






Mineralogical characterization and evaluation of chromite ore in Grevena and Kozani Vourinos massif, Western Macedonia, Greece

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Abstract

Purpose. Chromite samples from Aetoraches mine area in the southern part of the Vourinos complex in Western Macedonia, Greece were examined from mineralogical-geochemical perspective.

Methods. X-ray Diffraction (XRD) mineral phase analysis, elemental Scanning Electron Microscopy coupled with Energy Dispersive Spectroscopy (SEM-EDS) analysis and Thermogravimetry/Differential Thermogravimetry (TG/DTG) were carried out.

Findings. The XRD results showed that all the samples contain mainly magnesium- and aluminum-chromite (“aluminum-picrochromite”) phases, along with forsterite (magnesian olivine), serpentine and chlorite occurrences. Based on the SEM-EDS results, the computed average chemical formula indicative of this specific chromite type is: $(\text{Fe}_{0.4}\text{Mg}_{0.6})(\text{Cr}_{1.6}\text{Al}_{0.4})\text{O}_4$. The TG-DTG weight losses found to be in the range of 4.4-14.36%, at temperatures between 600 and 750°C, indicated the presence of the hydroxyl-rich silicate minerals, serpentinite and chlorite, in agreement to the Loss of Ignition (LOI) results. The mineral phases detected in the present analyses appear in the dunite/diorite/harzburgite/peridotite main rocks of the ophiolitic complex that hosts the chromite ore.

Originality. In the current research, an original characterization, via thorough elemental, phase and thermal analysis, is carried out aiming to enlighten the geochemistry aspects of the Vourinos chromite complex, Region of Western Macedonia, Greece, particularly of easily accessible and exploitable chromite deposits of the Aetoraches mine area.

Practical implications. The chromite mineral, and especially the metallurgical type, is of substantial importance in metal industry. In that sense, the findings of the present investigation of chromite purity and mineral structure is a prerequisite for future exploitation of the Aetoraches chromite deposits in particular and broadly for the ongoing exploitation of chromite ore in the Vourinos complex, situated in Region of Western Macedonia, Greece, an area with high unemployment and rather slow economic growth.

Keywords: chromite ore, Vourinos massif, Aetoraches mine area, mineralogical characterization, geochemistry, XRD, SEM-EDS, TG/DTG

1. Introduction

Chromite is a mineral that belongs to the spinel group and is found in nature in ultrabasic rocks (dunite, harzburgite). The technological classification of chromite ores into categories depends on the Cr/Fe ratio and the aluminum content as follows: metallurgical chromite type Cr/Fe > 2.8:1; refractory chromite type Cr/Fe < 2.5:1. This mineral, a ferrous and chromium variant of spinel (MgAl_2O_4) with the general chemical formula $(\text{Mg}, \text{Fe}^{+2})(\text{Cr}, \text{Al}, \text{Fe}^{+3})_2\text{O}_4$ constitutes an insignificant phase of basic and ultrabasic rocks and is of petrogenetic significance [1], while the combination with the content of various trace elements in chromatic ores appears to have particular importance for chromitogenesis.

Generally, chemical composition of the chromite is characterized by large variation, mainly in trivalent elements, from Cr- rich (metallurgical type) to Al- rich (refractory type). Various trace elements, such as elements of the platinum group (Os, Ir, Ru, Rh, Pt and Pd), or PGE, Ni, Cu, Co, V, Zn and Ti could likely appear as self-existing minerals (PGM, oxides of Ti) or replace major elements on the chromite lattice. For instance, V and Ti replace Cr and Al into octahedral positions, while Mn, Zn and Co substitute Mg and Fe^{+2} into tetrahedral positions of chromite [2], [3].

Some ophiolitic complexes host large deposits of chromite of metallurgical type (i.e. the ophiolite complexes of Vourinos Greece, Bulqiza Albania, the Acoje on Philippines) or only of refractory type (Othrys Greece, Coto in the Philip-

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pinies). Other complexes contain the two types of Cr- and Al-rich chromites (Pindos, Skyros, Rhodope massive in Greece) [4][7]. Important chromite-bearing occurrences in Greece could be found in Halkidiki (80 km long and 10 km wide), Pieria (Livadi area), Soufli, Veria, Rhodes and finally the Pindos ophiolitic complex.

