the Harts Range mica fields. A geological sketch map of the locality (based on Williams, 1967) is given in Crohn and Gellatly (1969).

PREVIOUS WORK

The occurrence of apatite associated with magnetite and zircon was reported briefly by the North Australian Survey (Report for period ending 31/12/40) and described by Owen (1944) who made a plane table survey of the northeastern part of the carbonate-bearing area. A specimen of the magnetite, and one of an apatite-bearing iron-rich carbonate from this area have been examined by Pontifex (1964a,b) who regarded the carbonate rocks as metasomatised sedimentary limestone. A detailed aeromagnetic survey of the area around the Strangways Range carbonate rocks has been reported on by Tipper (1966).

The carbonate rocks were drilled by Geopeko Ltd in 1966 (Williams, 1967). Williams named the principal carbonate lenses Enterprise 2,3,4,5. Specimens described in this report are partly drill core samples from Geopeko DDH 2 in Enterprise 3, and partly surface samples collected by P.W. Crohn during a brief visit in 1968.

An occurrence of phlogopite, which may also be an expression of alkaline igneous activity, has been reported from nearby in the Strangways Range by Jensen (1943a,b): rocks from this locality have been described by Stillwell (1943) and Browne (1943).

GENERAL GEOLOGY

(After Owen, 1944; Tipper, 1966; Williams, 1967; and P.W. Crohn, pers. comm.).

The Arunta Complex, in which the carbonate rocks are found, consists essentially of strongly folded schist, gneiss, amphibolite, and metamorphosed limestone, with acid, basic, and ultrabasic intrusives. The principal country rocks recorded from the immediate vicinity of the carbonatites are semi-pelitic biotite schists (locally garnetiferous) and basic intrusives.

The carbonates form low outcrops in flat country. Three main areas of carbonate outcrop are present, aligned in a northeasterly direction, and extending for 1½ miles. A fourth outcrop occurs a further

$1\frac{1}{2}$ miles west-southwest. Two of these areas measure approximately 600 feet by 200 feet; the most northeasterly mass (mapped by Owen) is 700 feet across and roughly triangular in outcrop. Aeromagnetic results suggest that the three main outcrops represent separate masses.

Contacts with the enclosing muscovite-quartz schist are not exposed. Available evidence strongly suggests that the contacts are at least broadly concordant. The suggestion by Owen that the "limestone" overlies the schist unconformably was based on the mistaken identification of weathered biotite-rich carbonate rocks as part of the schist sequence.

Apatite and magnetite in the carbonate bodies are concentrated into irregular bands, veinlets, and irregular masses. The carbonates are ferruginous and are weathered in outcrop: fresh material is obtainable only from drill cores.

METHODS

Microscopic examination of 18 thin sections and 2 polished surfaces was supplemented by examination of the cut surface of the remaining part of each specimen which was stained by immersing for 40 seconds in a solution of 0.1% alizarin red S in $\frac{N}{15}$ HCl at 20°C (a slight modification of the method of Mitchell, 1956). This allows differentiation between calcite (stained pink), on the one hand, and dolomite and other carbonates, on the other. This staining method was also used on chips of the analysed specimens.

One of the specimens was crushed to -5 mesh (BS sieve), and the carbonate dissolved in approximately 2N HCl. From the resulting mineral residue, amphibole was separated for refractive index determinations, ilmenite for electron microprobe examination, and other minerals for x-ray diffraction identification.

Trace and minor element contents were determined by Australian Mineral Development Laboratories (A.M.D.L.) by optical emission spectrography, except for P and Ti, which were determined by X-ray fluorescence.

In addition all the specimens were examined under short-wave ultra-violet light. Apart from the usual weak crimson fluorescence from calcite, one orange-fluorescing grain of zircon was the only fluorescent mineral noted.

The salient petrographic features of the carbonatites and country rocks are outlined in the following sections. Descriptions of individual thin sections are given in Appendix 1. Both macroscopic and microscopic evidence are strongly suggestive of a carbonatitic origin for the carbonate rocks. They are thus allocated igneous rock names. Non-genetic mineralogical rock names are given in parentheses.

Approximate modal compositions given are based on visual estimation: the compositional variations within each specimen (particularly of the carbonate rocks (Table 1)) and from one specimen to another, of essentially similar rocks, would render accurate micrometric analyses no more meaningful than the approximate values quoted.

PETROGRAPHY

COUNTRY ROCKS

Country rocks in the vicinity of the carbonate outcrops were examined principally for evidence of fenitisation. Biotite schist and phyllonite and mylonite, probably derived from schist and gneiss, can be traced to within 50 feet of the contact but no evidence of fenitisation has been noted. However, the closest rocks to the carbonates are mylonites and blastophyllonites , and they may not have been in close proximity to the carbonates at the time of their emplacement. If, as is likely, the northeasterly carbonate body (Enterprise 2) is separated from the rest by a transcurrent fault, then country rocks now immediately to the south of it may originally have been more than half a mile from the carbonates. In other localities, however, there is no evidence of faulting.

In view of the lack of exposures near the carbonatite, the lack of evidence for fenitisation in the specimens examined is less surprising than it might otherwise be. Also, fenitisation is characteristically best developed in granitic rocks, whereas more micaceous rocks may undergo minor alkali metasomatism without showing much evidence of this petrographically.

The presence of cordierite porphyroblasts in one specimen (0527) is of interest in that it could suggest contact metamorphism related to the intrusion of carbonatite magma.

Country rocks are mainly semi-pelitic quartz-biotite-muscovite schists, phyllonites, and mylonite. They commonly contain porphyroblasts of K-feldspar and an intermediate plagioclase, and a few examples contain garnet with or without sillimanite. Minor accessory minerals are apatite, rutile, magnetite, zircon, epidote, clinozoisite, altered allanite, and a chlorite.

Feldspar porphyroblasts have resisted the strong shearing that has affected some of these rocks and, in most phyllonites and mylonites, remain as porphyroclasts, although their original porphyroblastic nature may still be inferred by comparison with their equivalents in less sheared rocks.

Quartz grains in most of these rocks are small and intensely strained, and show good preferred orientation. Most garnets are partly altered to a chlorite (and locally also to biotite). In schists and phyllonites they are elongate in cross-section due to deformation, and in extreme examples are broken into trains of fragments. They are absent from the mylonites. Sillimanite has been noted in one garnet-bearing schist where it is partly altered marginally to sericite.

BASIC ROCKS

Basic rocks are found as large gabbroic masses to the west of the carbonate rocks and as lenses (presumably xenolithic) within the carbonates. Only three specimens have been examined so far. Of these, one is a hornblende gabbro from a locality 1 mile northwest of Enterprise 4. The other two, which occur within the carbonates, are amphibole-rich rocks that appear to show signs of slight metasomatism.

The gabbro consists of labradorite (An_{65}), a pleochroic (pale pink to pale green) pigeonitic augite, hornblende, minor magnetite and pleochroic orthopyroxene, and traces of apatite and quartz. The clinopyroxene is unusual in its relatively strong adsorption and pleochroism which are essentially similar to those of the orthopyroxene. The hornblende shows normal birefringence, and extinguishes completely, and thus differs from the amphibole of possible basic inclusions within the carbonates.

Two types of amphibolite inclusion have been found; both have a high mafic index (80-90). A surface sample from Enterprise 2 consists of coarse-grained amphibole (70%), interstitial symplectics of plagioclase (An_{15}) and a diopsidic pyroxene, and minor apatite, sphene, biotite, and goethite. The amphibole is distinctive in that it fails to extinguish in sections parallel to the <u>ac</u> plane, and shows anomalous birefringence, especially in transverse twin bands which generally have an abnormally bluish Z absorption colour and high extinction angle ($Z'c = 42^{\circ}$). Optics suggest that the pyroxene is an intermediate member of the diopside-hedenbergite-acmite system.

A drill core specimen from Enterprise 3 consists of amphibole (65%), calcite (15%), small essential amounts (ca.5%) of plagioclase (An_{35}), magnetite, and biotite, minor apatite and dolomite, and traces of quartz and zircon. The amphibole ($Z'c = 42^{\circ}$) is similar to that in the specimen from Enterprise 2, but has stronger anomalous birefringence, and probably has affinities to hastingsite. Apatite grains are ovate. Calcite, dolomite, magnetite, and apatite occur in association, and occupy interstices between amphibole crystals.

ALKALINE PEGMATITES

The only alkaline rocks associated with the carbonatite crop out as small lenses of sodic pegmatite, generally less than 10 feet long, within the carbonatite; field relations are uncertain. These lenses may represent parts of poorly exposed dykes, and are here considered to intrude the carbonates (see "Discussion"). In hand specimen the pegmatites are pale cream-pink and consist of very coarse-grained feldspar (2 cm and more) and scattered elongate grains of dark green pyroxene.

Albite is the only essential feldspar present. It occurs as large equant crystals containing small irregular exsolution blebs of microcline showing undulose extinction, as small peripheral grains without exsolved K-feldspar, and as small inclusions in the large albites and in aegirines. $X'c = 15^{\circ}-16^{\circ}$. Both albite and Carlsbad twinning are found, the former predominating in the larger grains, and the latter in the small peripheral grains.

Aegirine occurs mainly as small peripheral grains surrounding large albites, as more elongate inclusions within albite, and as large poikilitic grains, some of them forming a symplectic with a sodic amphibole. The aegirine is pleochroic from X = emerald green to Z = pale leaf green, and has $X'c = 7^{\circ}$.

A sodic amphibole has been noted in only one thin section where it is intergrown with aegirine. Pleochroism is X = very pale brown, Y = indigo, Z = blue-green. Birefringence (μ = .003) is anomalous, with a colour change from blue to orange replacing extinction. $Z'c = 40-42^{\circ}$ (Na light) and Y = b. It is thus similar in certain of its properties, especially the high extinction angle and low birefringence, to arfvedsonite, but differs from it in its optical orientation which is similar to that of glaucophane.

Quartz, apatite, sphene, and small spherical aggregates of the microcrystalline mineral (?columbite or ?fersmite) noted in carbonatite *0513 (see below) are minor accessory minerals.

CARBONATITES

In hand specimen the carbonatites are mainly coarsely crystalline white carbonate rocks and carbonate-biotite rocks with minor amounts of prominent magnetite, pale yellow-green apatite, and dark green chlorite. One specimen (0516) consists chiefly of pale yellow-green apatite with only minor amounts of carbonate. Specimen 0513 shows rusty-brown staining of carbonates possibly due to alteration of magnetite.

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*0513. Numbers such as this refer to B.M.R. registered specimen numbers in the series 68070501 to 68070535.

In thin section the carbonatites are seen to consist of dolomite and calcite with variable amounts of biotite and apatite, and minor magnetite, ilmenite, phlogopite, chlorite, goethite, zircon, pyrite, chalcopyrite, quartz, and pseudomorphs of possible columbite (or ?fersmite) after ?pyrochlore.

Calcite and dolomite are present in approximately equal amounts, but vary considerably from one specimen to another. Their relative proportions vary from about 18/1 to 1/12. The rocks are thus termed either calcitic beforsite (carbonatite with dominant dolomite) or dolomitic sövite (with dominant calcite).

1. Mineralogy

Dolomite (25 to 55%) invariably occurs as large (1 to 1.5 cm) clear, colourless, irregular, ovate grains. It contains rare discrete inclusions of calcite, magnetite, ilmenite, apatite, and phlogopite. With the exception of calcite which in general is randomly distributed within the dolomite, the other inclusions, especially magnetite, ilmenite and apatite, tend to occur only in the outer parts of the grains. Calcite inclusions are irregularly shaped, commonly elongate; most other inclusions are equidimensional.

