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OLIVINE CONTENT OF CHONDRITES MEASURED BY X-RAY DIFFRACTION

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Abstract

Quantitative analysis of the olivine content in chondrites has been carried out using X-ray diffraction. The procedure is applicable when the olivine contains 60–100 mole percent forsterite and can be used for terrestrial rocks as well. The average olivine contents of the H4, H5, and H6 petrologic types are very similar (approximately 28 percent) as are the average olivine contents of the L4, L5, and L6 (approximately 40 percent).

Introduction

An X-ray diffraction procedure for the quantitative determination of the olivine content in rocks, when the olivine contains 60–100 mole percent forsterite, has been developed. Yoder and Sahama (1957) published a curve for measuring the mole percent forsterite in olivine and the present work carries the study of olivines a step further because it not only does this, but also determines the *amount* of olivine in rocks in which the olivine contains between 60 and 100 mole percent forsterite. Although Zoltai and Jahangabloo (1963) suggested developing quantitative schemes for minerals with varying compositions, as far as we know this is the first one that has been carried out. This procedure was developed mainly for the study of chondritic meteorites which contain mainly olivine, orthopyroxene, kamacite, and taenite but could also be used if plagioclase feldspars, pigeonite, or diopside were mixed with the olivine. Orthoclase or microcline in large amounts or augite would interfere with the analysis. For rocks which contain both orthopyroxene and olivine, the two most useful olivine lines are the (020) and the (130). The (130) is much stronger and the one that was used as the measure of olivine present in the samples. Quantitative analysis using an internal standard with a compound of uniform composition is described very completely in Klug and Alexander (1954). The important modification presented here is that the one system can be used to analyze olivines varying in composition from 60 to 100 mole percent forsterite. To do this, we make use of three curves. Figure 1 shows the variation of the ratio

$$R = \frac{\text{integrated intensity olivine (130)}}{\text{integrated intensity } ZnF_2(101)} \text{ with mole percent } Mg_2SiO_4.$$

The mixtures used in preparing this curve contained a constant ratio of olivine to ZnF_2 of 2.2. Table 1 lists the samples used in preparing this curve. Figure 2 contains a plot of d olivine (130) versus mole percent Mg_2SiO_4. The measurements shown on this curve were made using the (101) reflection of ZnF_2, $d = 2.608$ as an internal standard. Figure 3 contains the third curve used in the analysis, a plot of the ratio

$$\frac{\text{grams peridot (94.5 mole percent } Mg_2SiO_4)}{\text{grams } ZnF_2}$$

against the ratio of integrated intensities of

$$\frac{\text{peridot (130)}}{ZnF_2 \text{ (101)}}.$$

Analytical Techniques and Procedures

Approximately 0.7 g. of meteorite is weighed out and then crushed using a hammer and plattner mortar and pestle. The sample is crushed until all but the larger pieces of metal pass through a 60 mesh sieve (0.25 mm. opening). Then the whole sample is placed in a mechanical mortar and pestle with 95 percent ethanol and ground for 30 minutes. The sample is again passed through a 60 mesh sieve and usually all that remains on top of the sieve is metal. Both

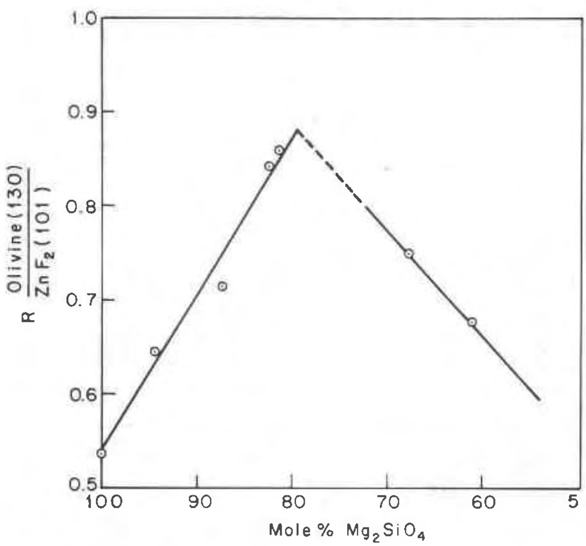

FIG. 1. Mole percent Mg_2SiO_4 vs. $R = \frac{\text{integrated intensity olivine (130)}}{\text{integrated intensity } ZnF_2 \text{ (101)}}$

