POST-APTIAN CAMPTONITE DYKES IN SOUTH-EAST ALEXANDER ISLAND

By R. R. HORNE *and* M. R. A. THOMSON

ABSTRACT. Five lamprophyre dykes, intruding the Aptian sediments of the central east coast of Alexander Island, are described for the first time. On the basis of their content of titaniferous hornblende (kaersutite), titanaugite and plagioclase, they are classified as camptonites. By analogy with comparable dyke suites in other parts of the world, and on the basis of their regional igneous association with a circum-Pacific Tertiary to Recent basaltic province, they are believed to be late-stage differentiates of an olivine-basalt parental magma. Their intrusion post-dates the major regional deformation of the Aptian sediments and, in view of their proposed association, they are probably late Tertiary in age.

FIVE camptonite dykes intrude the gently dipping Aptian sedimentary rocks in the cliffs between Uranus and Neptune Glaciers on the east coast of Alexander Island (Fig. 1; Table I).

TABLE I. CAMPTONITE DYKES OF SOUTH-EAST ALEXANDER ISLAND

Dyke	*Rock type*	*Width* (m.)	*Trend* (true)	*Remarks*
Waitabit Cliffs; station KG.68 (north dyke)	Olivine-camptonite	0·8	078°	Cut by shear zone
Waitabit Cliffs; stations KG.68, 103 (south dyke)	Olivine-camptonite	2·3	054°	? Multiple intrusion
Station KG.71	Camptonite	0·8	105°	Not sampled
Station KG.70 (west dyke)	Olivine-camptonite	7·0	040°	—
Station KG.70 (east dyke)	Camptonite	1·5	065°	Not sampled

The dykes are vertical or nearly so and they cut the major thrust structures which affect the sediments. However, at least one of these dykes is displaced by an irregular shear zone (Fig. 2a), which is believed to represent a late-stage adjustment to tectonic stress. The southern dyke at Waitabit Cliffs bifurcates at the top of the cliff and thins out. None of the dykes could be traced beyond the coastal exposures into the hinterland. The dykes are less resistant to weathering than the mudstones but they are more resistant than the friable arkosic sandstones. The southern camptonite dyke at Waitabit Cliffs which cuts mottled arkosic sandstones forms a wall-like erosional remnant (Figs. 2b and 3).

In the hand specimen these camptonites are blue-black in colour and mottled with white amygdales. They possess a crude prismatic jointing perpendicular to the dyke walls and a poorly developed longitudinal jointing. In the southern dyke at Waitabit Cliffs most of the amygdales are concentrated in two zones about one-quarter of the thickness of the dyke in from each margin. The outward extent of the amygdale zones is limited by two well-developed longitudinal joints (Fig. 4). The distribution of amygdales and the longitudinal jointing pattern could be interpreted as indicating multiple intrusion of the dyke. No internal chilled margins were recorded and, with the exception of the kaersutite content (Table II), no significant differences between the outer and central parts of the dyke were observed. Thus the evidence for multiple intrusion is inconclusive. The other dykes tend to show a more general distribution of longitudinal joints and amygdales.

The relationship between the intrusion of these dykes and the tectonic evolution of this area (Horne, 1967) is far from clear, particularly in view of the small number and limited distribution of the dykes so far discovered. The intrusion of the dykes post-dates the latest phase of