In the ophiolitic complexes that host a chromite type, the contents of Ti, V, Zn, Co, and Cu are higher in the refractory type (Othrys) than in the metallurgical one (Vourinos), consistent with the behavior of Cr, Al and trace elements during its process of partial melting [8]. Greece could be one of the chromite producing countries with potential exploitable reserves of over 5 million tons with a floating content between 8 and 54% Cr₂O₃. A new promising investment is expected in the wider Kozani-Grevena area of the Western Macedonia Prefecture, for extraction and processing/enrichment of chromite by the mining company Hellenic Mines S.A.

In the current study, a thorough elemental, phase and thermal analysis is carried out, aiming to shed light on the geochemistry and exploitation aspects of the Vourinos complex and especially of the easily accessible and exploitable chromite deposits of the Aetorachi mine area.

2. Geologic and geotectonic setting

Most ophiolitic complexes included in the Greek mountain ranges mainly appear in the central and northern section of the country:

- a) the series of ophiolites in the western margin of the Pelagonian massif (ophiolitic complexes of Orthos and Pindos mountains), in the Pelagonian mountain range (Vourinos massif) and in the eastern margin of Pelagonian range (Vermio, Veria and EasternThessaly);
- b) in the Western Halkidiki (Vavdos, Ormylia Gerakini);
- c) in Serbo-Macedonian massif (Gomati, Nigrita) and Rodopi mountain range (Soufli, Exohi Drama) [6].

The geotectonic environment where the ophiolitic complexes are formed is positioned above a submerged plate or as it could be called *supra subduction zone*, where in most cases an evolution of the geotectonic environment is observed. Most peridotites, accompanied by dunites are in Greece characterized by a relatively strong degree of extraction [2].

Some ophiolitic complexes are known to host exclusively large metallurgical chromite deposits, such as the massifs of Vurinos, Bulgaria, Albania, Acoje in the Philippines, or only refractory type (Othrys Greece, Coto in the Philippines) and others containing the two types of Cr- and Al-rich chromites, for example Pindos, Skyros, and Rhodope massif [4], [7].

Since the ophiolitic complexes to which Al- and Cr-rich chromite deposits or chromium occurrences are linked with, are characterized by petrological and geochemical characteristics that are consistent with a specific geotectonic environment, the composition of chromite ores is related to the composition of the parent magma and this in turn with the geotectonic environment.

In Region of Western Macedonia, Northern Greece, chromite deposits are observed both in Pindos and Vourinos ophiolite complex. However, Vourinos ophiolites [9] (Fig. 1) are much larger and most exploited [10], [11]. The ophiolitic complex of Vourinos is a Jurassic emplacement (Upper Lias-Lower Malm) representing alterations of dunite and harzburgite with compact peridotites embedded by mainly pegmatites of gabbro-pyroxenite in the transition zone.

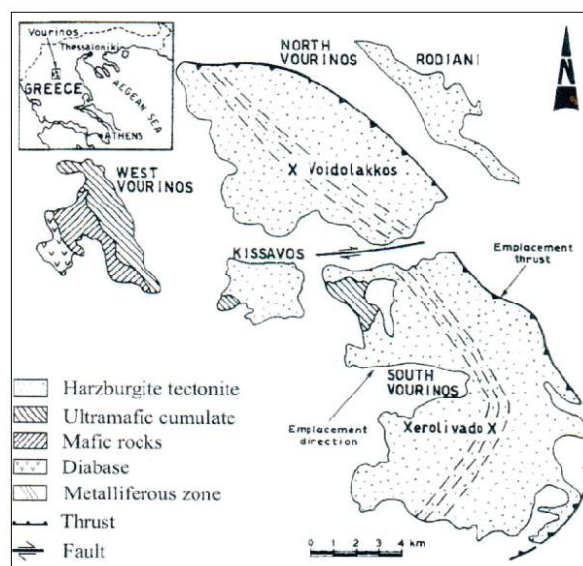


Figure 1. Vourinos ophiolite complex

In particular, this complex represents a mid-Jurassic ophiolitic slab thrust during upper Jurassic time towards the east over the Pelagonian Margin representing a sedimentary-tectonic mélangé [12]. A serpentinite alteration zone after dunite and harzburgite is observed, showing a main direction SE-NW close to Chromium village. In the past, many chromite mines were operating in several localities of Northern, Central and Southern Vourinos district [11] (Fig. 2).

