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THE OLIVINE AMPHIBOLITE OF BLACK-ROCK ISLAND, ONTARIO, CANADA

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ABSTRACT. An island, approximately 260 by 150 feet, made up of olivine amphibolite is located in Blackstone Lake 15 miles southeast of Parry Sound. The rocks of the western part of the island show curvi-columnar structure.

The amphibolite consists of cummingtonite, olivine, and serpentine with small amounts of spinel, magnetite and chlorite; chlorite is locally abundant. A colorless amphibole, perhaps gedrite, forms coronas between olivine and the cummingtonite.

With the exception of olivine, the minerals of the amphibolite are of secondary origin and have probably formed from olivine and pyroxene and perhaps from feldspar, while serpentine and chlorite also formed from amphibole. The chemical composition of the rock comes closest to that of a picrite.

Diorite dikes cut the amphibolite. The cummingtonite is believed to have formed from an original pyroxene, a reaction in which the feldspar of the original rock may have taken part. Mg and Fe ions in excess of those required for amphibole formation aided the formation of spinel. The aluminum of the spinels is likely to have been derived from feldspar. Near the dikes the rock is essentially a spinel-amphibolite and olivine is absent, introduction of Fe from the dikes and redistribution of the alumina characterizing the major changes. It is possible that some Al has been introduced by the dikes.

INTRODUCTION

ROCKS made up of cummingtonite, olivine, and serpentine are rare, and a rock almost entirely composed of these components merits some attention. The olivine amphibolite forms an island, the so-called Blackrock Island (plate 1, fig. 1), in the southeastern part of Blackstone Lake, Conger Township, in the Parry Sound District of Ontario about 15 miles southeast of Parry Sound (fig. 1). It is located on lot 13, on the borders of concessions 8 and 9.

GENERAL GEOLOGY

The area is underlain by Precambrian metamorphic rocks which have been injected by pegmatites. The dominant rocks are granite gneisses. Besides small pegmatites which have been forced between the planes of foliation of the gneisses (lit-par-lit) or which cut the gneisses, there are large pegmatite dikes, some of which have been commercially exploited in the past.

The island is composed entirely of the olivine amphibolite, except for three small diorite dikes which cut the amphibolite in the southeastern part. These dikes are bordered by a narrow reaction zone of spinel-amphibolite.

STRUCTURE

The island has an approximate length of 260 feet and a maximum width of about 150 feet. It is separated from the mainland to the north by about 70 feet of water. The cliffs of the island's north shore drop off steeply; on the south side a submerged continuation of the amphibolite forms shoals. Likewise eastern and western extensions of the amphibolite are beneath the surface of the water. Faulting is probably responsible for the steep cliffs of the north shore.

The columnar structure in the amphibolite deserves particular attention. This structure extends for about 60-80 feet

