AMYGDULAR CAMPTONITE DIKES FROM MOUNT JO, MOUNT MARCY QUADRANGLE, ESSEX COUNTY, NEW YORK*

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ABSTRACT

Three small, amygdular camptonite dikes intrude the Marcy anorthosite in Mount Jo, Mount Marcy quadrangle, Essex County, N. Y. They show a northeasterly strike, 80° to 90° dip, and are 13 to 20 inches thick. They are similar to the post-Ordovician camptonite dikes from the Lake Champlain valley. Three modal analyses, one chemical analysis, one spectrographic analysis, and optical properties of the individual minerals are presented. The dikes are porphyritic, with phenocrysts of olivine, zoned augite-pigeonite, brown hornblende, and magnetite in a holocrystalline groundmass composed essentially of plagioclase, An_{22-35}. Modal analyses show 75 per cent of mafic minerals, 23 per cent of plagioclase, and 2 per cent of amygdular calcite. The norm shows 45 per cent of salic minerals composed of albite, anorthite, orthoclase, and nepheline. The poor agreement between mode and norm is due to the presence of major amounts of the abnormative minerals, augite and hornblende. The dikes may be classified as camptonite (family 3216H, Johannsen), subbasalt (DVMγ-75, Shand), or CIPW III.5.3.4 (Washington). Formation of the camptonites is attributed to the injection of crystals of olivine, augite, and alkalic liquid as small dikes into cold anorthosite under conditions of low pressure and moderate to high temperature.

INTRODUCTION

Camptonite dikes from the northeastern Adirondack region have been described by Kemp and Marsters (1889 and 1893), Kemp (1921), Hudson and Cushing (1931), and Buddington (1939 and 1941). Detailed modes of these rocks are lacking, and the only two chemical analyses in the literature are those of Kemp and Marsters (1889 and 1893) and Leeds (1878) cited by Kemp (1921). Five camptonite dikes reported by Kemp (1921) from the Mount Marcy Quadrangle, Essex County, N. Y. (Fig. 1) were only briefly described. In the summer of 1949 the author found three additional camptonite dikes in the quadrangle. These were investigated in detail and this report gives data on their geological occurrence, mineralogy, and chemistry.

OCCURRENCE

Three camptonite dikes, DMJ-1, 2, and 3, intrusive into the Marcy anorthosite, are exposed near the summit of Mount Jo near Heart Lake in the northwestern part of the Mount Marcy quadrangle, Essex County, N. Y. (Fig. 1). The summit of Mount Jo can be reached in less than half an hour by means of a good trail leading from the Adirondack Loj at Heart Lake. The lake is 9 miles by road from the village of Lake Placid,

* Publication authorized by the Director, U. S. Geological Survey.

FIG. 1. Index map of the Adirondack region, New York. (Anorthosite massif after Balk, 1931.)

N. Y. The strike, dip, and thickness of the three dikes are compared in Table 1 with the camptonite dikes reported by Kemp (1921) from the Mount Marcy quadrangle.

Dikes DMJ-1 and 2 (Table 1) have been considerably eroded away from the anorthosite, forming two steep-sided erosional slots. All of the dikes in the Mount Marcy quadrangle are less resistant than the essentially monomineralic anorthosite host rock, and many of the numerous small waterfalls in the quadrangle are located on eroded post-anorthosite dikes. Dikes DMJ-1 and 2 show parallel strike and dip, N. 31° E., 80° S.E., and discordantly cut the Marcy anorthosite. A marked foliation in the anorthosite, enhanced by large plagioclase crystals, strikes N. 78° W.

TABLE 1. CAMPTONITE DIKES, MOUNT MARCY QUADRANGLE, ESSEX COUNTY, NEW YORK

Location	Strike	Dip	Thickness
1. DMJ-1, Mount Jo	N. 31° E.	80° S.E.	13 inches
2. DMJ-2, Mount Jo	N. 31° E.	80° S.E.	20 inches
3. DMJ-3, Mount Jo	N. 52° E.	90°	15 inches
4. E. br. Ausable R.	N. 75° W.	90°	5 to 6 feet
5. E. br. Ausable R.	East	90°	5 feet
6. John's Brook	N. 27° E.	—	1 to 3 feet
7. John's Brook	N. 67° E.	—	1 to 3 feet
8. John's Brook	N. 62° E.	—	1 to 3 feet

Dike DMJ-3 outcrops in the trail about a quarter of a mile below the summit of Mount Jo. It shows a more easterly strike, N. 52° E., and has a vertical dip.

