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STRUCTURAL AND TEXTURAL RELATIONSHIPS OF AMPHIBOLE AND PHLOGOPITE IN PERIDOTITE INCLUSIONS, DISH HILL, CALIFORNIA[1]

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ABSTRACT

Peridotite inclusions in basanite at Dish Hill and Siberia craters near Ludlow, California, contain abundant amphibole, smaller quantities of phlogopite and apatite, and rare plagioclase. These minerals occur as veins transecting the peridotite and as interstitial components. Veins of undeformed amphibole cut across wehrlite-lherzolite layering and metamorphic foliation in lherzolite and offset kink bands in olivine, indicating that the amphibole postdates both anhydrous mineral layering and plastic deformation of the peridotite. Gradations in textural behavior of amphibole from veins to interstitial modes of occurrence suggest that all of the amphibole and associated minerals are post-consolidation additions to the peridotite, unrelated to its original crystallization. This conclusion is supported by the presence of amphibole with the same textural relations in all types of peridotite, irrespective of their modal composition or degree of deformation and recrystallization.

The source of the secondary hydrous minerals is not known. They may predate the basanite and have contributed to its formation, or they may have been derived from the basanite or related magma. The absence of amphibole phenocrysts in the basanite, as well as similar occurrences of amphibole in alpine-type peridotites that were not carried into the crust by mafic alkaline magma, support the former view. Both alternatives are currently under investigation.

INTRODUCTION

Dish Hill and the adjacent Siberia crater[2] are cones of basanite and nepheline basanite agglutinate (Table 1, nos. 1–3) located about 70 miles east of Barstow, California and one-half mile north of U. S. Highway 66. The cones rest on Mesozoic (?) granitic rocks, fragments of which are enclosed in the basanite. The fission-track age determined by C. W. Naeser, U. S. Geological Survey) of apatite from a granitic inclusion shows the cones to be late Pliocene or early Pleistocene (2.1 ± 0.2 m.y.). Fission tracks in sphene and zircon were not completely annealed, and the zircon age of 78 m.y. is the minimum age of the granitic rocks.

White (1966, p. 255) mentioned the presence of polished selvages composed of amphibole, biotite, and apatite on peridotite inclusions

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[1] Publication authorized by the Director, U.S. Geological Survey.

[2] The largest cone at this locality, called Dish Hill on the Bagdad 15′ quadrangle, was apparently (W. S. Wise, written communication, 1969) referred to as Siberia crater by Brady and Webb (1943). A smaller cone, heretofore unrecognized, immediately adjacent to Dish Hill at its south flank, is called Siberia crater in this report. Other authors refer to the locality in general as Ludlow, California (Ross and others, 1954; Hess, 1955) or Trojan siding (Carter, 1965).

TABLE 1. CHEMICAL ANALYSES AND CIPW NORMS OF ROCKS

	1	2	3	4	5
SiO_2	44.41	44.26	44.85	44.35	44.08
Al_2O_3	14.05	14.7	15.87	2.97	3.62
Fe_2O_3	4.28	6.4	3.10	.67	1.06
FeO	7.89	6.51	8.18	7.59	8.21
MgO	7.59	7.68	8.52	40.80	39.06
CaO	8.99	8.17	9.37	2.55	2.85
Na_2O	4.09	4.20	4.00	.20	.29
K_2O	2.49	2.23	2.16	.01	.01
H_2O^+	.86	.98	.00	.06	.01
H_2O^-	.47	.01	.00	.03	.01
TiO_2	3.37	3.41	2.97	.14	.12
P_2O_5	1.30	1.27	.62	.02	.01
MnO	.19	.23	.19	.13	.16
CO_2	.10	.17	.01	NIL	.03
Cl			.04		.00
F			.08		.01
Cr_2O_3			.05	.41	.36
NiO			.02	.31	.25
Less O=F			.04		
Total	100.08	100.22	99.99	100.24	100.14
or	14.70	13.15	12.76	0.06	0.06
ab	15.55	21.44	10.94	1.69	2.45
an	12.61	14.64	19.12	7.16	8.54
ne	10.31	7.60	12.25		
hl			.07		
wo	9.53	6.87	9.63	2.23	2.20
en	6.69	5.61	6.48	16.32	15.38
fs	2.03	.43	2.41	2.18	2.28
fo	8.55	9.44	10.32	59.60	57.29
fa	2.86	.80	4.24	8.78	9.37
mt	6.20	9.26	4.49	.97	1.54
cm			.07	.60	.53
il	6.40	6.46	5.64	.27	.23
ap	3.08	3.00	1.47	.05	.02
fr			.05		.02
cc	.23	.39	.02		.07