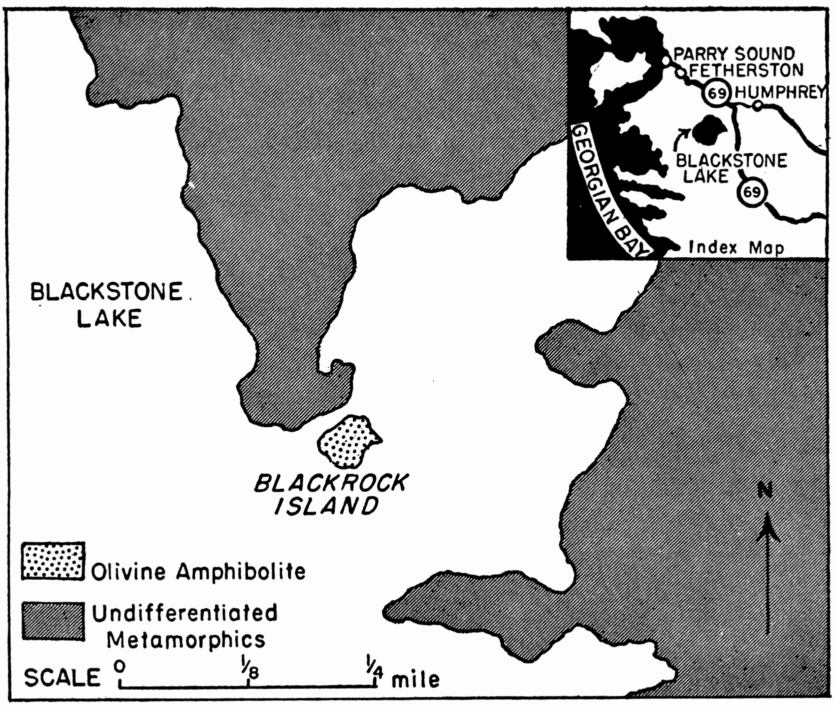

Fig. 1. Map of the southeastern part of Blackstone Lake showing the location of the olivine amphibolite.

from the extreme western tip of the island (plate 1, fig. 2). It then grades, almost imperceptibly, into a joint pattern of two approximately perpendicular joint sets. Although some columns have well-developed hexagonal prisms, many are pentagonal, quadrilateral, or even triangular (plate 2, fig. 1). Principles controlling the formation of hexagonal prisms have been explained by Mallet (1875), Bonney (1876) and Hewes (1948). It is frequently difficult to determine whether an exposure in the transitional zone shows columnar structure or not, as the intersecting joint pattern resembles quadrilateral columns.

Near the edge of the western cliff, columns diverge radially and downward from a center and curve considerably. At water level they are inclined at a low angle, but the angle rises steeply to almost vertical before flattening out again near the center from which the columns radiate. The columns therefore present an S-shaped pattern. For the sake of contrast it may be noted that columns about 20 to 30 feet southeast of the center are horizontal, while many on the cliff are almost vertical. Similar observations have been made by Iddings (1886, p. 322-323) at Watchung, New Jersey. Locally two sets of columns, one below the other, are inclined toward each other giving rise to a tapering columnar structure. Iddings (1909, p. 324) has described similar structures in the basalts of Watchung.

Columnar structures in igneous rocks are essentially confined to lava flows or sills, neither of which have solidified at great depth. A section in the type localities, Giant's Causeway, Ireland, or Watchung, N. J., shows the following columnar zones (Tomkeieff, 1940; Bucher and Kerr, 1948, p. 109):

(1) vertical columnar zone (bottom);

(2) curvi-columnar zone;

(3) pseudo-columnar zone (top).

The zone of vertical columnar joints is made up of thick, well-defined columns and is lowest in a typical section, but it was not observed in the area under discussion. The curvi-columnar zone is represented in the western part of the island (fig. 2), and grades into the pseudo-columnar zone to the east, where ill-defined columnar jointing is exhibited.

Only one well-defined center from which columns diverge has been noted on the island. In the Watchung basalt, where radiat-

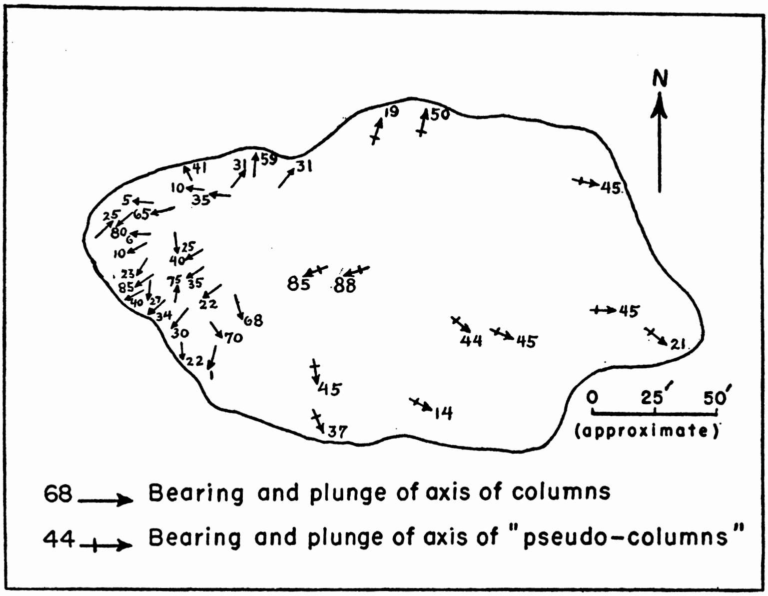

Fig. 2. Map of Blackrock Island showing the attitude of the columns.