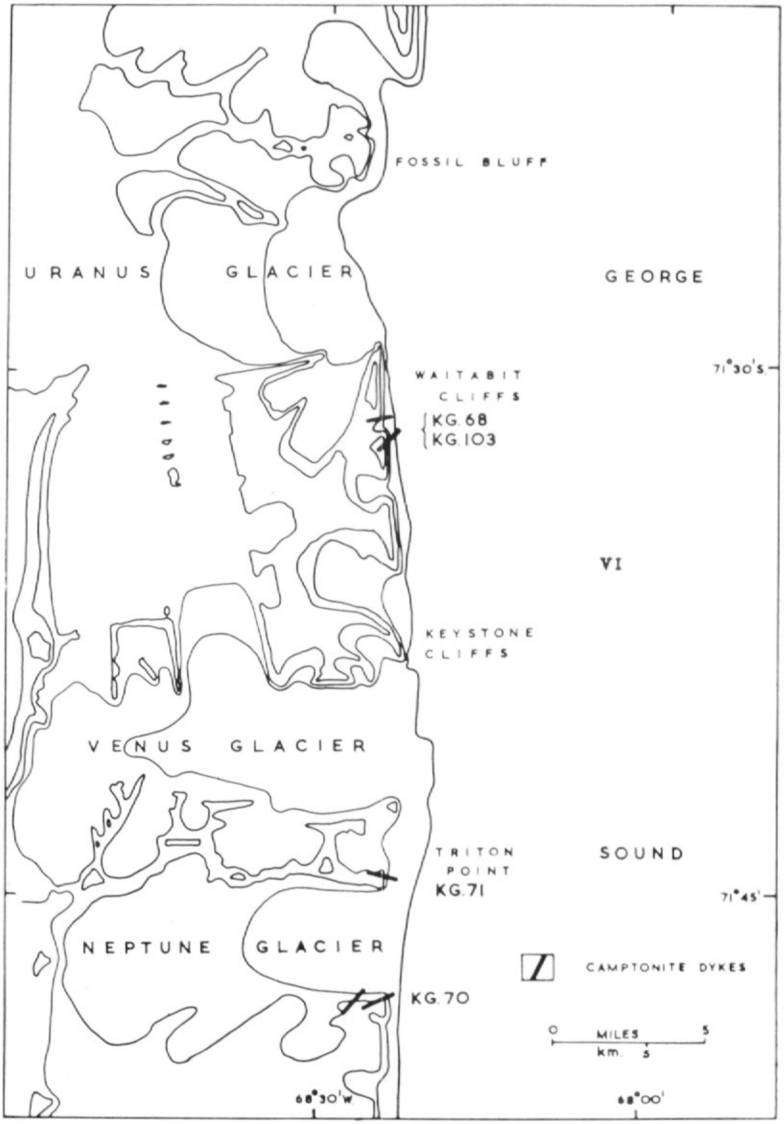

Fig. 1. A map of south-east Alexander Island, showing the locations of the five known camptonite dykes.

thrusting within the sediments which is believed to have established the steep, eastward-facing thrust scarp of the east coast of Alexander Island. These dykes have only been recorded from this scarp despite quite extensive study of inland exposures along the line of their strike. If their outcrop is indeed limited in an east—west direction, their intrusion may be related to the uplift of the coastal mountains following underthrusting of the basin of deposition by the eastern foreland. Their age and regional relationships are discussed in more detail on p. 22-23.

Contact metamorphic effects in the sediments adjacent to the walls of these dykes are restricted, presumably because at the time of intrusion the camptonite magma was at a relatively low temperature. There is some evidence that flow of magma through the dyke was limited. The impervious and refractory mudstones have been baked and their induration