Nos. 1, 2 from Wise (1966); zeolitic basanite, Dish Hill; No. 3, basanite bomb, Siberia crater; no. 4 from Hess (1955); peridotite, Dish Hill; No. 5, amphibole lherzolite, Siberia Crater Nos. 3, 5 new analyses by Elaine L. Munson, U.S. Geological Survey.

from Dish Hill. Wise (1966) gave an analysis (Table 2, no 1). of a kaersutite xenocryst from Dish Hill. In addition to occurrences as selvages and xenocrysts, our samples also include a large number of peridotites

TABLE 2. CHEMICAL ANALYSES OF MINERALS

	1	2	3	4	5	6	7	8	9
SiO_2	38.79	40.34	40.91	54.40	51.42	0.44			
Al_2O_3	14.35	13.81	.13	4.10	5.97	41.68		3.7	5.8
TiO_2	6.30	4.36	.01	.003	.24	2.71		.08	.37
Fe_2O_3	6.35	4.80	.00	.00	1.43	7.96			
FeO	6.95	6.33	8.96	6.83	2.57	8.64	9.6	6.2	2.8
MnO	.12	.14	.15	.13	.15	.13	.15	.15	.08
MgO	12.08	13.59	48.95	32.84	16.17	19.71	49.3	33.5	15.2
CaO	10.78	11.13	.17	.82	19.95	.00	.07	.74	19.9
Na_2O	2.32	2.74	.02	.04	1.36				1.5
K_2O	1.70	1.39	.00	.00	.10				
H_2O^+	.50	1.0							
			.20	.15					
H_2O^-	.16	.01							
P_2O_5	.14								
F		.14							
Cr_2O_3			.03	.76	.80	18.34		.37	.95
CoO			.01	.005					
NiO			.34	.07	.045		.39		
V_2O_5					.03				
Less O=F		.06							
Total	100.54	99.72	100.28	100.14	100.24	99.61			

No. 1, kaersutite xenocryst, Dish Hill; no. 2, kaersutite selvage on lherzolite, Siberia crater; nos. 3, 7, olivine from lherzolite; nos. 4, 8 orthopyroxene from lherzolite; nos. 5, 9 clinopyroxene from lherzolite; no. 6 spinel from lherzolite. No. 1 from Wise (1966); No. 2, new analysis by C. O. Ingamells, U. S. Geological Survey; nos. 3–6 from Ross and others (1954); nos. 7–9 averages of partial analyses from White (1966).

with interstitial amphibole and phlogopite, and a few with veins composed of amphibole, phlogopite, rare apatite, and very rare plagioclase. The multiple modes of occurrence of amphibole and mica offer an unusual opportunity to determine the relations between the peridotite and hydrous minerals.

XENOCRYSTS[1]

Fragments of amphibole are abundant in the basal agglomerates of Dish Hill and Siberia craters but are less common in the basanite agglutinate and flows. The amphibole grains, as much as 3.5 cm long, typically have highly irregular shapes, but a number of them were broken along the prismatic cleavages. The freshness of such cleavage surfaces, in contrast

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[1] Xenocrysts of anhydrous minerals derived from the peridotite are common, as are large, black aluminous clinopyroxenes (not described in this paper).

to the more common wavy, glazed, and pitted surfaces, suggests breakage shortly before or during eruption at the surface. Gradations are readily observed in the basal agglomerates between large peridotite xenoliths with selvages of amphibole and aggregates or single grains of amphibole with very small remnants of attached lherzolite. Irregular shapes of the isolated amphibole grains apparently result from comminution of amphibole-bearing peridotite to grain size or smaller thereby indicating that the isolated grains were derived from veins in the peridotite; that is, they are xenocrysts, not phenocrysts.

The composition (Tables 2 and 3, no. 1) of an amphibole xenocryst is substantially different from that of a selvage amphibole (Tables 2 and 3, no. 2), the xenocryst having higher iron, TiO_2 and K_2O and lower SiO_2, MgO, and H_2O. Similar compositional trends between selvage and interstitial amphibole were established with probe data to be reported elsewhere.

OCCURRENCE AND COMPOSITION OF THE XENOLITHS

A large number of xenoliths were ejected in the earliest eruptions at Dish Hill and Siberia craters. Basanite magma apparently was rapidly chilled during initial venting, as most of the xenoliths have only very thin skins of basanite or no coating at all.