Calcite (5 to 60%) forms an interstitial mosaic of anhedral interlocking grains from about 0.5 to 2 mm across. It is very pale grey-brown in colour, is mostly slightly turbid due to the presence of minute inclusions, and is generally more turbid where it is enclosed in, or abuts against dolomite. Apatite, magnetite, and ilmenite are invariably associated with the calcite.

Apatite (up to 65%) occurs mostly as scattered anhedral, ovate grains, 0.2 to 3 mm long. Grains are mostly fractured and in specimen 0517 contain thin veinlets of a more highly birefringent mineral (μ = .018). Apatite is almost invariably associated with calcite, although a few small grains are enclosed in marginal parts of dolomite grains. In specimen 0516 it forms a massive aggregate of anhedral grains up to 9 mm across, and containing thin fracture-fill veinlets of quartz.

Biotite (up to 50%) is abundant in certain bands within the carbonate sequence. It occurs as 0.5 to 2 mm flakes in lenticles and thin irregular bands interspersed with bands of calcite. It consists locally of interlayered red-brown and olive-green varieties. The red-brown variety, which is the primary one, predominates; the green variety is secondary, and occurs preferentially as deformed flakes or in deformed marginal areas of red-brown flakes. The green variety is regarded as a biotite rather than a chlorite on account of its high birefringence (the same as that of biotite). Pleochroism of the two types are X = pale ginger, Y = pale foxy red-brown, Z = green-brown and Y = pale buff, Z = dark grey green (X orientation not present).

Phlogopite: rare scattered tabular grains of a pleochroic mineral (very pale yellow-brown to bright foxy red-brown) with a perfect (001) cleavage are referred to phlogopite but differ from normal phlogopite in having maximum absorption normal to (001). The phlogopite is partly or wholly replaced by a strongly pleochroic (pale green to deep leaf green) chlorite which has maximum absorption parallel to (001), is length-slow, has parallel extinction, and 2V = Ca.10°.

An amphibole (up to 1%), present in only two of the specimens, occurs as elongate grains up to 2.5 mm. It has X = colourless, Y = very pale grey green, and Z = pale blue-green; $Z'c = 30^{\circ}$ and Y = b; 2V ≑ 60°; μ = .015. It is locally associated with chlorite and in specimen 0511 is partly replaced by carbonate. Refractive indices determined by oil immersion are $n_x = 1.624$, $n_y = 1.639$.

Magnetite (up to 5%) forms rare euhedral grains and aggregates of 1 cm or more, generally associated with calcite. Small (0.1 to 1 mm) euhedral and rare elongate grains found in the marginal zones of dolomites may be either ilmenite or magnetite. In specimen 0513 rare (?) magnetite crystals have been partly replaced by calcite.

Ilmenite has been identified from X-ray powder diffraction photographs of grains from the insoluble residue of specimen 0513 and by electron microprobe analysis. It probably makes up about 50% of the opaque grains in this specimen. Ilmenite exsolution laminae had

TABLE 1

Approximate modal compositions of Strangways Range carbonatites

	Cal-cite	Dolo-mite	Bio-tite	Apa-tite	Magne-tite + ilmen-ite	Others
ESTIMATES FROM THIN SECTIONS						
Drill cores						
0513	40	55	-	Tr	2	phlogopite, amphibole, quartz, pyrite, ?columbite/?fersmite
0514	55	40	-	2	2	amphibole
0515	60	35	-	2	5	chlorite, amphibole
0516	10	25	-	65	Tr	quartz, goethite
0517	30	65	-	3	1	phlotopite
0534	40	Tr	50	3	2	pyrite, chalcopyrite, ?sphene
0535	90	5	5	1	Tr	pyrite
Surface specimens						
0531	5	60	-	-	15	goethite, zircon, ?collophane, ?columbite/?fersmite, muscovite*
0532	-	-	-	-	-	pale green amphibole, goethite microcline;* plagioclase muscovite* garnet*
0533	50	40	-	10	-	quartz*, red brown chlorite(after biotite) ?columbite
ESTIMATES FROM DRILL CORE CHIPS						
0501	65	30	-	Tr	Tr	chlorite(5)
0502	-	-	-	100	Tr	
0503	70	20	-	2	-	phlogopite(2) chlorite(5)
0504	5	95	-	Tr	Tr	chlorite
0505	35	60	-	1	Tr	chlorite(5)
0506	5	90	-	5	Tr	pyrite
0507	15	25	-	60	Tr	-
0508	20	75	-	5	Tr	chlorite
0509	40	55	-	1	-	chlorite
0510	75	25	-	Tr	Tr	chlorite
0511	70	25	-	-	5	chlorite
0512	50	30	-	-	20	pyrite

*Indicates minerals that have probably been derived through weathering of country rocks and are enclosed in recalcified material.

previously been noted (Pontifex, 1964a) in a large crystal of magnetite from this locality, but most of the material in the residue occurs as small euhedral or sub-rounded grains. It is probable that most of the small disseminated black opaque grains in these rocks are ilmenite, and that the larger crystals are mainly magnetite.

Two types of ilmenite are present: one is perfectly fresh; the other has alteration coatings of pale yellow-brown ?leucoxene. Semi-quantitative electron microprobe analyses carried out by R.N. England gave the following values (percent):

	Fe	Ti	Mn	Nb
Coated ilmenite	31	27	½	-
Unaltered ilmenite	32	23	½	-

These indicate that the ilmenites are normal varieties rather than unusual types, although both Fe and Ti are lower than that of pure ilmenite (37% and 32% respectively).

Traces of possible columbite pseudomorphing pyrochlore are noted in specimen 0513. This ?columbite forms globules of pale grey-brown disoriented microcrystalline material with high birefringence containing minute inclusions of black opaque material,and appears to pseudomorph a cubic mineral. T. Deans (pers. comm.) has suggested that this mineral may alternatively be fersmite (the calcium analogue of columbite). Efforts to isolate this mineral for X-ray powder diffraction have so far been unsuccessful.

Quartz has been identified in the residue of specimen 0513, where it forms small clear angular grains. It has also been observed as thin veinlets in specimens 0517 and 0533.

Zircon, present in residual material overlying the deposit, has not been detected in thin section, but one grain was present in a chip examined under U.V. light. The detrital zircons are up to about 4 cm long and 3.0 cm across. Prism faces (110) are short; (111) is the only pyramid form developed. Typical specimens have length/breadth ratio of the order of 1/1.4 and prism length/crystal length of the order 1/2.

Pyrite: small (0.3 mm) subhedral grains of fresh silvery yellow pyrite have been noted forming inclusions in magnetite in chips of analysed specimens 0506 and 0512, in the HCl- insoluble residue of specimen 0513 and in polished sections of specimens 0534 and 0535.

Chalcopyrite has been noted only in a polished section of 0534, where it forms small equidimensional composite grains with pyrite.

Part of the residue of 0513 consists of colourless flakes of a mica-type mineral resulting from acid leaching of the chlorite. During action with HCl this chlorite exfoliated, and may have vermiculite exfoliation properties. In addition, small amounts of a black micaceous mineral were present in the residue, but failed to give a recognizable X-ray pattern.

Identification of the amphibole, zircon, quartz, and pyrite has been confirmed by X-ray powder diffraction photographs.

2. Sequence of Crystallization

All the carbonatites examined show evidence of the same sequence of crystallization. Dolomite was the first mineral to crystallize, and was followed, although partly overlapped, by magnetite, apatite, phlogopite, and possibly calcite, all of which form inclusions in the marginal zones of dolomite but occur mainly interstitially to the dolomite grains.

Elongate blebs of calcite, some near the centre of dolomite grains, are interpreted as possible relics of exsolution from an originally impure dolomite. This is supported by the greater abundance of dusty inclusions in the calcite blebs in dolomite, than in the interstitial calcite. It is suggested that minor impurities were exsolved from dolomite along with calcite, and are now contained in the calcite as minute inclusions. This concept parallels that of albite exsolution from potash feldspar; the albite takes with it most of the anorthite present in the originally mixed feldspar with the result that the plagioclase of the perthite generally has a higher An content than that of free plagioclase in the same rock (Alling, 1921).

Post-consolidation changes include minor replacement of other minerals by carbonate, and alteration of phlogopite and (?) pyrochlore. The crystallization history is summarized in Table 2.

TABLE 2

Crystallization sequence of minerals in Strangways Range Carbonatites

Primary Crystallization		Post-consolidation
Dolomite		Possible exsolution of calcite
	calcite	Calcite veinlets in dolomite
	magnetite and ilmenite	Partial replacement by calcite
	apatite	Fractures infilled by quartz veinlets
	biotite	Partial alteration to green biotite and to chlorite
	phlogopite	Partial alteration to chlorite
	amphibole	Partial replacement by calcite
	(?) pyrochlore	Alteration to columbite or ?fersmite
	chalcopyrite	
	pyrite	

3. Discussion

Many of the petrographic characteristics of the carbonate rocks are suggestive of magmatic crystallization, and certain of them suggest that they are carbonatites.

1. Although zircon alone is not diagnostic of carbonatites (Deans, 1966) having been found in metasomatized limestone (Gillson,

1925), the assemblage apatite-magnetite-zircon is common in carbonatites but is very rare (if not unknown) in metamorphic limestone.

2. The shape and distribution of calcite inclusions in dolomite suggest possible exsolution of a mixed carbonate. According to the experimental work of Harker and Tuttle (1955), and Goldsmith and Heard (1961) considerable solid solution exists of dolomite in calcite, and minor solid solution of calcite in dolomite, and thus exsolution textures may be expected in high-temperature carbonate rocks, although the occurrence of such textures is rare since exsolution generally takes place rapidly and completely, leading to discrete calcite and dolomite grains. There would appear to be a greater possibility of preservation of such textures in carbonatites, particularly in chilled marginal rocks, than in metamorphic limestones. Probable exsolution textures have been reported previously from both carbonatites - by Coetzee (1963), Gellatly (1963), and Van der Veen (1965) - and metamorphic carbonates - among others, by Joplin (1935), Sederholm (1916), and Van der Veen (1965).

3. The zonal distribution of apatite and magnetite crystals in the marginal parts of the dolomite grains suggest magmatic crystallization.

4. The size of the magnetite crystals (up to 3 inches in residual material) is unknown in metamorphic limestones; also the occurrence of ilmenite in them suggests crystallization temperatures in excess of about 600°C.

5. The rounded form of the apatite grains, although possibly not diagnostic of carbonatites, is certainly characteristic of them (e.g. Garson, 1962; Gellatly, 1963).

6. The short prismatic form of the zircons <u>approaches</u> the typical form, i.e. very short prismatic crystals with pyramid forms dominant, or bipyramids with prism faces absent - normally

associated with alkaline rocks (e.g. Lacroix 1922; Poldervaart 1956; Coetzee 1963; Gellatly, 1963).

7. Phlogopite in these rocks shows reverse pleochroism, with maximum adsorption normal to (001), of parallel to it as in most phlogopites. Occurrence of reverse pleochroism of phlogopite has recently been reviewed by Boettcher (1967) who notes that "their occurrence appears to be almost entirely restricted to carbonatites and ultrabasic rocks" (mainly alnöites and kimberlites).

8. The presence of possible ?columbite (or ?fersmite) pseudomorphs after ?pyrochlore also suggests that these rocks may be carbonatites. (Although this tentative identification has not been confirmed it is significant that the only analysed rock containing this mineral has the highest Nb content). Pyrochlore is characteristic of many carbonatites, but is unknown in metasedimentary marbles. Also, the alteration of pyrochlore to columbite, possibly present in specimen 0513, has been reported previously only from alkaline rocks (James and McKie 1958; Gellatly, 1963).

GEOCHEMISTRY

INTRODUCTION

Trace elements in 13 specimens from the Strangways Range have been determined spectrographically by A.M.D.L. The results are given in Table 3, along with X-ray fluorescence analyses for P and Ti. A guide to the mineralogical composition of the analysed specimens is given in Table 1.

