GRANULITE AND PERIDOTITE INCLUSIONS FROM PRINDLE VOLCANO, YUKON-TANANA UPLAND, ALASKA

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Abstract.—Lava of Prindle Volcano, an isolated alkali-olivine basalt cone in the Tanacross C–2 quadrangle, Yukon-Tanana Upland, Alaska, contains abundant peridotite and granulite inclusions. Prindle Volcano reinforces the evidence for the existence of a belt of eruptive centers of similar peridotite-bearing alkali-olivine basalt along the western margin of North America from Mexico to Alaska.

Prindle Volcano is a small inactive basaltic cone located on the southeast flank of the ridge which forms the interstream divide between the East Fork and the Dennison Fork of the Forty Mile River, Tanacross C–2 quadrangle, Yukon-Tanana Upland, Alaska (fig. 1). The base of the cone is about 3,300 feet above sea level. Peaks along the adjacent ridge rise to elevations exceeding 4,500 feet.

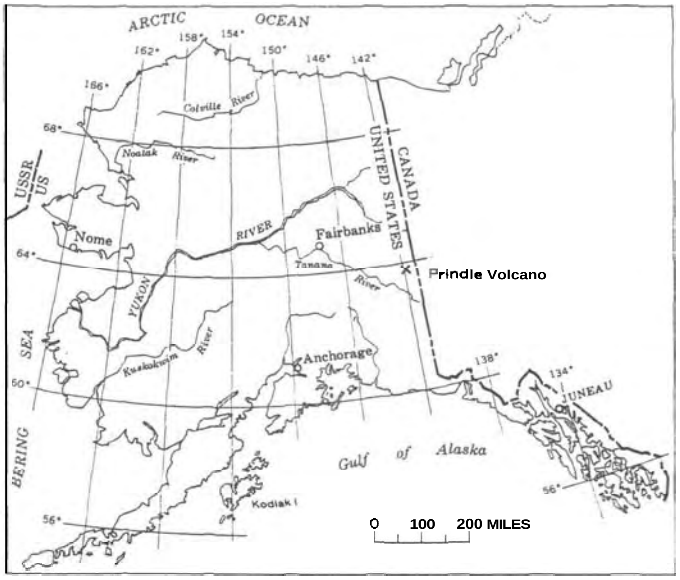

FIGURE 1.—Index map of Alaska, showing location of Prindle Volcano.

The volcano was first photographed and described by L. M. Prindle in 1905 (Mertie, 1931, p. 13, 39-40). It was again visited by geologists of the U.S. Geological Survey during the summers of 1963 and 1964. The cone is of particular interest because of its apparent youthfulness, its relative isolation from other occurrences of alkali-olivine basalt, and abundant ultramafic and granulite inclusions in the cone and adjacent flow.

The cone is approximately 3,000 to 3,500 feet in diameter at its base, and contains a crater about 300 feet deep, which is breached on the south (fig. 2). The highest elevation, 4,100 feet, is found on the northwest rim of the crater. A lava flow extends downslope from the breached crater to the southeast for approximately 4 miles, where it turns southwest and continues for 3 more miles along the west side of the valley of the East Fork.

The slopes of the cone are covered by grass, low bushes, and small spruce trees. Muskeg, containing

FIGURE 2.—Aerial view of Prindle Volcano. Ridge in background is composed of Birch Creek Schist. View north, 1963.

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frost-wedge polygons and small ponds, mantles the crater floor, and permafrost is present at a depth of 2 feet. The lava flow in the valley is covered with trees.

The cone shows little evidence of dissection and frost action, which suggests that the eruptive activity occurred during Quaternary time.