Triangular modal plots (Fig. 1) based on field estimates (Jackson, 1968) of mineral proportions in 100 xenoliths from each crater show that, exclusive of the hydrous minerals, the peridotites are predominantly olivine-

TABLE 3. STRUCTURAL FORMULAS OF AMPHIBOLES

	1	2		
Si	5.81	5.98	Cell Parameters (No. 2)	
Al^{IV}	2.18	2.02	a	9.846 Å
Al^{VI}	.35	.40	b	18.033 Å
Fe^{+++}	.72	.54	c	5.311 Å
Ti	.71	.49	β	105°15′
Mg	2.69	3.01	V	909.8 Å^3
Fe^{++}	.87	.79	ρ (calc.)	3.244
Mn	.02	.02		
Ca	1.73	1.77		
Na	.67	.79		
K	.32	.26		
OH	.50	.99		
F		.07		

Numbered as in Table 2.

Cell parameters for no. 2 determined by J. J. Papike, U. S. Geological Survey.

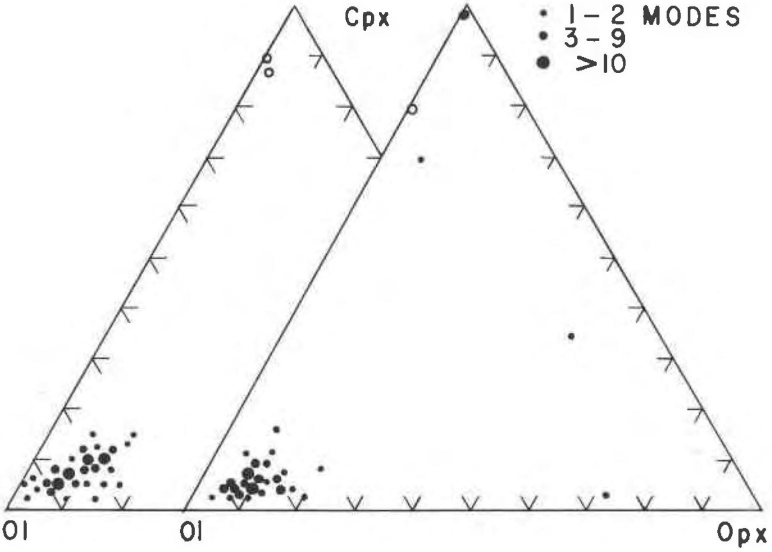

FIG. 1. Modal compositions of 100 xenoliths from Dish Hill (right side) and Siberia crater (left side). Layered xenoliths counted as two rock types. Open circles indicate rocks with either black clinopyroxene or green spinel or both. Cpx = clinopyroxene; Ol = olivine; Opx = orthopyroxene.

rich lherzolite (Table 1, no. 4), but smaller quantities of wehrlite and harzburgite also occur. These are two types of wehrlite: one has concentrations of green chrome-diopside like that in the lherzolite, the other concentrations of black clinopyroxene like the abundant clinopyroxene xenocrysts. Spinel, which is an accessory in all the peridotites, is brown in the chrome-diopside lherzolite and wehrlites and green in the black clinopyroxene rocks. Except for the abundance of amphibole and associated minerals, the peridotites are like those common as inclusions in alkaline basaltic rocks elsewhere in the world (Forbes and Kuno, 1965). The compositions of analyzed minerals (Table 2, nos. 3–9) are typical, and the usual metamorphic textures—granoblastic texture, kink banding of olivine, and local foliation resulting from mylonitization and recrystallization—are well displayed. Data of Peterman and others (1970) show that Sr isotopes of individual minerals in a lherzolite xenolith from Dish Hill have not equilibrated, nor are they in equilibrium with Sr isotopes of the host basanite. This suggests that the lherzolites are accidental inclusions in the basanite.

Amphibole is by far the most abundant of the minerals found in selvages (Table 2, no. 2), veins, and interstices of the peridotite. It is present in nearly half of the 200 inclusions examined. Phlogopite is present in about 10 percent of the samples from Dish Hill, but is rare in those from Siberia crater. It is present in veins and interstices of the peridotite, and it forms discrete crystals interlocked with amphibole. Apatite also occurs as discrete crystals interlocked with amphibole. Locally it forms as much as 35 per cent of amphibole selvages on peridotite, but more commonly makes up only 2 or 3 percent or is absent: apatite is very rare as an interstitial mineral in peridotite. Plagioclase is a very rare component of amphibole veins.

