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Oxygen and Hydrogen Isotope Study of Serpentinized Peridotite Rocks, Thrust Zone, North East Iraq

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ABSTRACT

This study concentrates on two serpentinite bodies (Mawat and Penjwin) within Zagros Thrust Zone, North East Iraq. The Mawat Serpentinite which represents lherzolite protolith show δ^{18}O of 6.77 – 8.33 ‰ and δD values of (-65) - (-61) ‰. The Penjwin serpentinite (harzburgite protolith) show δ^{18}O values of 10.90 – 13.29 ‰ and δD values of (-74) – (-69) ‰. Mawat serpentinization occurred by hydration of mantle wedge rocks along intraoceanic supra-subduction zone at temperature of 150 – 200 °C. On the other hand Penjwin serpentinization occurred during and after emplacement of Penjwin ophiolite suite at temperature of 50 – 100 °C. Emplacement of Mawat serpentinite as an isolated body into Walash volcano-sedimentary sequence took place by diapiric process. Penjwin serpentinite was emplaced due to tectono-metamorphic event.

دراسة نظائر الأوكسجين والهيدروجين لصخور البيريدوتايت المتسربنة، نطاق الزحف، شمال شرق العراق

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الملخص

تناول البحث دراسة صخور السربنتنايت في منطقتي ماوات وبنجوين ضمن نطاق انزلاق زاكروس شمال شرق العراق. تكونت صخور سربنتنايت ماوات من اصل اللارزولايت واظهرت قيم δ^{18}O ٦.٧٧ – ٨.٣٣ ‰ وقيم δD (-٦٥) الى (-٦١) ‰. اما صخور سربنتنايت بنجوين فانها تكونت من اصل الهارزبركايت واظهرت قيم δ^{18}O ١٠.٩٠ – ١٣.٢٩ ‰ وقيم δD (-٧٤) الى (-٦٩) ‰. ان سبب حدوث السربنتنة في ماوات هو تميؤ صخور اسفين الجبة على طول نطاق الغوران ضمن المحيط وفي درجة حرارة تتراوح ١٥٠ – ٢٠٠ درجة مئوية. اما بنجوين فان السربنتنة حدثت خلال وبعد تموضع صخور اوفيولايت بنجوين وفي درجة حرارة ٥٠ – ١٠٠ درجة مئوية. لقد حدث بعد ذلك تموضع صخور سربنتنايت ماوات على تكوين والاش البركاني-الرسوبي نتيجة عملية الاختراق (Diapiric). من ناحية اخرى تموضعت صخور سربنتنايت بنجوين نتيجة حدث تكتوني-تحولي.

INTRODUCTION

This study deals with serpentinization of ultramafic rocks in an area situated within Zagros Thrust Zone, NE Iraq (Fig. 1). All serpentinite rocks in Iraq are situated within Zagros Thrust Zone. This zone is located in an area of about 5000 km^2 along Turkey-Iran-Iraqi border (Buday and Jassim, 1987). The nappe block of Zagros Thrust Zone was thrusted along low angle thrust fault (Williams, 1974). Serpentinites are rocks composed predominantly of serpentine minerals: lizardite, chrysotile and antigorite with accessory magnetite, brucite and Mg and Ca-Al silicates. In this respect, serpentinization is a term used to describe the process by which serpentine is formed from preexisting anhydrous and less hydrous minerals such as olivine, enstatite and other Mg-rich silicate and carbonate (Hanley, 1996).

Serpentinites are usually formed by low-temperature hydrothermal metamorphism of peridotite, pyroxenite, gabbro, marble and silicate dolomite. Serpentinites found in different tectonic environments such as plate convergent margins, divergent margins and transform faults each is characterized by special textures, mineralogy and type of protolith.