ing columns also occur, similar centers are locally abundant. There vertical axes passing through central foci from which columns radiate outward and downward alternate with vertical axes toward which columns converge, as shown in figure 3. Bucher (1948), describing radiating columns in the Watchung basalt, suggested that as isothermal surfaces are normal to the attitude of the columns the same temperature must have been maintained at A and B, A′ and B′. Consequently the temperature along the axes DE and D′E′ was higher than in correspond-

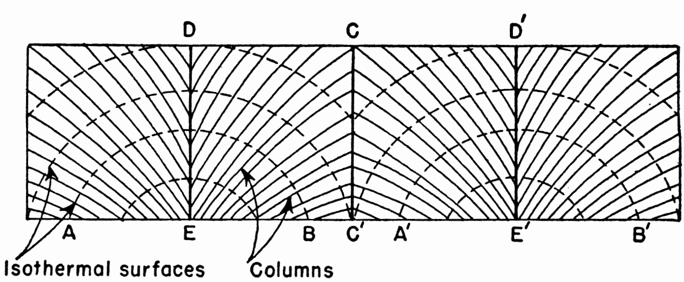

Fig. 3. Generalized cross section through the curvi-columnar zone showing radiating columns and isothermal surfaces. Modified after Bucher.

PLATE 1

Fig. 1. View of the olivine amphibolite island from the west. Evergreens on island serve as scale.

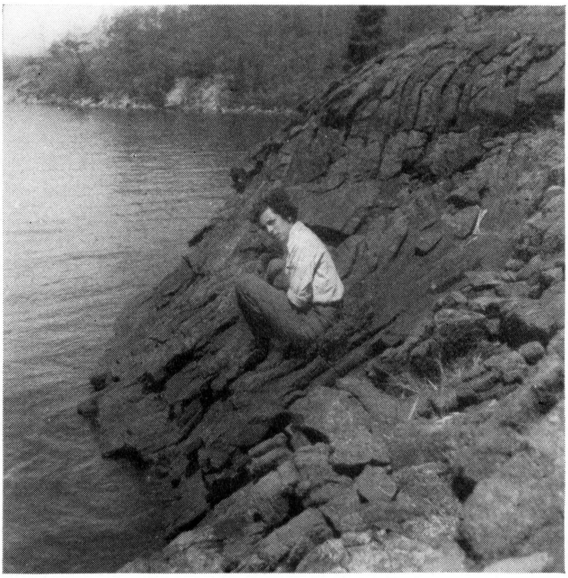

Fig. 2. Curvi-columnar structure in western part of island.

PLATE 2

Fig. 1. Columnar structure in western part of island. Hexagonal prisms as well as pentagonal, triangular and other poorly developed columns are shown. Note rough surface of rock. Pencil serves as scale.