Table 1

Reference Samples Used in Curves for Quantitative Analysis of Olivine

Sample	Mole % Mg_2SiO_4	Origin	Source
	100	Synthetic	Tem-Pres Inc.
Peridot	94.5	Rice Station School Talklai, Arizona	P. Desautel, U. S. National Museum No. 86128
Albin	87.5*	Meteorite	C. B. Moore, Arizona State University
Springwater	82.5*	Meteorite	C. B. Moore, Arizona State University
Eagle Station	81.5*	Meteorite	Gero Kurat Naturhist. Museum, Vienna
	68.3	Bufumbira, Uganda	H. S. Yoder Carnegie Geophys. Lab Washington, D.C.
	61.3	Bufumbira, Uganda	H. S. Yoder Carnegie Geophys. Lab Washington,D.C.

*Buseck and Goldstein

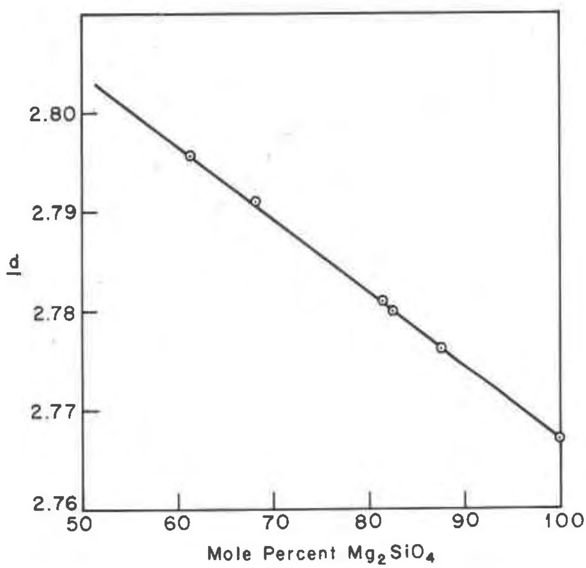

FIG. 2. Mole percent Mg_2SiO_4 vs. *d* (130).

fractions are then dried at 110°C. for two hours, weighed, and the X-ray analysis is carried out on the less than 0.25 mm. sample.

An aliquot of 0.16 grams is then mixed with 0.040 grams of ZnF_2, which is used as an internal standard. The mixture is then shaken in a Wiggle Bug dental mixer for three minutes and is ready for diffractometer study. A piece of aluminum with a cavity 10 × 10 × 0.5 mm. is used as a sample holder in a Philips goniometer mounted on a Philips generator. Copper X-rays shine on the sample, are diffracted, pass through a nickel filter and then enter a General Electric xenon filled proportional counter. Using a scanning speed of 1/4 degree two theta per minute, diffraction traces are made over the range 30 to 35° 2θ. Each sample is mounted four times and scanned once during each mount. The d values shown in Table 2, column 2, and the R values in column 4 represent the average of measurements from these four mounts. Integrated areas are obtained by measuring the height of each peak above background and multiplying this by the width at half-maximum. Then using the three figures shown earlier and the sample weight, the percentage olivine is obtained, as follows.