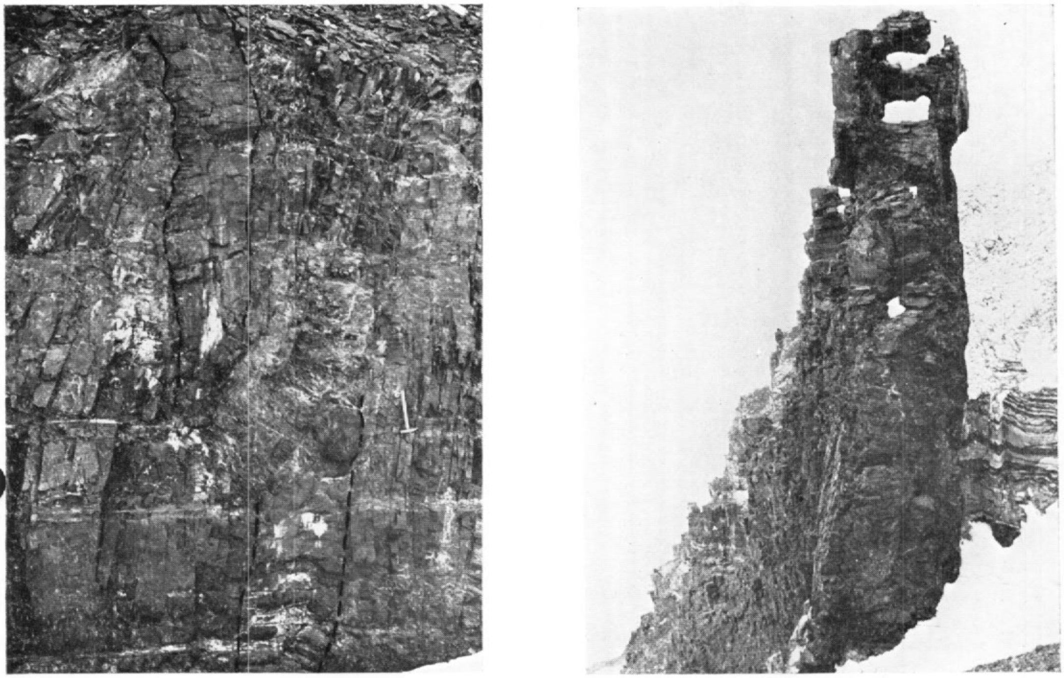

Fig. 2. a. The northern dyke at Waitabit Cliffs cut by a shear zone.
b. A view down the gully controlled by the southern dyke at Waitabit Cliffs. The dyke stands out as a wall about 6 m. high against the softer sandstones.

increased for distances up to 1 m. from the contact. A close parting is locally induced in them adjacent to and parallel to the dyke walls. Where the dykes intrude mottled sandstones, a distinct intensification of the colour of the sandstone from a mottled pale buff-green to a uniform, darker bluish grey occurs over a distance of several centimetres from the contact. This rock is also more indurated throughout this zone. No significant mineralogical changes have occurred in any of these contact rocks.

Mineralogy

These camptonites are composed essentially of euhedral phenocrysts of violet titanaugite, brown pleochroic hornblende, labradorite, olivine (partly altered to serpentine) and biotite with smaller crystals of titanomagnetite, irregular patches of chlorite and acicular apatite crystals set in a weakly polarizing groundmass containing chlorite, zeolite and probably analcite. The white amygdales are composed of calcite, chlorite and zeolites. The giant phenocrysts are kaersutite and biotite. Comparative modal analyses of specimens from different parts of the dykes are given in Table II.

Giant phenocrysts of biotite and kaersutite (Fig. 5a), whose dimensions are about 80 times those of the other phenocrysts in the rock are present in two of the dykes. Both minerals appear to be similar in composition to those in the rest of the dyke. The amphiboles show marginal rounding as a result of resorption and there is no reaction rim. The resorption gives the phenocrysts the appearance of obsidian with a conchoidal fracture, a deception noted by Campbell and Schenk (1950). The biotite phenocrysts are not so numerous as those of kaersutite and they do not show marginal rounding. They occur as equant, flat plates, the short axes of which were observed in the field as being aligned perpendicular to the dyke walls.

In addition to the giant phenocrysts, there is also a high modal percentage of kaersutite in the rock. It occurs both as discrete euhedral crystals and as overgrowths on titanaugite and

Fig. 3. A view looking up the gully controlled by the southern dyke at Waitabit Cliffs. The arrow indicates the position of Fig. 4.

Fig. 4. A close-up view of the southern dyke at Waitabit Cliffs, showing the attitude of the jointing and the two amygdaloidal zones about one-quarter of the width of the dyke from each margin. The staff is graduated in feet.

TABLE II. MODAL ANALYSES OF CAMPTONITE DYKES FROM ALEXANDER ISLAND

	Specimen numbers					
	KG.103.225	KG.103.224	KG.68.21	KG.68.12	KG.68.11	KG.70.1
Plagioclase	18·8	17·0	18·0	14·6	21·5	31·4
Titaniferous pyroxene	11·0	17·0	14·5	13·0	16·4	24·5
Titaniferous amphibole	17·1	8·0	8·9	21·9	12·0	5·8
Olivine*	2·0	—	7·1	12·4	10·3	10·2
Iron ore	9·6	7·9	7·4	10·8	8·5	6·9
Chlorite	4·8	—	1·8	3·3	10·2	—
Zeolite	0·5	0·8	0·4	3·2	2·8	—
Calcite	4·3	2·3	1·2	0·3	1·5	6·6
Matrix	31·9	47·0†	40·7	20·5	16·8	14·6

* Including chlorite and serpentine replacing or completely pseudomorphing olivine.
† The matrix is highly chloritic and this figure includes all the chlorite within the rock, i.e. in amygdales, in pseudomorphs after olivine and in the matrix.

