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Geochemical, Petrographic and Magnetic Characteristics of Spinel Lherzolite Mantle Xenoliths from Jabal Remah Volcano, Jordan

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Abstract: Peridotite ultramafic mantle xenoliths are occurring abundantly in the Harrat Al-Shaam basaltic province. Jabal Remah volcano is located in the Jordanian parts of the plateau and contains considerable amounts of mantle xenoliths within its pyroclastic successions. Mineralogical investigations show that the xenoliths are mostly of the spinel lherzolite type, which are characterized by a protogranular texture. Modally, the xenoliths are composed of olivine (55-65%), orthopyroxene (12-16%), clinopyroxene (10-15%) and spinel (~ 5%). The xenoliths are classified as Type I and belong to the Cr-diopside group. They are characterized by a high content of MgO (42.1-43.2%), Cr (2465-2538 ppm) and Ni (2196-2301 ppm). Three selected mantle-xenolith samples were analyzed for their magnetic characteristics. They were found to behave similarly in their ferrimagnetic phase, as indicated by their narrow hysteresis curves and because they never reach saturation even at high applied field. They exhibit ferrimagnetic hystertesis curves similar to world known mantle xenoliths, which is due to the presence of Fe in the form of oxides.

Key words: Mantle, xenoliths, spinel lherzolite, magnetic hysteresis, iron-based compounds, ferrimagnetic

INTRODUCTION

Magnetic investigations regarding natural substances become a wide and interesting field. These investigations cover not only the magnetism of basaltic rocks[1,2] attention is also, given to other natural substances such as manganese deposits[3] and soils[4].

In this study, spinel lherzolite xenoliths from the NE-basaltic plateau were investigated for their chemical and magnetic characteristics. Similar research was carried out by many workers[5-8] pictured out that mantle peridotite is usually contains spinel and non-magnetic sulphides, but some of them may contain fine-grained magnetic minerals such as magnetite as opaques. In contrast, in crustal xenoliths Fe-Ti oxides cause the magnetization, while upper mantle xenoliths are composed of spinel with little Fe^{+3} and ilmenite. Therefore, there is a magnetic mineral contrast between the mantle and the continental crust; the mantle-crust boundary appears to be a magnetic mineralogical discontinuity[5]. Therefore, it is vital to determine the magnetic characteristics of crust and mantle rocks, which can be obtained from xenoliths.

Extensive xenolith assemblages have been reported in the Tertiary-Quaternary basaltic fields of Harrat Al-Shaam[9-12]. This plateau basalt covers an area of 45 000 km^2 and lies in the NW part of the Arabian plate. This plateau extends from Syria to Saudi Arabia through Jordan. It is considered to be one of the largest alkali olivine basalt plateaus globally[13,14] studied the oxidation of olivine in lherzolitic xenoliths from NE-Jordan using petrographic and Moesbauer methods. They showed that water oxidized the Fe and takes the Mg and Si out.

Jabal Remah lies in the Jordanian part of Harrat Al-Shaam which is locally known as Jordanian Harrat or Harra El-Jabban[15] about 15 km north of the Mafraq-Baghdad road and 5 km south of the Syrian-Jordan border Fig. 1. It occupies 4 km^2 and lies at latitude 32°23' 48'' North and longitude 36°55' 42'' East. The volcano is built of voluminous scoria-fall pyroclastic rocks that are arranged in beds and form three distinct horizons (named: lower, middle and upper horizons). The volcano possesses features similar to those observed for volcanoes of the Strombolian type[16]. The xenoliths were mainly collected from the middle horizon. This horizon is xenolith-rich, particularly in spinel lherzolite and spinel dunite and minor pyroxenite. These xenoliths intercalate the pyroclastic rocks and occur as cored bombs.