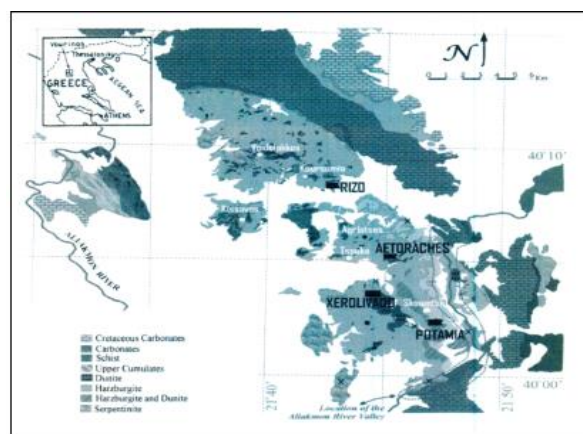


Figure 2. Chromite mines of Vourinos complex

3. Materials and methods

3.1. Sampling

Various chromite mines of Vourinos complex were mined in the past. In Table 1, the most significant of those are shown.

All samples characterized in this study were collected from “Aetorache” area in the North of Vourinos complex. Specifically two samples were collected from each site. The GPS coordinates of each site are 40°06'23.6", 21°43'09.2" for position A and 40°06'24.1", 21°43'09.1" for position B.

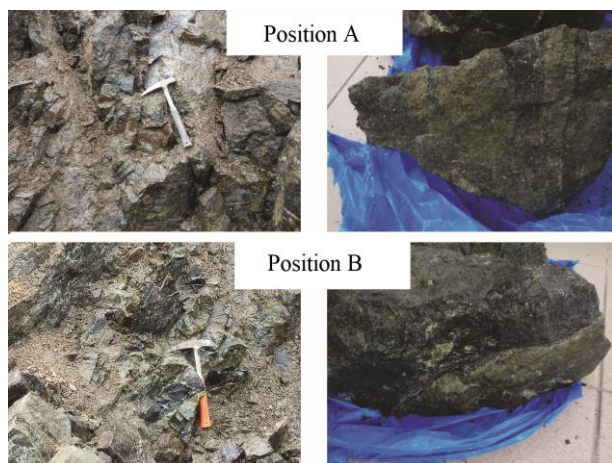
In Table 2, sampling areas and sample names are listed while, in Figure 3, photographs of the two sampling positions are shown.

Table 1. Selected data of main chromitite mines of Vourinos complex mined in the past

Mine	Location	Reserves	Form	Host
Xerolivado (Skoumtsa)	Centre of the southern Vourinos District	The largest ore body in the complex. Its total reserves are estimated at about 3.2 Mt of which 2.2 Mt has been exploited	Schlieren chromite ores. Also pods of massive ore bodies	Hosted by the largest dunite body within Vourinos
Aetorache	Southern Vourinos District to the north of Xerolivado mine	A hundred of thousands of tons	Often massive with minor schieren and disseminated ores	Hosted by dunite within regional harzburgite
Rizo	Northern Vourinos district	A hundred of thousands of tons	Dominantly disseminated ore with small massive chromitite lenses	Hosted by dunitites – harzburgites and serpentinites
Potamia	Small mine to the south of the Xerolivado mine	Reserves are calculated to just 30.000 t	Disseminated and rare schlieren ore	Hosted by dunitites – harzburgites and serpentinites
Frourio	Located in the eastern-most part of southern Vourinos	Only some thousands tons	Disseminated ore out of the metalliferous zone	Hosted by a thin dunite envelop within regional harzburgite

Table 2. Sampling area, positions and sample names

Area	Position	Sample name
Aetorache	A	A1
		A2
	B	B1
		B2

**Figure 3. Photographs of the two sampling positions, where the four samples were collected**

3.2. Analytical methods

X-Ray Diffraction (XRD) was carried out in order to identify the mineralogical phases which are present in the chromite samples. In order to conduct the XRD measurements, the chromite samples were mechanically crushed and sieved through a 45 µm stainless steel sieve to obtain fine powder. XRD analysis was performed using a SIEMENS 5005 Diffractometer (Ni filtered, Cu $K_{\alpha 1} = 1.54050 \text{ \AA}$). The 2θ scan range varied from 2 to 65°. Phase identification and quantification were carried out by matching the acquired diffractograms with the EVA software, COD-AMCSD database. The phase identification and the XRD measurement procedure includes approximate instrumental error 2 wt %, regarding the phase composition.