Texture

In the field the dark, dense camptonite dikes may be readily mistaken for the abundant diabase dikes of the quadrangle, which also have a northeasterly strike. With the aid of a hand lens, observation of the small, round, white amygdules characteristic of the camptonites serves to distinguish them from the diabase. Weathered portions of the camptonite show pitting due to the removal of calcite from the amygdules. In thin section the camptonite and diabase show different textures. The diabase shows an ophitic texture with rudely oriented laths of andesine-laboradorite, and interstitial augite, the latter extensively altered to serpentine and calcite. The camptonite is porphyritic and amygdular, showing abundant phenocrysts of olivine and clinopyroxene, and round amygdules in a groundmass of sodic plagioclase containing laths and microlites of brown hornblende, biotite, and pyroxene (Fig. 2). Only the mafic minerals olivine and augite, and to a lesser extent hornblende and magnetite, form phenocrysts. The camptonite is much fresher than the diabase.

Hudson and Cushing (1931) describe a camptonite dike from the Lake Champlain area as follows: "Abundant large phenocrysts of augite, which is nearly colorless in thin section, but with lilac-colored borders

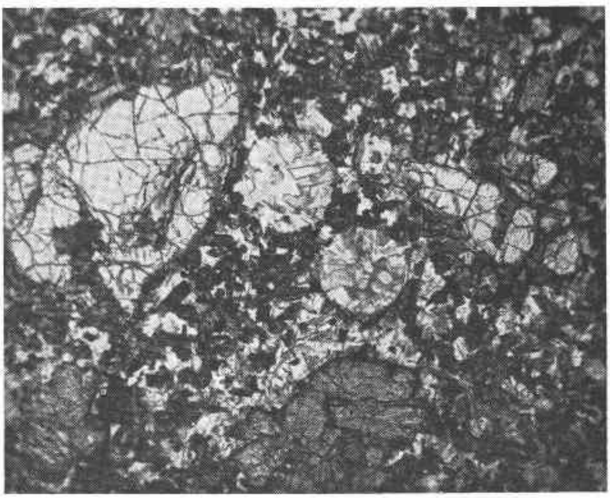

Fig. 2. Camptonite dike, DMJ-3, showing phenocrysts of olivine (white), clinopyroxene (gray, near bottom of photograph), and two calcite-filled amygdules (center of photograph) in a groundmass of plagioclase, hornblende, clinopyroxene, and magnetite. (Plane polarized light ×25.)

and crammed full of inclusions, in part arranged zonally. A few small, rotted olivines. Groundmass of feldspar laths, small augites and magnetite and some apparently devitrified glass base. Some calcite-filled amygdules." Buddington (1941) has also noted similar amygdular camptonite dikes in the Willsboro quadrangle, N. Y., near Lake Champlain. Both Hudson and Cushing (1931) and Buddington (1941) consider these camptonites to be post-Ordovician rocks. In all probability the Mount Jo camptonite dikes are of the same age. It is interesting to note that the late Pleistocene camptonite dikes near Boulder Dam, Arizona, described by Campbell and Schenk (1950), also contain amygdules.

Mineralogy

Modes of the three camptonite dikes, DMJ-1, 2, and 3, are given in Table 2. The modal analyses were made of thin sections, using the point counter mechanical stage described by Chayes (1949). The three dikes are similar in mineralogy. Although the pyroxene and hornblende percentages are variable, in each dike their sum is almost 50 per cent. Amygdules (0.1 to 0.5 mm. in diameter) form 1 to 3 per cent of the rock and are always completely filled with calcite and sodic plagioclase. Dike DMJ-3 contains 2.7 per cent of amygdules represented in Table 2 by 1.8 per cent of modal calcite and 0.9 per cent of modal plagioclase.

Table 2. Modes* of Three Camptonite Dikes from Mount Jo, Essex County, N. Y.