STRUCTURES OF THE XENOLITHS

Planar fractures.—As the xenoliths lack basanite coatings, their shapes are readily seen. A striking feature is the abundance of xenoliths having one or more (to a maximum of 6) planar bounding surfaces. Despite the angularity of such xenoliths, the planar surfaces commonly show a moderate polish. A few such xenoliths are cut by planar fractures, and are so fragile that they break easily along these planes. The surfaces of these internal fractures are also polished, suggesting that faceted xenoliths resulted from breakup of larger peridotite blocks that were cut by a network of intersecting planar fractures, and that the polish was caused by shear before exposure of these surfaces at the edges of the xenoliths. Gradations from angular, faceted xenoliths to well-rounded ones indicate that breakup occurred at different levels in the conduit, the more angular ones having achieved their present size at higher levels. Since these fractures cleanly transect interstitial amphibole, they are the youngest structures in the peridotite.

Amphibole selvages. About 11 percent of the inclusions examined have amphibole selvages (with or without phlogopite and apatite) on one or two parallel or intersecting surfaces of the peridotite. The selvages range in thickness from a very thin, discontinuous veneer to 0.8 cm. The average grain size of amphibole appears to increase away from the peridotite, the outermost grains being more than 2 cm long. We infer that grain sizes larger than the size of xenocrysts were once present. All amphibole selvages are on flat surfaces of the peridotite, and in no case do they completely envelop a xenolith. Figure 2 shows an example of an amphibole selvage on a single, flat surface of a lherzolite inclusion in a basanite bomb. Except where the selvage is present, peridotite is in direct contact with the basanite, showing that the amphibole is not a product of reaction between basanite and peridotite as suggested by Lausen (1927) for similar occurrences.

The habitual occurrence of amphibole selvages on flat surfaces on the peridotite suggests that the selvages are veins that once cut larger blocks of peridotite and were exposed at edges of xenoliths when the blocks broke apart along the veins. Veins of amphibole are in fact present in

FIG. 2. Selvage of amphibole (black) on a single flat surface of a lherzolite inclusion enclosed in a basanite bomb.

some xenoliths, though generally thinner than the selvages. Fractures in a few xenoliths follow thin amphibole veins, but the xenoliths remained intact. Other surfaces of the selvages range from rough, exposing many fresh cleavage faces on the amphibole, to very smooth and glazed. Numerous small pits on these surfaces have equally smooth, glazed walls, suggesting that such surfaces result from fusion of the amphibole rather than abrasional polish. These relations indicate, as do the uncoated planar faces, that breakup of veined peridotite occurred at different levels in the conduit, the fresher, rough surfaces having been exposed at higher levels.

The modal variations of the xenoliths (Fig. 1) suggest an inhomogeneous, probably layered or banded, distribution of anhydrous minerals in the source peridotite. Some xenoliths contain both pyroxene-rich and olivine-rich rocks separated by moderately sharp planar contacts. One such xenolith has an amphibole selvage that crosses the plane of mineral layering at a high angle, indicating that the amphibole veins postdate anhydrous mineral layering of the peridotite.

Amphibole veins. Several xenoliths are cut by thin veins of amphibole with or without phlogopite and apatite; plagioclase occurs as small blebs with amphibole in one vein and forms another very thin (about 1/10 mm) vein without amphibole. One lherzolite xenolith with prominent foliation resulting from partial recrystallization has a thin phlogopite vein that crosses the foliation at a high angle. The thinnest veins tend to be irregular and, through parts of their course, follow grain boundaries of the anhydrous minerals. Where the veins locally cross single grains of olivine, they offset kink bands in the olivine (Fig. 3). Apparent lateral offsets of kink bands and grain boundaries occur only where veins cross them obliquely, suggesting that the fractures dilated normal to their walls. These relations indicate that the amphibole postdates plastic deformation of the peridotite, a conclusion that is supported by the lack of deformation of amphibole and phlogopite. In places along these veins, thin stringers of amphibole extend laterally from the vein along grain boundaries of adjoining anhydrous minerals (Fig. 3) suggesting that the fluid from which the vein-forming hydrous minerals crystallized readily penetrated the lherzolite along grain boundaries.