Morphological examination was conducted by means of Scanning Electron Microscopy (SEM), using a JEOL 6610LV. The elemental analysis was carried out using an X-Max 80 (Oxford Instruments) Energy Dispersive Spectroscopy (EDS) detector attached to the SEM. Images, ele-

ments maps and spectra were obtained and analysed using AZtech-Nanoanalysis software. Prior to SEM observation all samples were coated with carbon to avoid charging under the electron beam.

Loss on Ignition (LOI) measurements were conducted using a LECO TGA701, in the low temperature range of 25-107°C with a heating rate of 6°C/min in N_2 atmosphere, while in the high temperature range of 107-950°C with a heating rate 43°C/min and O_2 atmosphere.

Thermogravimetric analyses (TG/DTG) were conducted using a LECO TGA701 device in the temperature range of 25 to 1000°C with a heating rate 10°C/min, under air atmosphere with a flow rate of 3 L/min.

All analytical methods and measurement, except XRD methodology, were conducted in the laboratory of Applied Geochemistry, Mineral Resources Engineering Department, at University of Western Macedonia, Greece.

4. Results and discussion

In Figure 4, the XRD patterns of the A1 (a) and A2 (b) samples are shown, while the characteristic peaks corresponding to the major crystallographic phases are indicated. Phase identification analysis on samples A1 and A2 has shown that chromite is found in two forms: magnesio-chromite $(Mg, Fe)(Cr, Al)_2O_4$ and aluminian chromite $Fe(Al, Cr)_2O_4$. Moreover, on these samples, forsterite (Mg_2SiO_4) and clinochrysotile $Mg_3Si_2O_5(OH)_4$ phases were detected.

In Figure 5, the XRD patterns of the B1 (a) and B2 (b) samples are presented, where the characteristic peaks corresponding to the major crystallographic phases are indicated. Phase identification analysis on samples B1 and B2 has shown that except the aforementioned crystallographic phases detected in A1 and A2 samples, pyroaurite $Mg_6Fe_2CO_3(OH)_{16} \cdot 4H_2O$ and clinocllore $Mg_5Al(Si_3Al)O_{10}(OH)_8$ may also be present in these samples.

In Table 3, the major phase analysis results from the XRD measurements are summarized. In overall, XRD results interpretation indicates that all samples collected from the investigation site (Aetorache, North Vourinos) mainly contain magnesium and aluminium chromite (“aluminium picrochromite”), accompanied with forsterite minerals (magnesium containing olivine), serpentine and chlorite occurrences.

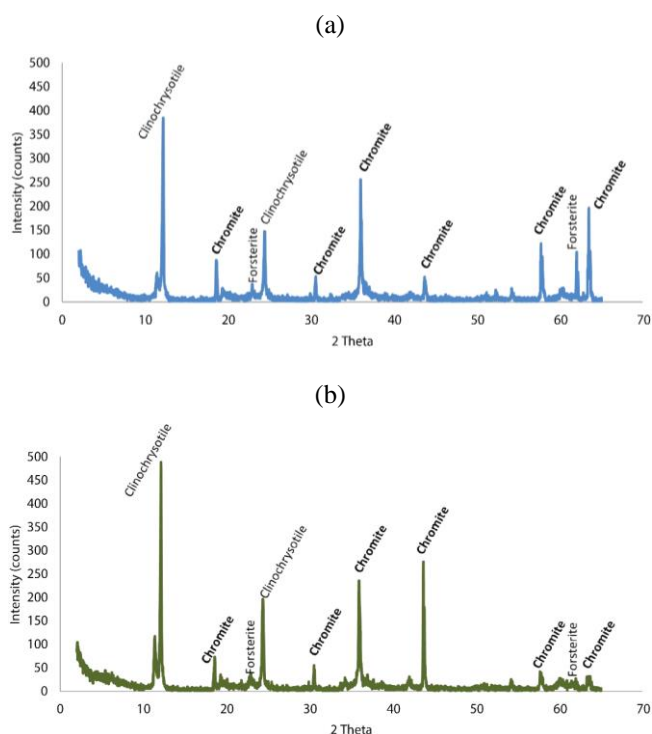


Figure 4. XRD patterns of samples A1 (a) and A2 (b)