Comparison of the results with trace element contents of limestones (Table 4) confirms the suggestion, based on petrographic evidence, that these rocks are carbonatites, and not metamorphosed sedimentary limestones. The trace element values in the Strangways Range carbonatites are comparable with those from many other

carbonatites (1925) (Table 4) [illegible] is not greatly
enriched in carbonatites but is very rare (if not unknown) in
metamorphic limestone.

COMPARISON WITH SEDIMENTARY LIMESTONES

2. The shape and distribution of calcite inclusions in dolomite
suggest possible exsolution of a mixed carbonate. According
The principal elements considered by Higazy (1954) to be
to the experimental work of Harker and Tuttle (1955), and
significantly higher in carbonatites than in limestones - namely, Ba,
Goldsmith and Heard (1961) considerable solid solution
Sr, La and Y - are now firmly established, along with Nb, as elements
exists of dolomite in calcite, and minor solid solution of
which are characteristically higher in carbonatites although not all
calcite in dolomite, and thus exsolution textures may be
carbonatites may show appreciable enrichments in these. Nb, La, and
expected in high-temperature carbonate rocks, although the
Y are more reliable indicators of the sedimentary or igneous origin of
occurrence of such textures is rare since exsolution
carbonate rocks than are Ba and Sr, which may attain moderately high
generally takes place rapidly and completely, leading to
abundance in sedimentary limestones. Cr, Co and Ni, on the other hand,
discrete calcite and dolomite grains. There would appear
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reliable indicators of the origin of carbonate rocks.
textures in carbonatites, particularly in chilled marginal

In comparing trace element compositions, [illegible]
because often [illegible] systematic variations between [illegible]
a wider spread [illegible] than in
sedimentary limestones, [illegible] diagnostic
elements of carbonatites, Nb, La, and Y, have rarely been determined
3. The zonal distribution of apatite and magnetite crystals in
in studies of sedimentary carbonates. Although limited data are
the marginal parts of the dolomite grains suggest magmatic
available, the differences between the trace element contents of sedi-
crystallization.
mentary limestones and the Strangways Range carbonates are sufficient
to make reliable conclusions regarding the origin of the latter.
4. The size of the magnetite crystals (up to 3 inches in residual
material) is unknown in metamorphic limestones; also the
Niobium. No Nb values greater than 20 ppm are known from sed-
occurrence of ilmenite in them suggests crystallization
imentary limestones, whereas the lowest values in the Strangways Range
temperatures in excess of about 600°C.
rocks equal this, and most exceed it substantially, and their average
exceeds that of sedimentary limestones by a factor of about 30.
5. The rounded form of the apatite grains, although possibly not
diagnostic of carbonatites, is certainly characteristic of
Barium. There is an overlap in Ba values between those
them (e.g. Garson, 1962; Gellatly, 1963).
normally found in sedimentary carbonates and those in the Strangways
Range carbonates, but the latter average about five times the concen-
6. The short prismatic form of the zircons approaches the typical
tration normally found in sedimentary carbonates (Muir et al., 1956;
form, i.e. very short prismatic crystals with pyramid forms
Weber, 1964; Graf, 1960).
dominant, or bipyramids with prism faces absent - normally

TABLE 3

Trace and minor element contents of Strangways Range carbonatites

	0501	0502	0503	0504	0505	0506	0507	0508	0509	0510	0511	0512	0513
Nb	30	50	40	20	60	100	50	20	20	30	30	120	450
U	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Th	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50
Zr	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Cu	30	30	40	10	70	10	150	40	15	250	25	100	150
Pb	3	3	3	3	3	2	5	3	5	5	6	3	2
Zn	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Co	30	8	20	10	25	30	30	15	20	30	8	60	30
Ni	80	60	60	60	50	60	80	60	15	50	10	120	120
V	60	10	50	30	40	40	80	60	12	60	30	600	120
Cr	20	10	12	10	20	40	10	10	12	6	20	60	30
Be	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Ga	4	1	5	2	3	2	3	5	2	5	3	8	3
Ge	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Ba	800	250	800	500	700	600	500	500	800	800	1,000	700	300
Sr	1,000	1,000	1,200	1,200	1,500	1,000	800	1,000	1,000	1,200	1,500	1,000	1,000
Ti	1,500	200	2,500	500	2,000	2,500	2,500	3,000	300	1,200	1,000	+10,000	+10,000
La	150	700	100	100	100	-100	200	200	100	100	400	-100	-100
Ce	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300
Pr	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	100	-100	-100
Nd	-300	300	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300	-300
Y	120	200	120	200	150	120	100	120	120	150	200	80	100
Te	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Tl	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
P	7,000	+10,000	+10,000	8,000	4,000	8,000	+10,000	+10,000	100	1,500	200	-100	1,000
Rb	12	-3	15	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Cs	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10

All values in p.p.m. - indicates less than; + indicates greater than. Spectrographic analyses and X-ray fluorescence analyses (P, Ti only) by Australian Mineral Development Laboratories, Adelaide.

TABLE 4

Comparison between Trace Element Contents of Carbonatites and Sedimentary Limestones

CARBONATITES	Nb			Ba			Sr			La			Y		
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
Strangways Range (This work)	20	450	78	200	1000	635	800	1500	1108	-100	700	173±12	80	200	137
Tundulu (Garson, 1962)	20	1000+	557+	500	1000+	886+	1000	1000+	1000+	450	1000+	854+	70	1000+	431
Chilwa Island (Garson & Smith, 1958)	x	2500	Ca520	300	4000	1783	2000	1%+	3885+	300	1500	917	25	300	101
Darkainle (Gellatly, 1963)	13	290	80	20	160	55	45	550	211	-100	700	326±10	50	350	145
Iron Hill (Coetzee, 1963)	27	315	121	-	-	-	700	8600	5000	-	-	-	-	-	-
Dorowa (Johnson, 1961)	30-	30	17±13	55	3200+	771+	950	3200+	1270+	35	100	50±19	30-	120	66±3
Sangu (Coetzee, 1963)	5	1000+	127	-	-	-	200	2500	1200	-	-	40	-	-	28
Mbeya (Coetzee, 1963)	-	-	-	-	-	-	6800	7300	7050	-	-	180	-	-	95
Spitzkop (Coetzee, 1963)	15	646	201	-	-	-	200	2500	1200	-	-	-	-	-	-
Russian Localities (Kapustin, 1966)	-	-	-	-	-	-	-	-	-	18	34	26			
Tanganyika (Bowden, 1962)	1500	1.05%	-	1500	1.05%	5730	2500	1.24%	5730	200	700	483	5-	100	45
General averages (Gold, 1966)	-0	0.52%	1198	tr	8.40%	3800	tr	18.24%	9100	-	-	-	0	1000	138
(Weber, 1964)	-	-	-	64	130	144	680	2100	214	-	-	-	-	-	-
(Higazy, 1954)	-	-	-	290	4000	1985	1000	1%+	7750+	140	700	435	45	300	140

SEDIMENTARY LIMESTONES	Nb Min.	Nb Max.	Nb Av.	Ba Min.	Ba Max.	Ba Av.	Sr Min.	Sr Max.	Sr Av.	La Min.	La Max.	La Av.	Y Min.	Y Max.	Y Av.
Dolomitic Limestones (Weber, 1964)	-	-	-	tr	1600	102	tr	2800	214	-	-	-	-	-	-
Chilwa Island (Garson & Smith, 1958)	x	x	x	100	600	350	1000	2200	1600*	x	x	x	x	20	15
Scottish Limestones (Muir et al., 1956)	-	-	-	5	8000	220	10	6000	420	-25	50	14±11	-20	80	13±8
General averages (Turekian and Wedepohl, 1961)	-	-	0.3	-	-	10	-	-	610	-	-	x	-	-	30
(Coetzee, 1963)	0	20	4	-	-	-	-100	1400	200	-	-	-	-	-	-
(Higazy, 1954)	-	-	-	-5	-5	-5	-5	300	150	-	-	-	-	-	-
(Graf, 1960)	-	-	-	-	-	150±110	-	-	475±50	-	-	**	-	-	-
Rankama and Sahama, 1950)	-	-	-	-	-	120	-	-	595±170	-	-	-	-	-	0
(Haskin and Gehl, 1962)	-	-	-	-	-	-	-	-	-	4	8	6	4	9	5

- indicates less than. All values are in ppm except where otherwise indicated.

+ indicates greater than. x indicates general order of magnitude (0-10 ppm,)

* The high Sr and Ba of the Basement Complex limestones of Chilwa Island may be due in part to contamination by Ba-Sr-bearing carbonate veins or fluids from the adjacent carbonatites.

** La and Y values quoted by Graf are taken from Muir et al., (1956).

<u>Strontium</u>. Because of the wide range in values in sedimentary carbonates, Sr is a less reliable indicator of the genesis of crystalline carbonates than are the other elements considered here. The range of values in the Strangways Range carbonates falls entirely within the range known for sedimentary ones, but the average of the Strangways Range rocks - 1100 ppm - is two to three times higher than that for sedimentary carbonates.

<u>Lanthanum</u>. Data for lanthanum in sedimentary limestones are sparse, and show a wide range of values, but a general average of around 10-15 ppm is apparent, and contrasts strongly with the average of 165 ppm for the Strangways Range rocks.

<u>Yttrium</u>. The data available for the Y content of sedimentary limestones indicate an average of about 20 ppm or less. This is greatly exceeded by all the Strangways Range specimens, which have a minimum value of 80 ppm, and an average of 140 ppm.

Other rare earths sought are mostly below the limits of detection of the spectrographic method, but Pr (100 ppm) in specimen 0511, and Nd (300 ppm) in specimen 0502, greatly exceed the known values (Pr 1.4 ppm, and Nd 4.5 ppm - Haskin and Gehl, 1962) for sedimentary carbonates.

VARIATIONS WITHIN THE STRANGWAYS RANGE SUITE

In most carbonatites the early members of the suite are calcitic, and the later members dolomitic and ankeritic. Nb tends to be associated with the sövites, and rare earths with the beforsites and ankeritic carbonatites. In the Strangways Range rocks, however, dolomite has been the initial phase to crystallize, and thus the later varieties are more calcitic. The general variation in trace elements relative to the major ones is thus more complex than in most other carbonatites. Since all the rocks analysed are non-ankeritic types they may represent early stages of crystallization, or they may be members of a poorly differentiated suite.

Of the elements that show significant ranges in their abundances in the Strangways Range rocks, Cu, Co, Ni, V, and Cr in general reflect the magnetite and ilmenite contents and tend to vary sympathetically with them.

Ba, which has too large an ionic radius to replace Ca, tends to be concentrated in the later stages of potassium-free carbonatites where it generally crystallizes as barite. Thus within a given suite of carbonatites the Ba content of a specimen may be taken as an approximate guide to its position within the differentiation series. Although Sr may proxy for Ca (Mason, 1958), it apparently does this readily only at high temperatures, e.g., in plagioclase of basic igneous rocks. Consequently it too tends to be concentrated in the late-stage carbonatites, but may show a less marked tendency than Ba to do so. Thus Ba in these specimens tends to be more concentrated in the Ca-rich, probably later-stage varieties.

Nb in most carbonatites is concentrated chiefly in the early sövites, and is relatively depleted in the later-stage beforsites. In the Strangways Range specimens no correlation can be established between the Nb and Ca contents (although the possible pyrochlore pseudomorphs occur exclusively in the calcite phase), but Nb tends to be more abundant in the low-Ba Sr (probably early) types than in the high-Ba-Sr (probably late) ones. This tendency, however, is not well displayed (Fig.1). Many more analyses will be required before definite compositional trends can be established. Specimens with high P (>1%) apparently differ from the other specimens in their time element variations (Figs 1,2).