	DMJ-1	DMJ-2	DMJ-3
Olivine†	12.5	14.2	10.8
Augite+pigeonite	32.3	16.0	28.0
Brown hornblende	16.8	32.5	23.2
Biotite	2.0	3.1	2.0
Magnetite	10.2	14.2	8.4
Plagioclase (An_{22-35})	24.0	18.0	25.8
Calcite	2.2	2.0	1.8
Apatite	Trace	Trace	Trace
	100.0	100.0	100.0

* All percentages by volume.
† Includes some secondary serpentine and talc.

Data on the optical properties and the habits of the individual minerals are given in the following paragraphs. The minerals are discussed in their probable order of crystallization.

Olivine forms the largest phenocrysts, showing average grain diameters of 1.×0.5 mm. and maximum grain diameters of 2.×1. mm. Many of the phenocrysts are euhedral and remarkably fresh. They commonly show fresh cores with marginal corrosion and alteration to a mixture of fine-grained serpentine, talc, and magnetite. The mineral is colorless with $\alpha=1.660$, $\beta=1.679$, $\gamma=1.700$, $2V=88°(+)$, indicating a composition near forsterite—85 per cent: fayalite—15 per cent (Larsen and Berman, 1934).

Clinopyroxene forms euhedral, equant cross sections (0.25–0.5 mm.), stout prisms (0.1×0.5 mm.), and smaller narrow laths. Phenocrysts occur

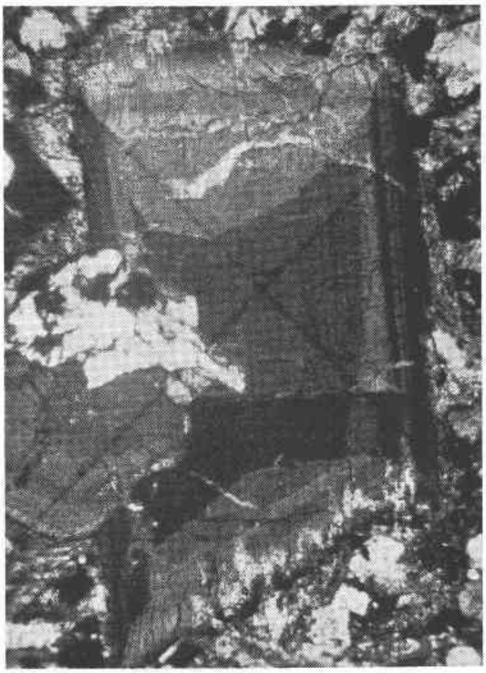

FIG. 3. Hourglass structure in clinopyroxene. (Crossed nicols ×150.)

isolated or in clusters sometimes mantling olivine. Virtually all of the pyroxenes show marginal opaque corrosion or rims of brown hornblende. All of the pyroxenes are intricately zoned, many showing well-developed hourglass structure (Fig. 3). Concentric zoning, observed on euhedral cross sections, shows cores of augite, succeeded by a narrow zone of pigeonite, a second zone of augite, and finally, pigeonite rims. Axial angles measured by Norman Herz with a Universal stage showed cores with a $2V=53°$ and rims with a $2V=28°$. Pigeonite rims show marked anomalous blue interference colors, and the optic axis emerging in {001} shows strong dispersion with $r>v$. Augite cores show weak to moderate dispersion, $r>v$, of the corresponding optic axis. Dispersion of the optic axis emerging in $\{100\}$ is reversed for both minerals with $v>r$, weak. Extinction angles were difficult to measure accurately because of the zoning. Longitudinal grains show maximum extinction angles, $Z\wedge c=51°$ for pigeonite rims and 44° for augite cores. Because of the intricate zon-