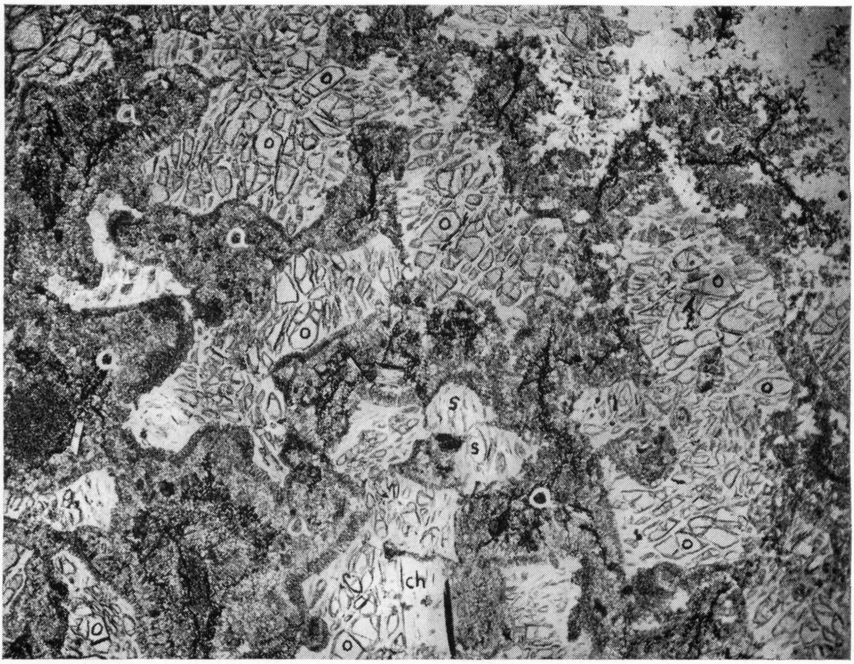

Fig. 2. Photomicrograph of olivine amphibolite showing the textural relations between the minerals. The minerals in this picture are: (a) cummingtonite, (o) olivine, (s) serpentine, (ch) chlorite. Note the reaction rims between olivine or serpentine and cummingtonite. The black opaque mineral is magnetite. A few spinel grains, too small to be marked, occur in the amphibole. 10x. (D. S. Robertson, photo.)

ing interaxial positions. He believes vents to have been located in the positions of DE and D′E′. The central focus of the western part of the island was probably located close to a vent. Only one such center was noted; erosion has perhaps obliterated evidence of others. For this reason the axis toward which the columns converge and the exact position of the vent cannot be established.

PETROGRAPHY

The rock on the island is surprisingly fresh. It has been affected by limited weathering which resulted in sharp and rough surfaces that resemble skin protuberances or minor honeycomb weathering. These pitted surfaces are particularly evident in the western part of the island. The columnar joints are covered by a brownish-red crust caused by the oxidation of the iron minerals. The protuberances, mostly dark green, are locally black and some are highly magnetic. The amphibolite is a fine- to medium-grained rock consisting of cummingtonite, olivine and serpentine (plate 2, fig. 2). Spinel, magnetite and carbonate are accessory minerals; locally spinel is abundant. Secondary amphiboles form thin coronas between olivine or serpentine and cummingtonite. Chlorite has replaced amphiboles and serpentine.

Modal analyses of this rock were run in duplicate and average values were taken. These are presented in table 1. The sections

TABLE 1

	Amphibole	Olivine	Serpentine	Spinel	Magnetite	Chlorite
1.	50.1%	..	38.0%	2.2%	9.7%	..
2.	38.8%	0.6%	53.0%	3.4%	3.9%	0.3%
3.	40.7%	..	52.5%	3.2%	2.9%	0.7%
4.	62.1%	15.1%	9.9%	7.1%	4.9%	0.9%
Aver.	47.9%	3.9%	38.3%	4.0%	5.4%	0.5%

Modes of olivine amphibolite, per cent by volume.

Sample 1 is from the northwestern part of the island; 2 is from the southwestern part; 3 approximately from the southcentral; and 4 from the eastern part of the island.

analyzed are believed to be representative except for chlorite. In several samples chlorite was abundant, but thin sections of these samples were not prepared. Two samples were composed of an estimated 35 per cent olivine, 45 per cent serpentine and 20 per cent amphibole.

Under the microscope (plate 3, fig. 1) an amygdaloidal structure is locally suggested. Whether or not these structures have at any time been true amygdules cannot be decided, but their appearance closely resembles that of amygdules. Some "amygdules" are elliptical or spherical, others are of widely varying shapes; several "amygdules" may have merged. They are usually separated from one another by olivine or serpentine and a reaction rim of a colorless orthorhombic amphibole borders them. Cummingtonite crystals, with their axes of elongation normal to the periphery of the "amygdules," stud their interior. The "amygdules" enclose spinels in intergranular relation to other minerals. Drop-shaped, worm-like, or sausage-shaped embryo spinel crystals are embedded in the amphiboles, with their long axes parallel to those of the latter, i.e., pointing in the approximate direction of the center of the "amygdule."