Variations in La and Y are irregular. In part they appear to increase with increasing Ba and Sr, i.e., they tend to show the expected concentration in the later stages of crystallization, and in part they tend to increase with increasing content of P (and thus of apatite) (Fig.2). This is in keeping with the fact that rare earths show little tendency to replace major elements during magmatic crystallization, except for some replacement of Ca by rare earths in apatite (Mason, 1958).

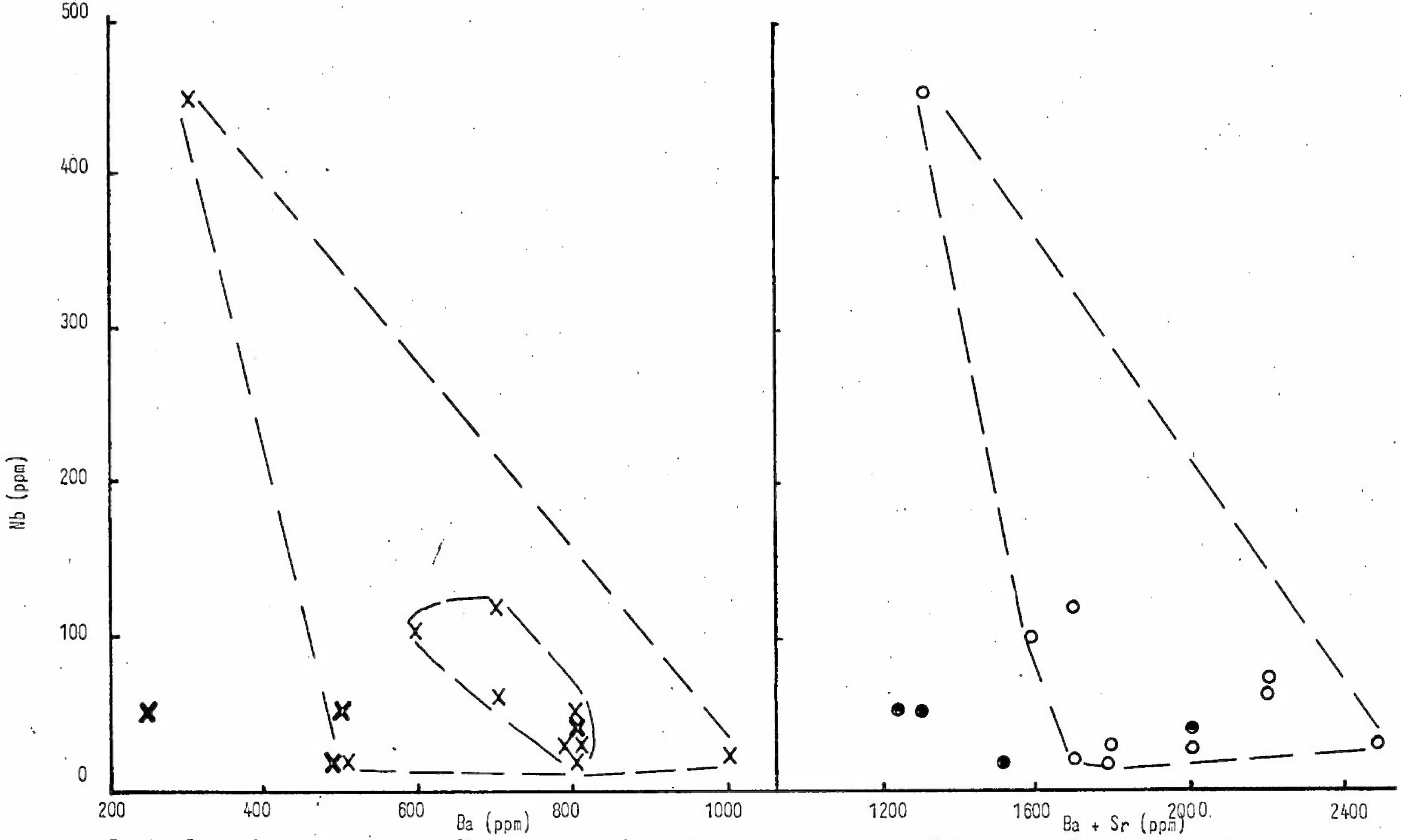

Fig.1. Trace element variations in Strangways Range Carbonatite, Variations in Nb relative to Ba and Ba + Sr. Heavy crosses and solid circles indicate specimens with more than 1% P.

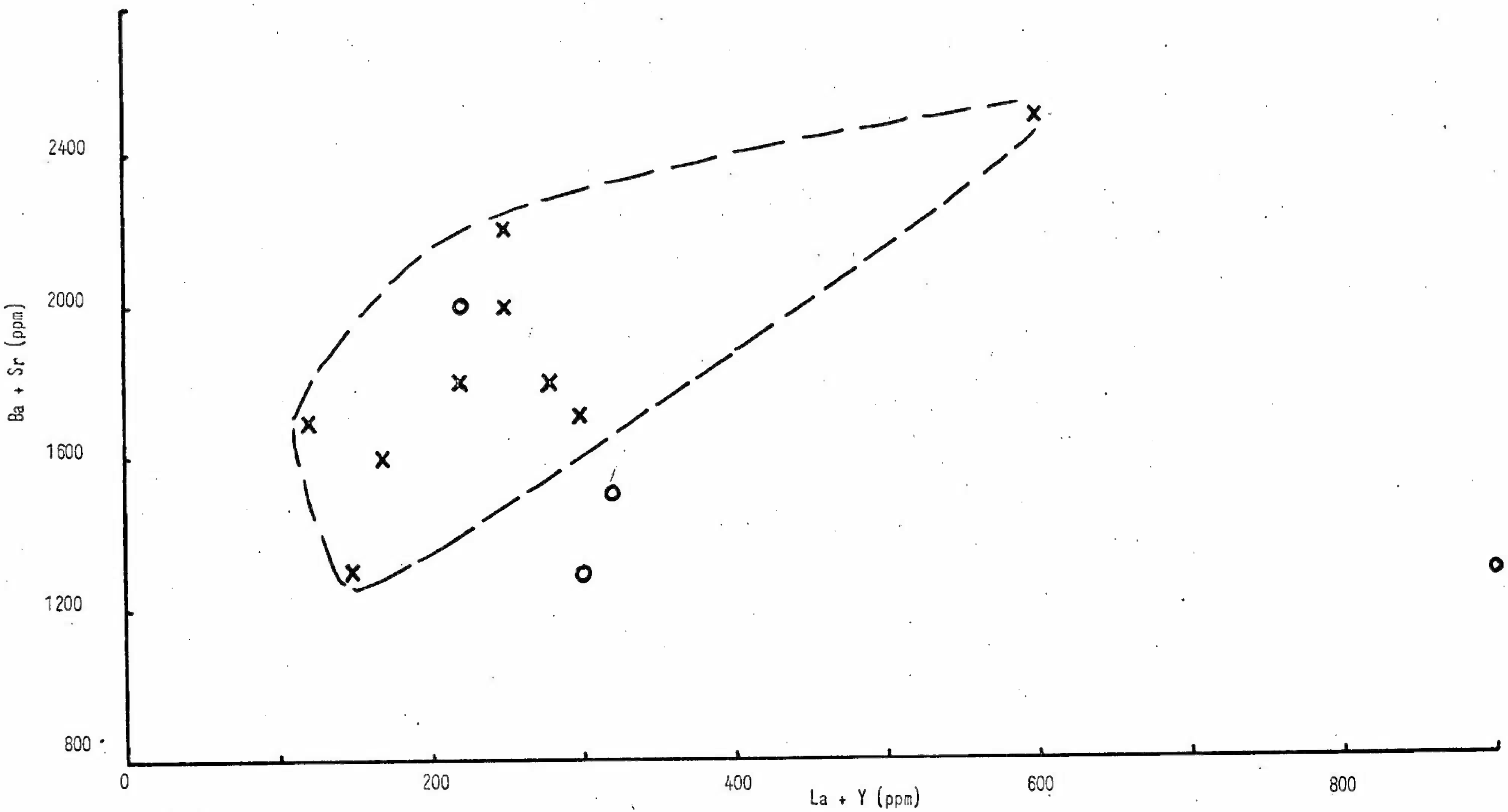

Fig.2. Trace element variations in Strangways Range Carbonatite. Variations in Ba + Sr relative to La + Y. Circles indicate specimens with more than 1% P.

COMPARISON WITH OTHER CARBONATITES

Comparison of the Strangways Range carbonatites with those from other areas necessitates recognition of the variations found between different carbonatite complexes and also those within individual carbonatite complexes. These depend at least partly on the stage or stages of differentiation represented in each complex. This in turn appears to be related at least partly to depth of emplacement: the high level ones tend to be more highly differentiated and to have higher trace element contents.

The Nb contents of the Strangways Range rocks are comparable with those from other Nb-poor complexes such as Spitzkop (Coetzee, 1963), Darkainle (Gellatly, 1963), and Sangu (Coetzee, 1963), and very much greater than those of Dorowa and Shawa (Johnson, 1961).

Ba and Sr values similarly are comparable with those of many other carbonatites, notably Tundulu (Garson, 1962), Dorowa and Shawa, and Sangu (only Sr data available), but are much lower than those from high-level carbonatites, e.g., Oldoinyo Lengai (Bowden, 1962), and from the late-stage phases of Chilwa Island (Garson and Smith, 1958)).

La and Y contents are comparable with those from other carbonatites, e.g., Mbeya (Coetzee, 1963) and Darkainle, but differ from those of Tanganyika (Bowden), Chilwa Island, and Tundulu (i.e., moderately late-stage ones) which are appreciably higher in La; Tundulu, which is higher in Y; the Russian examples (Kapustin, 1966), which are lower in La; and the Tanganyika ones which are lower in Y. These exceptions are all from high-level, probably highly differentiated carbonatites.

The only detectable Nd and Pr values are comparable with those reported from Sangu, but higher than those found by Kapustin.

Comparison of these elements, particularly of Nb, Ba, and Sr, from the Strangways Range carbonatites with those from other localities suggests that the Strangways Range specimens represent members of a poorly differentiated carbonatite suite, and that a deep part of the original carbonatite body is exposed at the present ground surface.

PETROGENESIS

Carbonatites

The unusual petrographic and geochemical features of the Strangways Range carbonate rocks have been detailed in the previous sections. Many of these features cannot be explained adequately by the previously held theory that they are metamorphosed metasomatized sedimentary limestones, but can be readily explained if they are carbonatites. In particular the association in them of apatite, magnetite, ilmenite, and zircon, the ovate form of the apatite grains, the reversed pleochroism of the phlogopite, the associated albite-aegirine pegmatites, and the evidence of metasomatism of inclusions of basic rocks (see below), strongly suggest that these rocks are carbonatites. Average trace element abundances, especially the high Nb, La, Y, and to a lesser extent the moderately high Ba and Sr, exceed those normally found in carbonates of sedimentary origin, and are characteristic of carbonatites.

The absence of fenitisation (at least at the present level of erosion) is unusual, but fenitisation is lacking from other carbonatites, such as Darkainle, Somali Republic (Gellatly, 1963) and Songwe Scarp, Tanzania (Brown, 1964). However, the alkaline pegmatites of the Strangways Range carbonatite may possibly be rheomorphic fenite, as is suggested below.

The Strangways Range carbonatite contains abundant micaceous phases interlayered with relatively pure carbonate rocks. This feature is unusual in carbonatites. At present there is no direct field evidence concerning the origin of these micaceous carbonatites. However, comparison with other localities suggests that the biotite-rich carbonatites have possibly been formed by reaction of carbonatite magma with country rocks. Such reaction producing "glimmerite" (biotite rock or biotite-muscovite rock) has been noted at Darkainle, and biotite reaction rims of similar origin have been reported from the Mrima Hill carbonatite, Kenya (Coetzee and Edwards, 1959). This type of reaction, involving the formation of a potash-rich rock, is probably a later stage phenomenon than that (soda metasomatism) causing fenitisation. The separate occurrence of these two phenomena may be a result of the differing mobilities of the K^+ and Na^+ ions.