KG.103.225	Specimen from the edge of the southern camptonite dyke at the northern end of Waitabit Cliffs.
KG.103.224	Specimen from the amygdaloidal zone of the southern camptonite dyke at the northern end of Waitabit Cliffs.
KG.68.21	Specimen from the centre of the southern camptonite dyke at the northern end of Waitabit Cliffs.
KG.68.12	Specimen from the edge of the northern olivine-bearing camptonite dyke at the north end of Waitabit Cliffs; 15 km. south of Fossil Bluff.
KG.68.11	Specimen from the centre of the northern olivine-bearing camptonite dyke at the north end of Waitabit Cliffs; 15 km. south of Fossil Bluff.
KG.70.1	Specimen from the centre of an olivine-bearing camptonite dyke; cliff on the south side of Neptune Glacier at its junction with George VI Sound.

small titanomagnetite crystals (Fig. 5d). The kaersutite is intensely pleochroic with α = pale yellow-brown, β = medium red-brown, γ = dark red-brown and $\gamma : c \simeq 10°$. It has a very high birefringence which is largely masked by the brown coloration. Its $2V\alpha$ is moderate to large and the optic axial plane is parallel to (010). The persistent separation of kaersutite into the final stages of crystallization is shown by the presence of tiny highly euhedral crystals in association with the zeolitic and chloritic matrix in patches (KG.68.12). These textural relationships indicate that kaersutite superseded titanaugite as the ferromagnesian precipitate during late and terminal stages of crystallization.

The plagioclase occurs as phenocrysts which poecilitically enclose earlier-formed crystals of titanaugite and magnetite (Fig. 5b). The average plagioclase composition is quite constant between the various dykes sampled, ranging from $Ab_{45}An_{55}$ to $Ab_{40}An_{60}$. The crystals show quite marked continuous normal zoning and the majority exhibit combined Carlsbad-albite twinning. In one dyke (Fig. 5c), invariably associated with the plagioclase crystals, are filiform and dendritic inclusions, probably ilmenite, rutile or magnetite (Ramsay, 1955). Many of these filiform clusters are randomly orientated with respect to the internal structure of their host mineral but others appear to have commenced their growth near the composition plane of the Carlsbad twin and to have grown and diverged towards the margin of the crystal.

The clinopyroxene, a titaniferous augite with a distinctive violet colour, occurs as euhedral laths and equant crystals. Zoning of continuous, oscillatory or sectoral (hour-glass) type occurs in almost every crystal. In ordinary light, the continuous zoning is revealed by a slight increase in the intensity of the violet colour towards the margins of the crystals but under crossed nicols the colour change is directly paralleled by an increase in birefringence, and in longitudinal sections by an increase in the extinction angle. A coincident increase in the dispersion

