Distribution of Platinum-Group Elements and Gold within the Vourinos Chromitite Ores, Greece

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Abstract

A geochemical study of chromite ores and host rocks of the Vourinos ophiolite complex leads to the distinction of three geotectonic units, corresponding to the North Vourinos, South Vourinos, and Kissavos geographic areas. This is based on the range and variability of Cr/(Cr + Al), (Pt + Pd)/(Os + Ir + Ru), and Pd/Ir ratios and the relative abundance of compatible platinum-group elements (PGE, Os, Ir, and Ru) within the three blocks. The platinum-group element Au, gold contents are low. Average concentrations (in ppb) are Os = 23, Ir = 19, Ru = 58, Rh = 12, Pt = 5.9, Pd = 3.3, and Au = 2.7. However, a few PGE-enriched chromite samples (up to 3,030 ppb) were also found. The South Vourinos area differs from North Vourinos as far as its remarkably constant chemical composition (major and trace elements), its lower Pd/Ir and (Pt + Pd)/(Os + Ir + Ru) ratios, its greater abundance of the (Os + Ir) sum relative to Ru, and its absence of PGE-enriched chromite ores.

There is no significant correlation between chromite composition and PGE data throughout the complex. The only exception is the Kissavos area, where the PGE content is higher and the Pd/Ir ratio lower in Cr-rich ores than in Al-rich ones, showing a strong negative correlation between the Cr/(Cr + Al) and Pd/Ir ratios ($r = -0.8$).

The low PGE content in the majority of the Vourinos chromite ores may reflect a lack of sulfur saturation during an early stage of their crystallization, whereas PGE enrichment may suggest a mixing of primitive and partially fractionated magmas. Assuming that the Vourinos complex formed in a suprasubduction zone environment, it seems likely that South Vourinos chromitites formed directly above the spreading center, whereas the North Vourinos chromitites formed at a distance from the spreading center. In addition, the strong depletion of PGE in the Kissavos Cr-rich ores, particularly Os, Ir, and Ru, may suggest that these chromitites were crystallized from magmas derived by partial melting of an already-depleted mantle source.

The geochemical trend throughout the Vourinos complex seems to provide valuable confirmation of a stratigraphic orientation in the mantle sequence of the complex.

Introduction

Investigations of the geochemistry of platinum-group elements (PGE) have indicated a significant variability in their distribution and proportions in chromite deposits related to ophiolites, which characteristically have low PGE concentrations, particularly Pt and Pd, compared to chromitites, related to layered intrusions (Page et al., 1982, 1986; Economou, 1983, 1986; Auge, 1985). However, although there is little interest in the economic potential of podiform chromitites as a major or by-product source of PGE (Page et al., 1986; Konstantopoulou and Economou-Eliopoulos, 1990), some PGE-enriched chromitites have been described (Agiorgitis and Wolf, 1978; Economou, 1986; Prichard and Lord, 1988; Bacuta et al., 1990; Konstantopoulou, 1990). Regarding the Vourinos ophiolite complex which hosts the largest chromite deposits of Greece, only very limited data concerning the PGE abundance have been published (Economou, 1983, 1986; Konstantopoulou and Economou-Eliopoulos, 1990).

In this paper, on the basis of a detailed study of the major and noble metal variations in chromite ores and host mineral separates, a stratigraphic orientation within the mantle sequence of the Vourinos complex is attempted and the behavior of PGE during the generation and crystallization of mantle magmas is discussed.

Geologic Setting

The Vourinos ophiolite complex located in northwestern Greece (Fig. 1) is about 30 km long by 15 km wide and constitutes a complete but tectonically disrupted ophiolite sequence. It is located on the western side of the Pelagonian zone, lying tectonically on marbles of Upper Triassic-Lower Jurassic age (Brunn, 1956). Detailed descriptions of its geology, petrology, and structure have been given by many...
investigators (Aubouin, 1965; Moores, 1969; Rassios, 1981; Roberts et al., 1988; and others).

Vourinos is now considered to belong to the suprasubduction-zone (SSZ) type of ophiolites (Becchiluva et al., 1984; Pearce et al., 1984; Konstantopoulos, 1990); these are considered to be promising for
economic concentrations of chromite ores (Roberts, 1988).