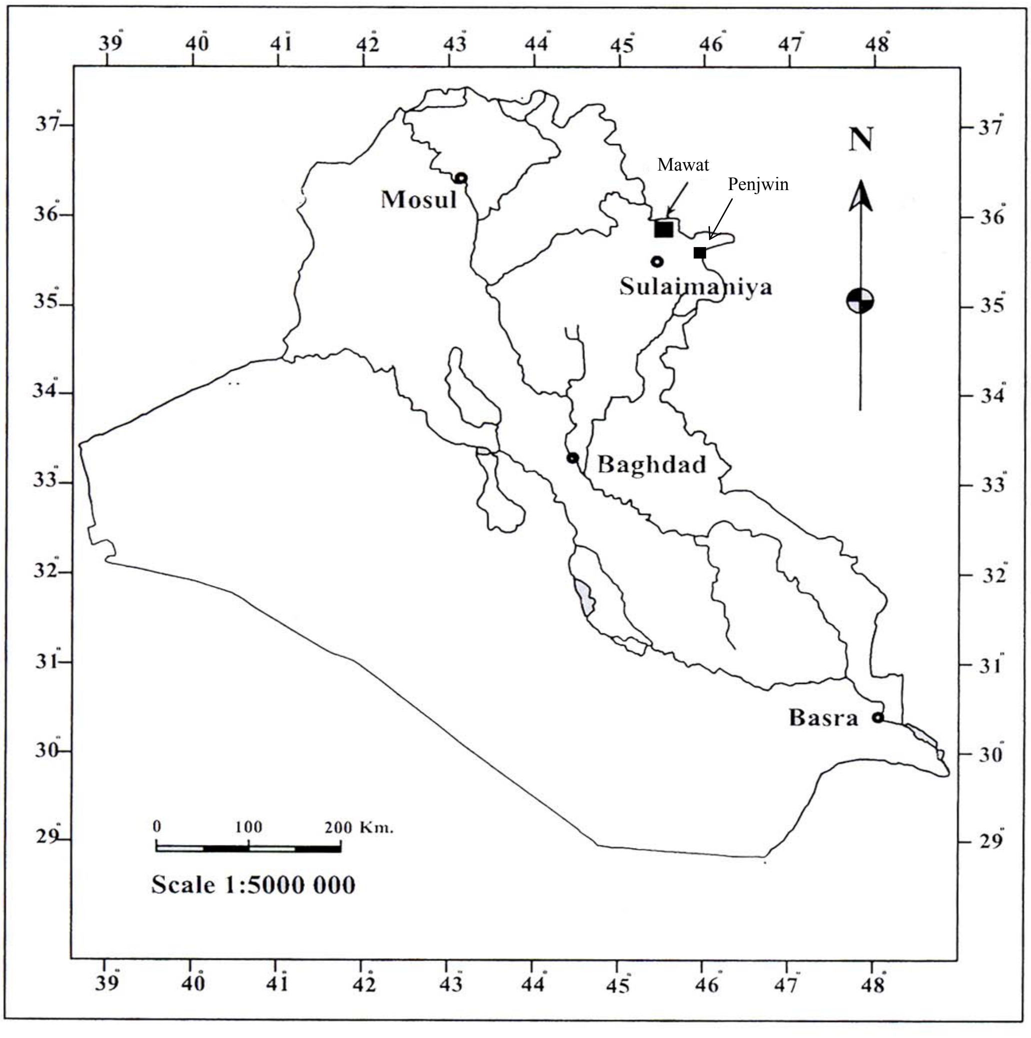

Fig. 1 : Simplified map of Iraq showing the location of the study areas.

Stable isotopes (particularly oxygen and hydrogen) study of serpentinites indicates that the water responsible for serpentinization of ultramafic rocks are of various sources (sea water, meteoric, magmatic and metamorphic waters) (Sakai et al., 1991; Cartwright and Barnicoat, 1999). It is significant, therefore to study serpentinite and serpentinization process and one of the approaches is the application of stable isotopes to determine the parent rock composition; to specify the temperature-pressure conditions under which the hydration took place; define whether serpentinization occurs in the crust or mantle; evaluate the possible source and composition of fluid phase necessary for hydration.

There are several serpentinite bodies within Iraqi Zagros Thrust Zone and this study concentrates on two bodies in Mawat and Penjwin areas (Fig. 1). The Mawat serpentinite is mostly of massive type, while all types of serpentinite are common in Penjwin especially massive and sheared types (Mohammed, 2004). The most common mineral assemblages in Mawat serpentinite are lizardite + chrysotile + amphibole, while the common mineral assemblages in Penjwin serpentinite are lizardite + chrysotile for the massive type and antigorite + chrysotile for the sheared type.

