Major and minor element geochemistry of chromite from the Xerolivado–Skoumtsa mine, Southern Vourinos: Implications for chrome ore exploration

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ABSTRACT

The concentration of major (Cr, Al, Mg, Fe) and minor (Ti, V, Mn, Ni, Zn) elements was studied in chromitite ores and accessory chrome spinels within serpentinite host rocks from the Xerolivado–Skoumtsa mine (Southern Vourinos, Western Macedonia, Greece) by means of electron microprobe techniques. Chrome ores in the mine occur in seven extensive ore bodies. Chromite was analyzed with respect to its position within or between ore bodies, including the following classifications: chromitite (schlieren ore) band, accessory chromite in intercalated serpentinite within the ore bodies, disseminated chromite in non-ore bearing host rocks, and chromite within serpentinites immediately adjacent to ore bodies. Chrome spinel originally forms at temperatures of around 1300 °C, but their hosts undergo ductile deformation to temperatures down to around 700 °C, thus facilitating solid state re-equilibration. Results showed that Mg in chromite was found to be substituted during re-equilibration mainly by Fe and, to a minor extent, by Mn and Zn. Cr is mainly substituted by Al and, to a minor extent, V. Compositions were found to vary in accessory chromite crystals as a function of their distance from chromitite bands. Specifically, the average concentrations of Cr and Mg are higher in spinels within chromitite ores than for the disseminated spinels in serpentinite gangue layers within chromitites. Chrome spinels in schlieren ore layers have higher Mg and Cr concentrations compared to the disseminated chromites in the serpentinites immediately adjacent to the chromite ore bodies and also slightly higher concentrations of Mg and Cr than the disseminated chromites in the host serpentinites. Fe2+, Mn, Zn, Al and V cations show exactly the opposite trend. We attribute these variations in the spinel chemistry to subsolidus reactions between chromite, silicate mineral phases and fluids. Geochemical maps presenting the spatial variation of these elements in disseminated Cr spinels of the Xerolivado mine can serve to delineate the precise position of the chrome ore bodies.

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1. Introduction

Chromite chemistry within ophiolitic suites has long been used as a petrogenetic indicator for establishing their geotectonic environment, the composition of the parental magma(s) and the genesis of chromitites of various types (e.g., Irvine, 1967, 1977; Pearce et al., 1984; Roeder and Reynolds, 1991; Ara, 1992; Ara, 1997; Malpas et al., 1997; Zhou and Robinson, 1997; Ara and Matsukage, 1998; Barnes and Roeder, 2001; Kamensky et al., 2001; Ahmed and Economou-Eliopoulos, 2008; Pagé and Barnes, 2009; Kapriotis et al., 2011; Kapriotis, 2013; Grieco et al., 2014; Rollinson and Adetunji, 2015; Uysal et al., 2015; Zhou et al., 2015). Chromite chemistry can be affected during subsolidus reactions by re-equilibration processes with silicate mineral phases and fluids (Irvine, 1967; Ara, 1980; Ozawa, 1985; Roeder and Campbell, 1985; Auge, 1987; Christodoulou and Michailidis, 1990; Rassios and Kostopoulos, 1990; Van der Veen and Maaskant, 1995; Peltonen, 1995; Filippidis, 1997). In general, Mg and Cr in chromite may be substituted by other bivalent (e.g., Fe2+, Ni) and trivalent (e.g., Fe3+, Al) cations, respectively (e.g., Irvine, 1967;
Roeder and Campbell, 1985; Roeder and Reynolds, 1991; Michailidis, 1993, 1995; Peltonen, 1995; Filippidis, 1997; Kapsiotis, 2013). The purpose of the present investigation was the study of the substitution relations between bivalent and trivalent cations—with special emphasis on substitution of minor elements—in chromite from chromitite (ore) bands (spinel–spinel re-equilibration) and accessory chromite of host serpentinites (spinel–olivine re-equilibration) of the Xerolivado–Skountsa mine in the southern part of the Vourinos ophiolitic complex (Western Macedonia, Greece) (Fig. 1). We also examine whether these substitutions and the spatial distribution of the elements show any kind of pattern which could be useful for the implementation of a geochemical tool for chrome ore exploration. Geochemical anomaly maps of the major and minor element concentrations in chromite (following the suggestions of Rassios and Kostopoulos, 1990) were constructed in effort to investigate their spatial distribution as an aid in chrome ore exploration. We propose that geochemical mapping could provide an added prospecting methodology that could significantly reduce the cost of exploratory drilling.