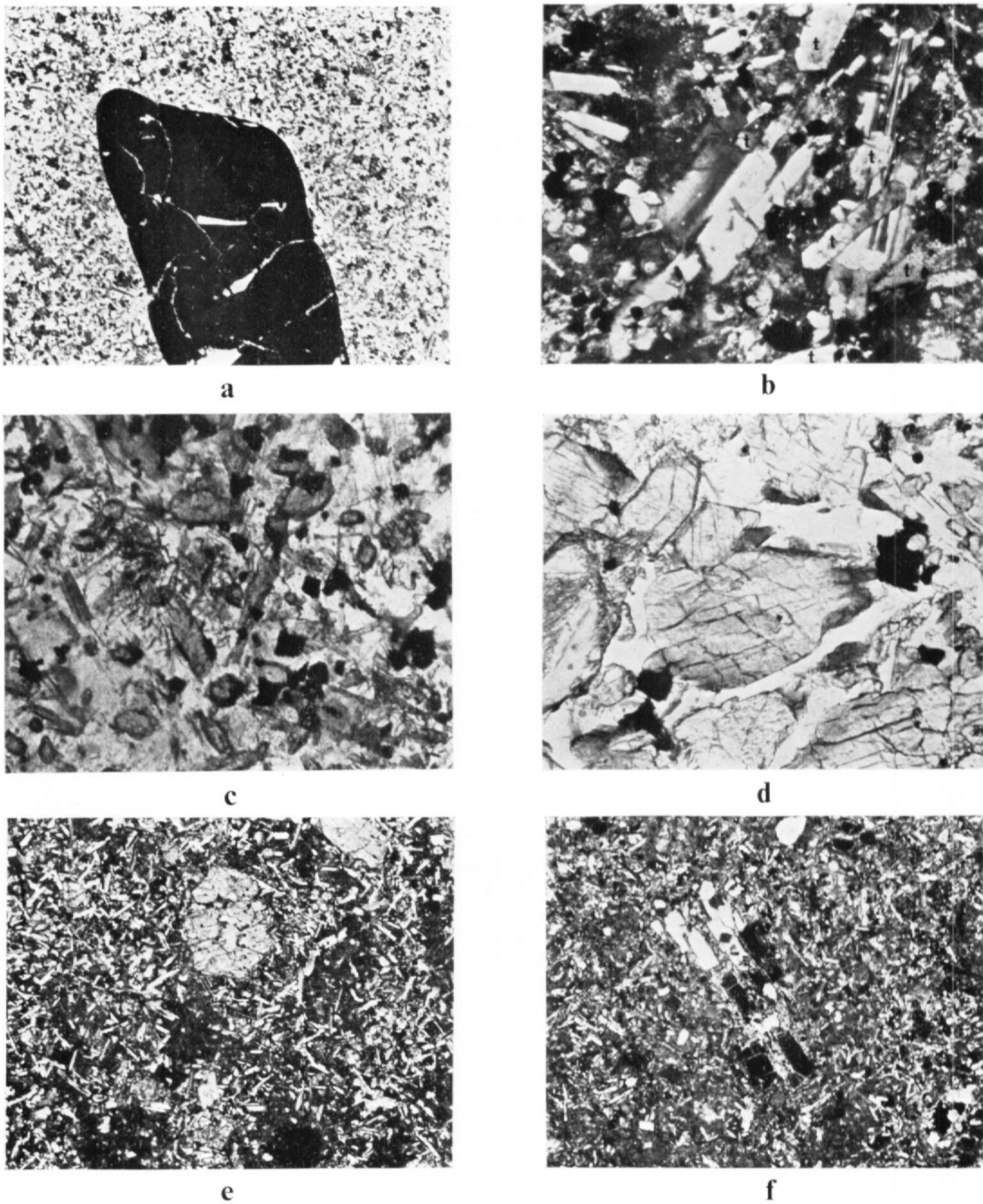

Fig. 5. a. A rounded and slightly embayed kaersutite phenocryst in the fine-grained marginal zone of the southern dyke at Waitabit Cliffs. (KG.103.236; ordinary light; ×16)

b. A poecilitic plagioclase crystal enclosing titanaugite (t) and iron ore (black). (KG.68.21; X-nicols; ×114)

c. Filaments of iron ore within a plagioclase crystal. (KG.68.20; ordinary light; ×117)

d. Overgrowths of brown kaersutite (darker margins) on titanaugite. (KG.70.1; ordinary light; ×87)

e. An olivine phenocryst completely pseudomorphed by serpentine and with calcite in the core. Note the dark patches of matrix. (KG.70.1; X-nicols; ×15)

f. An olivine phenocryst partially replaced by chlorite. (KG.68.11; X-nicols; ×18) of the bisectrices is also perceptible. Several different developments of the hour-glass structure, both alone and in association with concentric zoning and contact twinning on {100} are present. The individual sectors rarely meet sharply at the centre of the crystal and they usually have curved boundaries. The titanaugite has $2V\gamma = 0$–$30°$, and therefore some of the interference figures appear to be almost uniaxial. The dispersion of the bisectrices is very strong ($r > v$) with the result that those sections approximately normal to an optic axis show anomalous blue interference colours and other sections show incomplete extinction. This degree of dispersion appears to increase towards the more intensely coloured parts of the crystals.

Euhedral and subhedral olivine crystals, in various stages of alteration are present in some specimens. Both fresh and totally altered olivine occur in one specimen. Incompletely pseudomorphed olivine in the northern dyke at Waitabit Cliffs has $2V \simeq 90°$, indicating that its composition is forsteritic. The pseudomorphs are composed of calcite (Fig. 5e), a red-brown non-pleochroic mineral with high relief and birefringence, referred to as iddingsite, and a pale green chloritic mineral (? bowlingite) (Fig. 5f) with anomalous interference colours. Where total replacement has occurred, the outline of the original olivine has been preserved in the pseudomorph (Fig. 5e). A rim of small magnetite crystals surrounds those pseudomorphs composed of iddingsite or the chloritic mineral.

