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Rapid determination of olivine compositions in thin section using dispersion staining methodology

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Abstract

The linear relationship between olivine compositions and indices of refraction permits the quick and easy determination of olivine compositions. Indices of refraction are determined directly in thin section using dispersion staining techniques. Individual olivine crystals of proper orientation can be chemically characterized using the following equations:

$$\text{mole \% fayalite} = \frac{(n\text{D alpha} - 1.6325)}{0.0020} \tag{1}$$

$$\text{mole \% fayalite} = \frac{(n\text{D beta} - 1.6490)}{0.0022} \tag{2}$$

$$\text{mole \% fayalite} = \frac{(n\text{D gamma} - 1.6651)}{0.0022} \tag{3}$$

Accuracy with this technique is ±2 percent fayalite.

Introduction

The presence of olivine in a thin section leaves the petrographer with the problem of determining the exact chemical composition. This determination is possible with the microprobe, but has not been possible with the standard petrographic microscope except when adapted with a universal stage (Poldervaart, 1950; Wyllie, 1959). The index of refraction of a specific mineral or crystal in thin section can be measured directly using a dispersion staining objective (Laskowski *et al.*, 1979). This method involves the creation of a liquid–grain interface directly on the thin section; observation of the resulting dispersion colors leads to a precise determination of the *n*D (index of refraction for sodium D light) of the mineral in the orientation tested. Determination of the principal indices (α, β, γ) of an olivine crystal allows the mineral to be chemically characterized, as all indices of refraction increase predictably as the composition of the olivine changes through the solid-solution series from Mg_2SiO_4 to Fe_2SiO_4 (Bowen and Schairer, 1935; Deer and Wager, 1939; Poldervaart, 1950). These determinations can be made rapidly and accurately on the thin section without appreciable damage to the slide.

Our purpose here is to determine, using dispersion staining and atomic absorption methods, the relationships between indices of refraction and chemical compositions from a suite of seven natural olivines. These relationships match or nearly match the results obtained by previous workers for the olivine series, thus permitting a petrographer to determine the composition of an olivine crystal by making a single *n*D measurement directly on the thin section.

Analytical methods

Indices of refraction (sodium D light) of seven natural olivines and six Cargille calibrated refractive index standards (optical glasses of known *n*D) were measured in thin section using the method described by Laskowski *et al.* (1979), adapted with the addition of a cover glass to the mount for index liquids with *n*D greater than 1.700. Results of these measurements are given in Table 1. Based on the measurements of the optical standards, *n*D accuracies of ±0.002 or better were attained in all cases.

Bulk samples were crushed and sieved; olivine was separated with a Franz Isodynamic Separator and carefully hand-picked with the aid of a binocular mi-

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Table 1. Results of dispersion staining and atomic absorption measurements on olivines and optical standards

Sample	Locality	nD measured in thin section				Mg	Fe	Ca	Ni	Wt.%	Mol.%
		Iso.	α	β	γ	ppm	ppm	ppm	ppm	Fa	Fa
OL-15	unknown	--	1.6480	1.6628	1.6828	289,615	54,289	210	2848	10.57	7.55
OL-14	Addie, N.C.	--	1.6493	1.6680	1.6840	292,413	59,259	560	2849	11.33	8.11
OL-14	Addie, N.C.	--	1.6493	1.6680	1.6840	278,315	58,164	552	2708	11.64	8.34
OL-5	Webster, N.C.	--	1.6514	1.6710	1.6874	265,942	61,588	2714	2528	12.74	9.16
OL-25	Jackson Co. N.C.	--	1.6560	1.6720	1.6880	280,969	83,210	737	2426	15.74	11.42
OL-6	Stillwater, Mont.	--	1.6610	1.6789	1.6960	247,929	95,274	4344	1975	19.51	14.33
OL-35	Duluth Complex	--	1.6960	1.7235	1.7350	188,464	211,875	6052	1368	41.48	32.86
OL-12	Mesaba, Minn.	--	1.8110	1.8430	1.8620	17,877	316,720	4382	23	91.78	88.52
S-1	Cargille std. *n*D=1.650	1.652	--	--	--	--	--	--	--	--	--
S-2	Cargille std. *n*D=1.690	1.689	--	--	--	--	--	--	--	--	--
S-3	Cargille std. *n*D=1.730	1.729	--	--	--	--	--	--	--	--	--
S-4	Cargille std. *n*D=1.770	1.769	--	--	--	--	--	--	--	--	--
S-5	Cargille std. *n*D=1.810	1.812	--	--	--	--	--	--	--	--	--
S-6	Cargille std. *n*D=1.860	1.862	--	--	--	--	--	--	--	--	--

croscope. Samples were then pulverized in preparation for atomic absorption analyses.