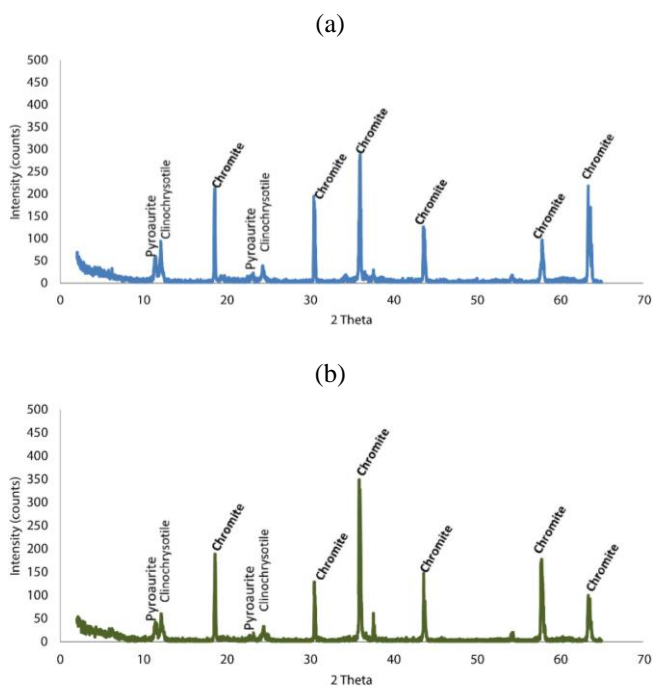


Figure 5. XRD patterns of samples B1 (a) and B2 (b)

Additionally, occupancies of the pseudo calcite-hydrotralcite group (pyroaurite, stichtite) are observed. These minerals occur in dunite/diorite/harzburgite/peridotite assemblage as the main rocks of the ophiolite complex which hosts the chromite ore.

LOI (Loss of Ignition) measurement results are summarized in Table 4. According to these results, it is clear that samples with high amounts of minerals belonging to serpentine group and moderate amounts of chlorite group minerals and pyroaurite correspond to higher LOI values (11.04 to 12.96%, on dry basis) likely at lower temperatures.

Table 3. Phase analysis results from the XRD

(wt %)	Sample A1	Sample A2	Sample B1	Sample B2
Magnesiochromite (Mg, Fe)(Cr, Al) ₂ O ₄	23.99	22.17	50.57	50.53
Aluminian chromite Fe(Al, Cr) ₂ O ₄	25.71	23.77	24.89	24.88
Forsterite, Syn (Mg ₂ SiO ₄)	5.06	4.68	11.43	11.43
Clinochrysoile Mg ₃ Si ₂ O ₅ (OH) ₄	45.24	49.37	0	0
Pyroaurite Mg ₆ Fe ₂ CO ₃ (OH) ₁₆ ·4H ₂ O	0	0	10.37	10.42
Clinochlore Mg ₅ Al(Si ₃ Al)O ₁₀ (OH) ₈	0	0	2.74	2.74

Table 4. Moisture and LOI measurements

Sample ID	Moisture (%)	LOI (%)	LOI (dry basis) (%)
Sample A1	1.10	10.18	9.18
Sample A2	1.56	12.43	11.04
Sample B1	0.52	4.36	3.86
Sample B2	1.63	14.38	12.96
Sample A1 + B1	0.44	4.65	4.23

On the other hand, samples with chromite dominated assemblages show lower values of LOI (3.86 to 4.23%) probably at higher temperatures mainly due to the presence of minor hydrous and carbonaceous phases and the high resistance character of chromite to decompose at moderate temperatures.

Thermogravimetry (TG) and Differential Thermogravimetry (DTG) results for samples A1 (a), A2 (b) and B1 (a), B2 (b) are recorded below in Figures 6 and 7 respectively. Four main peaks are identified, which reflect four different temperature ranges, as follows:

- 40-120°C, most likely referring to partial decomposition of pyroaurite (belonging to hydrotralcite group);
- 170-230°C, where a second split of pyroaurite occurs;
- 370-420°C, with the decomposition probably of chrysoile (kaolinite-serpentine group); and
- 650-720°C, with partial cleavage of clinochlore (chlorite group).

