Al-AUGITE AND Cr-DIOPSIDE ULTRAMAFIC XENOLITHS IN BASALTIC ROCKS FROM WESTERN UNITED STATES: STRUCTURAL AND TEXTURAL RELATIONSHIPS.

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Common ultramafic xenoliths in basalts from the western United States are divisible into Al-augite and Cr-diopside groups (Table 1). The Al-augite group is characterized by black Al, Fe, Ti-rich clinopyroxene, Fe-rich olivine and orthopyroxene, and Al-rich spinel. The Cr-diopside group is characterized by green Cr, Mg-rich clinopyroxene and spinel and by Mg-rich olivine and orthopyroxene. Both groups have a wide range of subtypes (Fig. 1), but augite-rich types dominate the Al-augite group and lherzolites dominate the Cr-diopside group. These two groups are of world-wide occurrence (Forbes and Kuno, 1965); in the United States, as elsewhere (Kuno, 1969), members of the Cr-diopside group are dominant.

Pyroxene-rich members of the Al-augite group are typically irregularly interleaved with olivine-rich members. Where contacts are sharp, branching and intersecting augite-rich bands isolate angular fragments of the olivine-rich rocks (Fig. 2). Gradational contacts result from granular disaggregation of the olivine-rich rock. The textures of the augite-rich bands appear, with a few exceptions, to be igneous (hypidiomorphic granular), but they are not cumulus textures as is widely held (e.g., Frechen, 1963; White, 1966; Carter, 1970; Kutolin and Frolova, 1970). Poorly developed unmixing and reaction textures are widespread but not abundant. Cataclastic textures are locally well developed, and a few augite-rich members of the group are extensively recrystallized. Textures of olivine-rich members of the group are metamorphic; visibly foliated or lineated fabrics occur, but granoblastic recrystallization textures predominate.

The structures and textures of members of the Al-augite group indicate that the augite-rich rocks are dikes and veins, and that the olivine-rich rocks are their metamorphic wall rocks. The wall rocks have been modified in places by extraction of melt, in others by saturation with the melt phase, and generally by reaction with melt producing the more iron-rich compositions that identify the group. The veins have been modified by reaction with the wall rocks and by vein-forming processes. These structural, textural, and compositional relationships are like those in some alpine peridotites (Dickey,1970; Boudier and Nicolas, 1972).

The general lack of deformation and recrystallization of the dike rocks and isotopic similarity (Steuber and Murthy, 1966) to the basaltic magma that brought them to the surface suggest that most of the Al-augite pyroxenites are cognate. This conclusion is strengthened by the generally poor development of unmixing and reaction textures which, in the absence of recrystallization, indicate that the rocks have had little opportunity to equilibrate at subsolvus temperatures. Accordingly, we postulate that xenoliths of the Al-augite ultramafic group are complex mixtures of dikes and reacted wall rock derived from the source areas of the basalts that brought them to the surface.

The Cr-diopside ultramafic group also consists of pyroxene-rich units interleaved with olivine-rich units but differs from the Al-augite group in that the lithologic layering is normally plane parallel and all members have dominantly metamorphic textures (Table 1). However, at some localities, especially well represented by San Carlos, Arizona, intersecting and branching diopside-rich layers are found. Dunitic zones (see

Boudier and Nicolas,1972) also occur adjacent to some diopside-rich bands and large, deformed pyroxene grains with unmixing textures that have survived recrystallization attest to a former high temperature history. The textures of these rocks (deformed diopside with coarse enstatite exsolution lamellae surrounded by granoblastic intergrowths of diopside and enstatite) are nearly identical to those of clinopyroxenite vein networks in some alpine peridotites. The intersecting and branching pyroxene-rich bands in lherzolite inclusions from San Carlos could represent pieces of similar vein networks, but generally both the original structures and textures have been largely eradicated by solid flow and recrystallization.

The similarities of structure and texture of xenoliths in the Al-augite group to the relict structures and textures of xenoliths in the Cr-diopside group are sufficient to support the hypothesis that both originated in the same way. That is, that the pyroxene-rich members are veins formed by crystallization in the mantle of partial melts that failed to escape to volcanic conduits and the olivine-rich host rocks of the pyroxene-rich bands are the wall rock of such veins modified in varying degrees by extraction or addition of melt and by reaction. The Al-augite series appears generally to be cognate with basalt that carries the xenoliths, whereas the extensive exsolution, deformation, and recrystallization of rocks in the Cr-diopside group indicate that they represent older episodes of melting. These relationships are illustrated in figure 3.

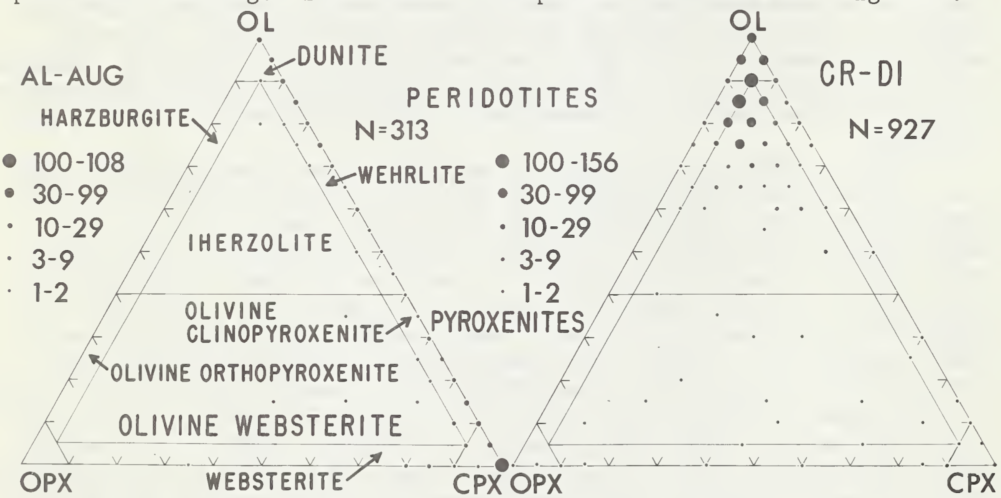

Fig. 1. Triangular plots showing distribution of lithologies in Al-augite and Cr-diopside ultramafic groups. Boundaries and names follow IUGS recommendations.