The mantle sequence of Vourinos forms about 85 percent of the complex and consists of highly deformed tectonite-hartzbursite, interlayered dunite-hartzbursite, and irregular dunite bodies enclosing chromitite of various morphologies and textures. The magmatic part of the complex includes a complete cumulate and sheeted dike complex plus erosional remnants of an extrusional unit (Bassios, 1981).

The Rodiani area is located about 3 km east of the North Vourinos area and is tectonically separated from Vourinos by Jurassic platform carbonates (Fig. 1). It exhibits serpentinized harzburgite containing dunite and chromite ores as in the mantle sequence of Vourinos, and other rock types such as pyroxenite, rondzitted gabbro, and diabase, indicating the presence of magmatic sequence rocks. The structural and/or genetic relationship between the Rodiani and Vourinos ophiolitic sections is not well understood.

General Characteristics of Chromite Ores within the Vourinos Complex

The economic deposits in the Vourinos complex are located in the uppermost part of the tectonized harzburgite either within isolated dunite bodies or enclosed in narrow dunite envelopes. Schlieren (most common), banded, massive, disseminated, orbicular, and nodular types of chromite are all present. In some cases different types coexist within the same body, but commonly a single textural type dominates. The chromite ore has usually been affected by high-temperature deformation, superimposed on primary magmatic textures.

In the cumulate terrane chromite ore layers are found in the dunite bases of the cyclic units (Bassios, 1981). Although all chromite ores are found in dunite bodies, there is no systematic relation between the size of the dunite body and that of the orebody. The size, form, and quality of the orebodies vary widely. Schlieren ores form the bulk of the economic deposits of Vourinos such as the Xerolivado-Skountsa and Aerorches mines and the ore reserves of Konivos and Rizo. Schlieren orebodies contain bands of schlieren ore, each being 8 to 15 cm thick, alternating with low modal spinel dunite. Disseminated orebodies are generally small in size and are rarely enriched to economic level. Disseminated orebodies of reserve quality occur at the Kerasitsa area of northern Vourinos. Massive orebodies are less common but have been exploited at the Voidolakkos, Kokkinodromos, Kissavos, and Rodiani areas. Nodular (or orbicular) ore is rare and no exploitable orebodies of this type occur. The best known localities are Koursoumia, Aga Kouri, Doumarachi, and Tsouka (Fig. 1).
Analytical Methods

Due to the heterogeneous platinum-group element distribution in chromite ores and ultramafic rocks, samples of a minimum of 2-kg size are necessary to approximate statistical homogeneity.

The preconcentration procedure employed for the analysis of the PGE and gold in this study utilized a nickel sulfide fire-assay technique, being a slight modification of the method of Hoffman et al. (1978). This method allows for the complete dissolution of up to 40 g of concentrated (>98%) chromite ore. Information on detection limits, precision, and accuracy is given by Hoffman et al. (1978).

Platinum and palladium contents are very low, usually lower than the detection limits of the Hoffman method. These elements were redetermined by atomic absorption spectroscopy (AAS) using a heated graphite atomizer.

Electron microprobe analyses were carried out at the Institute of Geology and Mineral Exploration (IGME), using the Cameca superprobe wavelength-dispersive automated system.

Chemistry of the Chromite Ores

Vourinos

A number of chromitite samples representative of all ore textures, size of deposit, and type of deformation were analyzed for major elements and PGE (Tables 1 and 2). A systematic approach was also employed to the economically most important chromite deposits at Xerolivado and Voidolakkos areas (Fig. 1). Silicate separates from schlieren-type chromite ore and spinel separates from host dunite and harzburgite were also analyzed for PGE (Table 3, Fig. 2).

The average contents of PGE and gold in chromite ore from the whole Vourinos complex are Os, 23 ppb; Ir, 19 ppb; Ru, 58 ppb; Rh, 12 ppb; Pt, 5.9 ppb; Pd, 3.3 ppb, and Au, 2.7 ppb. The PGE total for most of the samples analyzed is less than 200 ppb. However, six samples from the northern part of Vourinos and one sample from Rodiani gave unusually high concentrations for one or more PGE (Table 2, Fig. 3).