2. Geologic setting

2.1. The Vourinos ophiolite complex

The Vourinos Complex in northern Greece (Fig. 1) is a mid-Jurassic ophiolitic slab emplaced onto the Pelagonian continental margin during the upper Jurassic: its emplacement, long considered

Fig. 1. Major units of the Vourinos ophiolite complex and location of the Xerolivado–Skountsa mine (red circle) (after Grivas et al., 1993). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 2. Chrome ore samples from the Xerolivado–Skountsa mine showing (a) typical schlieren form (parallel dark-gray to black chromitite and serpentinized dunite, oily bands) and (b) folded chromitite band.
Fig. 3. Distribution and form of the schlieren chromite ore bodies of the Vourinos Xerolivado–Skoumtsa mine (modified after Filippidis, 1996). Samples studied were collected from vertical section +90.

Fig. 4. Sampling methodology: (a) samples from chromitites (A), serpentinites near the chrome ore bodies (B) and between the chromitites (C). (b) Samples from chromitites: chromite band samples (1) and serpentine band samples (2).

Fig. 5. Back scattered electron images of chromite grains (gray) from the Xerolivado–Skoumtsa mine chromitite. (a) Pull apart texture, (b) pull apart texture, porous texture and alteration to Fe-chromite (light gray).
a “type” obduction process (Zimmerman, 1968, 1969), was toward the east (Smith and Rassios, 2003), over the Pelagonian Margin, creating a sedimentary-tectonic mélangé (Agios Nikolaos or Zavordas mélangé, Rassios et al., 2003; Gkikas et al., 2010). The Vourinos ophiolite covers an area of ~400 km² and constitutes a complete ophiolite sequence dominated by mantle rocks and including a well-exposed “petrologic Moho” (Jackson et al., 1975). Even though the Vourinos ophiolite complex is separated from the nearby Pindos ophiolite by the Eocene–Miocene Mesohellenic Trough, both ophiolitic belts are considered to be outcropping parts of a huge unique ophiolitic nappe known as the Pindos Basin Ophiolites (Bortolotti et al., 2004; Rassios and Moores, 2006; Rassios et al., 2008; Grieco and Merlini, 2012). The dominating petrological unit of Vourinos is its mantle section consisting of highly deformed harzburgite that has been variably serenitized, grading from non-serenitized to totally serenitized (Moores and Vine, 1971; Ross et al., 1980). This harzburgite hosts abundant irregularly shaped dunite bodies. Some of the dunite bodies host chromitite ore bodies (Saccani et al., 2004; Bortolotti et al., 2004; Grieco and Merlini, 2012). All economically interesting chrome ore bodies at Vourinos are hosted by dunite within harzburgite (Grivas et al., 1993; Filippidis, 1996; Economou-Eliopoulos, 1996; Kapsiotis, 2014). The chrome ore deposits found at Vourinos were exploited in the post WWII era, and the mines were closed in 1991 due to economic fluctuation in the world price of chrome. The geologic ore reserves at Vourinos are estimated to be about 12.5 million tons (Moores, 1969; Jackson et al., 1975; Harkins et al., 1980; Beccaluva et al., 1984; Paraskopoulos and Economou, 1986; Konstantopoulos and Economou-Eliopoulos, 1991). The initial precipitation of chrome spinel in dunite occurred at about 1300 °C with re-equilibration between spinel and silicate phases (primarily olivine) continuing down to temperatures as low as 600 °C (Rassios and Kostopoulos, 1990). The predominant processes of the structural evolution and deformation that affected chrome ore-bearing dunite bodies were: a) dunite and chrome formation within the upper mantle, b) high-temperature plastic deformation resulting from mantle flow, c) low-temperature plastic to semi-brittle deformation during incipient obduction that resulted in folding of dunite and ore bodies and d) brittle deformation (faults and thrusts) displacing the dunites and chrome ore bodies as the ophiolite passed from ductile to brittle conditions, and e) late (Tertiary to present) tectonism (Ross et al., 1980; Roberts et al., 1988; Konstantopoulos, 1993; Filippidis, 1996, 1997; Smith and Rassios, 2003; Grieco and Merlini, 2012).