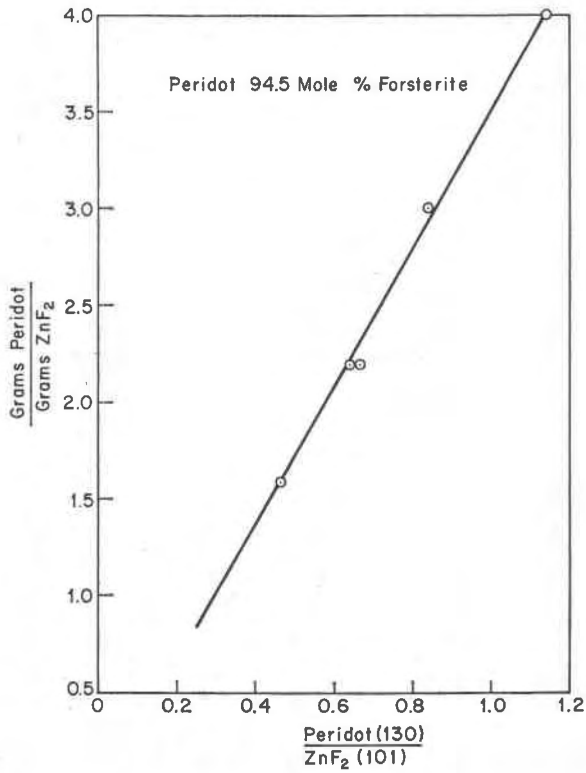

FIG. 3. Calibration curve for olivine analysis.

$$\frac{\text{integrated intensity peridot (130)}}{\text{integrated intensity } ZnF_2 \text{ (101)}} \text{ vs. } \frac{\text{grams peridot}}{\text{grams } ZnF_2}$$

Table 2

Calculations Carried Out in Quantitative Analysis of Olivine

1	2	3	4	5
Meteorite	d	Mole % Fo	R $\frac{\theta \ell}{ZnF_2}$ Exper.	$\frac{g\ \text{Peridot}}{g\ ZnF_2}$ Fig. 3
Allende	2.7947	62.0	.960	3.365
Winona	2.7707	94.4	.168	.501
Arapahoe	2.7836	77.0	.574	1.969
Walters	2.7850	75.1	.602	2.071
Hugoton	2.7802	81.6	.379	1.264
Oakley	2.7805	81.2	.464	1.572

	6	7	8	9	10
Meteorite	g. Olivine of Peridot Comp.	R from Fig. 1	$\frac{.624}{\text{Col. 7}}$	g. Olivine in 0.16 g. minus 0.25 mm. frac.	% Olivine in Sample
Allende	.1346	.676	.923	.1242	77.6
Winona	.0200	.625	.998	.0200	12.5
Arapahoe	.0788	.857	.728	.0573	34.4
Walters	.0828	.834	.748	.0619	38.4
Hugoton	.0506	.844	.740	.0374	23.2
Oakley	.0629	.850	.734	.0461	28.6

#Peridot contained 94.5 mole % forsterite.

From Figure 2 and the measured *d* for the olivine (130) the mole percent forsterite is determined and listed, as in column 3 of Table 2. Column 4 lists the values of *R* obtained from measuring the integrated areas of peaks on the traces. Figure 3 shows a curve which indicates directly the percentage of a peridot $(Mg_{94.5}Fe_{5.5})_2SiO_4$ in an unknown. Since we know the amount of ZnF_2 added to each sample and the *R* can be experimentally determined then the percentage of an olivine of this composition can easily be computed. Column 5 lists the grams peridot/grams ZnF_2 for each sample, using Figure 3. Since all the unknowns studied had compositions different from the peridot, a correction had to be made. Column 7 lists the *R* values (from Figure 1) that pure olivines of the compositions shown in column 3 would have. However, Figure 3 was made using a peridot containing 94.5 mole percent forsterite. From Figure 1, this peridot should have an *R* value of 0.624. In column 8 are listed the ratios

$$\frac{0.624}{R \text{ from column 7}}$$

These ratios are the correction factors due to the fact that the (130) peak intensity of olivine varies with composition. While column 6 contains the grams olivine in a sample if it had this peridot composition $(Mg_{94.5}Fe_{5.5})_2SiO_4$, column 9 which is obtained by multiplying the value in column 8 by that in column 6 lists the grams olivine for the compositions shown in column 3. Column 10 lists the percent olivine in the samples and is calculated by dividing the olivine weight in column 9 by 0.16 and then multiplying by the percent of sample less than 0.25 mm. in diameter.