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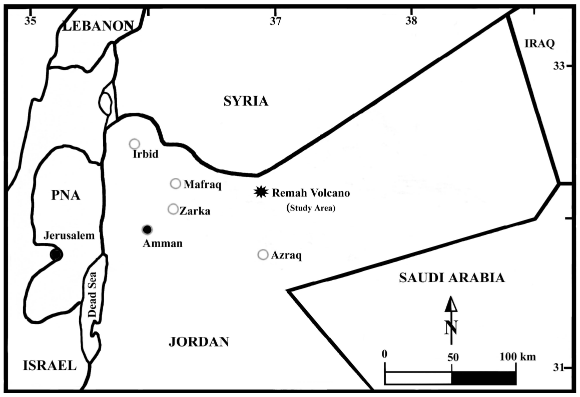

Fig. 1: Location map of Jabal Remah Volcano, Jordan

The xenoliths are fresh with size ranges from 2-15 cm and an average diameter of 8 cm. The xenoliths are light to dark green in color and mostly spherical in shape.

MATERIALS AND METHODS

Geochemical investigations were carried out on selected xenoliths and scoria samples. Whole rock samples were analyzed for major oxides of Si, Ti, Al, Fe, Mg, Mn, Ca, Na, K and P as well as selected trace elements using X-ray Fluorescence (XRF) method in the Department of Mineralogy, Wuerzburg University, Germany. LOI was determined by weight loss after drying at 1000°C.

The magnetic measurements were carried out using the Super-conducting Quantum Interference Device (SQUID) magnetometer, at the Department of physics, Kansas State University, USA. The measurements were made in the temperature range 4.0-400 K and the applied magnetic field was up to 5.5 Tesla. In addition we performed hystreresis and initial magnetization measurements at room temperature using a Vibrating Sample Magnetometer (VSM). Magnetization as a function of temperature was done by, the Zero Field Cooling (ZFC) as well as Field Cooling (FC). In the method (ZFC) way we cool the basalt samples down to liquid helium temperature without an applied magnetic field, while in the second (FC) we cool down in presence of a small applied field of 200 Oe. Magnetization was then measured (for ZFC and FC) while the sample was heated to 400 K with an applied magnetic field of 200 Oe. The spontaneous magnetization at 10 K for FC (0.11 emu g^{-1}) is greater than that for ZFC (0.06 emu g^{-1}), because in case of the magnetic moments are frozen with some order, while in case of ZFC the magnetic moments are frozen with random orientation.

RESULTS AND DISCUSSION

Mineralogy: The ultramafic xenoliths of Jabal Remah are mostly peridotite dominated by spinel lherzolite with some pyroxenites. This study concentrates on lherzolites.

Spinel Lherzolite: The lherzolites are composed of olivine, orthopyroxene, clinopyroxene and spinels; they have a protogranular texture similar to those defined by[17]. The samples are classified as Type I following the classification of[18], while the geochemical composition classifies them as Cr-dioposide peridotite following the classification of[19].

Olivine is the main component and occurs as subhedral to anhedral, medium to coarse-grained (up to 5 mm) crystals. Clusters of crystals are frequently recorded between the altered ones. The crystals are occasionally iddingsitized at the rims and following the outline of the crystals. The orthopyroxene of enstatite and forms up to 18% of the xenoliths. The crystals are subhedral to anhedral and coarse-grained (up to 5 mm). Moreover, deformation lamellae and exsolution lamellae of clinopyroxene are observed in some of the enstatite crystals. Clinopyroxene (up to 12%) is of the diopside type. The crystals are subhedral in shape with grain sizes between 2-4 mm. Spinel is a minor constituent (2 to 4%). The crystals are anhedral in shape and occur interstitially in the enstatite and diopside. Spinel crystals are dark brown in color and vary in grain size between 0.3 and 5 mm. Opaque mineral oxides (1-3%) are mainly of euhedral to subhedral in shape dominated by magnetite. Their petrographical characteristics show that they are of the chromium type.