Chromite ores of the South Vourinos area, including Xerolivado, one of the world’s largest alpine-type chromite deposits (about 6 million tons of ore) are remarkably homogeneous in major elements and PGE compositions (Table 1). The compositions of ores from North Vourinos differ significantly from those of South Vourinos. Apart from the presence of Al-rich ore in some parts of North Vourinos, such as Koursoumia (Al₂O₃ = 18.4), Kerasitsa (Al₂O₃ = 16.1), and Agios Konstantinos (Al₂O₃ = 16.7), Konstantopoulou and Economou-Eliopoulos, 1990), the PGE distribution is heterogeneous, the total ranging from 53 to 3,030 ppb.

### Table 2. Platinum-Group Element-Enriched Chromite Ores from the Vourinos and Rodiani Ophiolites

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Location</th>
<th>Os</th>
<th>Ir</th>
<th>Ru</th>
<th>Rh (ppb)</th>
<th>Pt</th>
<th>Pd</th>
<th>Au</th>
<th>Cr/(Cr + Al)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>940B</td>
<td>Voidolakkos</td>
<td>830</td>
<td>1401</td>
<td>749</td>
<td>35</td>
<td>11.3</td>
<td>3.3</td>
<td>2.8</td>
<td>0.78</td>
<td>3032</td>
</tr>
<tr>
<td>573</td>
<td>Kerasitsa</td>
<td>161</td>
<td>107</td>
<td>34</td>
<td>14</td>
<td>1.8</td>
<td>4.8</td>
<td>1.0</td>
<td>0.78</td>
<td>354</td>
</tr>
<tr>
<td>200</td>
<td>Koursoumia</td>
<td>217</td>
<td>131</td>
<td>237</td>
<td>27</td>
<td>17.7</td>
<td>8.5</td>
<td>2.1</td>
<td>0.66</td>
<td>640</td>
</tr>
<tr>
<td>957</td>
<td>Rizo</td>
<td>998</td>
<td>763</td>
<td>234</td>
<td>6</td>
<td>22.8</td>
<td>3.1</td>
<td>0.3</td>
<td>0.80</td>
<td>2028</td>
</tr>
<tr>
<td>203</td>
<td>Pelka</td>
<td>10</td>
<td>8</td>
<td>17</td>
<td>5</td>
<td>142</td>
<td>440</td>
<td>11.7</td>
<td>0.76</td>
<td>633</td>
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<tr>
<td>944</td>
<td>Rodiani</td>
<td>23</td>
<td>6</td>
<td>25</td>
<td>8</td>
<td>275</td>
<td>10.8</td>
<td>2.3</td>
<td>0.55</td>
<td>350</td>
</tr>
<tr>
<td>TOY-1</td>
<td>Doumarachi</td>
<td>122</td>
<td>22</td>
<td>558</td>
<td>13</td>
<td>2.1</td>
<td>1.8</td>
<td>10.0</td>
<td>0.80</td>
<td>729</td>
</tr>
<tr>
<td>Average (data from Table 1)</td>
<td></td>
<td>23</td>
<td>19</td>
<td>58</td>
<td>12</td>
<td>5.9</td>
<td>3.3</td>
<td>2.7</td>
<td>0.80</td>
<td>124</td>
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### Table 3. Platinum-Group Element Analyses in Separated Fractions from Schlieren-Type Chromite Ores

