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Chromitite and peridotite from Rayat, northeastern Iraq, as fragments of a Tethyan ophiolite

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Abstract Ophiolitic rocks (chromitites and serpentinized peridotites) were petrologically examined in detail for the first time from Rayat, in the Iraqi part of the Zagros thrust zone, an ophiolitic belt. Almost all the primary silicates have been altered out, but chromian spinel has survived from alteration and gives information about the primary petrological characteristics. The protolith of the serpentinite was clinopyroxene-free harzburgite with chromian spinel of intermediate Cr# (=Cr/[Cr + Al] atomic ratio) of 0.5 to 0.6. The harzburgite with that signature is the most common in the mantle section of the Tethyan ophiolites such as the Oman ophiolite, and is the most suitable host for chromitite genesis. Except for one sample, which has Cr# = 0.6 for spinel, the Cr# of spinel is high, around 0.7, in chromitite. The variation in Cr# of spinel in chromitite observed here has been also reported in the Oman ophiolite. The peridotite with chromitite pods exposed at Rayat was derived from an ophiolite similar in petrological character to the Oman ophiolite, one of the typical Tethyan ophiolites (fragments of Tethyan oceanic lithosphere). This result is consistent with the previous interpretation based on geological analysis.

Key words: chromitite, harzburgite, Iraq, Oman ophiolite, Rayat, Tethyan ophiolite.

INTRODUCTION

The northeastern corner of Iraq has an ophiolitic belt, the Zagros thrust zone, which extends south-eastward to Iran and north-westward to Turkey. The ophiolitic belt of this area forms an ophiolitic mélangé within the Zagros orogen (Alavi 1991). It has been well-recognized that the ophiolite belongs to the Tethyan ophiolitic belt of Mesozoic age in tectonic division (Fig. 1) (Moores et al. 2000). Ophiolitic complexes are exposed in the Rayat area of northeastern Iraq (Kurdistan region) (Fig. 1). Bolton (1958) performed the first reconnaissance description of geology of the Rayat area, and made a geological map indicating an extent of distribution of ultramafic bodies. He referred to occurrence of chromitite pods (Bolton 1958). A group of Russian geologists published a more comprehensive report for the geology of the area (Vasiliev & Pentelikov 1962). Their work was oriented to an exploration of chromitite and other sulfides, and they modified the earlier map of Bolton (1958) by adding detailed structural and stratigraphical descriptions. Buda and Al-Hashimi (1977) presented detailed mineralogy, chemistry, and genetic interpretations of podiform chromitites in the ophiolitic complexes from the Iraqi Zagros Mountains. Al Jawadi (unpublished data, 1980) gave petrological and geochemical aspects of the constituent rocks of the area, showing distributions of major and trace elements. He concluded that the peridotite and associated chromitites are of alpine-type (M. R. Al Jawadi, unpublished data, 1980).

We present detailed petrographical and mineral chemical descriptions for the first time about representative samples of chromitite and associated peridotite (ten and five samples, respectively) from the Rayat area, northeastern Iraq, to grasp the petrological characteristics of the mantle section of the ophiolitic complexes in this part of Zagros Thrust Belt. All the primary silicate minerals have
been altered except for minute inclusions in chromian spinel. The only preserved primary mineral is chromian spinel, which is, however, a powerful petrogenetic indicator (Irvine 1965; Dick & Bullen 1984; Arai 1992, 1994) even in highly altered ultramafic rocks (Ahmed et al. 2005). We mainly describe spinel chemistry and compare the ophiolitic rocks with other Tethyan ophiolites (fragments of the Tethyan oceanic lithosphere), especially the Oman ophiolite, in terms of spinel composition and petrography. The Oman ophiolite is the best preserved and investigated of all the Tethyan ophiolites, and is suitable for comparison. Chemical characteristics concerning alteration of chromian spinel in chromitites from Rayat were reported by Arai et al. (2006b).