The aim of the present research is to study the genesis of serpentinization process on peridotite rocks in Mawat and Penjwin areas applying oxygen and hydrogen analyses of five samples.

METHODOLOGY

Oxygen which is the most abundant chemical element in the earth crust occurs in silicate, oxide, carbonate, phosphate and sulphate minerals. The isotopic composition of oxygen in these minerals varies widely depending on the temperature of crystallization. Generally, silicate minerals are enriched in ^{18}O whereas meteoric water and sea water are depleted in this isotope. In this context, ^{18}O content increase as magmatic differentiation proceeds from ultrabasic-basic towards acidic rocks.

Oxygen (atomic number Z=8) has three stable isotopes with abundances: ^{18}O=0-200 %, ^{17}O=0.038 % and ^{16}O=99.762 %. The isotopic composition of oxygen varies as a result of isotope fractionation during various chemical and physical processes (Faure, 1977). The isotope composition of oxygen is expressed in terms of the $\delta^{18}O$ parameter (per mil) defined as:

$$\delta^{18}O = \frac{(^{18}O/^{16}O)\text{sample} - (^{18}O/^{16}O)\text{standard}}{(^{18}O/^{16}O)\text{standard}} \times 10^3 \text{ ‰ (per mil)}$$

The standard used for this purpose is Standard Mean Ocean Water (SMOW). Analyses of oxygen and hydrogen isotopes were done at University of Gottingen in Germany using McKinney type mass spectrometer. Oxygen was extracted from the samples by reaction with bromite pentaflouride (BrF5) in nickel reaction vessels at 650-700 °C for 24 hours. The released oxygen was converted to carbon dioxide for measurement by mass spectrometer. All oxygen isotopic ratios are reported as δ-value in per milliliter (per mil) ‰ relative to SMOW and the reproducibility of $\delta^{18}O$ analysis is +0.1 ‰.

Hydrogen is an important constituent of many minerals including clay minerals, zeolite, mica, amphibole, chlorite, serpentine, gypsum and many oxide minerals. The isotope geology of hydrogen is especially interesting because of its occurrence as H_2O, OH, H_2 and CH_4. Hydrogen (atomic number =1) has two stable isotopes ^1H and ^2H (Deuterium) with abundances 99.9852% and 0.0148% respectively. The isotopic composition of hydrogen in the sample is expressed as δD relative to SMOW:

$$\delta D = \frac{(D/H)\text{sample} - (D/H)\text{SMOW}}{(D/H)\text{SMOW}} \times 10^3 \ ‰ \text{ (per mil)}$$

To analyze hydrogen isotopes the first step is to outgas the adsorbed water at 200 °C for at least 2 hours in vacuum. The remaining water is extracted by inductive heating at 1300 °C and the small amount of hydrogen gas which is generated by the reaction of water with ferrous iron during dehydration process is converted to water by heating with CUO at 400 °C. The extracted water is then passed over heated uranium metal (650 °C) and converted to hydrogen gas. The hydrogen is manometrically measured to give the H_2O+ content. The hydrogen isotopic composition of H_2 gas is determined with reproducibility equal to +1.0 ‰ .

RESULTS AND DISCUSSION

The oxygen and hydrogen isotopic results are listed in Table (1) and all values are measured relative to SMOW. As shown in Table (1), the measured $\delta^{18}O$ and δD values of lizardite-chrysotile in Mawat area are 6.77–8.33 ‰ and (-65) – (-61) ‰ respectively. On the other hand, $\delta^{18}O$ and δD values in Penjwin area range from 10.90 – 13.29 and (-74) – (-69) ‰ respectively. It is clear that $\delta^{18}O$ values in Mawat are lower than those values in Penjwin, while δD values are higher in Mawat.

Table 1 : Oxygen and hydrogen isotope ratios (‰) relative to SMOW of whole rocks.

Sample	Rock Type	$\delta^{18}O$	δD
1M	Lizardite-chrysotile serpentinite	8.33	-65
2M	Lizardite-chrysotile serpentinite	6.77	-61
1P	Lizardite-chrysotile serpentinite	13.29	-74
2P	Lizardite-chrysotile serpentinite	11.46	-70
3P	Lizardite-chrysotile serpentinite	10.90	-69

M : Mawat area.
P : Penjwin area.