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample no.</th>
<th>Os</th>
<th>Ir</th>
<th>Ru</th>
<th>Rh (ppb)</th>
<th>Pt</th>
<th>Pd</th>
<th>Au</th>
<th>Cr/(Cr + Al)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xerolivado</td>
<td>538chr</td>
<td>17</td>
<td>17</td>
<td>42</td>
<td>13</td>
<td>1.3</td>
<td>1.8</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>538sil</td>
<td>12</td>
<td>11</td>
<td>30</td>
<td>5</td>
<td>2.1</td>
<td>3.0</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Aetoraches</td>
<td>Dk</td>
<td>15</td>
<td>3</td>
<td>16</td>
<td>1.5</td>
<td>0.9</td>
<td>1.7</td>
<td>1.9</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>960chr</td>
<td>28</td>
<td>26</td>
<td>56</td>
<td>4.5</td>
<td>43.8</td>
<td>3.0</td>
<td>2.1</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>960sil</td>
<td>16</td>
<td>17</td>
<td>26</td>
<td>4</td>
<td>0.4</td>
<td>2.3</td>
<td>1.9</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Voidolakkos</td>
<td>567chr</td>
<td>23</td>
<td>20</td>
<td>139</td>
<td>15</td>
<td>31</td>
<td>3.3</td>
<td>1.9</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>567sil</td>
<td>8</td>
<td>8</td>
<td>91</td>
<td>4</td>
<td>5</td>
<td>1.4</td>
<td>1.2</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Da</td>
<td>12</td>
<td>3</td>
<td>11</td>
<td>2</td>
<td>1.4</td>
<td>0.5</td>
<td>3.4</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Voidsolakkos</td>
<td>BD</td>
<td>28</td>
<td>18</td>
<td>&lt;36</td>
<td>20</td>
<td>9.7</td>
<td>&lt;0.2</td>
<td>5.3</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BLH</td>
<td>22</td>
<td>19</td>
<td>26</td>
<td>30</td>
<td>16</td>
<td>40</td>
<td>21</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: BD = separated chrome spinel from dunite; BH = normal harzburgite; BLH = harzburgite with a low orthopyroxene content; chr = separated chromite fraction; D = host dunite without accessory spinel; sil = separated silicate fraction.
ppb. The majority of the analyzed samples from North Vourinos show Ru \( \gg (\text{Os} + \text{Ir}) \) in contrast to the southern part of the complex, where Ru < (Os + Ir). In addition, Pd/Ir and (Pt + Pd)/(Os + Ir + Ru) ratios are much higher in the northern than in the southern part (Table 1).

A few chromitites, representing about 15 percent of the analyzed chromitite samples, from various localities of North Vourinos, gave unusually high concentrations in one or more of the PGE, compared to the mean values of the PGE concentrations in the Vourinos chromitites (Table 2, Fig. 3). Total PGE contents in the enriched samples range from 0.5 to about 3 ppm. Detail sampling around the PGE-enriched ores showed that at a distance of a few centimeters from the position of the enriched sample, PGE content falls to the usual range. Thus, chromitite enrichment in PGE seems to be a common but local phenomenon in northern Vourinos.

The Kissavos chromite ores show a wide range in the major element composition, as exemplified by Cr/(Cr + Al) of 0.46 to 0.82 (Fig. 4). At some localities
metallurgical and refractory ores coexist in the same chromite body. Both Al- and Cr-rich ores of Kissavos have very low total PGE contents, compared to chromitites of North and South Vourinos. Al-rich chromitite is found to be slightly enriched in incompatible PGE, Pt, and Pd and depleted in the compatible elements Os, Ir, and Ru. It is noticeable that there is a strong correlation between Pd/Ir and Cr/(Cr + Al) ratios ($r = -0.82$). Kissavos is the only place in the Vourinos complex where such a correlation was found.

**Rodiani**

Chromitite ores from the Rodiani area are the refractory type, with Cr/(Cr + Al) ratios ranging from 0.56 to 0.64 (Table 1). These chromitites are characterized by very low concentrations of compatible PGE, Os, Ir, and Ru and relatively high Pt + Pd contents; one chromitite sample has as high as 275 ppb Pt (Table 2).

**Host-rock spinel separates and schlieren ore silicate separates**

Spinel separates from Vourinos dunites concentrate Os, Ir, and Ru relative to Pt and Pd in the same way as massive chromitite ore. Spinels from low pyroxene harzburgite and normal harzburgite contain lower Os, Ir, and Ru and higher Pt and Pd compared to spinels from dunites. In all cases, the PGE contents of spinel separates are higher than in their respective host rock. The silicate separates from schlieren ores show relatively uniform PGE contents and PGE patterns similar to those demonstrated by their coexisting ore.
separates (Table 3, Fig. 2). The PGE content in the silicate separates from ores is always much higher than that of dunite bodies hosting the ores (Fig. 2).