The concentrations of Fe, Mg, Ca, and Ni were determined using a Perkin-Elmer Model 303 atomic absorption spectrophotometer adapted with a Perkin-Elmer DCR1 concentration read-out (Table 1). Accuracy of the analyses was evaluated by analyzing the U.S. Geological Survey rock standard PCC-1, peridotite. Table 2 shows a comparison of values obtained in this study with those quoted by Flanagan (1973). The accuracy for Mg is 1.9, for Fe 0.4, for Ca 4.1, and for Ni 6.7 percent of the amount present. The reproducibility of the analyses was established by duplicate analyses of sample OL-14 (Table 1). These data show a range of 4.8 percent for Mg, 1.8 percent for Fe, 1.4 percent for Ca, and 4.9 percent for Ni of the amount present.

Table 2. Comparison of PCC-1 elemental concentrations from this study and Flanagan (1973)

Element	This study ppm	Flanagan values ppm
Mg	255,521	260,419
Fe	60,928	60,665
Ca	3,495	3,645
Ni	2,506	2,339

Discussion

All analytical data are given in Table 1. A plot of *n*D of the alpha, beta, and gamma indices of seven natural olivines versus the compositions determined by atomic absorption (mole percent Fe_2SiO_4) of the olivines is shown in Figure 1. This plot shows that the *n*D of each index increases linearly as the composition of the olivine becomes more fayalitic, and resembles the relations observed by Bowen and Schairer (1935) for synthetic olivines, Deer and Wager (1939) for a suite of four natural olivines, and Poldervaart (1950) for a combination of natural and synthetic olivines. As the plot for the *n*D of each index *vs.* composition in Figure 1 is nearly linear (correlation coefficients are 0.99985, 0.99943, and 0.99967 for the alpha, beta, and gamma plots respectively), the composition of a given olivine crystal may be calculated from any of the following equations once the *n*D of a particular index has been measured on the

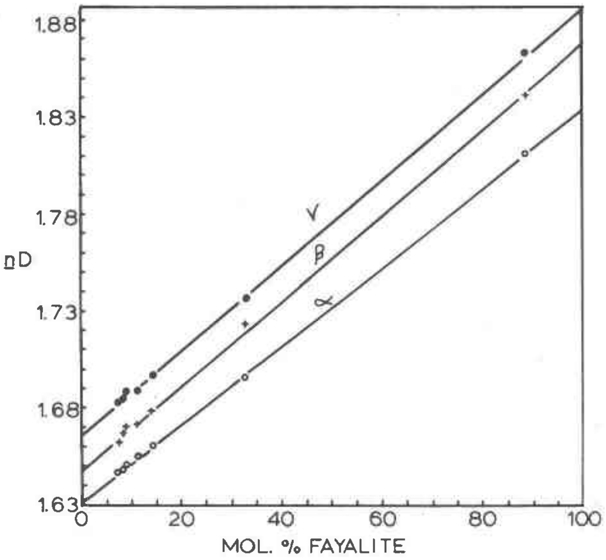

Fig. 1. Plot of *n*D-alpha, *n*D-beta, and *n*D-gamma *vs.* mole % Fe_2SiO_4 for a suite of seven natural olivines.

thin section by the dispersion staining method:

$$\text{mole \% fayalite} = (n\text{D alpha} - 1.6325)/0.0020 \quad (1)$$

$$\text{mole \% fayalite} = (n\text{D beta} - 1.6490)/0.0022 \quad (2)$$

$$\text{mole \% fayalite} = (n\text{D gamma} - 1.6651)/0.0022 \quad (3)$$

Accuracy with this method is estimated to be ±2 percent fayalite, based on the variation caused by *n*D uncertainties of ±0.002 and the accuracies determined for Fe and Mg concentrations (0.4% and 1.9% of the amounts present respectively).

Similar equations derived from the combined data of Bowen and Schairer (1935) and Deer and Wager (1939) are as follows:

$$\text{mole \% fayalite} = (n\text{D alpha} - 1.6375)/0.0019 \quad (1)$$

$$\text{mole \% fayalite} = (n\text{D beta} - 1.6526)/0.0021 \quad (2)$$

$$\text{mole \% fayalite} = (n\text{D gamma} - 1.6702)/0.0021 \quad (3)$$

The composition of olivine in weight percent fayalite is also related to the indices of refraction of the alpha, beta, and gamma indices by quadratic expressions following the form $Y = A + BX + CX^2$ where $Y = n$D of a given principal vibration direction, X = the weight percent fayalite, and A, B, and C are constants. For *n*D-alpha: A = 1.6361, B = 0.0011 and C = 0.00001; correlation coefficient = 0.99649. For *n*D-beta: A = 1.6473, B = 0.00159 and C = 0.000006; correlation coefficient = 0.99841. For *n*D-gamma: A = 1.6694, B = 0.00116 and C = 0.00001; correlation coefficient = 0.99611.

The importance of these determinations is that an olivine grain of appropriate size, state (highly weathered grains are undesirable), and proper grain orientation (determined in this study by the use of interference figures) may be measured and the chemical composition determined without removing the grain from the thin section and without any special equipment except a dispersion staining objective (the objective can be easily constructed following the instructions of Grabar and Principe, 1963, p. 61–62). This method is especially useful with a zoned olivine crystal because the *n*D of each zone can commonly be measured and the composition determined by the above equations, by the plot in Figure 1, or by the plots of Bowen and Schairer (1935), Deer and Wager (1939), or Poldervaart (1950).

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