Bulk geochemistry: The content of major oxides in weight% is given in Table 1. Bulk chemistry of four representative samples show that the xenoliths have similar amounts of major oxides. They have low silica contents that range from 40.9-43.1 wt% classified as therefore ultramafic rather than mafic. They are characterized by high MgO (42.07-43.18%), Cr (2465-2538 ppm) and Ni (2196-2301ppm) contents and relatively low Al_2O_3, Na_2O, CaO and K_2O concentrations. Their chemical range is similar to the average chemical composition of lherzolite of upper mantle origin reported by different authors[20]. A slightly high FeO total content (8.21-9.19 wt%) (Table 1), accounts for the Fe present in spinel, olivine, pyroxene and opaques.

Magnetic results: For the three samples the ZFC and FC measurements behave nearly in the same manner at different temperatures as shown in Table 2.

Table 1: Whole rock chemical analyses of spinel lherzolite xenoliths from Jabal Remah

	R1	R2	R3	R4
Major oxides				
SiO_2	42.31	42.26	42.07	43.18
TiO_2	0.10	0.23	0.28	0.19
Al_2O_3	1.79	1.86	1.42	1.66
FeOt	8.86	9.19	8.75	8.21
MnO	0.12	0.12	0.13	0.14
MgO	44.28	44.08	44.12	45.07
CaO	1.78	1.98	1.85	1.64
Na_2O	0.13	0.18	0.70	0.16
K_2O	0.04	0.04	0.04	0.05
P_2O_5	0.02	0.04	0.05	0.03
LOI	0.49	0.65	1.05	0.42
Sum	99.92	100.63	100.46	100.75
Trace elements (ppm)				
Sc	8	7	8	6
V	41	38	52	44
Rb	4	3	4	2
Ba	26	18	31	28
Co	109	115	124	105
Cr	2572	2465	2505	2538
Ni	2288	2196	2254	2301
Y	6	5	6	4
Sr	32	28	31	24
Zn	54	50	48	70
Zr	17	15	14	20

Table 2: Magnetic measured parameters for the three analyzed samples

Sample	1 (emu g^{-1})	2 (emu g^{-1})	3 (Oe)	4 (emu Oe.g^{-1})	5 (emu g^{-1})
T1	0.08649	0.10125	29.3119	0.00306	0.03439
X1	0.10608	0.113399	24.42599	0.00436	0.03425
X2	0.06761	0.09976	24.42599	0.00311	0.03471

1: Magnetization from ZFC (4.5 k), SQUID measurements; 2: Magnetization from FC (4.5 k), SQUID measurements; 3: Coercivity H_c, VSM measurements; 4: Initial susceptibility, VSM measurements; 5: Magnetization at certain field (H = 9000 Oe) at room temperature. VSM measurements

The presence of magnetization in these samples was attributed to the presence of iron bound to oxides such as spinel, magnetite and since the Fe contents contributes about 9% of the whole sample composition, we observed a small magnetic moment (emu g^{-1}) even at low temperature.

The narrow magnetic hysteresis curves (very low H_c) for the three samples give an indication that we have a ferrimagnetic phase at room temperature. The ferrimagnetic behavior is attributed to the presence of oxides, where the magnetization in different sub-lattices couple antiferromagnetic by the super exchange interaction via oxygen ions. This is supported by the mineralogical results which shows that spinel is the main mineral phase. In addition to that we never reached the saturation even with an applied field up to 5.5 Tesla (Fig. 2 and 3).