GEOLOGIC SETTING

The subvolcanic basement is composed of biotite and hornblende gneisses and schists, including augen gneiss with large feldspar porphyroblasts (Pelly Gneiss of Mertie, 1937, p. 203). The gneisses and schists have been intruded by fine- to medium-grained biotite-muscovite granite, porphyritic rocks, and pegmatite. Fine-grained biotite-muscovite granite underlies basalt at the southeastern base of the cone, and outcrops of similar granite occur on the ridge northwest of the cone. Porphyritic granitic rock crops out 1½ miles southeast of the volcano. The gneisses and schists that compose the ridges surrounding the cone are cut by granitic and pegmatitic dikes. Although mineral assemblages ranging from greenschist to amphibolite facies have been recognized in crystalline schists collected by the senior author during reconnaissance geologic mapping of areas adjacent to Prindle Volcano in the Tanacross quadrangle, granulite facies assemblages have not been detected.

The probable absence of exposed granulite facies terrane in the surrounding area is reinforced by petrographic data given by Mertie (1937, p. 48–52), which include amphibolite but not granulite facies mineral assemblages.

The gneisses and schists were mapped as Birch Creek Schist by Mertie (1937, p. 47 and pl. 1) and were considered by him to be of early Precambrian age (Mertie, 1937, p. 55). New regional stratigraphic and structural evidence has suggested that some units currently mapped as Birch Creek Schist may be younger (Forbes, 1960, p. 2085). The Birch Creek Schist is, at least in part, polymetamorphic (Forbes, 1960, p. 2085), and the dates of the events are still in question.

The granitic rocks exposed near the base of Prindle Volcano are similar in lithology and occurrence to those of Mesozoic age (Mertie, 1937, p. 210; Wasserburg and others, 1963, p. 258–259) cropping out elsewhere in the Yukon-Tanana Upland.

HOST BASALT

The cone and lava flow are composed of vesicular alkali-olivine basalt, made up of (1) clinopyroxene, (2) olivine, (3) opaque minerals, and (4) a fine-grained to microcrystalline groundmass believed to contain occult nepheline and potassium feldspar. Plagioclase feldspar is conspicuously rare or absent. Two bulk chemical analyses, one of the scoriaceous phase (PVF–1–1–63) and the other of the flow phase (PVF–2–9–63) of the basalt, are shown in table 1, together with their respective norms.

TABLE 1.—*Bulk chemical analyses and molecular norms of basalt from the cone of Prindle Volcano*

[Analyst: M. Chiba, Japan Analytical Chemistry Institute, Tokyo, 1964]

	PVF 1-1-63 (scoriaceous phase)	PVF 2-9-63 (flow phase)
Chemical analyses (weight percent)		
SiO_2	42.87	42.84
Al_2O_3	11.17	10.45
Fe_2O_3	7.98	4.64
FeO	4.78	8.14
CaO	9.56	9.96
MgO	13.82	14.36
Na_2O	3.71	3.78
K_2O	1.88	1.83
H_2O+	.39	.15
H_2O-	.45	.27
TiO_2	2.71	2.67
P_2O_5	.96	1.03
MnO	.16	.17
Cr_2O_3	.06	.07
Total	100.50	100.36
Molecular norms		
Or	10.95	10.59
Ab	9.03	3.89
An	8.16	6.01
Ne	14.29	17.61
Di	25.95	28.63
Ol	18.49	22.74
Mt	5.74	4.75
Il	3.72	3.64
Ap	1.98	2.10
Ht	1.65	.00
	99.96	99.96

The comparative analyses are similar, but the flow phase is less oxidized than the scoriaceous phase, as shown by the difference in the Fe_2O_3:FeO ratio. The flow phase of this basalt contains 17.61 percent normative nepheline, and because of the presence of both nepheline and olivine in the norm, it is clearly an alkali-olivine basalt, as defined by Yoder and Tilley (1962, p. 352), or a basanitoid as defined by Macdonald and Katsura (1964, p. 86). Although nepheline is present in the norm, it has not been detected in the groundmass of the basalt.

PERIDOTITE INCLUSIONS

The basalt of Prindle Volcano is rich in phenocrystal and xenocrystal olivine as well as inclusion aggregates. Xenocrystal material also includes orthopyroxene, clinopyroxene, spinel, and plagioclase. The xenocrysts have apparently been derived by attrition from an unusually rich suite of ultramafic and feldspathic inclusions.