In most specimens almost half the rock is composed of a complex interstitial matrix. In one specimen (KG.70.1) a smaller proportion of an identical matrix is present in discrete and isolated areas of the rock. It is composed of a fine intergrowth of chlorite, a fibrous zeolite (probably stilbite or thomsonite), calcite and an isotropic mineral which is probably analcite.

One of the dykes enclosed xenoliths of the wall rocks, particularly mudstone fragments (KG.103.236). In thin section the boundaries of these fragments are diffuse but they can be delimited. Iron pyrites and small calcite-filled areas, the latter probably representing steam bubbles, are concentrated round the margins of the xenolith. A single xenolith of a coarse-grained igneous rock, containing microcline, shows marginal rounding and embayment due to assimilation. Whether this xenolith is a detrital fragment derived from the sediments or whether it was carried up in the dyke from the basement cannot be determined.

Textures and crystallization

These camptonites possess the typical panidiomorphic texture of the lamprophyres. With the exception of the partly resorbed kaersutite phenocrysts, all the ferromagnesian minerals are euhedral. Another characteristic of these rocks is that the euhedral boundaries of the replaced olivine crystals are preserved in the serpentine pseudomorphs. The plagioclase poecilitically encloses the earlier-formed titanaugite, which is frequently developed as radiating clusters of interpenetrating twins or more generally as aggregates. A similar association exists where small opaque magnetite or titanomagnetite crystals are clustered round orange-coloured iddingsite pseudomorphs. This rim of opaque minerals is also present where the olivine has been totally replaced by ? bowlingite.

In thin section the amygdales which were observed in the field can be divided into two types. The first includes large ellipsoidal amygdales, which are composed of an outer zone of chloritic fibrous matrix lining the edge of the body and grading outwards into the matrix of the rock. This is succeeded inwards by a layer, of variable width, of colloform green chlorite as radiating fibres. The core is filled with coarsely crystalline calcite, a zeolite (possibly chabazite or heulandite) and more rarely analcite in variable proportions. The second type of amygdale is generally smaller and subspherical, filled with radiating crystal groups of stilbite, and occasionally with a little chloritic material. Acicular kaersutite crystals are arranged tangentially around the rims and very occasionally they project inwards into the amygdale. In some cases, these amygdales appear to grade into another type of body filled with small euhedral kaersutite crystals set in a zeolitic matrix. They are characteristically free from the titanaugite crystals which frequently occur in the surrounding rock.

The concentration of the zeolitic groundmass and amygdales towards the centres of the dykes and the relative induration and resistance to weathering of the marginal parts appears to have resulted from the relative chilling of the magma in contact with the walls and the entrapment and progressive concentration of the volatiles in the cores of the dykes.

From these textural relationships the order of crystallization of the various mineral phases can be determined. The giant phenocrysts of kaersutite and biotite, and the large ones of olivine and possibly the spinel, appear to have been present in the magma before its intrusion as a dyke, because they are evenly distributed throughout the dyke and appear to have been suddenly removed from an environment in which they were the stable phases into one in which they were unstable.

The first mineral to crystallize on intrusion of the dykes was titaniferous pyroxene. As crystallization proceeded, titanaugite was superseded by kaersutite as the stable phase. It seems that, in terms of the percentages of FeO, CaO and MgO, the Alexander Island camptonites lie near the pyroxene—amphibole boundary in Kennedy's (1935) diagram. As a result, the succession of pyroxene by amphibole as the stable ferromagnesian mineral and the resulting occurrence of the amphibole both as discrete crystals and as overgrowths on pyroxene characterizes camptonites of olivine-basalt parentage (Vincent, 1953; Challis, 1960). The normally zoned plagioclase crystals with an initial labradorite composition began to crystallize during the later stages of titanaugite crystallization. The thermal gradient across the dyke would tend to result in the concentration of the alkaline and volatile-rich fraction towards the centre of the dyke.

Nomenclature

The establishment of a widely acceptable classification of the lamprophyres has proved difficult for two main reasons: first, the inherent complexity of the mineralogy of these rocks, and secondly the tendency of earlier classifications to have dubious genetic implications. A classification based on the compositions of the principal ferromagnesian minerals and the content of feldspar, feldspathoids or analcite, as outlined by Hatch, Wells and Wells (1961), is generally recognized as having considerable practical value. According to this terminology, lamprophyres containing brown hornblende and/or augite, and containing plagioclase, are camptonites. The plagioclase content of some Alexander Island specimens, however, is much lower than that of camptonites described from other parts of the world, possibly indicating that the trend of differentiation of the parental magma was towards a monchiquitic lamprophyre. This terminology is in agreement with that used by Vincent (1953) for rocks of a very similar type from the Skaergaard, Greenland, which are believed to be differentiation products of an olivine-basalt magma.