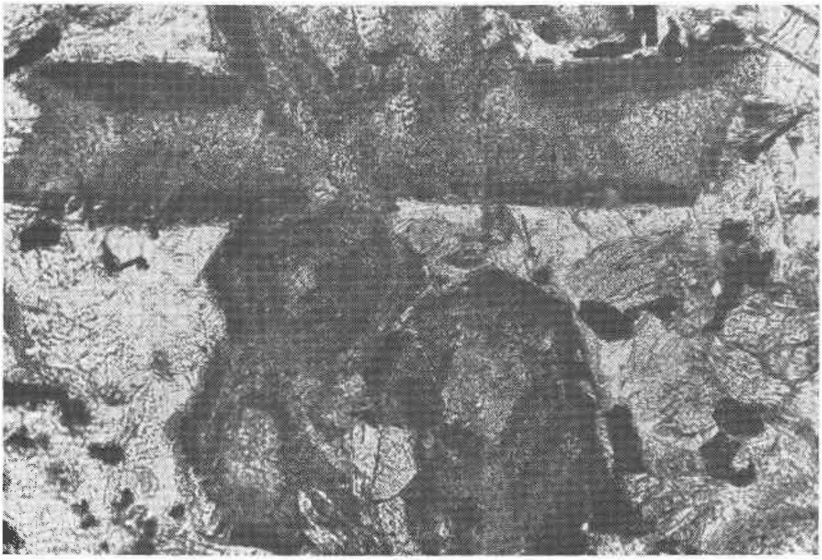

FIG. 4. Ghost pyroxenes showing relict hourglass structure (elongate grain) and relict augite-pigeonite zoning (equant cross-sections). The pyroxenes are completely replaced by serpentine and talc (light zones were augite) and magnetite, hornblende, and biotite (dark zones were pigeonite). (Plane polarized light ×175.)

ing and frayed crystal margins, all of the indices of refraction could not be measured. Index of refraction measurements for pigeonite gave $\beta=1.732$ and $\gamma=1.752$, indicating an abnormally high iron content. Variable measurements were obtained on the augite, which may indicate a continuous compositional change within this pyroxene. Poldervaart and Hess (1951) suggest a continuous reaction series from magnesian augite to ferroaugite in basaltic rocks and a discontinuous reaction series from magnesian olivine through orthopyroxene to pigeonite. As both minerals become enriched in iron they may react with the liquid to form hornblende.

In thin section the pyroxene is feebly pleochroic from pale grayish green to pale brown, with many of the grains showing a purplish tinge presumably due to titanium (Hess, 1949). Where hourglass structure is present the hourglass centers show a lighter color and a lower index of refraction than the sides of the grain. Alteration of these grains produces ghost pyroxenes (Fig. 4) with light-colored centers of serpentine and talc bounded on both sides by fine-grained magnetite, which is in turn bounded by a narrow rim of hornblende or biotite. In altered cross sections of the zoned pyroxenes, the zonal structure may persist (Fig. 4), augite being replaced by serpentine and pigeonite replaced by fine opaque material, presumably magnetite. Some of the basal sections show simple contact twins with a $\{100\}$ composition plane. Cruciform twinning, relatively uncommon in clinopyroxene, is illustrated in Figure 5.

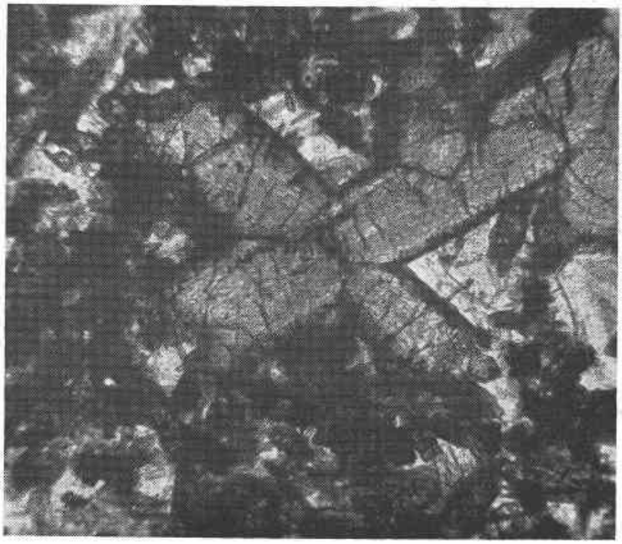

FIG. 5. Cruciform twinning in clinopyroxene. (Plane polarized light ×125.)

Magnetite occurs in small euhedral and skeletal grains less than 0.1 mm. in diameter. Some very fine grained magnetite is exsolved from the alteration of pyroxene and olivine.