All calculations are now carried out by a computer which is fed columns 2 and 4 of Table 2 plus the equations for Figures 1, 2, and 3. Quantitative estimates of the olivine content are reproducible to ± 5 percent of the olivine content, and the compositions of the olivine are reproducible to ± 1.5 mole percent forsterite, when X-ray measurements are made on two aliquots of a single ground sample. It is difficult to assess the absolute accuracy because sampling problems become a major consideration since only about 0.7 gram or less of each meteorite was used. Weathering of the chondrites by oxidation of the iron and preferential solution of the more easily weathering olivine possibly distort some of the analyses.

Results and Discussion

In 1951, Wahl developed a procedure for converting a chemical analysis of chondrites to their mineralogical composition. These results indicated 75.03 percent olivine for the Warrenton, C3, and 35.42 percent olivine for the Oakley, Kansas, H6. He also averaged the chemical composition of 12 white chondrites (which in the Van Schmus and Wood classification are mainly H5 and H6) and calculated the average olivine content in these as 44.52 percent. Mueller and Olsen in 1967 calculated the Wahl normative mineralogical composition of 50 chondrites using data from the literature and among these are 10 for which we have measured the olivine content. In eight samples, the calculated and the measured differed by 15 percent or less of the percentage olivine measured. The other two differed by about 30 percent. Half of the ten were H and half were L, but there is better agreement between the H chondrites. There is good general agreement between Wahl's calculated estimate and those measured by the X-ray technique, however, the latter is a more direct procedure.

A table which lists all the meteorites that have been studied is available[1]. The results of this table are summarized in Table 3, where the average olivine composition, range of compositions and number of samples are shown for the petrologic types analyzed. Within the H and L chemical groups, the olivine content is very similar; however, the average olivine content of the L group chondrites is 41 percent, 14 percent more olivine than the H group average of 27 percent. Only six LL chondrites have been analyzed, but these results suggest

[1] A table listing all meteorites studied may be obtained from the author, or ordered 01713 as NAPS Document from National Auxiliary Publications Service of the A.S.I.S., c/o CCM Information Corporation, 866 Third Avenue, New York, N. Y. 10022; remitting in advance $2.00 for microfiche or $5.00 for photocopies, payable to CCMIC-NAPS.

Table 3

Average Olivine Content of Chondrites Listed According to Petrologic Type

		3	4	5	6
Ave. Comp.	H	30	28	27	29
Range		26-33	26-34	20-31	27-35
No. Samples		2	8	17	7
Ave. Comp.	L	36	39	39	41
Range			37-42	34-47	32-51
No. Samples		1	4	14	19
Ave. Comp.	LL	51	51	49	45
Range					41-49
No. Samples		1	1	1	4
Ave. Comp.	C	60	45		
Range		42-78	29-61		
No. Samples		2	2		

that the LL group contains more olivine than the L chondrites. These results compare well with the estimates of olivine in chondrites made by Mason (1962, p. 80) if the H, L, and C chemical groups are substituted for olivine-bronzite (25–40 percent), olivine-hypersthene (35–60 percent), and olivine-pigeonite (65–70 percent), respectively. Since only six LL samples were studied, it is not possible to be sure that the similarity of olivine composition in these types is real. The average olivine contents of L4, L5, and L6 are almost identical and the range of compositions is quite similar. In the H group, the average compositions vary slightly more than the L group, but the range of composition shows less variation. We are presently trying to develop a scheme for the quantitative analysis of orthopyroxene in meteorites and eventually hope that the major minerals in all rocks can be measured quantitatively using an X-ray diffraction procedure.

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