Interstitial amphibole. Amphibole selvages have gradational contacts with lherzolite (Fig. 4) and characteristically show a rapid decrease in

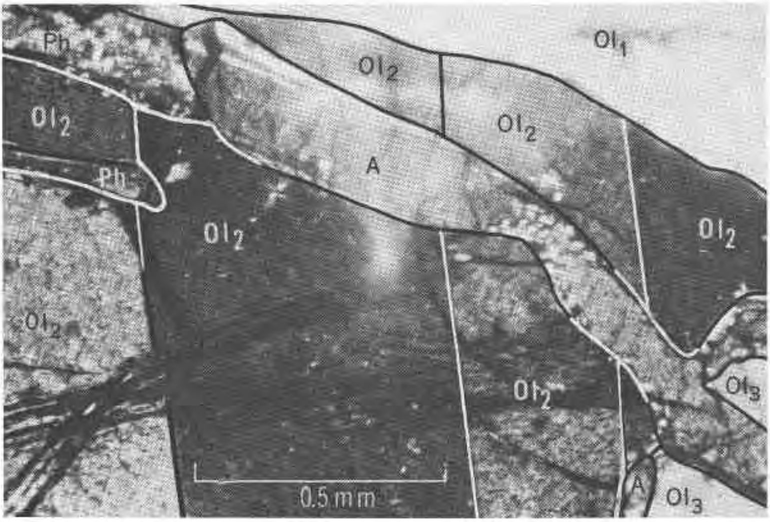

FIG. 3. Amphibole (A)-phlogopite (Ph) veinlet offsets kink bands (near vertical lines are traces of kink bands) in olivine (Ol) grain of lherzolite inclusion. Optically continuous amphibole stringer penetrates grain boundary between olivines 2 and 3 at right side of photograph.

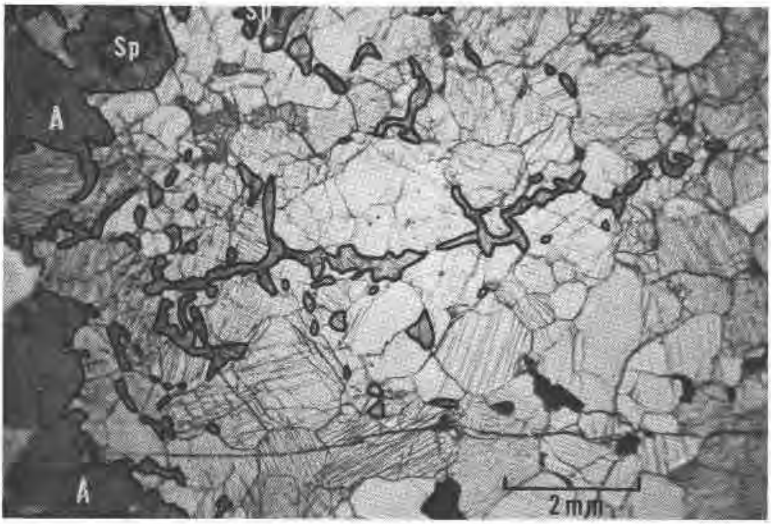

FIG. 4. Amphibole selvage (vertical along left side of photograph) and distribution of kaersutite in lherzolite near selvage. Amphibole (outlined) is mainly interstitial, but locally (near center of photograph) crosses single grains of anhydrous minerals. A = amphibole, Sp = spinel. Dark line across lower part of photograph is a thin basanite vein.

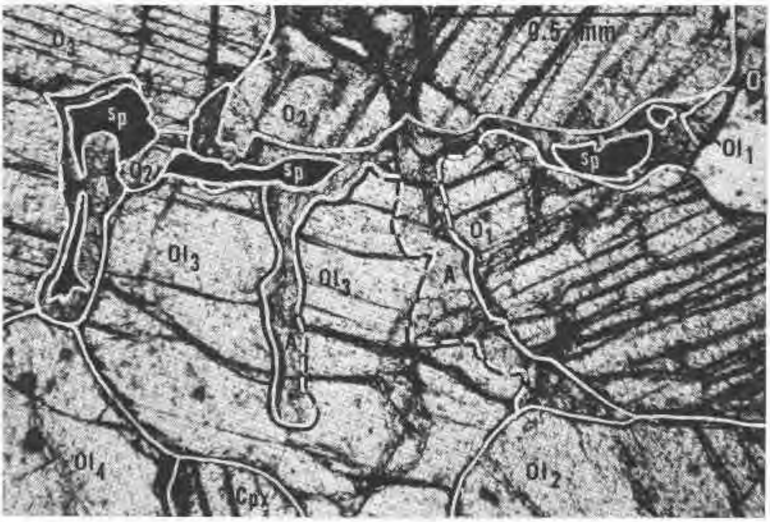

FIG. 5. Interstitial films of amphibole (A) between olivine (Ol), orthopyroxene (O), and, spinel (Sp); dashed lines indicate amphibole-anhydrous mineral contact is at a low angle to plane of thin section. Olivine 3 is cut by a thin finger of amphibole that is continuous with interstitial amphibole. Cpx = clinopyroxene.