Brown hornblende occurs in laths with maximum grain dimensions of 0.02×0.15 mm. and may occasionally show basal sections. It commonly forms narrow rims around pyroxene phenocrysts, presumably the result of reaction of lime-poor pigeonite rims with the liquid. The mineral is strongly pleochroic with $\alpha=1.678$ (yellow), $\beta=1.700$ (red-brown), $\gamma=1.708$ (dark red-brown), $2V=62°$ (−), dispersion $v>r$ moderate, and $Z\wedge c=9°$. The optical properties are similar to those reported for brown hornblende, "kaersutite," from the camptonite near Bounder Dam (Campbell and Schenk, 1950). The latter has $\alpha=1.670$, $\beta=1.692$,

$\gamma=1.701$, $Z\wedge c=8°–10°$, and $2V=81°$. If these indices of refraction are correct, the value for 2V is in error and should be 64° (−) rather than 81° (−).

The groundmass is birefracting and is composed essentially of plagioclase An_{30-35}. The feldspar occurs in simple laths and felted aggregates showing poorly developed albite twinning. Plagioclase An_{22} occurs in small laths as projections into amygdules (Fig. 6) and as radial groups in amygdules. An *x*-ray powder diffraction pattern of feldspar concentrated from the rock showed the spacing 3.01, which is diagnostic of high-tem-

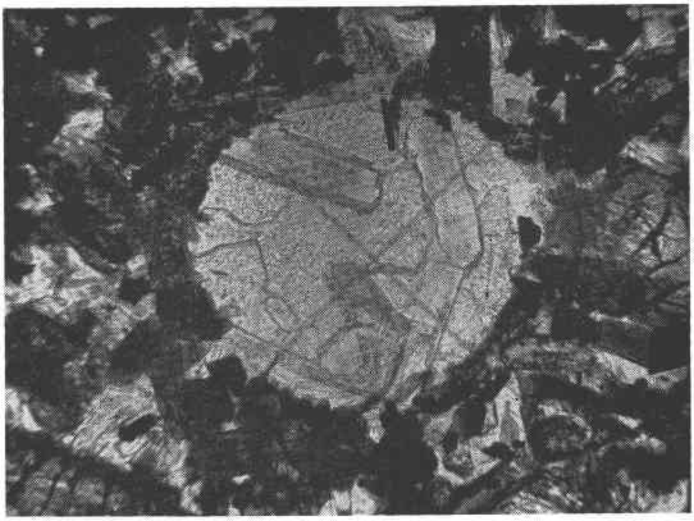

FIG. 6. Plagioclase laths and calcite in an amygdule. (Plane polarized light ×150.)

perature albite (Tuttle and Bowen, 1950). The concentrate was submitted to Tuttle for further examination. Tuttle (personal communication, 1950) could not decide whether high- or low-temperature plagioclase was present because it is difficult to distinguish between them in the range An_{30-35}. The spacing 3.01 may be due to an impurity. He confirmed the presence of two feldspars, one with $\beta=1.550$, $2V=70°$ (−), An_{30-35}, high- or low-temperature, and another with $\beta=1.540$, An_{22}, low-temperature. Although the feldspars are unaltered, the presence of very fine laths of augite, hornblende, and biotite in the groundmass made it impossible to obtain a feldspar concentrate of high purity.

Calcite, $\omega=1.658$, occurs as well-developed grains completely filling amygdules or filling feldspar interstices in the amygdules (Fig. 6).

Serpentine, talc, and fine-grained magnetite are alteration products of olivine and pyroxene.

Analysis and Classification

A chemical analysis of one of the camptonite dikes (DMJ-3) is given in Table 3. The CIPW norm, modal analysis, and spectrographic analysis are also compared in the same table. Table 4 compares analyses of camptonites and olivine diabases. The poor agreement between mode and norm is due to the presence of large amounts of the abnormative minerals augite and hornblende and some biotite. Orthoclase and nepheline were looked for in numerous immersions but could not be identified. In all probability, the brown hornblende contains an appreciable amount of the alkalies indicated by the normative orthoclase and nepheline. Biotite makes up only 1.9 per cent of the rock and could account for a maximum of 0.2 per cent K_2O. Brown hornblende ("kaersutite") from the camptonite near Boulder Dam (Campbell and Schenk, 1950), with similar optical properties contains 1.72 per cent K_2O and 2.29 per cent Na_2O. Horn-

Table 3. Chemical, Spectrographic, Normative, and Modal Analyses of Camptonite Dike, DMJ-3, Mount Jo, Mount Marcy Quadrangle, Essex County, N. Y.