Discussion

Differences defined in PGE distribution among the South Vourinos, North Vourinos, Kissavos, and Rodiani areas, are much more striking compared to the major and trace element distributions. Only the Kissavos area shows a strong negative correlation \( r = -0.82 \) between the Pd/Ir and Cr/(Cr + Al) ratios. Elsewhere in Vourinos, no correlation was observed between the total PGE concentration or PGE ratios and the Cr/(Cr + Al) ratio in chromite ores, a condition similar to that mentioned by Agiorgitis and Wolf (1978) and Economou (1983, 1986) for chromite ores from various ophiolites of Greece. Due to the incompatible behavior of Al, Pt, and Pd in contrast to the compatible nature of Cr, Os, Ir, and Ru (Barnes et al., 1985), the PGE distribution in the Kissavos chromite ores may suggest parent magmas derived by a varying degree of partial melting and a relatively extensive degree of fractionation (Economou, 1986; Konstantopoulou and Economou-Eliopoulos, 1990).

Thus, the range and variability of Cr/(Cr + Al), Pd/Ir, and \((Pt + Pd)/(Os + Ir + Ru)\) ratios and the relative abundance of compatible and incompatible PGE within the four studied geographic units may be affected by the processes of the degree of partial melting in a primitive upper mantle, the degree of fractional crystallization, mantle heterogeneity, and sulfur saturation at an early stage or during fractionation.

Partial melts produced over a large region of the upper mantle mobilize upward and mix as they are progressively drawn toward the ridge axis, with an increase in the size of magma pockets toward the base of the crust (Nicolas, 1986; Ribe, 1988). Thus, it is reasonable to suggest that melts resulted from varying degrees of partial melting of both pristine and residual mantle material are mixing. Irvine (1977) described the magma-mixing and hybridization mechanism to explain chromite genesis in layered intrusions. Such magma mixing can also account for chromite precipitation in ophiolite complexes and sulfide immiscibility (Campbell and Naldrett, 1979; Campbell et al., 1983). Furthermore, Irvine and Sharpe (1986) have suggested that chromite-rich layers in layered intrusions can result from mixing of a magnesian magma and an aluminum-rich tholeiitic magma. Boninitic lavas, which also are considered to be derived from magnesian-rich magmas, produced in turn by multistage melting of a refractory peridotite (Jaques and Green, 1980; Cameron, 1985), have been reported in several ophiolite complexes, including the Vourinos complex. Therefore, between chromite precipitation that resulted from the interaction of boninitic and tholeiitic magma could be a reasonable mechanism for the Vourinos complex, too.

Sulfur saturation attained at an early stage of fractional crystallization results in sulfide segregation. Campbell and Naldrett (1979) have stressed the importance of the magma/sulfide ratio (R factor) in the formation of PGE-enriched sulfides. Such a process removing the PGE, particularly Pt and Pd, is considered to be one of the main reasons for the higher amounts of Pt and Pd in layered intrusions like Bushveld and Stillwater (Campbell and Naldrett, 1979; Campbell et al., 1983; Talkington and Watkinson, 1986). Thus, low values of the \((Pt + Pd)/(Os + Ir + Ru)\) ratios throughout the Vourinos complex (Table 1), compared to layered intrusions, appear to indicate a low original sulfide content (Talkington and Watkinson, 1986) and probably no sulfide immiscibility.
However, there is a slight increase of this ratio in the North Vourinos and Rodiani areas and a significant increase in two samples from the Rodiani and Pefka districts (Fig. 1), reaching values of 5 and 17, respectively. Such a variation may suggest a lack of sulfur saturation at the early stage of chromite crystallization. This may correspond to the Xerolivado area, whereas PGE-enriched samples, particularly the (Pt + Pd)-enriched chromites from the Rodiani and Pefka localities, may reflect the presence of sulfides, implying mixing with fractionated (to some extent) magmas.

Three distinct mantle environments can be hypothesized for Vourinos, corresponding to the following geographic areas.

**South Vourinos**

The limited compositional variation in South Vourinos (Table 1, Figs. 4 and 5) may indicate a low degree of fractionation in the parent magma. It seems likely that South Vourinos has formed directly above a suprasubduction zone spreading center, since in such an environment the degree of mantle hydration and heat flow is expected to be high enough to produce a high degree of partial melting in the upper mantle (Jaques and Green, 1980; Pearce et al., 1984). Xerolivado probably represents a somewhat lower stratigraphic level compared to the Konivos, Kokkinodromos, and Aetoraches areas. The ores from the latter areas crystallized from slightly more evolved magmas than those of Xerolivado, as documented by the decrease of Cr/(Cr + Al) and increase of Pd/Ir and (Pt + Pd)/(Os + Ir + Ru) ratios (Table 1).