GEOLOGICAL BACKGROUND

The study area is part of the Iraqi Zagros thrust zone, situated east of Rayat village within the northeast corner of Iraq. It is located about 110 km east of Erbil and 10 km west of the Iraqi-Iranian border (Fig. 1). The Zagros thrust zone consists of three structural units of a Tertiary age: the Walash, Naopurdan, and Quandil groups.

There has been very little geological research available for this area, and chronological data of the rocks are poorly accumulated. The Rayat ultramafic body is situated within the Walash Group (Al Mehaidi 1974), which consists of volcanosedimentary sequences of unmetamorphosed basalt (sometimes pillowed), dolerite, andesite, tuff, agglomerate, greywacke, limestone, and radiolarian chert. Eocene age was proposed for the Walash Group by stratigraphy (Bolton 1958; Al Mehaidi 1974) as well as radiometric age determination on its basaltic rocks (32–43 Ma) (A. M. A. Koyi, unpublished data, 2006). Structurally, the Rayat area is characterized by the presence of two major thrust zones that divide the area into three structural belts or stages. As a result of the lower thrust activity, serpentinized peridotite and metamorphosed limestone (Walash Group) came to lie on the folded calcareous sediments of the Walash.
Group (Fig. 2). Ferruginous mottled conglomerates of the Walash Group (including conglomerates, greywackes, and grey limestones) were overthrusted on the serpentinite and enclosing rocks (especially metamorphosed limestone blocks) (Vasiliev & Pentelikov 1962) (Fig. 2).

The ultramafic body is one of the small ophiolitic complexes including the Mawat, Bulfat, and Penjwin bodies, emplaced in parallel with each other within the Zagros thrust zone. The ultramafic body at Rayat is relatively small, about 1 km long and 200 to 400 m wide in plan (Vasiliev & Pentelikov 1962) (Fig. 2).

The chromitite samples examined were taken from podiform blocks, massive or brecciated, within sheared serpentinite (Fig. 3). The serpentinite forms a mélange complex, composed of strongly sheared and comminuted serpentinite with various kinds of blocks including serpentinated peridotites and chromitites (Fig. 3). Due to the highly sheared nature of the serpentinite, the dunite envelope was not recognized just around the chromitite pods.

PETROGRAPHY

PERIDOTITES

Peridotites are almost completely serpentinized, and mesh-textured chrysotile/lizardite after olivine is widespread (Fig. 4a). Anhedral bastite pseudomorphs after pyroxene are prominent, and they sometimes exhibit wavy extinction indicating distortion of precursor pyroxene (Fig. 4a). Clinopyroxene is absent. The bastite is very clear and uniform in texture and appearance, indicating an orthopyroxene precursor. Bastite after clinopyroxene, if any, is usually turbid due to disseminated fine alteration minerals (sphene and others). Chromian spinel is anhedral and reddish brown in thin-section (Fig. 4a). It is evenly disseminated and less than 1 vol.% in harzburgites. Alteration products with high reflectivity and sharp optical boundaries with unaltered parts were produced along rims and cracks of chromian spinel (Arai et al. 2006b). Chromian spinel contains rounded silicate inclusions. Neither saussurite after plagioclase nor amphibole is present. The primary peridotite is most probably plagioclase-free harzburgite with a protogranular texture. Dunite has not been sampled from massive parts of the complex.

CHROMITITES

Chromitite is massive and contains more than 70 vol.% of chromian spinel. Chromian spinel is
brecciated and the matrix is rich in carbonates (dolomite and calcite) to various extents (Fig. 4b). Chlorite flakes with grayish brown interference colors are commonly associated with carbonates. Lizardite/chrysotile serpentinite is also found in the matrix. The brecciation is enhanced in parallel with the degree of carbonation. Carbonate is highly variable in grain size; relatively coarse-grained pools were found at the center of fine-grained portions in the matrix. Arai et al. (2006b) gives more detailed descriptions of alteration of chromian spinel.