Chemical analysis*		Spectrographic analysis†	Norm			Mode Volume	Mode Weight
SiO_2	42.58	>10.0	Orthoclase	7.78	Plagioclase (An_{22-35})	25.8	20.8
TiO_2	3.38	0.3 –3.0	Nepheline	1.99	Olivine	10.8	11.1
ZrO_2		0.01–0.1	Albite	21.48	Augite / Pigeonite	28.0	29.4
Al_2O_3	12.00	>10.0	Anorthite	13.62	Hornblende	23.2	22.7
Fe_2O_3	5.09	>10.0 (Fe₂O₃ and FeO)	Olivine	18.28	Biotite	2.0	1.9
FeO	8.82		Diopside	15.87	Magnetite	8.4	12.6
Cr_2O_3		0.01–0.1	Magnetite	7.42	Apatite	Trace	Trace
Ga_2O_3		<0.01	Ilmenite	6.38	Calcite	1.8	1.5
Sc_2O_3		<0.01	Apatite	1.34			
V_2O_5		0.02 –0.2	Calcite	2.84		100.0	100.0
MnO	0.40	0.02 –0.2	Water	2.02			
MgO	10.44	>10.0					
CaO	9.21	>10.0		99.02			
BaO		0.1–1.0					
NiO		0.005–0.05					
CuO		<0.01					
PbO		0.002–0.02					
Na_2O	2.98	0.5–5.0					
K_2O	1.34	0.5–5.0					
Li_2O		0.008–0.08					
H_2O-	0.23				CIPW—III.5.3.4		
H_2O+	1.79						
CO_2	1.25						
P_2O_5	0.62						
	100.13						

* Ruth Holzinger, analyst.
† M J. Peterson, analyst.

TABLE 4. ANALYSES OF CAMPTONITES AND OLIVINE DIABASE

	A	B	C	D	E	F	G
SiO_2	42.58	42.26	43.41	41.00	41.94	40.70	48.54
TiO_2	3.38	3.18	0.35		4.15	3.86	1.31
Al_2O_3	12.00	14.61	19.42	21.36	15.36	16.02	15.24
Fe_2O_3	5.09	5.38	5.72	13.44	3.27	5.43	3.06
FeO	8.82	4.56	6.69		9.89	7.84	8.88
MnO	0.40	0.05			0.25	0.16	0.21
MgO	10.44	6.12	5.98	3.85	5.01	5.43	8.08
CaO	9.21	9.40	9.11	10.40	9.47	9.36	9.38
BaO		0.16					
Na_2O	2.98	2.64	4.39	2.86	5.15	3.23	2.69
K_2O	1.34	1.48	0.47	1.31	0.19	1.76	0.98
H_2O-	0.23	2.72					
H_2O+	1.79	3.93	3.00	5.00	3.29	2.62	1.35
CO_2	1.25	2.99	2.00		2.47	2.97	
P_2O_5	0.62	0.62				0.62	0.28
S		0.09					
	100.13	100.19	100.54	99.22	100.44	100.00	100.00

A. Camptonite, DMJ-3, Mount Jo, Mount Marcy quadrangle, Essex County, N. Y., Ruth Holzinger, analyst.
B. Camptonite, 8 miles south of Boulder Dam, Ariz., F. A. Gonyer, analyst (Campbell and Schenk, 1950).
C. Camptonite, Mount Marcy quadrangle, Essex County, N. Y., A. B. Leeds' analysis, 1876, cited by Kemp (1921).
D. Camptonite, Whitehall, Washington County, N. Y., Kemp and Marsters (1889 and 1893).
E. Camptonite, Campton, N. H., original camptonite, G. W. Hawes, analyst (1879)
F. Daly's average of 15 camptonites (1933).
G. Daly's average of 12 olivine diabases (1933).

blende would also account for the excess of normative anorthite and probably some of the normative ilmenite. The brown hornblende from the camptonite near Boulder Dam contains 5.70 per cent TiO_2. The purplish tinge on some of the pyroxene phenocrysts suggests that this mineral is also enriched in titanium (Hess, 1949).