**North Vourinos**

North Vourinos differs in major ways from South Vourinos. PGE contents of a few samples suggested near-economic levels in chromitite ores. Nodular and massive ores are far more common than in South Vourinos. Significant amounts of pyroxenite occur as thick dikes and irregular massive bodies. A widespread ductile deformation is represented in North Vourinos that is totally lacking in the south (Roberts et al., 1985).

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**FIG. 5.** Chondrite-normalized platinum-group element patterns for chromite ores from the Vourinos and Rodiani ophiolites. Data from Table 1.
et al., 1988). This, coupled with the geochemical characteristics which were referred above, indicates a different geotectonic environment for the North Vourinos block.

The high PGE and trace element heterogeneity observed in North Vourinos, and the lower values of the Cr/(Cr + Al) ratio and higher Pd/Ir and (Pt + Pd)/(Os + Ir + Ru) values (compared to south Vourinos), may be the result of crystallization in small magma chambers at a distance from the spreading center. The correlation coefficient between Cr/(Cr + Al) and PGE ratios is low but is much higher than those of South Vourinos, indicating a higher degree of fractionation in some areas of North Vourinos (Table 1).

The chemistry of chromites suggest a crude stratigraphy in North Vourinos, though it is less well defined than in the south. This stratigraphy proceeds from southwest to northeast, or from the Aga Kouri mining district and Prosilion locality of Voidolakkos to the Kerasitsa, Rizo, and Koursoumia areas (Fig. 1). Within the Voidolakkos valley, the southwestern (Prosilion) and northeastern (Anilion) sides show different geochemical characteristics, indicating that they may not represent the same stratigraphic level of the upper mantle, which is consistent with the structural data and suggests a tectonic separation (Roberts et al., 1988; Konstantopoulou and Wright, 1990). The area from east of the Voidolakkos district to Koursoumia belongs to the same stratigraphic horizon of upper mantle as defined by spinel chemistry evolution.

**Kissavos**

The depleted levels of PGE among Kissavos ores (particularly the compatible elements in the Cr-rich ores) may suggest that chromitites crystallized from magmas generated from a mantle source that was already depleted in PGE (Table 4, Fig. 6).

**Rodiani**

The composition of chromite ores within the Rodiani ultramafic block do not show any systematic geochemical variation indicating a stratigraphic succession from area to area. The attempt to correlate the Rodiani area to Vourinos led to the following two hypotheses: Rodiani represents a higher stratigraphic level of the mantle sequence relative to the Vourinos mantle section, or Rodiani represents a totally different geotectonic environment from Vourinos. The latter is the most probable.

In summary, the compositional variation in the studied chromite ores of the Vourinos complex is consistent with its suprasubduction zone environment. The geochemical trend follows a stratigraphic up-section direction, which is accompanied by a higher degree of fractionation in magmas parental to chromite ores. Therefore, PGM trapped mainly by

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**Table 4. Platinum-Group Element Concentrations in Metallurgical and Refractory Chromite Ores from the Kissavos Area**

<table>
<thead>
<tr>
<th>Sample</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Cr₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>NiO</th>
<th>MgO</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>no.</td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>563</td>
<td>0.56</td>
<td>0.01</td>
<td>0.56</td>
<td>0.63</td>
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<tr>
<td>SE-5</td>
<td>0.10</td>
<td>0.01</td>
<td>0.10</td>
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<td>0.14</td>
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</tr>
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</table>
chromite and reflected in the bulk rock analyzed supply valuable information for a stratigraphic orientation, especially in the mantle sequence of the complex which is characterized by a homogeneous composition.

Conclusions

1. The low PGE content in the majority of the Vourinos chromitites may reflect a lack of sulfur saturation during an early stage of their crystallization, whereas the presence of PGE-enriched ores may suggest a mixing of primitive and partially fractionated magmas.

2. The PGE distribution throughout the Vourinos complex seems to provide valuable information for a stratigraphic orientation in the mantle sequence of the complex.

3. On the basis of the range and variability of Cr/(Cr + Al), (Pt + Pd)/(Os + Ir + Ru), and Pd/Ir ratios, and the relative abundance of compatible PGE in chromitites, a distinction of three geotectonic units in the Vourinos ophiolite complex can be made—North Vourinos, South Vourinois, and the Kissavos area.

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