By examining the $\delta^{18}O$ values of serpentinized peridotite rocks in both Mawat and Penjwin areas, it is clear that the existence of ^{18}O enrichment as the expected $\delta^{18}O$ value in ultramafic rocks is ~ 5-7 ‰ (Hall, 1987). It is evident that the δD values in Mawat (-65 to -61 ‰) and in Penjwin (-79 to 70 ‰) all fall midway between those values for upper mantle and sea water. The Mawat serpentinized samples, however, plot within the field of continental antigorite and overlapping continental lizardite-chrysotile field (Fig. 2). In this respect, the Mawat serpentinites have δD values similar to oceanic serpentinite (-68 to -35 $\%_0$) but its $\delta^{18}O$ values is higher. The Penjwin serpentinite samples have $\delta^{18}O$ and δD values have close similarity to the values in the field of ophiolitic lizardite-chrysotile type (Fig. 2).

The Mawat serpentinites which have originated from lherzolite rocks (rich in olivine, orthopyroxene and clinopyroxene) show $\delta^{18}O$ values (~7 ‰ average) lower than those in Penjwin serpentinite (~12 ‰ average) originated from harzburgite rocks (rich in olivine and orthopyroxene). It should be the opposite, as $\delta^{18}O$ values increases by increasing SiO_2 content since lherzolite has more SiO_2 than harzburgite. The disparity in the $\delta^{18}O$ values between the two areas is perhaps due to the influence of alteration process. In this regard, the role of meteoric water and the greater rate of alteration in Penjwin serpentinite are probable reasons for the higher $\delta^{18}O$ values compared with those in Mawat serpentinite. Various isotopic studies of ophiolites (Sheppard, 1980) and other ultramafic bodies (Barnes and O'Neil, 1969) suggest that meteoric water can act as serpentinizing fluid. For such water to penetrate and make influence, the igneous rocks must have sufficient permeability which possibly has generated during emplacement process (Sheppard, 1980). However, the existence of microfracures filled with serpentine and a recrystallized groundmass (partly consisting of serpentine) are positive evidence. The water responsible for serpentinization of ultramafic rocks in Mawat serpentinite is possibly derived from dehydration of descending oceanic slab via intraoceanic supra-subduction probably occurred during Paleocene-Eocene (Aziz, 1986). On the other hand, Fig. (3) shows that sea water is responsible for serpentinization of basal ultramafic rocks of Penjwin ophiolite but later on meteoric water participitated during the ascending process (fore-arc). To determine the temperature of crystallization the model of Sakais et al. (1991), was applied. It seems to be that serpentinization of ultramafic rocks in Mawat has occurred at 150-200 °C, while the serpentinization of basal ultramafic rocks of Penjwin ophiolite has ocured at about 50-100 °C (Fig. 3). However, a clear shifting in the isotopic composition of Penjwin serpentinite from its field is noticed which is due to the late effects of meteoric water. The determined values of temperature agree with the mineral assemblage lizardite-chrysotile in both areas as the stability limit of both minerals do not exceed 200 °C (Alt and Shanks, 2003).

CONCLUSIONS

The following significant conclusive points can be drown from this study :

1. Mawat serpentinite represents an isolated body of fore-arc type formed by hydration of ascending mantle wedge rocks (lherzolite) along subduction zone. While Penjwin serpentinite represents Alpine Peridotite (sub-oceanic harzburgite) formed during and after diapiric emplacement of Penjwin ophiolite suite.
2. The water responsible for serpentinization of Mawat ultramafic rocks was derived from dehydration of downgoing oceanic crust subjected to intraoceanic supra-subduction probably during Paleocene-Eocene. The water responsible for serpentinization of Penjwin ultramafic rocks was oceanic water with minor effect of meteoric water.
3. Serpentinization of ultramafic rocks in Mawat and Penjwin occurred at temperature of about 150-200 °C and 50-100 °C respectively.
4. Mawat serpentinite was emplaced as isolated body along supra-subduction zone into Walash volcano-sedimentary sequence by diapric process. On the other hand, Penjwin serpentinite emplacement was due to tecton-metamorphic event (obduction mechanism).

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