Finally, the most serious shortcoming of the norm is that it shows 45 per cent of salic minerals, whereas the mode shows only 20 per cent. Thus, a camptonite cannot be distinguished from many diabases and gabbros by the CIPW classification. The CIPW classification of the Mount Jo camptonite is camptonose: class III, order 5, rang 3, subrang 4, the same as that obtained from the analyses of many diabases. Using Johannsen's system (1937), the rock would be classified as camptonite, family No. 3216H. Using Shand's classification (1943), the rock would be categorized as sub-basalt, DVMγ (75). This category includes rocks that have been classed as camptonites, a name firmly entrenched in the literature.

Regardless of which name is used, the Mount Jo dikes, classified as DVMγ (75) after Shand, would meet the following requirements:

D—The rock has crystallized rapidly under conditions of low pressure and moderate to high temperature. This is confirmed by the presence of zoned pyroxene and the fine-grained groundmass.

V—The alkalies are saturated with respect to silica and no feldspathoids are present. Conversely, the dark minerals are unsaturated, as indicated by the presence of essential amounts of magnesian olivine.

M—The molecular proportion of Al_2O_3 exceeds that of Na_2O and K_2O combined but is less than that of Na_2O, K_2O, and CaO combined. Some alumina may enter the dark silicates and usually there are non-aluminous dark silicates present with aluminous dark silicates. In this case olivine occurs with zoned augite mantled with brown hornblende.

γ—The character of the feldspar must be An > Or and Ab > An.

(75)—The rock contains 75 per cent of dark minerals.

This provides a much more accurate description of the rock than the CIPW normative classification, which indicates only 50 per cent of dark minerals and an exceedingly poor agreement between norm and mode.

Petrogenesis

The three camptonite dikes in Mount Jo are in every way typical of rocks generally classed as lamprophyres, a term that has had a diversity of usage. The Mount Jo dikes are lamprophyres in the sense of Bowen (1928): "characteristically porphyritic rocks, the porphyritic elements highly femic (olivine, hornblende, mica) and the groundmass notably alkalic." The Mount Jo dikes also conform to Grout's usage (1932): "rocks that are dark, basic, mostly of sugary texture and mostly occurring in dikes"; Johannsen (1937) notes further that characteristically only the dark minerals form phenocrysts, feldspar being almost wholly limited to the groundmass. Bowen (1928) states that there is no evidence for the existence of a liquid of the total composition of the olivine-bearing lamprophyres. He suggests that these rocks may be formed by the injection of crystals of olivine and augite in an alkalic liquid. This femic-alkalic association of crystals and liquid may result from fractional resorption of complex minerals, notably hornblende and biotite. Injection of the olivine, augite, and alkalic liquid as small dikes into cold anorthosite would produce rapid cooling and the formation of the Mount Jo camptonites. The rock contains 75 per cent of femic minerals and only

25 per cent of sodic plagioclase (An_{22-35}). Magnesian olivine is mantled by zoned augite, with iron-rich pigeonite rims, which is in turn mantled by brown hornblende. The brown hornblende, presumably rich in alkalies, continued to crystallize as fine needles with plagioclase (An_{30-35}) until crystallization was nearly completed. Near-surface conditions of injection permitted separation of a vapor phase, giving rise to the formation of amygdules containing projections of plagioclase (An_{22}) and cores of calcite. Alteration of olivine and pyroxene to serpentine, talc, and magnetite accompanied the formation of the amygdules. Each amygdule shows a narrow halo of intensely altered ghost pyroxenes. The preservation of the perfectly round, calcite-filled amygdules in dikes only 1 to 2 feet thick in massive anorthosite is indicative of the absence of significant deformation since the emplacement of the dikes. Hudson and Cushing (1931) describe deformed amygdules from the camptonites of the Lake Champlain valley. They state that these dikes were emplaced below 4000 feet of beds of Chazy age and that the amygdules therefore cannot be explained on the basis of near-surface intrusion. They ascribe the amygdules to a sudden widening of tension fissures filled with partly crystallized magma. Relief of pressure and gas expansion permitted formation and localization of amygdules at viscous dike centers. Amygdules in the Mount Jo dikes are not localized and need have had no such origin but probably formed because of near-surface intrusion. Mount Jo is situated in the core of the Adirondack anorthosite massif, which is believed never to have been covered with sediments since its intrusion into the Grenville series.

Acknowledgments

The author is indebted to O. F. Tuttle of the Geophysical Laboratory for making optical and *x*-ray studies of two plagioclase feldspars separated from one of the camptonite dikes.

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