The chrome ore deposits at Vourinos were exploited in the post WWII era, and the mines were closed in 1991 due to economic fluctuation in the world price of chrome. The geologic ore reserves at Vourinos are estimated to be about 12.5 million tons (Stamoulis, 1990). Verified (via back-up drilling) chrome ore reserves are over 2,500,000 tons and are mainly found in the following localities: Xerolivado–Skoumtsa (1,000,000 tons), Aetoraches (500,000 tons), Skoumtsa (1,000,000 tons), Xerolivado (2,500,000 tons) and Kerasitsa (500,000 tons). The location of geologically predicted ore continuations at Xerolivado would raise tonnage estimates to 5 million tons.
2.2. The Xerolivado–Skoumtsa Chrome Mine

The largest chromiferous dunite body of the Vourinos Complex occurs at the Xerolivado locality (Fig. 1). The dunite body has an approximate surface exposure of 3 km² (3 × 1 km), and extends at least 400 m into the subsurface. The dunite is hosted by harzburgite tectonite (Filippidis, 1996, 1997). The Xerolivado Skoumtsa mine is one of the world’s largest "ophiolite-hosted" chrome deposits with a potential of 6 million tons of ore assaying at ~22 wt.% Cr₂O₃ (Stamoulis, 1990; Filippidis, 1996, 1997). Even so, chrome ore bodies compose less than 1% of the volume of the dunite, and their exploration consisted chiefly of expensive drilling programs.

The chromite ore itself is a type called "schlieren" ore, consisting of highly intra-deformed bands of serpentinite-rich and chromite-rich rock (Fig. 2). Each spinel-rich band varies from one to fifteen cm in thickness (Stamoulis, 1990; Filippidis, 1996). Three Tertiary-aged normal fault zones (F1, F2 and Fm) divide the Xerolivado mine into four sectors: the northern, the central, the southwestern sector and continue in the central sector. Three of the schlieren ore bodies also continue in the northern sector; because of structural evidence, the southern ore bodies are predicted to continue into the southwestern sector at a greater depth, with a possible future for renewed exploitation.

Within the Xerolivado dunite body, serpentinization is so pervasive that only relict grains of olivine can be found within the ore bodies.

3. Materials and methods

Samples used in the present study come from a well-documented suite collected during the final years of operation of the Xerolivado–Skoumtsa mine (1987–1988). The collection includes seventy-one (71) samples of: chromitite (20 from chromite ores and 20 from serpentinite bands, gangue within the ore bodies) and serpentinite (31 samples). Most samples were taken on (or near) the same vertical section of the southern sector of the mine (Fig. 3) and the sampling scheme presented in Fig. 4 includes:

1. Chromitite, the chief constituent of the schlieren-type chrome ore bodies (A1).
2. Serpentinite: altered primary dunite tectonically included within the schlieren ore body zones (A2).
3. Serpentinite from the hosting dunite body adjacent to and surrounding the chrome ore bodies (B).
4. Serpentinite lenses from the hosting dunite body interfolded with the ore bodies, which appear as "layers" between the chrome rich ore bodies (C).

For each sample, a thin-polished section was mounted and studied under optical microscopes using both transmitted and reflected light. Back scattered electron images (BSI) were then taken (Fig. 5) and major and minor oxides were analyzed from all samples with a JEOL.
8200 electron microprobe equipped with a wavelength dispersive system (SEM-WDS) at the University of Milan. The system used an accelerating voltage of 15 kV, a sample current on brass of 15 nA, a counting time of 20 s on the peaks and 10 s on the background. A series of natural minerals was used as standards. For each sample, four to fifteen spots of unaltered chromite grains were analyzed and their compositions averaged to produce a statistically result.

Representative chemical analyses of chromites from twenty-four sampling sites are given in Table 1. The FeO and Fe$_2$O$_3$ concentrations were calculated from total iron assuming perfect spinel stoichiometry (RO:R$_2$O$_3$ = 1:1). Table 2 presents the average and standard deviation data for the measured parameters. The database of these analyses was used for the construction of the diagrams in Figs. 6 to 13 which represent projections within the spinel prism after (Irvine, 1967).

The exact location of all samples and the distance of the serpentinite samples are from the underground mining tunnels. GPS location was retro-fitted to the sample localities onto the underground database and the position of the chromite bodies were measured on the sampling locations.
maps by the use of CorelDRAW X5 software. Microprobe analysis data and spatial information data were entered in ORIGIN software for the creation of the geochemical maps which are presented in Figs. 14 to 17. The parameter “total points increase factor” was set at value 10,000 and parameter “Smoothing parameter” was set at value 0.0001.