MINERAL CHEMISTRY

GENERAL REMARKS

Minerals were analyzed on polished thin-sections for major and minor elements with a wavelength dispersive microprobe (JEOL Superprobe JXA-8800) at Kanazawa University. Raw intensities for each element were corrected by the ZAF method, and weight percents of oxides were calculated. We used various natural and synthetic minerals as standards. We adopted 15 kV for accelerating voltage, 20 nA for beam current, and 3 μm for beam diameter on MgO (periclase). Counting time was 20 s on the peak of characteristic X-ray for each element. We assumed all iron in silicates is ferrous. Ferrous and ferric irons in chromian spinel were calculated from raw analyses assuming spinel stoichiometry. Mg# is Mg/(Mg + total Fe) atomic ratio for silicates and Mg/(Mg + Fe3+) atomic ratio for chromian spinel. Cr# is Cr/(Cr + Al) atomic ratio for chromian spinel. Representative microprobe analyses are listed in Tables 1 and 2.

CHROMIAN SPINEL

The unaltered part of the chromian spinel is described in this article. Chromian spinel is relatively high in Cr#, 0.70 to 0.72, in almost all (nine of ten) chromitite samples, but is distinctly lower in Cr#, 0.60 to 0.64, in the remaining one sample (Table 1, Figs 5,6). The Mg# is relatively high and is roughly in negative correlation with the Cr#; around 0.68 to 0.76 for spinel with Cr# of 0.7, and around 0.85 for spinel with Cr# of 0.6 (Fig. 6, Table 1). The TiO2 content of spinel is around 0.2 wt% (Fig. 7).

Chromian spinel in serpentinized harzburgite is lower in Cr#, 0.50 to 0.64, than that in chromitite (Fig. 5). The Mg# of spinel in the Rayat serpentinized harzburgite ranges from 0.52 to 0.64, systematically lower at a given Cr# than in chromitite (Arai 1980). The TiO2 content of spinel is less than 0.1 wt% in harzburgite, being markedly lower than that in chromitite (Arai 1980).
Alteration drives the spinel composition ultimately to magnetite through ferritchromite. High-Cr#, low-Fe3+ spinels which are different from ferritchromite that formed during relatively high-temperature alteration stage can be easily discriminated from the primary spinels by optical characteristics (high reflectivity and inclusions of secondary hydrous minerals for the former) under the microscope (Arai et al. 2006b). The alteration process of chromian spinel in the chromitite from this area was discussed by Arai et al. (2006b).

SILICATES AND CARBONATES

Relic olivine was only found as inclusions in chromian spinel in chromitite samples (R1c and R8c). It is high in Fo (=100 Mg#), around 97, and in NiO (~0.9 wt%) (Table 2). Clinopyroxene enclosed by chromian spinel in chromitite (R2c) is also high in Mg# (0.97), and low in TiO2 (<0.1 wt%) and Al2O3 (1 wt%). These characteristics are common to silicate inclusions in chromian spinel in chromitite (Talkington et al. 1986). Orthopyroxene enclosed by chromian spinel in serpentinized harzburgite is relatively low in Mg# (0.914), being similar in chemistry to ordinary mantle orthopyroxene in peridotite (Table 2). This is due to low abundance and fine grain size of enclosing chromian spinel (Arai 1980). Serpentine and chlorite are all high in Mg# (mostly >0.95) (Arai et al. 2006b).

Carbonate is mostly dolomite and subordinately calcite. Calcite sometimes contains up to 3 wt% MgO.

DISCUSSION

CHARACTERIZATION AND ORIGIN OF RAYAT PERIDOTITE AND CHROMITITE

The harzburgite of the Rayat area, which contains chromian spinel with intermediate Cr# 0.5 to 0.6, is the most common to the mantle section of
ophiolites including Tethyan examples such as the Oman ophiolite (Kadoshima 2002; Le Mée et al. 2004). This is also similar in petrography and mineral chemistry to the most refractory harzburgite from the present-day ocean floor, especially of fast-spreading ridge origin (Arai & Matsukage 1996; Dick & Natland 1996).