The ultramafic inclusions range in size from xenocrysts to rounded polycrystalline masses up to 5 inches in diameter. Most of the ultramafic inclusions are relatively unaltered, but some specimens contain secondary iddingsite along olivine grain boundaries, and orthopyroxene grains occasionally display marginal clinopyroxene reaction zones in contact with the host basalt.

Peripheral alteration zones are more commonly developed in the feldspathic (granulite) inclusions, as characterized by the partial fusion of quartz and plagioclase grains, and albite exsolution in potassium and plagioclase feldspar.

Although Ross and others (1954, p. 696–703), Forbes and Kuno (1965), and others have discussed the dominance of the assemblage diopside-enstatite (bronzite)-olivine-spinel in worldwide peridotite inclusion suites, several other volumetrically important peridotite mineral assemblages occur in the Prindle inclusion suite. Assemblages recognized to date include:

olivine-orthopyroxene-clinopyroxene-spinel
olivine-orthopyroxene-spinel
olivine-clinopyroxene-spinel
clinopyroxene-spinel
orthopyroxene-spinel

The textures and the fabrics of the inclusions are typical of those found in other peridotites. Variations in the textures of the different inclusion types are chiefly related to the proportion of two types of olivine grains. Coarse grains (up to 2 mm) with ragged boundaries and abundant deformation banding are often markedly inequidimensional; fabrics defined by these grains show no evidence of preferred form orientation. These large grains are surrounded by smaller (less than 1 mm), equidimensional grains which display little or no evidence of straining. Characteristically, these small second-generation grains have straight grain boundaries that meet at angles of approximately 120°. These same textures and structures have been found in other inclusions (Talbot and others, 1963, p. 164) and in intrusive dunite masses (Ragan, 1963, p. 563), and they indicate solid-state deformation and recrystallization, at least in the later history of the rock.

The fabric of the smaller olivine grains in several samples was determined. Crystallographic orientations of 50 grains of approximately uniform size were measured. Partial diagrams, using measurements from widely spaced traverses, were constructed; these diagrams showed the same basic patterns thus demonstrating the statistical homogeneity of the fabric on the scale of a single thin section. Crystallographic Z forms a point maximum; X forms a broad girdle approximately to the Z maximum, and Y, though with greater scatter, also shows participation with the ,girdle. Identical patterns of preferred orientation have also been found in other peridotite inclusions (Talbot and others, 1963, p. 167) and in intrusive bodies (Battey, 1960, p. 720).

GRANULITE INCLUSIONS

Many of the fragments in the suite of inclusions are not peridotite, but crystalline schists of the granulite facies. Gneissose structure is common in these fragments as defined by the preferred orientation of pyroxene and the alternating compositional layers of pyroxene and plagioclase; the texture is typically crystalloblastic. The assemblages are characterized by hypersthene and (or) clinopyroxene and plagioclase.