4. Results

4.1. Petrography

The chromitite samples of the Xerolivado mine are typical of schlieren or banded type chrome ores: schlieren ore consists of irregular lense-shaped disseminations of chromite in a dunite (now serpentinite) matrix. These lensing structures were created by initial high-temperature ductile deformation. The chromite-rich bands (dark gray color) alternate with the serpentine bands (oily green color) (Fig. 2a). Each band is 1 to 15 cm thick and the lithologic alternations are, in most cases, parallel or sub-parallel on hand sample scale. In many samples, banding displays folds, a continuation of deformation (Fig. 2b).

Microscopic examination of the schlieren chromitites shows that the chromitite bands of the samples are dominated (>70% modal) by interpenetrating chromite grains. Chromites display a much younger pull-apart texture imprinting the high-temperature tectonic events they have undergone (Fig. 5). Serpentine bands of the samples are dominated by the presence of serpentine having a typical mesh texture, a relict of the shapes of olivine grains in the original dunite. Disseminated chromite grains (5–10% modal) are also found in the serpentine lenses within the ore bodies.

4.2. Chromite mineral chemistry

4.2.1. Major elements

The cation number (based on 32 oxygens) of the major elements (Mg and Fe$^{2+}$) occupying the tetrahedral sites in the chrome spinel lattice shows an opposite trend in the Xerolivado–Skoumtsa mine...
The average Mg cation number is 5.270 ± 0.248 in the concentrated spinels (ore bands) and gradually decreases to an average of 4.213 ± 0.188 among the disseminated chromites in the serpentine lenses that separate the ore bodies. Fe²⁺ is the lowest within the chrome ores (2.694 ± 0.246), and gradually increases to 3.712 ± 0.181 among the disseminated chromites in the serpentinites between the ore bodies.

The cation number of the major elements (Cr, Al and Fe³⁺) occupying the octahedral sites in the lattice of chromites shows the following averages in the Xerolivado–Skoumtsa mine (also see Table 3):

- Cr decreases from 12.335 ± 0.199 in the spinels concentrated within ore bodies, to 11.967 ± 0.235 in disseminated chromites in the serpentine gangue within the ore bodies, and 12.006 ± 0.232 in the disseminated chromites in the serpentinites that separate individual ore bodies.
- Al shows an average value of 2.907 ± 0.314 in chromite within schlieren ore bodies, and gradually increases to an average of 3.250 ± 0.267 in the serpentinites separating the ore bodies.
- Fe³⁺ has an average of 0.699 ± 0.138 in chromite in schlieren ores, 0.716 ± 0.142 in the disseminated chromites in the serpentine bands within ore bodies, 0.797 ± 0.123 in disseminated chromites in the serpentinites adjacent to the chromite ore bodies and 0.672 ± 0.123 in disseminated chromites in the serpentine lenses separating the chromitites.

Fig. 6 depicts the Fe²⁺ # vs. Cr# relation for the Cr-spinels of the Xerolivado–Skoumtsa mine. Chromites from spinel-rich chromitite ores clearly show lower Fe²⁺ # values than chromites in host serpentinite. This observation has also been shown in studies of the Rhum Intrusion (Scotland), Bushveld (S. Africa), Bird River Sill (Canada) (Henderson, 1975; Cameron, 1977; Henderson and Wood, 1988).
1981; Hatton and von Gruenewaldt, 1985; Ohnenstetter et al., 1986) and locally at the central sector of the Xerolivado mine (Filippidis, 1997). This result is also shown in Fig. 7, where the negative correlation between Fe$^{2+}$ and Mg cations in chromite is presented.

4.2.2. Minor elements

The cation number of some minor elements (V, Mn and Zn) shows significant variations between different categories of samples. Vanadium, manganese and zinc contents appear the lowest in spinels within the chrome ore schlieren bands: 0.020 ± 0.003, 0.013 ± 0.005 and 0.006 ± 0.005 respectively. The average values are slightly higher in disseminated chromites in the serpentine bands within the ores, 0.022 ± 0.004, 0.020 ± 0.007 and 0.008 ± 0.005 respectively. For the disseminated chromites in the host serpentinites adjacent to the ore layers the average values are 0.031 ± 0.006, 0.035 ± 0.005 and 0.023 ± 0.009 respectively. The highest average contents of V, Mn, and Zn of the studied samples are in disseminated chrome spinels in serpentinite lenses separating the ore bodies, with compositions of: 0.034 ± 0.007, 0.035 ± 0.005 and 0.027 ± 0.007 respectively.