The harzburgite with intermediate Cr# of 0.5 to 0.6, of spinel is the most suitable host for podiform chromitite (Arai 1997). This is consistent with the abundance of chromitite pods within serpentinite of this area (M. R. Al Jawadi unpublished data, 1980) (Fig. 2), and we can predict that the Rayat area has the potential to produce workable chromitite pods (Arai 1997). The chromitite is the most common of all podiform chromitites ever documented in terms of spinel compositions; that is, the Cr# is around 0.7 (Arai 1997).

Chromitite with relatively high Cr# of spinel had been produced at an arc-related setting (Arai & Yurimoto 1994, 1995) because of the high Cr# (~0.7) and low TiO₂ content (compare Arai 1992).

Magma chemistry of basalts varies depending on tectonic setting (Pearce 1975), and chemistry of spinel in equilibrium with the magmas is also changeable, reflecting this magma chemistry depends on the tectonic environments (Arai 1992). The relatively Al-rich chromitite with lower Cr# (~0.6) of spinel might also have been derived from the ocean floor (compare Arai & Matsukage 1996, 1998). The Rayat harzburgite had been possibly representative of the abyssal mantle peridotite, especially of a fast-spreading ridge as stated above.

**DERIVATION OF RAYAT OPHIOLITIC ROCKS: COMPARISON WITH OMAN OPHIOLITE**

The peridotites and chromitites of the Rayat area are very similar in mineral chemistry to equivalents of the Oman ophiolite, possibly suggesting the petrological characteristics common to the Tethyan ophiolites. Chromian spinels from the Rayat ophiolitic rocks are plotted within the spinel compositional range for the mantle rocks of the northern Oman ophiolite inferred from chromian spinels (DCS) (Arai et al. 2006a), is also shown. See text for detailed discussion.

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**Table 2** Selected microprobe analyses of primary silicates

<table>
<thead>
<tr>
<th>Mineral sample</th>
<th>R1c</th>
<th>R1c</th>
<th>R8c</th>
<th>R2c</th>
<th>R4sb</th>
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<tr>
<td>SiO₂</td>
<td>41.62</td>
<td>41.29</td>
<td>42.34</td>
<td>53.95</td>
<td>57.16</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.07</td>
<td>0.00</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>1.00</td>
<td>0.94</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>0.52</td>
<td>0.72</td>
<td>0.21</td>
<td>1.43</td>
<td>1.45</td>
</tr>
<tr>
<td>FeO*</td>
<td>2.87</td>
<td>2.71</td>
<td>3.28</td>
<td>1.16</td>
<td>5.88</td>
</tr>
<tr>
<td>MnO</td>
<td>0.04</td>
<td>0.02</td>
<td>0.06</td>
<td>0.01</td>
<td>0.17</td>
</tr>
<tr>
<td>MgO</td>
<td>54.07</td>
<td>53.85</td>
<td>54.56</td>
<td>17.71</td>
<td>34.94</td>
</tr>
<tr>
<td>CaO</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
<td>25.49</td>
<td>0.49</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.07</td>
<td>0.00</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>NiO</td>
<td>0.87</td>
<td>0.94</td>
<td>0.88</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Total</td>
<td>100.05</td>
<td>99.57</td>
<td>101.39</td>
<td>100.98</td>
<td>101.11</td>
</tr>
</tbody>
</table>

All are inclusions in chromian spinel.

Cpx, clino.pyroxene; FeO* and Fe*, total iron as FeO and Fe, respectively; Opx, orthopyroxene; R4sb, harzburgite, and the others are chromitites.