The products of the above decomposition processes might likely correspond at low temperatures to volatile matter, and as temperature increases, several oxides and silicate phases are formed. The pattern for both TG and DTG curves are more or less the same for all samples examined. Specifically, the % weight loss, for all samples, is varying between 4.4 and 14.36%, in the temperature range 600 to 750°C. In this temperature range, the decomposition of some hydrated siliceous minerals (e.g. serpentinite, chlorite) towards the formation of metal oxides is probably taking place. These results are relevant to LOI data mentioned above.

Results from SEM-EDS mapping of A1 sample are indicated in Figure 8. As it can be observed from the individual elemental maps in Figure 8c, there are two distinct microphase types: one with the major elements being Cr, Fe and Al, and a second one where the major elements are Si and Mg. In order to shed light into the precise composition of each microphase type, several points in each distinct area were examined.

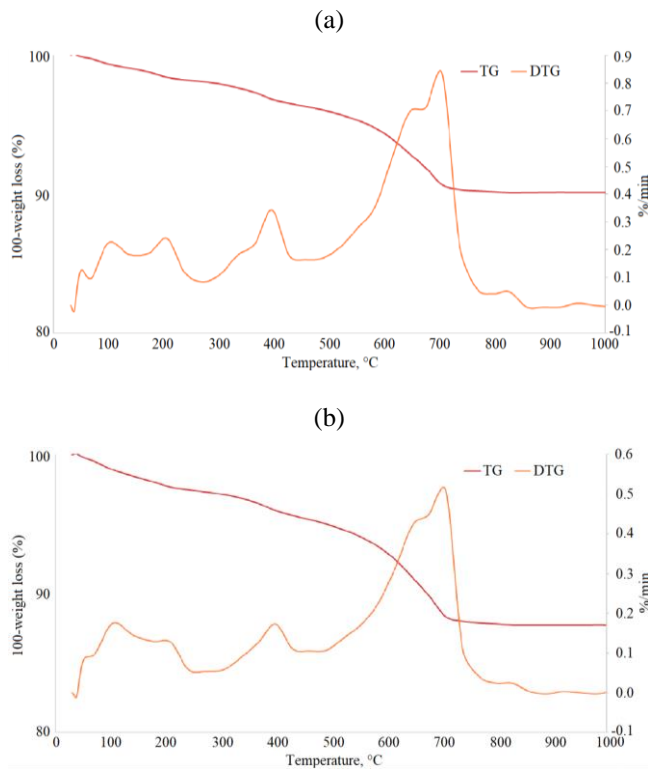


Figure 6. TGA and DTG curves for the A1 (a) and A2 (b) samples

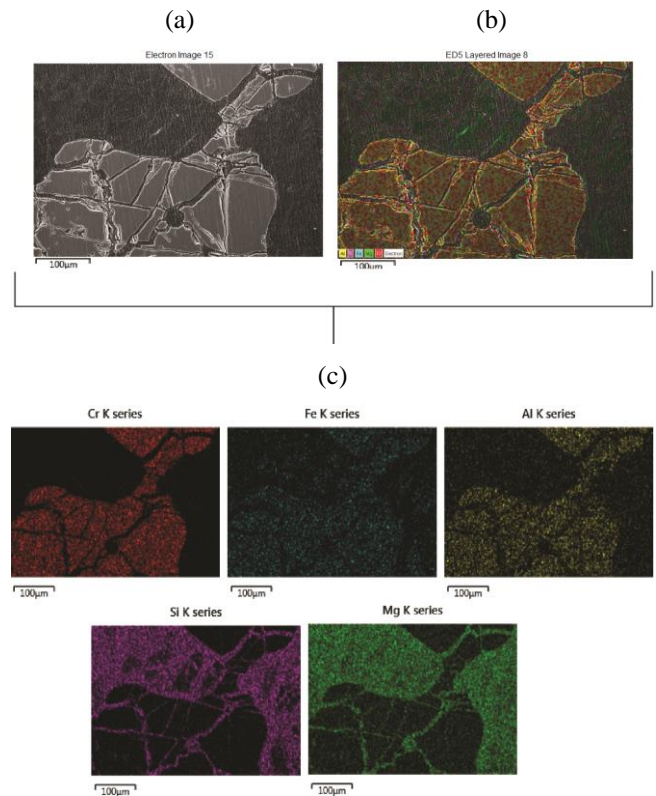


Figure 8. SEM-EDS maps from sample A1

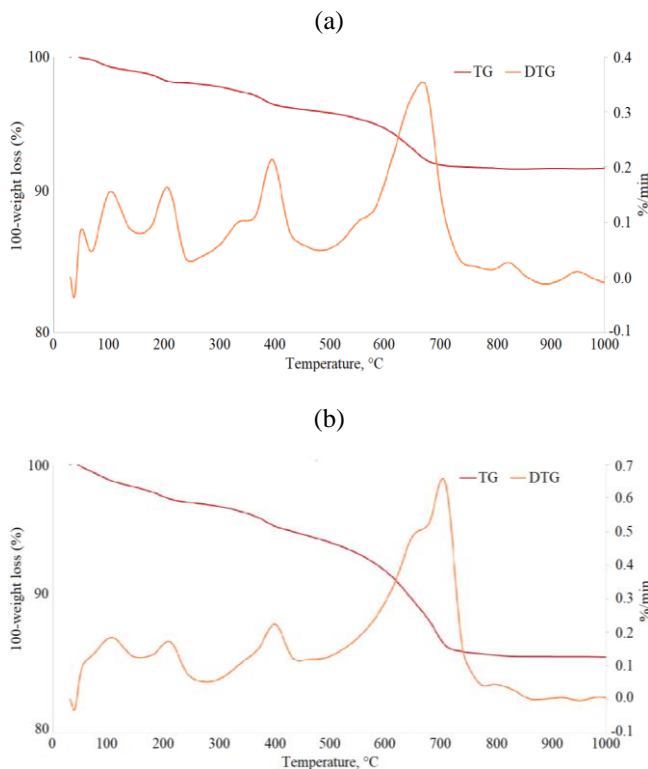


Figure 7. TGA and DTG curves for the B1 (a) and B2 (b) samples