The correlations between minor and major elements of the samples are presented in Figs. 8 to 13; Mn cations do not show a clear correlation with Cr cations (Fig. 8) but show a negative correlation with Mg cations (Fig. 9) and a positive one with Fe$^{2+}$ cations (Fig. 10). Zn cations also correlate positively with Mg cations (Fig. 11) and negatively with Fe$^{2+}$ cations (Fig. 12) whereas, V cations correlate negatively with Cr cations (Fig. 13).

4.3. Geochemical maps

The sampling scheme of this study provided an excellent coverage of some of the chief underground ore bodies: samples taken along the same vertical section of the mine were referenced on the topographic map. As Rassios and Kostopoulos (1990) demonstrated, chromitite samples are dominated by chromite–chromite re-equilibration, while the disseminated spinels in what was originally dunite, owe their
Fig. 13. Relation between V and Cr cations of the chromites from the Xerolivado–Skoumtsa mine. Symbols as in Fig. 6.

Fig. 14. Upper figure: Vertical section from which samples were collected showing the actual position of chrome ore bodies (digitized after Stamoulis, 1990). Lower figure: Geochemical map of the studied vertical section of the Xerolivado–Skoumtsa mine for Al cations.

Fig. 15. Geochemical maps of the studied vertical section of the Xerolivado–Skoumtsa mine for Cr (upper) and Mg (lower) cations.
compositions to spinel–silicate (olivine) re-equilibration. By excluding the chromitite analyses and using only the disseminated chromite analyses found in the serpentine bands of the schlieren ore samples and accessory chromite in the serpentinite samples, we created geochemical maps of oxides of the elements and compared them with the spatial distribution of the chromite bodies.

Figs. 14 to 17 present geochemical anomaly maps for the vertical section of the Xerolivado–Skoumtsa mine defined for the variations in Al, Cr, Mg, Fe$^{2+}$, Mn, V and Zn cations present in disseminated and accessory chromite.

5. Discussion

5.1. MgO and FeO

Microprobe analysis results show that chromites in different sample types show gradual differences in Mg and Fe$^{2+}$ contents. Similar results were found by Filippidis (1997) in analyses of chromites of the central sector of the Xerolivado mine. The variations in Mg and Fe concentrations are attributed to subsolidus reactions between chromite and silicate mineral phases. Subsolidus reactions, mainly displayed by divalent cations, explain the compositional variations in chromite previously studied by Hamlyn and Keays (1979), Wilson (1982), Yang and Seccombe (1993), Peltonen (1995), and Filippidis (1997). According to Irvine (1967), changes in the chromite composition due to subsolidus reactions depend on the amount of chromite present (Rassios and Kostopoulos, 1990). This is clearly confirmed by the microprobe results since in serpentinites the mineral chemistry of chromites from the Xerolivado mine showed that the most intense substitution of Mg by Fe$^{2+}$ during re-equilibration took place in the olivine phases (now serpentinized) separating the chrome ore bodies. This substitution was slightly less intense in the dunite near the ore bodies, and clearly less intense in the chromitites themselves; the substitution of Mg by Fe$^{2+}$ appears to be more efficient in dunite (now serpentine bands with disseminated chromite) than the chromite bands of the schlieren ore. This result is graphically presented in Fig. 7, showing the competitive relation between Mg and Fe$^{2+}$ cations.

Table 3

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* A1 = chrome spinel in chromitite ore layers, A2 = disseminated chrome spinel in serpentinitized dunite within the ore bodies, B = disseminated chrome spinel in serpentinitized dunite hosting the ore deposit, C = disseminated chrome spinel in serpentinitized dunite lenses separating individual ore bodies within metalliferous zone (see Fig. 3).
5.2. Minor oxides

Concentration of MnO in chrome spinels of Alpine-type chrome ore deposits does not generally exceed 1.00 wt.% (Scarpelli and Economou, 1978; Economou, 1984; Migiros and Economou, 1988; Michailidis, 1993; Michailidis et al., 1995; Michailidis and Sklavounos, 1996). Higher concentrations of MnO in ophiolites have only been reported for altered chromites (i.e. Paraskevopoulos and Economou, 1980; Michailidis, 1990, 1993). In the Xerolivado–Skoumtsa mine, the concentration of MnO (wt.%) is lowest in the chrome spinels of the chrome ores (chromitites), and the highest average values are found in the disseminated chromites within the serpentinites. The disseminated chromites in the serpentinite ganguies within the schlieren layers show an intermediate value. These relations suggest the effectiveness of re-equilibration of MnO between olivine and spinel.