abundance of interstitial hydrous minerals into the lherzolite. Concentrations of interstitial hydrous minerals commonly form thin fingers or sheets that penetrate the peridotite at high angles to the selvages. Amphibole and phlogopite in these zones typically occur as rows of grains, attached to one another or separated, or as thin optically continuous films along grain boundaries of anhydrous minerals. Here, as elsewhere in the peridotite, thin apophyses of the hydrous minerals locally branch off the interstitial films and cross or penetrate single grains of anhydrous minerals (Fig. 5). Accordingly, there appears to be no substantial difference in behavior of the hydrous minerals whether they are predominantly in veins or predominately in the interstices of the peridotite.

A common mode of occurrence of interstitial amphibole is as thin mantles on spinel grains (Fig. 6). This textural relation was observed whether amphibole separates spinel from olivine, clinopyroxene, or orthopyroxene, and boundaries between the amphibole and all other minerals are equally sharp. It is apparent from figure 6 that if the amphibole were removed and the rock squeezed together, the spinel would fit closely the boundaries of adjoining anhydrous minerals. Accordingly, we conclude that the shape of the spinel grain was controlled by mutual growth interference with the anhydrous minerals and that the amphibole was emplaced by rupturing that boundary. While replacement of spinel

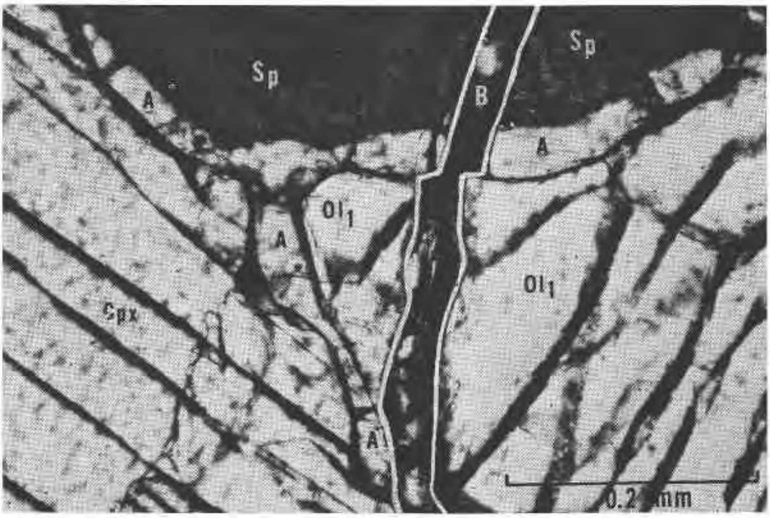

FIG. 6. Amphibole (A) mantle on spinel (Sp); thin film of amphibole extends from mantle along grain boundary between olivine (Ol) and clinopyroxene (Cpx). B = basanite veinlet; lack of reaction between basanite and amphibole is unusual.

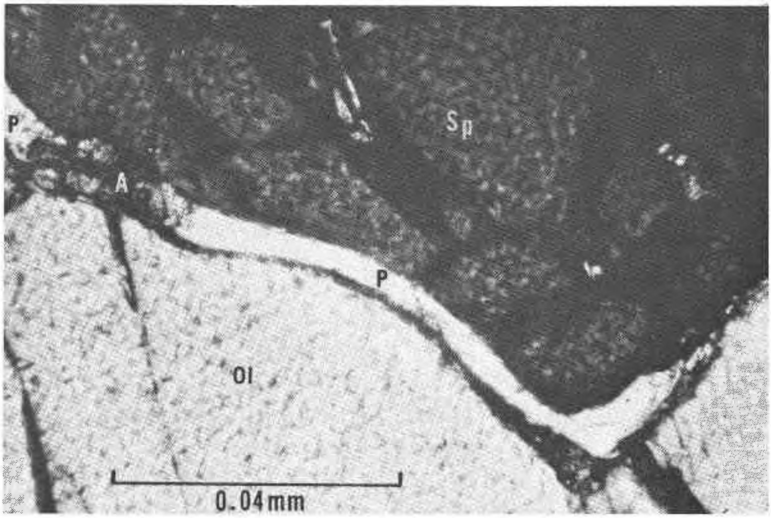

FIG. 7. Plagioclase (P) mantle on spinel (Sp); small bleb of amphibole (K) in plagioclase mantle. S = breakdown products of amphibole; Ol = olvine.