MINERALOGY

Amphibole.—The amphibole is a cummingtonite and makes up the larger part of the rock. It locally forms the "amygdules" previously described. In thin section it is colorless, but amphibole from the zone adjacent to the diorite dikes is green and pleochroic. The 2 V and extinction angle of amphibole in four different amphibolite specimens were determined on the universal

TABLE 2

Optical Data on Amphibole

Location	Pleochroism	2 V	$Z \wedge c$	Beta Index
SW part of island	colorless in thin section; fragments are pale green.	+87°	18°	1.649
SE part of island near the dikes	colorless in thin section; fragments are pale green.	+84°	18°	1.649
within ~5 ft. (±) of a dike	pale green to colorless in thin section.	+82°	18°	1.648
border zone of a dike	blueish-green to light green to light greenish-yellow in thin section.	+84°	17°	1.652

stage, the beta index was also taken. One sample was selected from the southwestern part of the island and three from the southeastern part; of the latter one was taken from the zone adjacent to the diorite dikes. The results are shown in table 2. The 2 V determinations were mostly obtained from a single optic axis by stereonet plots. Hess (1949) states that 2 V determinations from one optic axis can involve errors of the order of $\pm 5°$. This may in part explain the difference in the 2 V of the samples measured; on the other hand, an average of six independent determinations was taken on each thin section and the respective numerical differences were $\pm 2°$. The refractive index determinations are probably ± 0.003.

Bordering the diorite dikes is a zone of deep blueish-green spinel-amphibolite (plate 3, fig. 2) up to 8 inches wide carrying a strongly pleochroic amphibole. Color and pleochroism are indicative of a higher iron content and suggest that iron was introduced by the diorite dikes. The amphibole from this zone has a slightly higher refractive index than amphibole from other parts of the island. Winchell (1951) correlates the refractive indices of the members of the kupfferite-grunerite series, to which cummingtonite belongs, with their chemical composition. Exact compositions of amphiboles from optical data are impossible to obtain, but the approximate composition can be worked out from Winchell's curve. According to this curve the cummingtonite contains about 41 per cent of the grunerite molecule. Most amphibole crystals are approximately 0.05 to 0.3 mm in diameter.

Cummingtonite and olivine or serpentine are usually separated by a shell or corona of a colorless mineral which is biaxial negative, has straight extinction, and a 2 V of 80°. These properties correspond to gedrite, the aluminous anthophyllite.

Spinel.—The spinel (magnesia spinel) is green or blueish-green, but in some clusters grades marginally into grains of brownish tint. Embryo spinels are usually enclosed in amphibole, but large spinel crystals are intergranular. Many embryo spinel crystals present the appearance of "streaming" through amphiboles toward the intergranular spinels. Corroded amphibole crystals containing green embryo spinel grains are enclosed in serpentine. Spinel crystals of varying size also occur in serpentine, including clusters more than ½ mm in diameter.

These were probably interstitial between amphibole crystals, but the latter have been replaced by serpentine.

Olivine and serpentine.—Most of the olivine has been replaced and occurs as small anhedra surrounded by serpentine. That many individual crystal remnants are parts of original larger crystals is manifested by their optical continuity. Black streaks of magnetite cross serpentine at all angles.

The olivine has an optic axial angle of about 86°, optically negative; the alpha index is near 1.678. These figures indicate a molecular proportion of about 22 per cent fayalite in the olivine.

The serpentine is one of the most abundant constituents of the rock. It is mostly antigorite, some crossfiber veinlets suggest chrysotile. The serpentine has replaced olivine and amphibole.

Pyroxene.—Pyroxenes were not detected in the olivine amphibolite but were identified in the spinel-amphibolite. 2 V measurements on two different grains gave +61°, the extinction angle ($Z \wedge c$) of one grain was 54° (this last reading, however, was not considered satisfactory). These properties correspond to augite. The mineral is slightly pleochroic from light green to a very pale pink.