Basic Rocks

The origin of the basic igneous rocks is uncertain. They occur in close proximity to the carbonatite, but no genetic relationship has been established. The inclusions of basic rocks within the carbonatite could be metamorphosed equivalents of either basic intrusives or of impure calcareous sediments.

There is strong evidence of metasomatism of these basic inclusions by emanations from the carbonatite. The principal features indicative of metasomatism are the anomalous birefringence and high extinction angle of the hornblende (suggests similarities to hastingsite) the probable acmitic nature of the pyroxene, and the occurrence in one specimen of interstitial aggregates of calcite, dolomite, magnetite, and apatite, i.e., of the principal minerals of the carbonatites.

Alkaline Pegmatites

Although the alkaline pegmatites cut the carbonatite and could be much later than it, they are here considered because of their distinctive mineralogical composition, to be genetically related to the carbonatite, and are probably closely related to it in time.

Most carbonatites are associated with undersaturated magmatic rocks. Derivation from these of an acid magma by fractional crystallization is precluded by the high temperature ridge along the Ab-Or line in the system SiO_2-$NaAlSiO_4$ - $KAlSiO_4$-H_2O. It is thus suggested that the alkaline pegmatite may represent intrusions of rheomorphic fenite. Compositionally similar (albite-microcline-quartz-aegirine) intrusions of rheomorphic fenite have been described from Darkainle (Gellatly, 1963), where they are mineralogically and chemically identical to in situ fenites. Possible rheomorphic fenites have also been reported from Dorowa (Johnson, 1961).

The absence of alkaline rocks other than these alkaline pegmatites from the area is unusual, but the surrounding area has not yet been mapped. Detailed mapping of the area should be undertaken.

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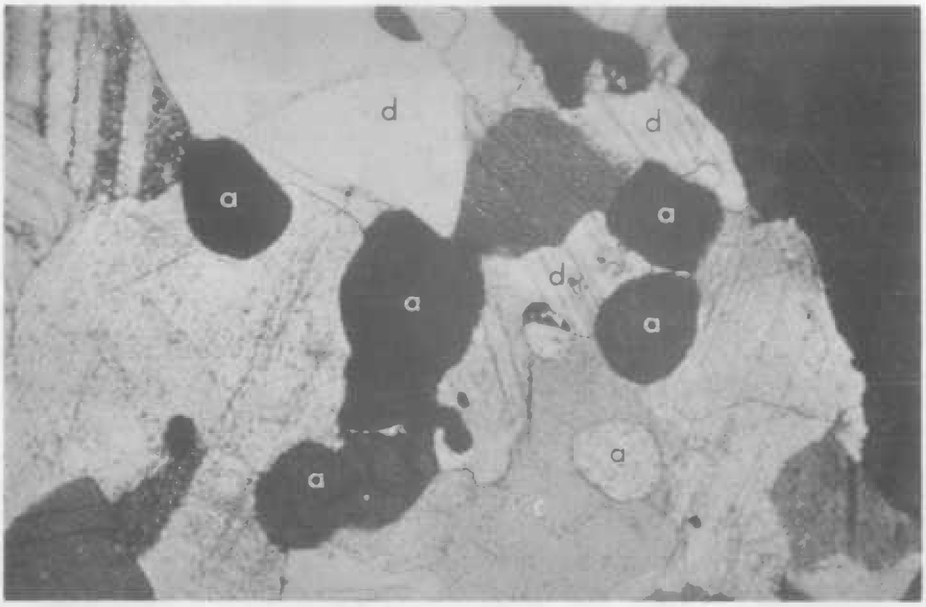
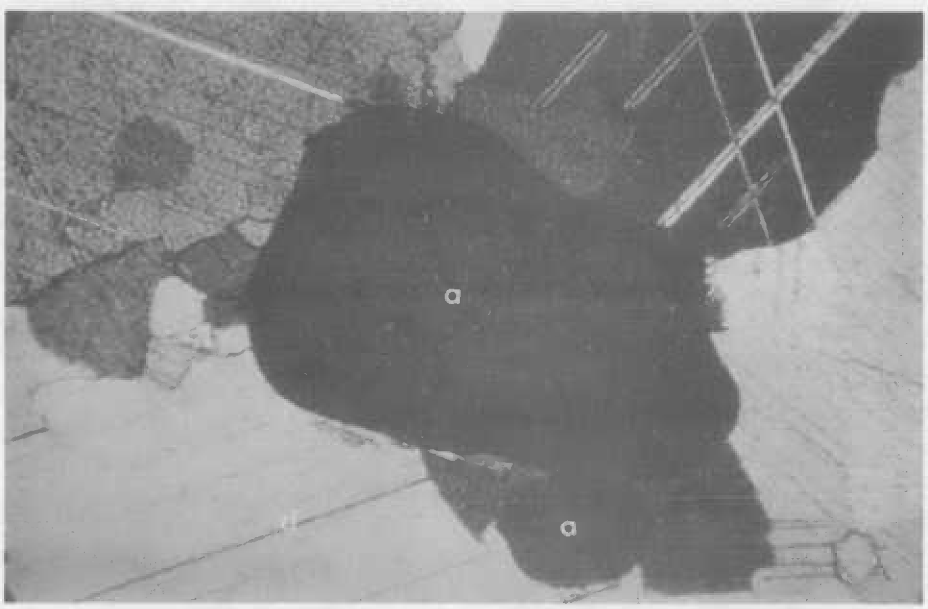
PLATES

Numbers of specimens illustrated in plates 1-6 have been changed as follows: M - 0514; N - 0515, O - 0516; P - 0517; Q - 0513.

PLATE 1.



(a) Apatite, showing rounded crystal forms, in clear dolomite (d) and turbid calcite (c). Specimen P. Crossed polarizers. X48.



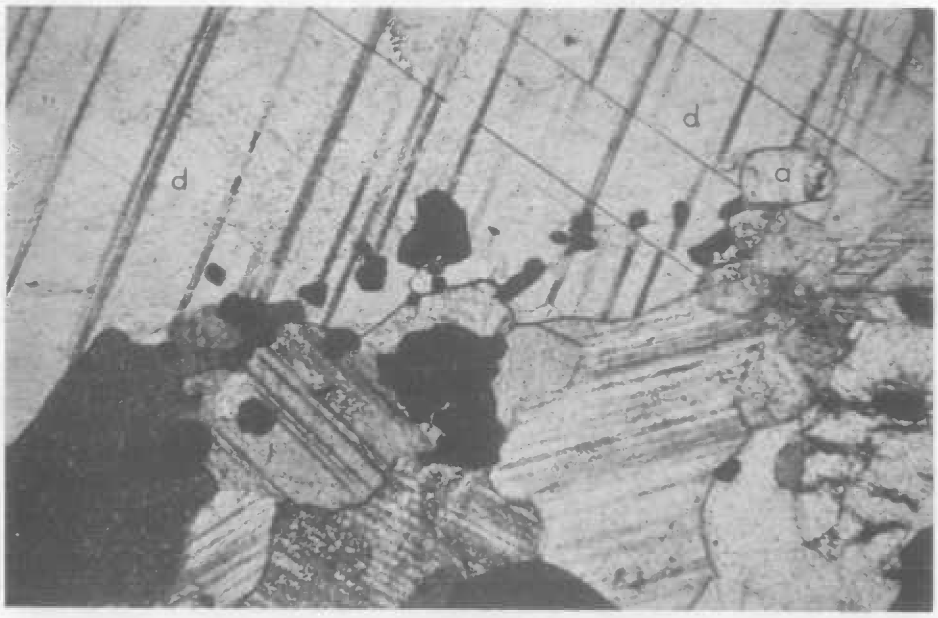
(b) Rounded apatite, clear dolomite (d) and clear calcite (c) in carbonatite. Specimen P. Crossed polarizers. X48.

PLATE 2.

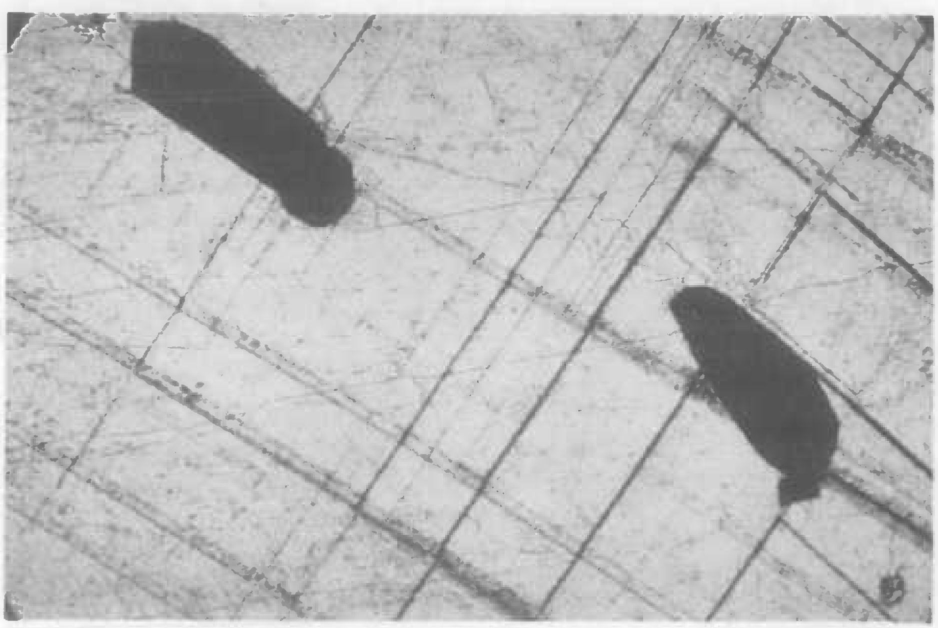
(a) Turbid ?exsolution spindles of calcite in dolomite.
Specimen P. Plane polarized light. X140.

(b) Spindle of calcite (due to exsolution?) in dolomite.
Specimen N. Plane polarized light. X140.

PLATE 3.

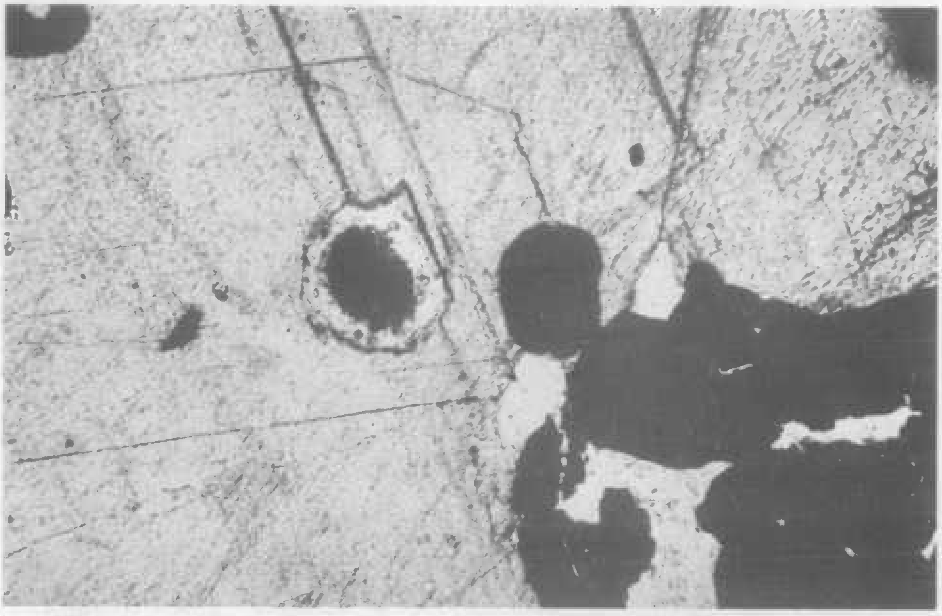


(a) Small inclusions of ilmenite near margin of dolomite (d).
Specimen P. Crossed polarizers. X48.