**Fig. 5** Trivalent cation ratios of chromian spinels in harzburgite and chromitites from Rayat, northeastern Iraq. Compositional ranges for chromian spinels in chromitites from the Oman ophiolite (Augé 1987; Ahmed & Arai 2002) are shown for comparison. The range for the rocks of the mantle section of the Oman ophiolite, inferred from detrital chromian spinels (DCS) (Arai et al. 2006a), is also shown. See text for detailed discussion.
Rayat harzburgite is very similar in spinel chemistry to the harzburgite most commonly found from the Oman ophiolite (Kadoshima 2002; Le Mée et al. 2004) (Fig. 6). We could not find, however, the highly depleted high-Cr harzburgite (Cr# of spinel ~ 0.7) and lherzolites (Cr# of spinel < 0.3) (Lippard et al. 1986; Takazawa et al. 2003) that are subordinately found in the Oman ophiolite (Augé 1987; Ahmed & Arai 2002) (Figs 5–7). As far as we know, only a few single ophiolites have chromitite pods with two different Cr#s; 0.6 and 0.7 in this case (Arai 1997). For example, the Tari–Misaka harzburgite (Southwest Japan), of which chromian spinel has Cr# around 0.5, is the host for relatively Al-rich chromitites, which contain chromian spinel with Cr# around 0.5 to 0.6 (Arai 1980; Arai & Yurimoto 1994). The northern Oman ophiolite contains podiform chromitites with a variety of Cr# of chromian spinel (Ahmed & Arai 2002), from the Moho transition zone to the upper mantle section, although the surrounding mantle harzburgite (Augé 1987) is rather uniform in petrological characteristics including Cr# of spinel (~0.5–0.6) (Kadoshima 2002; Le Mée et al. 2004). In the northern Oman ophiolite, the Cr# of chromian spinel in chromitite is relatively low in Cr# (0.5–0.6) around the Moho transition zone but high in Cr# (~0.7) within the mantle section (Augé 1987; Ahmed & Arai 2002) (Figs 5–7). The chromitites with high-Cr# spinel from Rayat are very similar in spinel chemistry to the chromitites in the upper mantle from the northern Oman ophiolite (Augé 1987; Ahmed & Arai 2002) (Figs 5–7). Ahmed and Arai (2002) ascribed the low-Cr# nature of chromitites from the Moho transition zone to assimilation of gabbroic rocks by relevant melts. In contrast, the chromitite with lower-Cr# spinel is equivalent to the chromitite around the Moho transition zone of the Oman ophiolite (Augé 1987; Ahmed & Arai 2002) (Figs 5–7). The slight difference in Mg# of chromitite spinel at a given Cr# (Fig. 6) is not due to modal variations of spinel (Arai 1980), because all of the chromitites examined are rich in chromian spinel (>70 vol.%). In conclusion, both the harzburgite and chromitites from Rayat are equivalent to the chromitite around the Moho transition zone of the Oman ophiolite (Augé 1987; Ahmed & Arai 2002) (Figs 5–7). The Rayat chromitites were added by high-Cr# chromitites formed at the latter setting as in the Oman ophiolite (Arai et al. 2006a).
the upper mantle part of the ophiolite have been mixed by tectonism to produce a tectonic mélange composed of sheared serpentinite matrix with rigid lens-shaped chromitite blocks. The apparent absence of dunite, which had been present in the Moho transition zone of the original ophiolite, is possibly due to selective shearing. The results of petrological examination are consistent with the previous interpretation solely based on the location of the Rayat area within the Tethyan ophiolite belts (Fig. 2) (Moores et al. 2000).

CONCLUSIONS

1. The ophiolitic mélange of the Rayat area at the northeast corner of Iraq is mainly composed of sheared serpentinite, of which the protolith was harzburgite with intermediate Cr#, 0.5 to 0.6, of chromian spinel. This is common to the mantle section of the Tethyan ophiolites such as the Oman ophiolite.

2. Chromitite is mostly Cr-rich, containing high-Cr#, around 0.7, chromian spinel. Only one chromitite is relatively Al-rich, with lower Cr# (0.6) of spinel. The higher- and lower-Cr# chromitites are similar to the mantle chromitite and Moho transition zone chromitite, respectively, of the Oman ophiolite.

3. The peridotite and chromitite have petrological characteristics very common to the Moho transition zone to upper mantle of the Tethyan ophiolites.

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REFERENCES