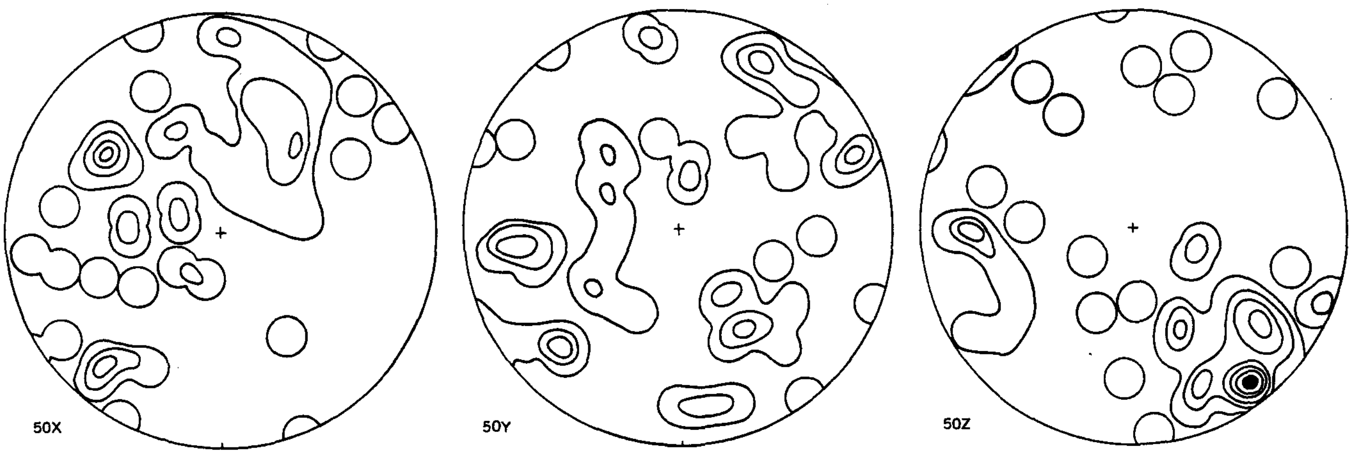

FIGURE 3.—Partial orientation diagrams of crystallographic X, Y, and Z for 50 olivine grains from inclusions in basalt from Prindle Volcano. Contours are spaced at 2-percent intervals, that is, 2, 4, 6 percent, and so forth, per 1 percent of area. (Equal area net, lower hemisphere.)

Mineral assemblages recognized to date include the following:

- plagioclase-clinopyroxene-carbonate
- plagioclase-clinopyroxene-carbonate-quartz
- hypersthene-andesine-quartz
- plagioclase-clinopyroxene-hypersthene-quartz
- plagioclase-clinopyroxene-hypersthene
- plagioclase-hypersthene-quartz

Accessory minerals include apatite, zircon, magnetite, and rutile. Minor sanidine has been detected in some of the above assemblages, but the role of sanidine as a stable coexistent phase remains in doubt, as secondary annealing from contact metamorphism may have recrystallized earlier potassium feldspar under conditions of the sanidinite facies. However, the uniform distribution of sanidine grains throughout the inclusions, seems to argue against a contact metamorphic origin.

Micas and amphiboles (hydrous phase) are absent. The occurrence of carbonate and quartz in some assemblages, without wollastonite, probably indicates that CO_2 pressures were higher than those associated with the stability field of wollastonite. These findings are in harmony with the views of Fyfe and others (1958, p. 234) who have noted that "wollastonite and grossularite characteristically are absent from these facies [granulite facies]." The presence of quartz + carbonate without wollastonite in the assemblage plagioclase-clinopyroxene-carbonate-quartz further supports the granulite facies origin of the feldspathic inclusions.

CONCLUSIONS

The occurrence of peridotite inclusions in the alkali-olivine basalt of Prindle Volcano reinforces the evidence for the existence of a regional belt of such occurrences along the western margin of the North American continent from Mexico to northwestern Alaska, and thence to the Pribilof and Kanaga Islands. Recently Forbes and Kuno (1965), in summarizing the regional petrology of inclusion-bearing alkali-olivine basalts, noted that over 200 of these occurrences are now known. The host basalts are characteristically alkali-olivine basalts with nepheline and (or) leucite in the norm, and a strong similarity exists between the bulk chemical compositions of the host basalts in both the continental and oceanic occurrences. The relative position of Prindle Volcano to other peridotite-inclusion localities is shown in figure 4.