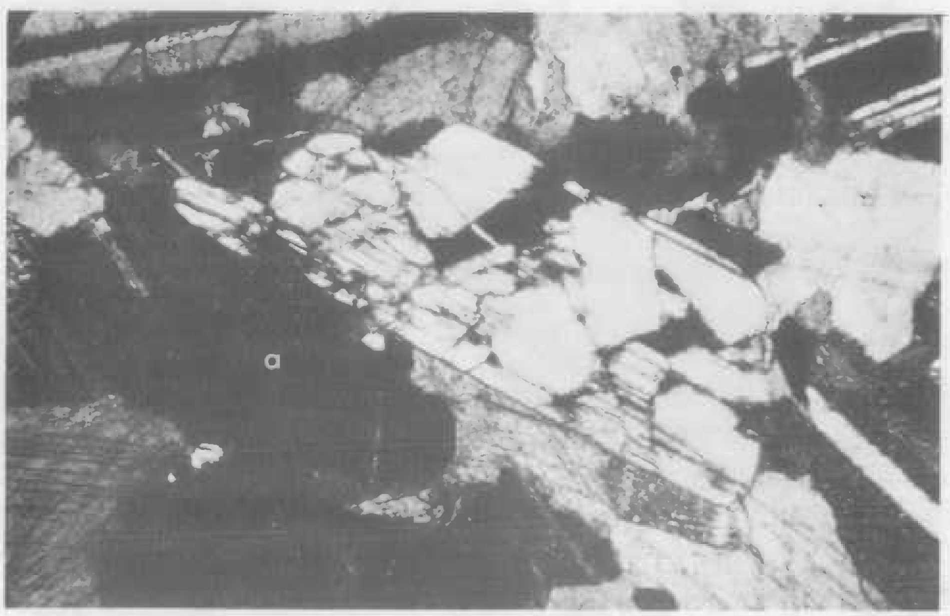


(b) Elongate crystals of ?ilmenite in dolomite.
Specimen M. Crossed polarizers. X48.

PLATE 4.



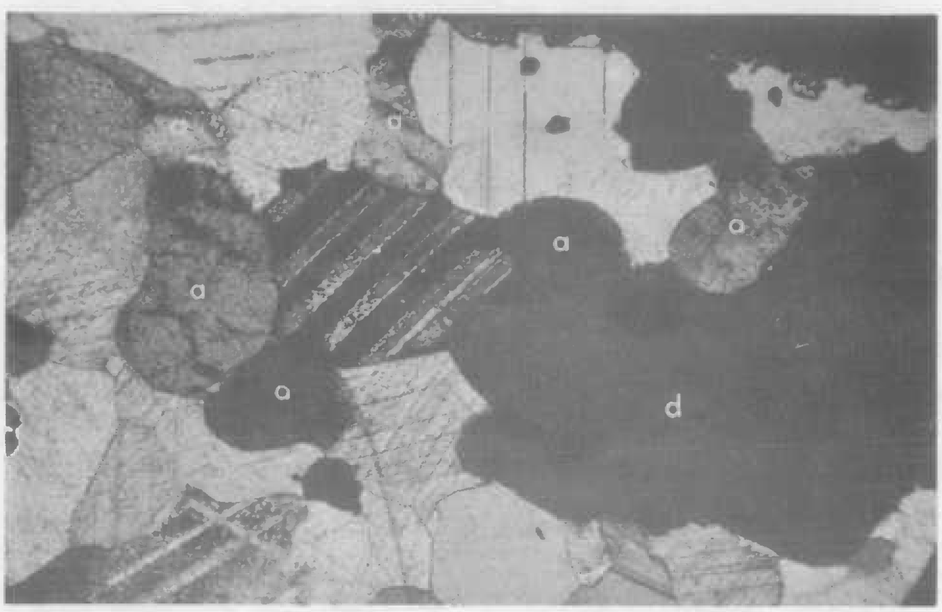
(a) Turbid microcrystalline aggregate of ?columbite (centre) pseudomorphing ? pyrochlore in calcite host. Specimen Q. Plane polarized light. X140.



(b) Elongate euhedral prismatic crystal of amphibole associated with calcite, dolomite and apatite. Specimen M. Crossed polarizers. X48.

PLATE 5.

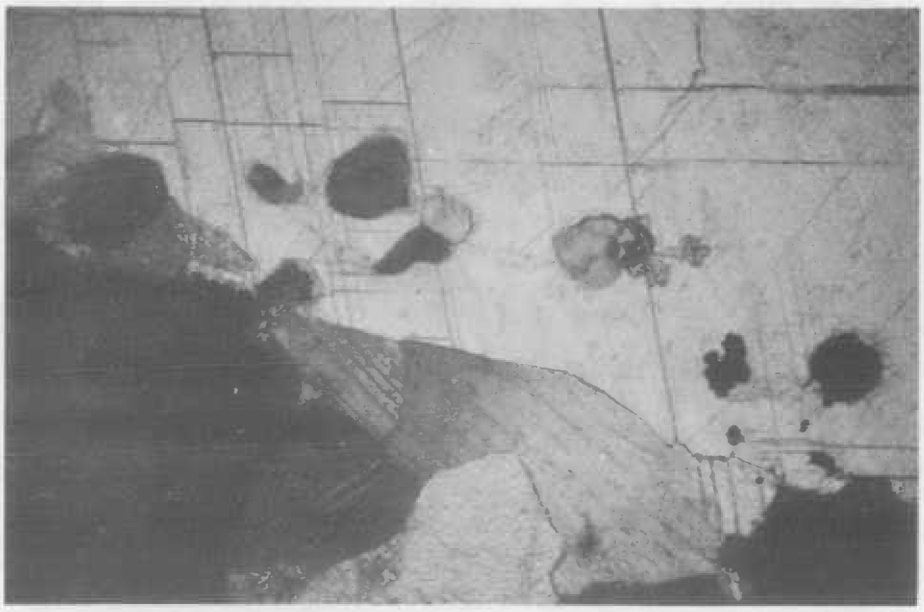
(a) Granular aggregate of apatite with minor interstitial carbonate (centre) and thin fracture veinlets of quartz. Specimen O. Crossed polarizers. X48.



(b) Clear dolomite and turbid calcite, with sub-rounded apatites, and small ilmenites. Specimen P. Crossed polarizers. X48.

PLATE 6.

(a) Clear dolomite and contrasting interstitial turbid calcite. Specimen M. Plane polarized light. X48.



(b) Small inclusions of apatite concentrated near margin of dolomite phenocryst. SpecimenP. Crossed polarizers. X48.

APPENDIX

PETROGRAPHY.

COUNTRY ROCKS

Sillimanite-garnet-biotite-sericite-quartz schist. R68.07.0519.

Locality: 200 yards south of Enterprise 5 Prospect.

Hand specimen: A grey-brown, fissile, banded, semi-pelitic muscovite-biotite schist.

Thin section: A partly retrogressed high-grade schist consisting of quartz, sericite, biotite, K-feldspar, sillimanite, garnet, and minor oligoclase, muscovite, chlorite, and magnetite.

Sillimanite is seen as equant anhedral oblique sections surrounded by sericite which appears to be replacing it. Garnet is altered along fractures to biotite and a chlorite which is at least partly penninite. Movement accompanying falling metamorphic temperatures has resulted in streaking out of garnet remnants into trains of fragments. Small patches of penninite studded with granules of magnetite probably represent completely altered garnet; quartz, which constitutes about 50% of the rock, occurs as small (0.2mm) anhedral highly sutured grains. Feldspar is mostly turbid streaky microcline; lesser amounts of turbid oligoclase are also present. Muscovite has developed locally from sericite. A few small rounded zircon grains present have not been refacetted despite the high grade of metamorphism.

Quartz-muscovite schist. R68.07.0520.

Locality: ¼ mile south of Enterprise 4 Prospect.

Hand specimen: A fine grained, fissile, grey-brown, semi-pelitic muscovite schist.

Thin section: Consists of muscovite (45%), quartz (50%), and minor amounts of biotite, magnetite, rutile, and zircon. The rock has a strong cleavage outlined by parallel flakes of muscovite and of lenticular quartz grains; the cleavage cuts across a strongly folded lamination (?bedding) resulting from alternating laminae of quartz and muscovite. The average grain-size is about 0.1mm.

Quartz grains are small, lenticular, and intensely strained; they have sutured margins, and show pronounced preferred orientation. Muscovite flakes are up to 0.5mm long, and mostly lie parallel to the cleavage. Locally they are oblique to it and form a chevron pattern. Rare yellow-brown biotite is closely associated with muscovite. Scattered euhedral (0.5mm) magnetite porphyroblasts cut across the muscovite cleavage.

Porphyroblastic quartz-biotite-feldspar phyllonite. R86.07.0521

Locality: ½ mile south of Enterprise 4 Prospect.

Hand specimen: A fine-grained dark grey-brown micaceous rock with prominent ovoids of feldspar up to 6mm.

Thin section: Scattered porphyroblasts of microcline and oligoclase are set in a fine-grained (a.g.d.=0.04mm) schistose matrix of quartz (60%), biotite (25%), muscovite (5%), and minor microcline, oligoclase, apatite, rutile, magnetite, zircon, and an unidentified pale red-brown microcrystalline mineral (altered ?allanite).

Porphyroblasts are rounded or ovate, and range from 0.5mm to 6mm. K-feldspar grains, some of which show typical microcline cross hatching, contain small inclusions of quartz and plagioclase. Less abundant oligoclase grains have small inclusions of K-feldspar, and have X'c=5°. Quartz forms small equant grains with simple margins. Biotite is a greenish-brown variety. Muscovite is mainly associated with a thin veinlet, and is probably a late mineral in the present paragenesis. Small grains of ?rutile oriented parallel to the cleavage are abundant throughout the rock. Apatite occurs as scattered crystals grains also parallel to the cleavage. Narrow borders of clinozoisite rim the pale red-brown material which is possibly metamict allanite.

Porphyroblastic garnet-biotite quartz aligoclase phyllonite. R68.07.0522.

Locality: Immediately south of Enterprise 4 Prospect.

Hand specimen: An extremely fine-grained dark grey rock of mylonitic appearance containing prominent grains of garnet up to 3mm, and scattered phenocrysts of feldspar up to 5 mm.

Thin section: Porphyroblasts of garnet, oligoclase, and microcline are set in a very fine-grained matrix of quartz and biotite; and minor oligoclase, K-feldspar, rutile and zircon.

Garnet porphyroblasts (up to 2mm) are mostly anhedral and strongly fractured. Some are elongated in the cleavage direction; others are fractured and disrupted. They contain inclusions of biotite, and biotite commonly fills fractures. Oligoclase porphyroblasts range from 0.5mm up to 4mm. Composition is about An_{25}. Larger porphyroblasts consist of a large grain bordered by several smaller subgrains. Smaller porphyroblasts have apparently been derived by fracturing and disruption of the larger ones, and are in fact porphyroclasts. Large (up to 5mm) microcline porphyroblasts have been partly polygonised, and scattered smaller microcline grains (ca.0.5mm) may be the result of disruption of larger grains.

The matrix consists mainly of anhedral sutured 0.05mm quartz grains showing good preferred optical orientation; minute flakes of yellow-brown to grey-brown biotite are subordinate. Sinuous trains of biotite indicate that appreciable shearing movement has taken place after the development of the porphyroblasts.

Porphyroclastic mylonite. R68.07.0523.