Petrogenetic association

The suggestion by early workers that lamprophyres are generated exclusively as late-stage differentiates of nepheline-syenites or sub-alkaline granites—"as the afterbirth of plutonic rocks" in Knopf's phrase—has dominated discussion of lamprophyre petrogenesis and classification in the past. However, in more recent studies, particularly those of Vincent (1953) in Greenland, Ramsay (1955) in Monar, and Challis (1960) in New Zealand, strong evidence has been assembled to suggest that a genetic connection between lamprophyres (particularly those of the camptonite—monchiquite suite) and alkaline plutonic masses is not exclusive, because camptonitic lamprophyres can also be produced as late alkaline differentiates of an olivine-basalt magma. The evidence presented by Vincent (1953) from the dykes of the Skaergaard is particularly convincing in that he has described a series of progressive differentiation products ranging between olivine-dolerite and true camptonite.

The widespread Andean Intrusive Suite of the Antarctic Peninsula has been described by Adie (1955). It is a normal granite-gabbro calc-alkaline suite, which has been assigned to a late Cretaceous or early Tertiary age, and post-intrusive dyke suites associated with these plutonic rocks have been briefly described from several areas (Hoskins, 1960; Goldring, 1962). The only occurrence of lamprophyres within these suites has been described by Nichols (1955) from a dyke phase cutting the Andean Red Rock Ridge granite in the Neny Fjord area. Alkaline plutonic rocks, such as nepheline-syenites, foyaites or other sodic syenites, are characteristically absent from this and other parts of the circum-Pacific orogenic zone. In view of these considerations, the petrogenetic association of the Alexander Island camptonites must be sought in the oceanic Tertiary to Recent olivine-basalt province. At King George

Island to the north-west of the Antarctic Peninsula, Hawkes (1961*a*) observed that the successive volcanic phases from the Miocene onwards show a distinct alkaline trend from andesites to olivine-basalts. This trend is fully developed in the Recent lavas of Deception Island which Hawkes (1961*b*) regarded as a local alkaline derivative of olivine-basalt parentage. A thick succession of mid-Miocene lavas and tuffs of olivine-basalt composition, termed the James Ross Island Volcanic Group, occurs both in the type area and at the Seal Nunataks (Nelson, 1966). In northern Anvers Island, Hooper (1962) recorded Tertiary basaltic lavas filling valleys cut in plutonic rocks of the Andean Intrusive Suite. To the south-west of Alexander Island, in the Thurston Peninsula area, a basement of foliated quartz-diorite yielding a Sr/Rb date of 280 m. yr. (Craddock and Hubbard, 1961) has been described by Drake (1962) as being intruded by "very fine-grained, mafic dykes of lamprophyric appearance". To the south-east of Thurston Peninsula are the Jones Mountains, where olivine-basalt tuffs and lavas dated as 22 m. yr. (Miocene) unconformably overlie a granitic basement intruded by felsites and basalts with respective K/Ar ages of 199 and 104 m. yr. (Craddock and others, 1964). Peter I Øy, which lies in the Bellingshausen Sea 400 km. north of Thurston Peninsula, is composed of olivine-basalt lavas and tuffs. In northern Marie Byrd Land several mountain groups, including the Executive Committee Range and the Crary Mountains, which are composed of lavas and pyroclastic rocks of olivine-andesite—olivine-basalt—trachyte affinity, have been briefly studied on American reconnaissance traverses (Doumani and Ehlers, 1962; Doumani, 1964). In this region the complete preservation of volcanic cones with large calderas and smaller parasitic cones, resulting from aligned but discrete centres of volcanicity, suggests that activity terminated quite recently and this conclusion is borne out by K/Ar dating of plagioclase from these lavas at 6·2 m. yr. (Middle Pliocene).

From these descriptions it can be seen that the Alexander Island camptonite dykes lie within a broad circum-Pacific zone of late Tertiary volcanicity of olivine-basalt parentage, and it therefore seems likely that these dykes represent the late-stage alkaline differentiation products of such a parental magma.

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