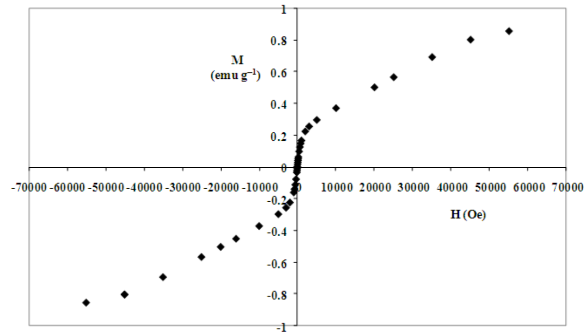

Fig. 2a: SQUID Isothermal hysteresis curve at 4.2 K for a representative sample

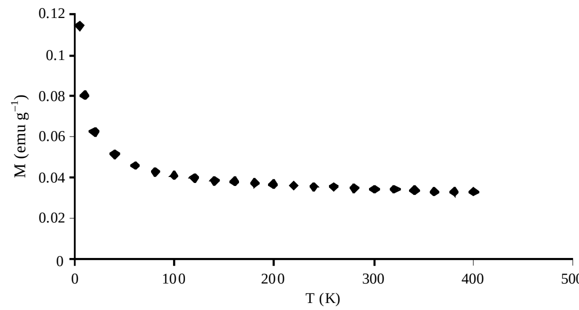

Fig. 2b: Field cooling curve for a representative sample using SQUID

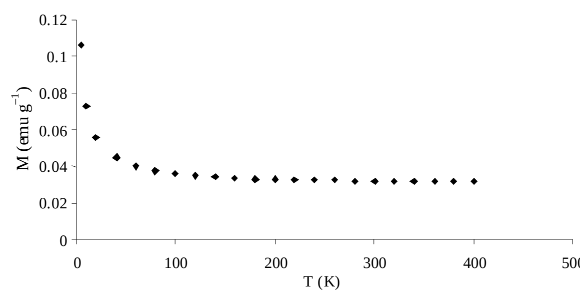

Fig. 2c: Zero field-cooling curve for a representative sample using SQUID

From Fig. 2 and 3 and Table 2 we can observe the effect of the temperature in reducing the magnetization of each sample and that is attributed to the increase of the thermal motion of magnetic ions with the increase in temperature.

Figure 2a and magnetization data of SQUID in Table 2, resembles those of mantle xenoliths samples analyzed by[8], due to the presence of similar mineral assemblage.

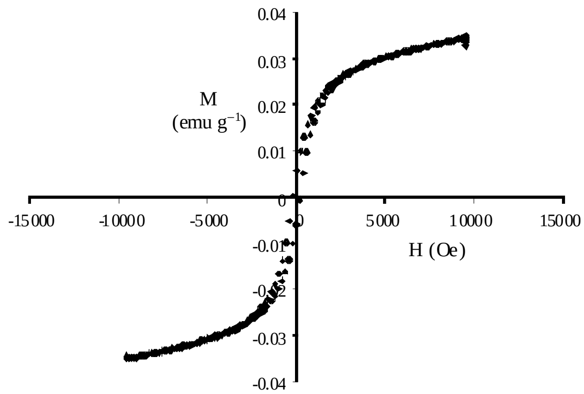

Fig. 3a: Magnetic hysteresis curve at room temperature for a representative sample using VSM

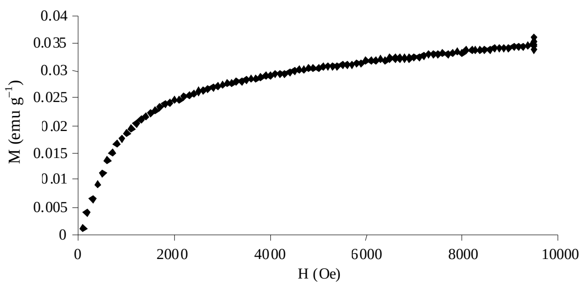

Fig. 3b: Initial Magnetization curve for a representative sample using VSM

CONCLUSION

Ultramafic spinel lherzolitic mantle xenoliths from Jabal Remah, NE-Jordan belongs to Type I and Cr-diopside group xenoliths. They contain relatively high Fe concentrations of up to 9-wt% accounted for by the Fe in olivine, pyroxene, spinel, etc, as well higher MgO contents. They exhibit ferrimagnetic behavior as indicated from the narrow hysteresis curves and the fact that they never reach saturation even at high-applied field. This may be attributed to the presence of iron as oxide (i.e., spinel), which produces the superexchange interaction via oxygen ions.

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