In Figure 9, the point-by-point identification SEM-EDS image is presented, while Table 5 summarizes the elemental compositions of all samples and the individual points marked in Figure 9, expressed in both wt % and at %. Rather similar results were obtained from the corresponding SEM-EDS analysis conducted for B1 sample, as shown in Figures 10 and 11 and Table 6.

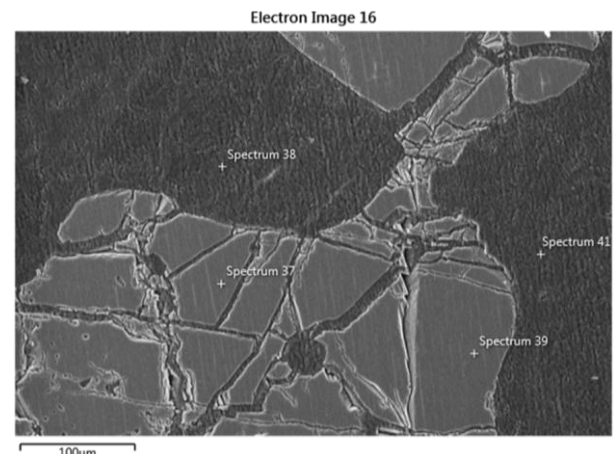


Figure 9. SEM image related to Point & ID analysis from sample A1

As indicated from the SEM-EDS maps above, the main elements Mg and Al that are included in lattice are present in relatively high but varying amounts. However, basic ophiolitic constituents of a peridotite/dunite complex, such as magnesium olivine, serpentinite, ortho-pyroxenes and chlorites should be also present based on the elemental compositions recorded. In that sense, the SEM-EDS results shown above are in good accordance with literature findings [13], [14] and the XRD and TGA results presented here.

According to Grivas et al. [9] all exploitable chromian spinel deposits mined from the '50s until the early '90s are developed within a characteristic zone named as "metalliferous zone". Analytical results of this study (Tables 5 and 6) for all samples investigated indicate that the average ratio of Cr/Cr + Al varies between 0.77 and 0.78, and that of Mg/Mg + Fe ranges from 0.56 to 0.59.