Chlorite.—The chlorite, probably pennine, is a common replacement product of amphiboles and serpentine. It is green in hand specimen and thick fragments, but colorless in thin sections. The beta index is near 1.584. The mineral is practically uniaxial, optically positive. It locally shows polysynthetic twinning and many flakes are bent. Chlorite occurs in veins with crystals up to 1½ feet in length. It is also found disseminated

TABLE 3

Table of Paragenetic Sequence

	Magmatic	Postmagmatic
Olivine	--------	
Pyroxene	--------	
Feldspar (?)	--------	
Amphibole		--------
Spinel		--------
Serpentine		--------
Magnetite		--------
Chlorite		--------

throughout a large part of the island. The chlorite encloses corroded amphibole crystals as well as spinel and magnetite. Magnetite grains are aligned parallel to the chlorite cleavage.

DIORITE DIKES

In the southeastern part of the island three small dikes cut the olivine amphibolite (plate 4); the biggest dike is about 9 inches in maximum width. The dikes are conspicuous because they stand out in relief and have a white color, which has probably been caused by kaolinization in the surface layer. The dikes are bordered on both sides by blueish-green spinel-amphibolite up to 8 inches wide. The dikes are composed of about 85 or 90 per cent labradorite of composition An_{60} to An_{65}; the other essential mineral is green hornblende. The dikes may almost be considered anorthosites. The feldspar has been highly sericitized.

TABLE 4

Chemical Analysis of Olivine Amphibolite

SiO_2	40.74
Al_2O_3	10.91
Fe_2O_3	4.51
Feo	6.24
MgO	24.16
CaO	5.17
Na_2O	0.80
K_2O	0.05
H_2O+	6.00
H_2O-	0.87
CO_2	0.08
TiO_2	0.10
P_2O_5	0.02
Cl	0.10
S	0.01
Cr_2O_3	0.05
MnO	0.15
	99.96
less O equivalent to S and Cl	0.03
Total	99.93

Specific gravity 26.5/4=2.928.

H. Baadsgaard, analyst.

TABLE 5

Norm of Olivine Amphibolite*

Albite	6.82
Anorthite	27.52
Olivine	37.73
Hypersthene	20.08
Ilmenite	0.15
Magnetite	6.96
Corundum	0.31
Halite	0.13
Total	99.70

*The norm was calculated after deducting from the analysis the H_2O, S, and CO_2.

TABLE 6

Qualitative Spectrographic Analysis of Olivine Amphibolite

Antimony	ND	Indium	ND	Titanium	trace (0.01)
Arsenic	ND	Lead	trace (0.001)	Tungsten	ND
Beryllium	ND	Manganese	trace (0.25)	Uranium	ND
Bismuth	ND	Mercury	ND	Vanadium	trace (0.005)
Boron	trace (0.03)	Molybdenum	ND	Zinc	trace (0.005)
Cadmium	ND	Nickel	low (0.15)	Zirconium	ND
Cerium	ND	Silver	trace (0.0005)	Yttrium	ND
Chromium	trace (0.01)	Strontium	trace (0.05)	Ytterbium	ND
Cobalt	trace (0.02)	Tantalum	ND	Scandium	ND
Columbium	ND	Tellurium	ND		
Copper	trace (0.005)	Thorium	ND		
Gallium	trace (0.002)	Tin	trace (0.001)		

Key to amounts:

low .... 0.1 to 1.0%
trace .... less than 0.10%
ND .... none detected

The values given in brackets are visual estimates based on line intensity; they are not quantitative figures.

CHEMICAL CHARACTERISTICS

The chemical composition of the olivine amphibolite comes closest to that of picrites. The norm of the rock likewise agrees with that of picrites. The presence of small amounts of boron, cobalt, copper, chromium, gallium, lead, manganese, nickel, silver, strontium, tin, vanadium and zinc found in the amphibolite, is commonly noted in basic rocks.