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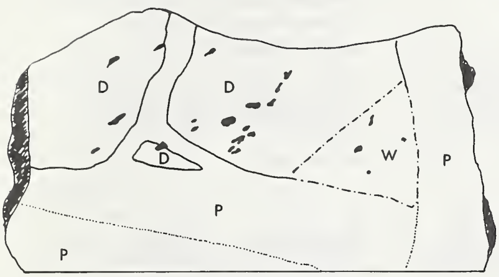

Fig. 2. Sketch of xenolith showing branching and intersecting Al-augite pyroxenite veins (P) in dunite (D). Black areas denote spinel. Note dunite inclusion in pyroxenite. Vein on right is coarser-grained than the vein it cuts; bottom vein is more spinel-rich below dotted line. Wehrlite (W) has gradational contacts with all adjacent lithologies.

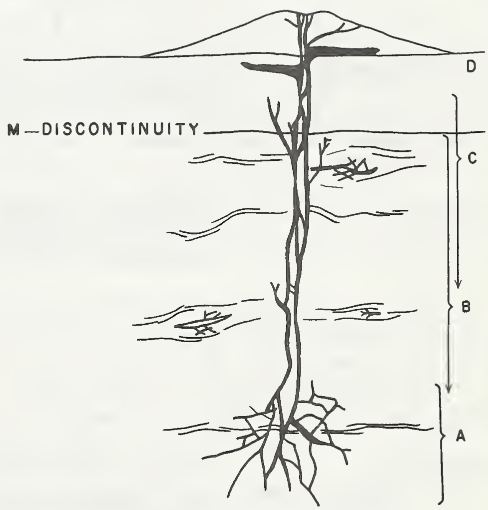

Fig. 3. Schematic diagram illustrating possible relationships of cognate Al-augite pyroxenite and Cr-diopside ultramafic groups. A. Mantle source zone; anastomosing feeders to main conduits. Al-augite ultramafic xenoliths with complex vein networks represent earlier melts and wall rock from this and higher zones. B. Gneissic mantle material composed of penetratively deformed Cr-diopside peridotites. Augen preserve parts of former complex vein networks. Depending on depth in mantle, these may belong to the Cr-diopside, garnetiferous, or feldspathic ultramafic groups. C. Offshoot veins from the main conduits penetrate crustal and mantle rock that was not involved in the youngest melting episode. Xenoliths from this horizon include veins in peridotite of the Cr-diopside and feldspathic ultramafic groups. D. Sill injections in upper crust and within contemporaneous volcanic pile yield cumulate differentiates that form locally important members of xenolith suites.

Table 1. Principal Features of Al-augite and Cr-diopside Ultramafic Groups[1/]

	Cr-diopside Group	Al-augite Group
Rock Types	LHERZOLITE; dunite; olivine websterite; websterite; wehrlite; olivine clinophyroxenite; harzburgite; clinopyroxenite; [olivine orthopyroxenite]; [orthopyroxenite]	OLIVINE CLINOPYROXENITE; WEHRLITE; CLINOPYROXENITE; dunite; lherzolite; [olivine websterite]; [websterite]
Structures A. Layering and cross-cutting	COMMONLY CONCORDANT SOLID FLOW LAYERS; branching but not cross-cutting	COMMONLY BRANCHING AND CROSS-CUTTING IGNEOUS LAYERS; pyroxene-rich dikes cross foliation of olivine-rich wall rock
B. Inclusions	Olivine-rich inclusions in pyroxene-rich rocks	OLIVINE-RICH INCLUSIONS IN PYROXENE-RICH ROCKS
C. Grain orientation	Common	Uncommon
Textures	TECTONITE TEXTURES; RECRYSTALLIZATION TEXTURES; unmixing textures	Pyroxene-rich rocks: IGNEOUS VEIN TEXTURES; unmixing textures; recrystallization textures; reaction textures; cumulus textures; cataclastic textures Olivine-rich rocks: RECRYSTALLIZATION TEXTURES; tectonite textures
Mineralogy A. Relative abundance	OLIVINE; ORTHOPYROXENE; clinopyroxene; spinel; pargasite; phlogopite	CLINOPYROXENE; OLIVINE; spinel; orthopyroxene; kaersutite; Ti-phlogopite

B. Composition[2/]

	Cr-diopside Cpx	Opx	Ol		Sp	Al-augite Cpx	Opx	Ol		Sp
Ca	45.1			Fe	8.1	46.0			Fe	7.4
Mg	49.3	89.6	86.8	Al	61.3	46.4	86.6	81.8	Al	88.6
Fe	5.6	10.4	12.2	Cr	30.6	7.8	13.4	18.5	Cr	4.0
Al	5.5	4.7				7.7	4.7			
Cr	.84					.23				
Ti	.56					1.28				

1/ All upper case indicates important or dominant feature or rock type; lower case indicates feature or rock type present but subordinate; lower case in brackets indicates rare feature or rock type.

2/ Compositions above line are normalized At.% and represent averages of 15 or more analyses in each of 12 samples. Compositions below line are wt.% oxides.