by amphibole is a possibility, it is considered unlikely because the boundaries between the two minerals are as sharp as those between amphibole and surrounding anhydrous silicates. Furthermore, a single amphibole vein was found that contains small blebs of plagioclase. Where the vein is close to a spinel grain, plagioclase forms a mantle on the spinel (Fig. 7) exactly like the amphibole mantles. The gross compositional differences of plagioclase and amplibole suggest therefore that this texture results from addition of the mantling material along mechanically weak boundaries between spinal and the anhydrous silicates rather than from replacement.

When the textural relations are considered in light of the fact that the hydrous minerals occur in all the types of peridotite whatever their modal compositions and whatever their degree of plastic deformation or recrystallization, and that the textural relations are the same in all the rock types, it is apparent that the hydrous minerals and their associates are post-consolidation, post-deformation additions to the peridotite. The fluid from which the secondary minerals crystallized gained access to the peridotite along channels that are now represented by veins. From these channels the fluid, under high pressure, permeated the adjacent peridotite, moving along grain boundaries and fractures through individual minerals, here and there finding points of special weakness where crystallization began. All of the main components of the secondary minerals apparently were carried by the fluids from which they crystallized. There is no textural evidence of reaction between anhydrous minerals of the peridotite and the secondary minerals, and probe traverses showed no substantial differences in composition of anhydrous minerals with respect to proximity to secondary amphibole. Figure 8 shows the results of probe traverses across orthopyroxenes adjacent to amphibole. The same lack of compositional variation with respect to proximity to interstitial amphibole was found for olivine, spinel, and clinopyroxene. Na, K, and Ti were run for clinopyroxene in addition to the constituents shown in Figure 8. Accordingly, proposals such as those of Holmes (1936) and Kushiro and Aoki (1968) that secondary hydrous minerals in kimberlite inclusions formed by reaction between a potassic aqueous phase and anhydrous minerals of peridotite do not apply to the Dish Hill occurrence.

Discussion

Considerable attention has been accorded hydrous alkaline minerais associated with peridotite xenoliths in recent years (for example, Oxburgh, 1964; Green and Ringwood, 1963; Mason, 1968a, b; Varne, 1968,

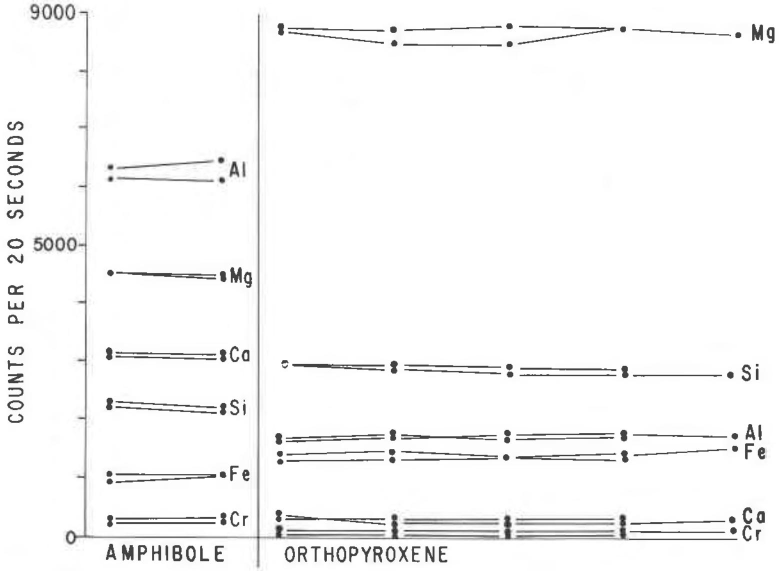

Fig. 8. Unmodified electron microprobe data for two orthopyroxene grains and interstitial amphibole. Counts registered per 20-second counting interval are shown for Al, Mg, Ca, Fe, and Cr. Amphibole counts were made at center and edge of grain nearest orthopyroxene. Orthopyroxene counts were made at approximately equal intervals over a distance of about 1 mm from the amphibole.