SIMILAR ROCKS FROM OTHER AREAS

Hadley (1949) described a troctolite-amphibolite associated with an edenite-amphibolite from the Buck Creek peridotite of North Carolina. Lawson (1903, p. 222-225) noted an amphibole olivinite at Spanish Peak, California, and Merrill (1898) described amphibole serpentine rocks from the New York metropolitan area. Rosenbusch-Mügge (1927, p. 515) cite similar occurrences from Austria. Daly (1914, p. 29), Washington (1917, p. 714, 724), and Hess (1933, p. 382) present analyses of rocks similar in composition to the rock under discussion.

PETROGENETIC CONCLUSIONS

The chemical composition of the rock comes closest to that of a picrite. The composition of picrites differs from that of peridotites essentially in a higher aluminum content. It may be argued that the original rock is unlikely to have been a picrite as some evidence of plagioclase would have probably remained; but Hadley (1949, p. 120) points out that in the edenite-amphibolite of Buck Creek, North Carolina, which has formed at the expense of an original troctolite-amphibolite, a spinel-amphibole intergrowth has apparently replaced the plagioclase. He suggested (1952, personal communication) that the olivine amphibolite of Parry Sound may have also been plagioclase-bearing. The presence of almost 6 per cent CaO in the analysis excludes dunite as a possible source rock. The olivine amphibolite is not considered a primary magnetic rock for the following two reasons:

(1) Cummingtonite and spinel are not typically magmatic minerals.

(2) In a discontinuous reaction series in a magma, pyroxene precedes amphibole and by the time the amphibole has formed the olivine has usually been dissolved.

A picrite is believed to have been the source rock.

The cummingtonite has probably formed at the expense of an original pyroxene, a reaction in which the feldspar of the original rock may have taken part. Magnesium and iron ions in excess of those required for amphibole formation aided the formation of spinel. The aluminum may have been derived from the feldspar. Hadley (1949, p. 120) contends that "the disseminated corundum [of Buck Creek, North Carolina] in the edenite-amphibolite appears to have resulted from concentration of alumina originally contained in the plagioclase of the troctolite."

With the exception of relic olivine anhedra the minerals of the amphibolite are of secondary origin. Serpentine and chlorite formed at the expense of the olivine and amphibole and, together with magnetite, which is contemporaneous with the serpentine, were the last minerals of the rock to form. Of interest is the variable modal composition of the rock, as shown by the four analyses, which probably largely depended on the paths of the modifying emanations.

Bordering the dikes the olivine amphibolite has given way to a spinel-amphibolite in which olivine has not been observed. This rock is composed of amphibole and spinel but also contains some clinopyroxene, probably augite. The disappearance of olivine and the unusual abundance of spinel (up to approx. 30% by volume) suggests a redistribution of the alumina. It is also possible that some aluminum ions have been introduced by the diorite dikes. The distinct color and pleochroism of this amphibole and the somewhat higher refractive index indicate an introduction of iron.

The "amygdaloidal" structure of this rock is as unusual as its mineralogical composition. Rocks exhibiting columnar structure are commonly amygdaloidal; the rocks of the Watchung Mountains and the Palisades of New Jersey may serve as examples. The filling of amygdules varies from quartz, calcite and zeolites to hydrated ferromagnesian minerals which Tyrrell (1926) calls "green earths." It seems possible that the "amygdules" of the olivine amphibolite were originally filled with hydrated ferromagnesian minerals which in the course of the changes that affected the rock were converted into amphibole—introduction of aluminum and dehydration characterizing the major changes. Magnesium and iron ions in excess of those required for amphibole formation gave rise to spinels on reacting with the aluminum. The pattern of distribution of the drop-shaped, worm-like or sausage-shaped spinel microlites that are embedded in the amphiboles of the "amygdules" seems significant. Usually somewhere in the "amygdules" is a large intergranular spinel crystal, and the elongated spinel microlites seem to converge toward it. The impression is conveyed that the components making up the elongated embryo spinels were "streaming" toward the intergranular spinels when final crystallization occurred.