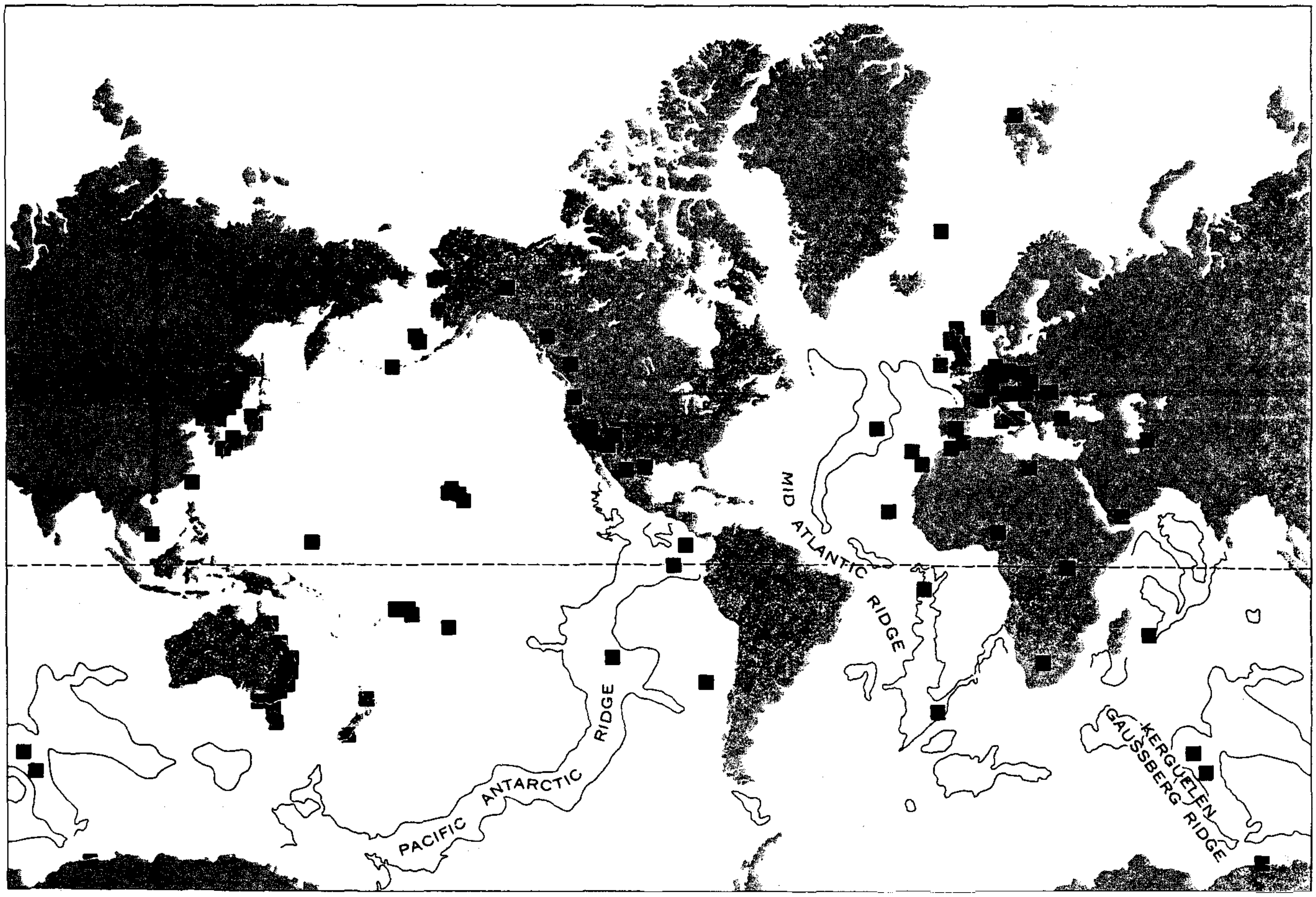

FIGURE 4.—Localities throughout the world where peridotite inclusions in basalt, including those from Prindle Volcano (area of report), are known. (After Forbes and Kuno, 1965.)

The coexistence of inclusions of hypersthene and hypersthene-diopside granulite, and peridotite, in the Prindle basalt is of great interest, as localities containing both inclusion types are rare. Eclogite fragments, such as those described from the basalt breccia pipes in eastern Australia (Lovering and Richards, 1964) may also exist in such occurrences; however, they have not been found in the Prindle basalt. It is possible that the granulite fragments were derived from the deep crust, as granulite-facies terrane is not known to occur in the surface exposures of the Birch Creek Schist in interior Alaska; however granulite-facies rocks have been reported from a fault block along the south margin of the Denali fault near the head of the Gulkana Glacier, about 130 miles southwest of Prindle Volcano (Hawkins and Ragan, 1965; Ragan and Hawkins, 1965).

Chemical and mineralogical studies of these inclusions and their constituent mineral phases are continuing, and it is hoped that the necessary evidence will be found to distinguish between a mantle versus a crustal origin for the inclusions.

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