1970; Ernst, 1968; Dawson and Powell, 1969) because they are potential sources of basaltic constituents that are normally of very low abundance in peridotite. Experimental work (Lambert and Wyllie, 1968; Ernst, 1963; Yoder and Kushiro, 1969) has shown that minerals such as alkaline amphiboles and phlogopite are stable at upper-mantle temperatures and pressures, and therefore potentially combine water, potassium, and other constituents that cannot be accommodated in the anhydrous minerals of typical peridotite inclusions.

Kaersutite[1] and phlogopite are commonly associated with lherzolite inclusions and have nearly as wide a geographic distribution as the peridotite inclusions. For example, these minerals have been found in Ross Island, Antarctica (R. B. Forbes and D. M. Ragan, unpublished data); Kerguelen (Talbot and others, 1963); New Zealand (Dickey, 1968; Mason, 1968a); several localities in eastern Australia (Kleeman and others, 1969; Wilshire and Binns, 1961; Binns, 1969); Japan (Kuno, 1967); Alaska (Hoare and others, 1968); western United States (Lausen, 1927; Wise, 1966; White, 1966; Carter, 1965; Mason, 1968b; Trask, 1969; Best, 1970); Germany (Ernst, 1936; Frechen, 1963; Carter, 1965; Aoki and Kushiro, 1968); France (Babkine and others, 1968); Uganda (Varne, 1968); southern Arabian peninsula (Varne, 1970); and in various kimberlites in Africa (see Dawson, 1967) and Russia (see Davidson, 1967).

Probably the most commonly reported mode of occurrence of amphiboles associated with peridotite inclusions is as xenocrysts unattached to the peridotite. Phlogopite, or biotite, is also common as xenocrysts. Opinions on the origin of the xenocrysts seem to be divided between support of high-pressure cognate origin (see, for example, Wise, 1966; Dickey, 1968; Binns, 1969) and primary mantle origin (see, for example, Varne, 1968; Mason, 1968a, b). Where amphibole and phlogopite occur as interstitial components of peridotite, they are with few exceptions assumed to be primary constituents that crystallized in equilibrium with other minerals of the peridotite (those regarding interstitial hydrous minerals as secondary include Ernst, 1936; Frechen, 1963; Holmes, 1936; Kushiro and Aoki, 1968).

Considering the broad stability fields of the alkaline amphiboles and phlogopite it seems likely that cognate, primary, and secondary origins will all ultimately be established for different occurrences. We would like to emphasize, however, that certain criteria—such as interstitial occurrence and apparent lack of reaction with anhydrous minerals—in use for supporting primary crystallization of kaersutite and phlogopite are not

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[1] Pargasite and amphiboles intermediate between pargasite and kaersutite occur in the same associations as kaersutite.

adequate; while such relations are very common in the Dish Hill and Siberia crater occurrences, other less conspicuous but inescapable textural relations indicate a secondary origin.

The source of the secondary minerals is not known, but two alternatives—derivation from the basanite and derivation from an earlier episode of magmatic activity—are considered. Although the basanite is the most obvious potential source, three lines of evidence suggest that the secondary minerals may predate the basanite:

1. No phenocrysts of amphibole or phlogopite were found in the basanite. Such phenocrysts might reasonably be expected if the secondary minerals had crystallized from basanite in contact with peridotite, either while the peridotite was still in the mantle or after fragments of it had been detached and brought to higher levels.
2. Both amphibole and mica in contact with basanite (at edges of inclusions or along thin veins of basanite that penetrated some inclusions) have undergone partial incongruent melting. This reaction occurred in amphibole exposed to the basanite at both high and low levels in the conduit as indicated by the relative amount of degrading and glazing of the selvage surfaces. While such relations may be explained as a result of reduced pressure, they are equally well explained by incorporation of relatively cold amphibole-bearing xenoliths in the basanite.
3. Similar amphiboles and micas occur in the St. Paul Rock alpine-type peridotite (Melson and others, 1967) that was tectonically emplaced in the crust rather than carried there by basalt magma. Deformation of the amphibole in the St. Paul Rock samples indicates crystallization before emplacement of the peridotite high in the crust. The modes of occurrence in alpine-type peridotite described by Ave Lallemant (1967) are remarkable similar to those inferred from the Dish Hill and Siberia crater xenoliths, but similarity of composition of the amphiboles has not been established.

For the reasons given, we have reached the tentative conclusion that solutions from which the amphibole and associated minerals were deposited were derived from lower in the mantle than the peridotite to which they were added, and that they predate the basanite that brought them to the surface. Other lines of investigation are being conducted to test this hypothesis.

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