Figs. 8, 9 and 10 demonstrate the relations between Mn and Cr, Mg, Fe\(^{2+}\) cations for the chromites of the Xerolivado mine. Fig. 8 shows a slight negative correlation between Mn and Cr cations, Fig. 9 shows a clear negative correlation between Mn and Mg cations and Fig. 10 shows a clear positive correlation between Mn and Fe\(^{2+}\) cations. From these relations, we may assume that during re-equilibration between chromite and silicates, Mn mainly substitutes for Mg in the lattice of chrome but also possibly substitutes some Cr in the octahedral sites. Further verification of this assumption, however, can only be given by measuring the valence number of Mn.

Zn also shows particularly interesting variations in the Xerolivado mine chromites. Spinel in chromitites have the lowest average values of ZnO. Spinel in serpentinites have \(\sim 3\) to 4 times higher average wt.% concentration in ZnO. Figs. 11 and 12 depict the relations between Zn and Mg, Fe\(^{3+}\) cations in spinels of the Xerolivado mine. The negative correlation between Zn and Mg cations and the positive correlation between Zn and Fe\(^{3+}\) cations show that Zn also behaves antagonistically, similar to Fe\(^{2+}\), and substitutes for Mg during re-equilibration.

The relation between V and Cr cations is presented in Fig. 13. A negative correlation between these two elements is verified. Chrome spinels in the ores of Xerolivado–Skoumtsa mine contain on average almost 2 times less V than spinels in hosting serpentinites. During re-equilibration processes, available V substitutes for Cr in the chromite lattice.

Thus, we have demonstrated that Cr-spinels in serpentinites contain more Mn, Zn and V than spinels in chrome ores (Figs. 8–13). There appears a slight variation in the presence of the latter elements within spinels in chromitite (schlieren ores) as follow; spinels in the chromitite ore layers contain less Mn, Zn and V than spinels in the serpentinitized dunite bands within the schlieren ore bodies. These differences in the concentrations of the elements can be explained by assuming that where the availability of silicates was higher and the amount of chromite lower, Cr and Mg substitution during re-equilibration was more effective, leading to a higher exchange of Mn, Zn and V into chromites.

5.3. Geochemical application of chrome chemistry

The chemical variations in major and minor oxides and consequent- ly in cations found in the Xerolivado mine chromites could provide a useful tool for the exploration of ophiolite hosted chrome bodies, in particular those in which the morphology of ore bodies are a result of ductile tectonic conditions. We can demonstrate this by constructing geochemical anomaly maps of the ore-hosting areas.

Such maps were first applied in surficial exposures of chrome ore by Rassios and Kostopoulos (1990): a geochemical traverse of an exposed layer of chrome ore and host at an exposed ore site of Xerolivado (the Xerolivado Trench profile) demonstrated re-equilibration, but the geochemical anomalies were very narrow.

Comparing the topographic map with the geochemical maps indicates with a good precision the location of the chrome ore bodies in the Xerolivado–Skoumtsa mine. The presence of ore bodies can be geochemically predicted at a scale of five to thirty meters. We thus believe that this geochemical tool could be applied for the exploration of the continuation of the chrome bodies at the southwestern sector of the Xerolivado–Skoumtsa mine. Analyses of disseminated spinels from a single exploratory borehole have been done (Rassios, unpub.), but more data is required to construct a suitable geochemical anomaly map. If so, such an exploration methodology could contribute to locating chrome ore bodies that have been predicted for the area based on structural analysis (Stamoulis, 1990).

6. Conclusions

Within the Xerolivado–Skoumtsa Chrome Mine, the contents of Cr, Al, Mg, Fe\(^{3+}\), Mn, Zn and V cations in spinels within chrome ore bodies and accessory chrome in host and gangue serpentinites demonstrate systematic variations due to subsolidus reactions between chromite and silicate mineral phases (now totally serpentinitized) during re-equilibration. Cr is substituted mainly by Al and to a minor extend by available V and –possibly– Mn. Mg is substituted mainly by Fe\(^{2+}\) and to a minor extent by available Zn and Mn. Geochemical anomaly maps demonstrate the chemical variation of these elements in such a way as to designate the position of the chromite ore bodies. The use of this geochemical tool could prove useful for chrome ore exploration not only for the unexploited part of the Xerolivado mine but also for podiform schlieren-type chromitites in other ophiolitic hosts.

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