Locality: Immediately southwest of Enterprise 4 Prospect.

Hand specimen: A dark grey very fine-grained streaky mylonitic rock containing abundant small porphyroclasts (up to 3mm) of feldspar.

Thin section: A very fine-grained, finely handed quartz-biotite mylonite containing abundant 0.25 to 1mm porphyroclasts of andesine and microcline.

The porphyroclasts are anhedral and mostly subrounded. Porphyroclasts of each mineral tend to occur in trains suggesting that several of them have been derived through breakdown of a single porphyroblast. Quartz occurs as minute sutured grains in well defined bands separated by thin bands of biotite. Quartz shows extremely good preferred optical orientation. Biotite is yellow-brown to grey brown, and forms minute flakes concentrated into thin films and bands. Zircon occurring as small rounded grains and finely granulated iron oxide, are rare accessory consitutents.

Garnet-muscovite-microcline-oligoclase quartz blastophyllonite.

R68.07.0524.

Locality: Immediately south of Enterprise 4 Prospect.

Hand specimen: Contains pale cream quartz-feldspar augen in a fine grained pale grey phyllitic matrix.

Thin section: Contains porphyroblasts of microcline and oligoclase each ca. 10%) up to 3mm in a fine-grained matrix (a.g.d.= 0.05mm) of quartz (50%), muscovite (15%), microcline (5%), oligoclase (5%) and minor accessory garnet, epidote, magnetite, and pale brown altered ?allanite.

Microcline porphyroblasts tend to be lensoid and composite due to granulation around the margins. Andesine (ca. An_{35}) porphyroblasts are also composite, and are mostly sericitised. Quartz in the matrix surrounding the porphyroblasts is highly deformed: grains appear elongate in thin section, have sutured margins, and show marked dimensional and lattice orientation that curves around each porphyroblast. Muscovite occurs as small scattered flakes and bands which show moderately good preferred orientation. Scattered granules and small aggregates of epdiote have possibly developed through alteration of matrix plagioclase. A single grain of garnet is undeformed and unaltered. Biotite forms rare small greenish brown flakes associated with muscovite in the matrix.

Muscovite-quartz schist: R68.07.0525.

Locality: Immediately south of Enterprise 4 Prospect.

Hand specimen: A pale cream and pale grey medium to coarse-grained muscovite-bearing quartz schist.

Thin section: Consists of quartz (75%), and muscovite (25%), and traces of goethite.

Quartz forms anhedral intensely strained grains (0.5 to 1mm) which locally have sutured margins. They show good preferred optical orientation, and tend to be slightly elongate or flattened normal to the c-axis. Muscovite occurs as small (0.3mm) flakes showing moderately well developed parallel orientation, and concentrated into lensoid patches.

Garnet-biotite-muscovite-oligoclase-microcline-quartz-gneiss:

R68.07.0526.

Locality: Immediately south of Enterprise 2 Prospect.

Hand specimen: A medium to coarse grained pale cream rock with irregular pale grey laminae of fine-grained mica.

Thin section: Has prophyroblasts (5%) of K-feldspar up to 4 mm in a matrix (a.g.d.=0.4mm), consisting of quartz (50%), micorcline (25%), oligoclase (5%), muscovite (10%), accessory biotite, relict fragments of garnet partly altered to a chlorite, and rare small zircon grains.

Quartz forms a sutured aggregate forming monomineralic subparallel bands, and locally shows good preferred dimensional orientation. Microcline occurs as ovoid grains, some showing well-developed cross-hatching; others show streaky banding, or no sign of twinning at all, and are identifiable only on account of their minute inclusions of plagioclase. Oligoclase is sparse and rarely twinned. Twinned crystals have X' c=10°, and are optically negative; composition is An_{25}. Muscovite forms small augen and thin sinuous bands, and has associated with it minor amounts of yellow-brown to red-brown biotite.

Quartz-cordierite-biotite-blastomylonite. R68.07.0527.

Locality: Immediately northwest of Enterprise 2 Prospect. Contact rock from margin of carbonatite.

Hand specimen: A fine-grained, finely banded pale brown siliceous rock with small scattered feldspar porphyroblasts.

Thin section: Consists of a fine-grained (0.1mm) aggregate of quartz (65%), orthoclase (15%), partly chloritised biotite (15%), with associated limonite staining (15%), small rare grains of goethite (less than 1%) and scattered 0.5 to 1 mm porphyroblasts of cordierite.

Quartz grains are strained, have sutured margins locally, and are elongate in the direction of the foliation. They show good dimensional and lattice orientation. Cordierite porphyroblasts $2V = 50-60^\circ$ are subhexagonal to subrounded with $2V_x \doteq 50 - 60^\circ$. Biotite, pleochroic from pale yellow brown to red-brown, occurs as small flakes and in fine-grained aggregates associated with a pale-brown, turbid, fibro-lamellar, length-slow. poorly birefringent ?chlorite.

The rock is essentially a mylonite, despite its relatively coarse (0.1mm) grain size. The extremely good preferred orientation of quartz suggests that the fabric is the result of strong shearing; the grain-size indicates that the temperature of deformation has been sufficiently high to permit simultaneous recrystallisation.

Hornblende-hypersthene gabbro: R68.07.0518.

Locality: 200 yards south of track to Southern Cross Bore.

Hand specimen: A coarse-grained basic rock containing pale greasy-brown feldspars.

Thin section: A coarse-grained hypidiomorphic mesocratic rock consisting of plagioclase (40%), augite (25%), hornblende (20%), and minor accessory magnetite, and traces of apatite and quartz.

Plagioclase occurs as anhedral equidimensional grains showing well-developed albite twinning and slight zoning; composition is around An_{65}. The dominant pyroxene is a pale green augite containing small amounts of (?exsolved) black opaque grains. Hypersthene is strongly pleochroic from pale green to pale pink, and lacks exsolved opaque inclusions. Hornblende has $Z'c = 17^\circ$, and is pleochroic from very pale green-brown to olive-green. A pale blue-green (actinolitic?) amphibole commonly forms a narrow reaction-rim round hypersthene grains, but most of the amphibole present appears to be primary. Magnetite occurs as small equant grains generally associated with hornblende, and is probably a late mineral.

Plagioclase-diopside "amphibolite". R68.07.0529.

Locality: Southern part of Enterprise 2 Prospect.

Hand specimen: A coarse grained massive, amphibole-rich rock.

Thin section: A coarse-grained xenomorphic-granular rock consisting of amphibole (70%), interstitial/symplectics (25%) of plagioclase and diopside, and minor accessory apatite, sphene, biotite, and geothite.

Amphibole forms irregular anhedral grains measuring up to 1 cm; $Z'c \doteq 34^\circ$, Y=b, and $2V_X \doteq 75^\circ$. Pleochroism is X-pale yellow-brown, Y-dark grey-green, Z-blue green. Birefringence is slightly anomalous in certain ac sections where a purple brown tint replaces extinction. Anomalous birefringence is extreme in localized transverse bands which have a more bluish Z absorption, and a change from anomalous blue to anomalous orange birefringence taking place at $Z'c = 42^\circ$. Diopside is interstitial to the amphibole, and is intimately intergrown with plagioclase which also forms a thin border between it and amphibole. It is pale green, has faint pleochroism, $Z'c = 68^\circ$, $2V_Z \approx 60 - 70^\circ$, and $\mu = .030$. These properties suggest an intermediate member of the diopside-hedenbergite-acmite systems. Plagioclase has $X'c = 3^\circ$, and $2V_Z$ near 90°. Composition is thus about An_{15}. Apatite grains are ovate, and up to 0.5mm across. Discrete grains of goethite up to 1 mm probably pseudomorph original pyrite.

Calcite-bearing hastingsite?"amphibolite" - (Calcite-hastingsite?-"meladiorite") R68.07.0530.

Locality: Peko DDH2 343 feet, Enterprise 3 Prospect.

Hand specimen: A coarsely crystalline hornblende-rich, carbonate-bearing rock.

Thin section: A coarse-grained rock with a xenomorphic-granular texture consisting of amphibole (65%), calcite (15%), plagioclase (6%), pyrite (5%), biotite (5%), apatite (3%) dolomite (1%), magnetite (1%), and a trace of quartz and zircon.

Amphibole occurs as large (5mm) poikilitic anhedral crystals containing rounded and irregular inclusions of calcite, plagioclase, and biotite, and rare magnetite. It is similar in its properties to that described from 0529, especially pleochroism and extinction angle ($Z'c = 42^\circ$), but differs in having slightly stronger anomalous birefringence. It has affinities to hastingsite but differs in having lower-birefringence (ca.010) and higher extinction. Plagioclase occurs as irregular grains up to 1mm, and as slightly smaller inclusions in amphibole. It has $X'c = 16^\circ$, $2V_X \doteq 70^\circ$, and composition therefore around An_{34}. It is perfectly fresh, and commonly untwinned. Calcite forms irregular 1mm grains occupying interstices between amphibole grains. With it are associated ovate apatite grains, anhedral and rare euhedral pyrite, and small grains of dolomite and magnetite. Biotite occurring as scattered flakes throughout the rock and as inclusions in the amphibole, is pleochroic in various tones of yellow-brown. Quartz forms rare anhedral grains up to 0.5mm distinguishable from untwinned plagioclase only by its interference figure.

Albite-aegirine pegmatites. R68.07.0528.

Locality: Northwest portion of Enterprise 2 Prospect.

Hand specimen: Pale creamy-pink very coarse-grained feldspar with scattered elongate dark green pyroxene.

Thin sections (a): Consists mainly of a single large crystals of albite containing small irregular blebs of microcline showing undulose extinction, and small elongate aegirine grains. Smaller peripheral grains of albite, with X'c=15°, have no exsolved K-feldspar. Minute grains of probable quartz occur in association with the aegirine inclusions. Interstitial aegirine is pleochroic from X=emerald green to Z=pale leaf green, has X'c=7°. Rare grains of apatite and a sodic amphibole are also present.

(b): In addition to the minerals above this thin section contains sodic amphibole, apatite, rare identifiable quartz and an unidentified mineral.

Albite in this thin section has X'c=16° (An_{10}); thin albite twin lamellae characterize the larger (up to 12mm) irregularly shaped grains whereas smaller ones with sub-rounded or simple polygonal outlines have broad albite twin lamellae, Carlsbad twins, or are untwinned. The smaller albite grains form inclusions in aegirine and in the large albite anhedra, and represent the earlier feldspar phase. A sodic amphibole (similar to arfvedsonite) occurs as intimate symplectic intergrowths with aegirine, which is the dominant phase. The amphibole has Z'c=40-42° (Na light) and Y=b; birefringence (μ =.003) is anomalous: a colour change from blue to orange replaces extinction. Extinction is almost complete in Na Light. Pleochroism is X=very pale brown, Y=indigo, Z=blue green. Also present are spherical aggregates of unidentified microcrystalline material similar to the (?) columbite (or ?fersnite) after pyrochlore noted in specimen 0513.

CARBONATITES

Dolomitic sövite (calcite-dolomite rock): R67.07.0514.

Locality: DDH 2 Enterprise 3 Prospect.

Thin section: A coarsely crystalline rock consisting essentially of 1.5mm dolomite phenocrysts (40%) set in a calcite matrix (55%)m along with minor accessory magnetite (2%), apatite (2%), and rare amphibole chlorite, phlogopite and pyrite.