ACKNOWLEDGMENTS

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PLATE 3

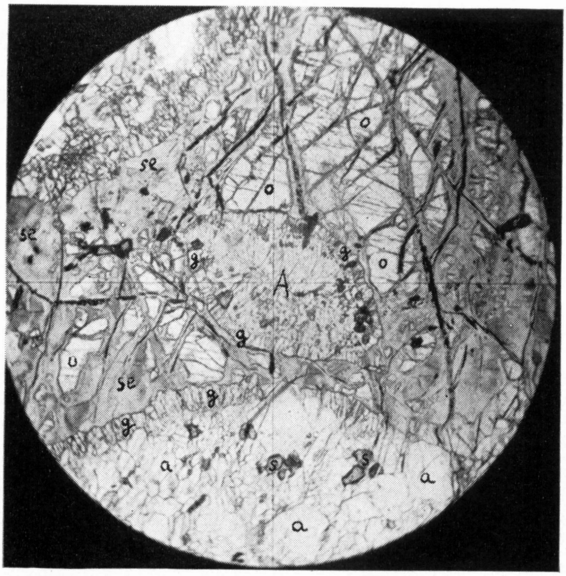


Fig. 1. Photomicrograph of olivine amphibolite showing an "amygdule" (A) bordered by othorhombic amphibole (g), and olivine (o), serpentine (se), cummingtonite (a) and spinel (s). 40x.

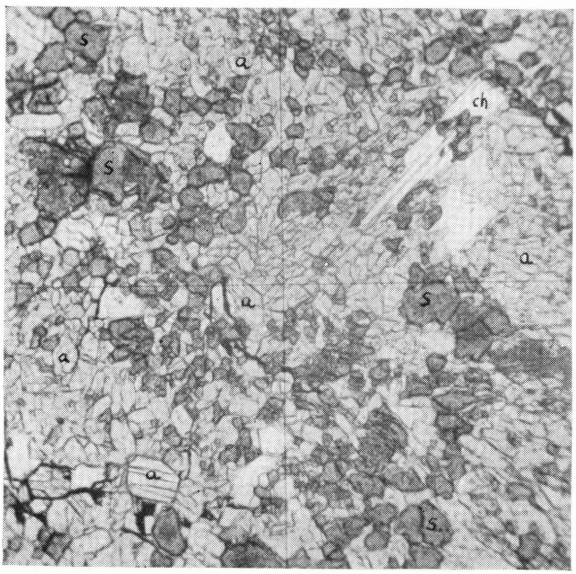
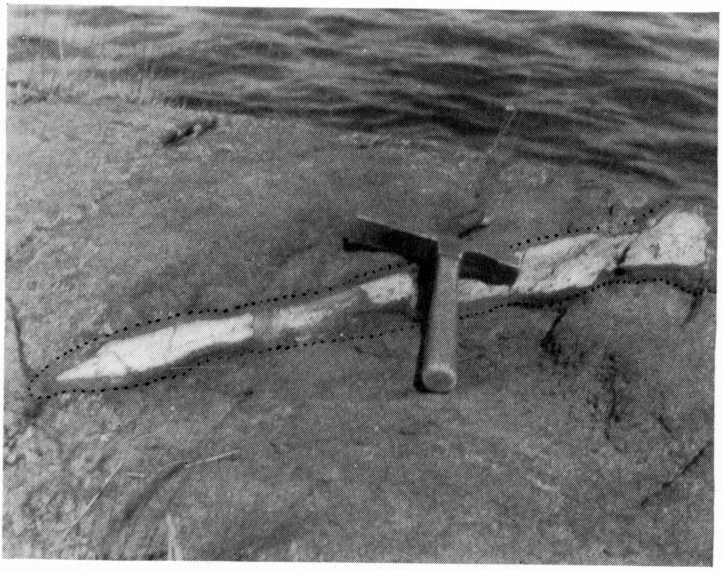


Fig. 2. Photomicrograph of spinel-amphibolite showing amphibole (a), spinel (s), and chlorite (ch). 55x.

PLATE 4



Diorite dike (under hammer) bordered by a reaction zone of spinel-amphibolite. The reaction zone is delimited by dots.

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