Dolomite forms large anhedral grains containing rare inclusions of magnetite (euhedral to sausage-shaped) and calcite. Magnetite inclusions tend to be located peripherally. Anhedral 0.5 to 2.mm calcite grains, very pale grey-brown and slightly turbid, form the matrix. Minor accessories: Magnetite (0.1 to 0.5mm): Pyrite occurs interstitially between calcite grains; ovate apatite (up to 2mm) are mostly enclosed in calcite, but a few small grains occur in the marginal areas of dolomites: two grains (up to 2.5mm) of a pale green amphibole has X=colourless, Y=very pale grey-green, Z pale blue green, $2V_x \doteq 60$, $n_z - n_x$=020, Z'c=30°, and Y=b (partly from slide 0513. Associated with the amphibole are small patches of pale green chlorite, which has apparently formed through alteration of phlogopite of which two relict flakes with reversed pleochroism have been noted. In addition there are rare 0.02mm colourless equant grains with high R.I. and birefringence occurring as inclusions in calcite; these are too small to permit identifications.

Dolomitic magnetite söv̈ite (calcite-dolomite-magnetite rock)
R67.07.0515.

Thin section:
Consists essentially of coarsely crystalline dolomite (35%), and calcite)55-60%), and minor accessory magnetite (5%), apatite (2%), and very rare chlorite and amphibole.

Dolomite forms 1.5% scattered irregular ovate phenocrysts containing rare inclusions of calcite (elongate) and marginal equant ones of magnetite. Calcite forms a closely interlocking aggregate of 0.5 t 2mm slightly turbid very pale grey-brown grains; apatite and magnetite are assocuated with it. Apatite forms ovate to subrounded grains up to 3mm long. Magnetite occurs mainly as euhedral or subhedral grains up to 1 mm across; part of a large crystal (over 1 cm) is also present in one corner of the slide. Traces of a strongly pleochroic (X=very pale yellow-green, Y near Z=leaf green) chlorite with a perfect basal cleavage, and a very small grain of a pale green amphibole (as in 0514 above) are also present.

Calcite-apatite-beforsite (apatite-dolomite-calcite rock).R67.07.0516.

Locality: DDH 2. Enterprise 3 Prospect.

Thin section: This is a coarsely crystalline rock consisting almost entirely of apatite (65%), dolomite (25%), calcite (10%), and minor accessory magnetite.

Apatite occurs mainly as a massive aggregate of anhedral grains ranging from 9mm to 0.2mm, and also as scattered subrounded grains (0.2 to 2mm) surrounded by carbonates. The apatite grains are heavily fractured and contain thin veinlets of quartz. Small intergranular patches of carbonate within the apatite aggregate contain scattered patches and specks of orange-brown goethite. The carbonate phase consists of clear dolomite surrounded by interstitial very pale grey-brown calcite with which are associated with scattered grains of magnetite and apatite. Locally, these three minerals form veinlets between the dolomite grains. The dolomite grains contain scattered inclusions of calcite and magnetite; these inclusions occur only near dolomite grain boundaries. The calcite locally contains feathery streaks of goethite around magnetite grains.

Calcite-apatite beforsite (Apatite-bearing dolomite-calcite rock)
R67.07.0157.

Locality: DDH 2. Enterprise 3 Prospect.

Thin section: A coarsely crystalline carbonate rock consisting essentially of dolomite (65%) and calcite (30%), and minor accessory apatite (3%), magnetite ($\frac{1}{4}$%), and phlogopite (traces).

Dolomite occurs as large anhedral grains up to 1.5 cm across. The grains have ragged boundaries, and are marginally intergrown with calcite or with other dolomite grains. Rare blebs of calcite in dolomite suggest possible exsolution. Calcite fills interstices between dolomite anhedra, and forms very pale grey-brown rather turbid anhedral grains (0.5 to 2mm); it tends to be more turbid (due to minute inclusions, close to dolomite grain boundaries. Inclusions of calcite in dolomite are particularly turbid. Apatite forms ovate grains from 0.15 to 2.5mm. Grains are fractured, and contain very thin veinlets of a more birefringent mineral (μ = ca. 0.018). Apatite is generally associated with the interstitial calcite, as is magnetite. Magnetite occurs as euhedral to anhedral grains and aggregates up to 1cm. It is almost invariably enclosed in calcite, but a few grains occur in the marginal areas of the dolomite grains. Phlogopite, present as rare thick tabular grains pleochroic from very pale yellow-brown to bright foxy-red-brown, is the only other mineral present.

Calcitic beforsite (Dolomite-calcite rock) R67.07.0513.

Locality: DDH 2. Enterprise 3 Prospect.

Thin section: A slightly more impure rock than the other carbonatites described. Contains dolomite (55%), and calcite (40%), and accessory magnetite, apatite, amphibole, phlogopite, chlorite, and possible columbite after pyrochlore.

As in other specimend dolomite forms large (up to 1.5mm) anhedral grains separated by finer grained intergranular calcite. The dolomite grains contain scattered inclusions, mostly marginal, of calcite magnetite, apatite, and phlogopite. Some grains contain thin secondary fracture-fill veinlets of calcite. Calcite occurs as anhedral interlocking (locally ragged) grains from 0.5 to 2mm. It is very pale grey-brown and slightly turbid, and is thus distinguishable from dolomite which is clear and colourless. Apatite (1-2%) occurs as ovate or irregular anhedral grains (0.25 to 1mm). Magnetite forms scattered small 0.1mm euhedral to large (5mm) anhedral grains; the larger ones are fractured and intergrown with, and locally replaced by, calcite. A pale green amphibole (as in slide 0815) occurs as 1 to 2mm grains partly replaced by calcite. It has $Z \wedge c \doteqdot 30^\circ$ and $2V \doteqdot 60^\circ$ (from interference figure). Chlorite is strongly pleochroic in various shades of green. Prominent (001) cleavage is length-slow. $2V = 10^\circ$; grains are tabular and up to 1mm. Rare small foxy red-brown pleochroic grains of phlogopite have maximum absorption normal to (001) and are partly replaced by the chlorite which has maximum absorption parallel to (001). Rare 0.2mm globules of very pale grey-brown slightly turbid microcrystalline disoriented material are possibly pseudomorphs of columbite (or?fersmite) after pyrochlore; They are surrounded by borders which have been plucked from the slide during grinding. The outlines of these borders are locally square or rhombic, suggesting the presence of an original mineral with cubic crystal symmetry. The globules themselves contain small specks of a black opaque mineral.

Biotite-sövite: Calcite-biotite (Calcite-biotite rock) R68.07.0534.

Locality: Enterprise 3, DDH 2, 495 feet.

Hand specimen: A coarse-grained crystalline rock consisting principally of biotite and colourless carbonate in approximately equal amounts.

Thin Section: A coarse-grained rock consisting of biotite (50%), calcite (45%), apatite (3%), magnetite (2%), and traces of dolomite, pyrite, chalcopyrite, and ?sphene.

Biotite flakes are mostly 0.5 to 2mm long, and arranged in lenticles and irregular bands interspersed with irregular bands of calcite. Biotite shows good parallel orientation, and has X=pale ginger, Y=pale foxy red-brown, Z=green-brown. It is interlayered with, and marginally altered to, minor amounts of green biotite. Calcite forms anhedral grains 1 to 4mm across that commonly contain dust-sized inclusions. Small euhedral of dolomite occur both interstitially between calcite grains and as small rhombs in calcite cores. Anhedral and irregular to ovate apatite green are scattered throughout both biotite and calcite; one apatite is cored by a small grain of pale brown ?amphibole. Subhedral to anhedral magnetite (up to 2mm.) is associated mainly with biotite. Pyrite occurs partly as discrete grains, and partly infills calcite cleavages and follows biotite boundaries. Pyrite granules are commonly associated with grains of chalcopyrite.

Biotite Sövite. R68.07.0535.

Locality: DDH 2, Enterprise 3 Prospect.

Hand specimen: A coarsely crystalline white carbonate rock containing scattered flakes of biotite and lenticles up to 5mm thick and more than 4cm across consisting almost entirely of biotite.

Thin section: Consists essentially of a granular aggregate of 1 to 3mm calcite grains, scattered small (0.5 to 1mm) dolomite grains (5%), biotite (5%), rare ovate grains of apatite (1%), small euhedra of magnetite, and traces of pyrite developed locally along calcite cleavages.

Biotite is unusual in that it consists locally of interlayered red-brown and olive green varieties. The red-brown variety, which is the primary one, is pleochroic from X= Y=pale foxy red-brown to Z=green-brown. The green variety, which has developed from the brown, and which characteristically occurs as deformed flakes or in deformed marginal areas of the red-brown flakes, is pleochroic from X= Y=pale-buff to Z= dark grey-green.

Weathered magnetite-bearing Carbonate rock. R68.07.0531.

Locality: Enterprise 2 Prospect.

Hand specimen: A rusty brown fine-grained carbonate rock with thin magnetite-rich bands.

Thin section: An almost completely altered rock. Little remains of the original mineralogy. Consists chiefly of fine-grained carbonate (65%), alternating with bands of magnetite and minor goethite (15%), bordered by limonite (15%), scattered patches of ?collophane, traces of muscovite, zircon, and globules of microcrystalline aggregates of ?columbite or ?fersmite (as in 0514 and 0533).

Carbonates are mostly microcrystalline or colloform in texture, and contain irregular films of limonite. Staining tests suggest that most of the carbonate is dolomite or siderite; calcite is present apparently only in minor amounts. Magnetite grains are up to 5mm across, but most are fractured, and some have been broken down into patches of angular fragments with a secondary carbonate matrix. Scattered grains of goethite associated with the magnetite may possibly be altered pyrite. Anhedral 1 to 2 mm patches of pale yellow-brown isotropic material are tentatively identified as collophane, thought to have been derived through weathering of apatite.

Weathered calcitic carbonate. R68.07.0532

Locality: Enterprise 2 Prospect.

Hand specimen: A rust-brown fine-grained nodular carbonate rock.

Thin section: Consists of patches of coarsely crystalline calcite with associated apatite, biotite, a pale green amphibole, and goethite, in a matrix of very fine-grained rusty limonitic calcite containing small angular fragments of quartz, biotite, apatite, microcline, plagioclase; a pale green amphibole (similar to that in the carbonatite) a dark green amphibole (similar to that from basic intrusives in the carbonatite), muscovite, garnet and magnetite. The matrix immediately surrounding the carbonatite remnants is very fine-grained and mostly free from crystal fragments.

The calcite of the carbonatite remnants contain limonite films along cleavages and fractures. In addition one crystal has associated with it vermicular intergrowths of pale orange brown limonite or limonitic carbonate. Biotite appears slightly altered, and is pleochroic from pale yellow-brown to orange-brown. Apatite grains are ovate . Grains of very dark red-brown goethite probably pseudomorph original magnetite. Amphibole similar to that in specimen 0514, is pleochroic from very pale grey-green to pale green, has $X'c = 30^{o}$, and has anomalous birefringence with a change from deep blue to orange taking place at extinction. It differs in orientation from that in 0514 in being elongate in the X direction rather than the Z. The rock is probably a calcrete containing material derived from weathering of the country rocks as well as from the carbonatite.

Weathered dolomitic apatite sövite: R68.07.0533,

Locality: Enterprise 2 Prospect.

Hand specimen: A rust-brown coarsely crystalline carbonate rock with large grains of apatite prominent on the weathered surface.

Thin section: Consists mainly of calcite (50%), dolomite (40%), apatite (10%), and minor quartz, altered biotite, and possible pyrochlore pseudomorphs. All minerals except apatite contain secondary limonite as cleavage and fracture-fill veinlets and as fine mossy growths.

Both calcite and dolomite form large grains several millimeters across. They are distinguishable only by staining with alizarin red, although a few small areas of clear, limonite-free carbonate are consistently of dolomite. Apatite is mostly subspherical or ovate, and measures up to 8mm. Small patches (up to 1mm) of orange brown chlorite possibly pseudomorph biotite. Veinlets of quartz with scattered swellings and druses up to 2mm cut the rock.

Scattered 0.1 to 0.5mm globules of microcrystalline, high relief, poorly birefringent, very pale grey-brown material (similar to that in 0513) are present in calcite.