Table 5. Point & ID results based on the SEM image of Figure 9

Sample name	Spectrum No.	Elemental composition in wt %								Elemental composition in at %							
		Cr	Fe	Al	Mg	Si	O	Ni	Mn	Cr	Fe	Al	Mg	Si	O	Ni	Mn
A1	37	43.0	14.7	6.6	8.1	–	27.5	–	–	24.4	7.8	7.3	9.9	–	50.7	–	–
A1	38	–	3.1	–	28.6	21.5	46.7	–	–	–	1.1	–	23.9	15.6	59.4	–	–
A1	39	43.8	14.4	6.5	7.9	–	27.4	–	–	24.9	7.7	7.1	9.6	–	50.8	–	–
A1	41	0.4	16.5	–	28.5	6.4	48.1	–	–	0.2	6.3	–	24.9	4.8	63.8	–	–

Table 6. Point & ID results based on the SEM image of Figure 11

Sample name	Spectrum No.	Elemental composition in wt %								Elemental composition in at %							
		Cr	Fe	Al	Mg	Si	O	Ni	Mn	Cr	Fe	Al	Mg	Si	O	Ni	Mn
B1	32	44.8	12.5	6.8	7.9	–	27.9	–	–	25.3	6.6	7.4	9.5	–	51.2	–	–
B1	33	–	2.5	–	28.6	23.4	45.4	–	–	–	0.9	–	24.0	17.0	58.0	–	–
B1	34	44.6	13.3	6.6	8.0	–	27.5	–	–	25.3	7.0	7.3	9.7	–	50.7	–	–
B1	35	–	6.7	–	28.0	17.8	47.1	0.4	–	–	2.5	–	23.7	13.0	60.6	0.1	–

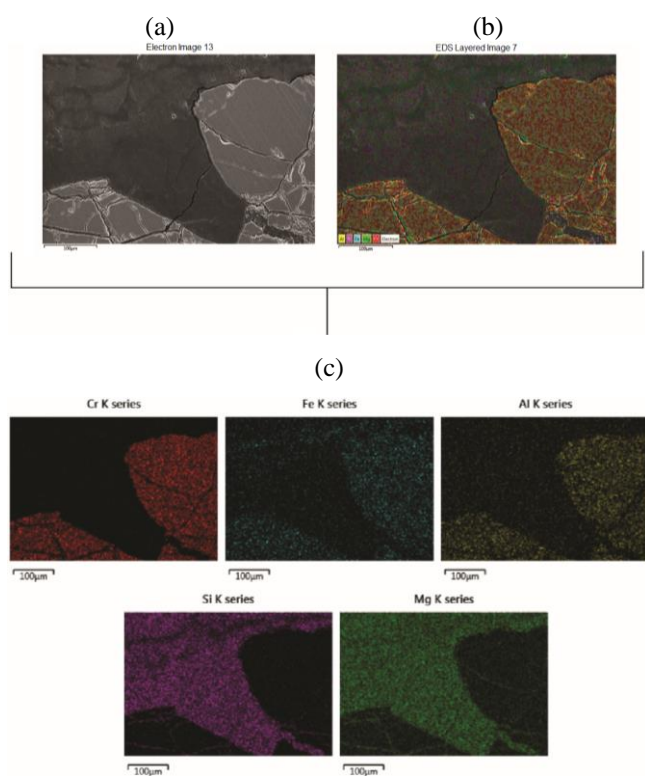


Figure 10. SEM-EDS maps from sample B1

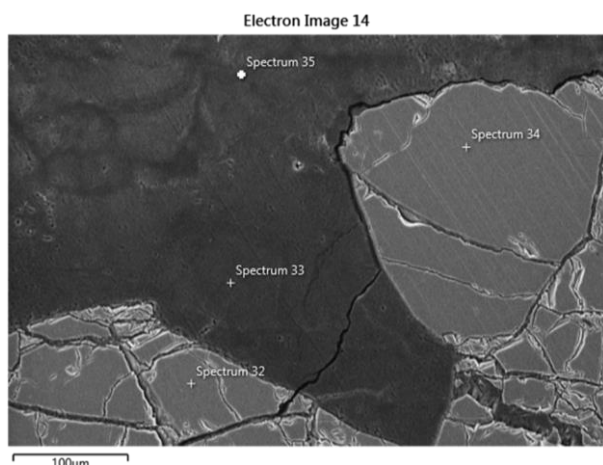


Figure 11. SEM image related to Point & ID analysis from sample B1

These figures are very close to those reported by Kapsiotis [13] from the Voidolakos and Xerolivado mines, Vourinos ophiolite complex. Thus, these chromites could be classified as magnesium chromites in the solid solubility system, shown in the form of a simplified quadratic solid solutions chart in Figure 12.

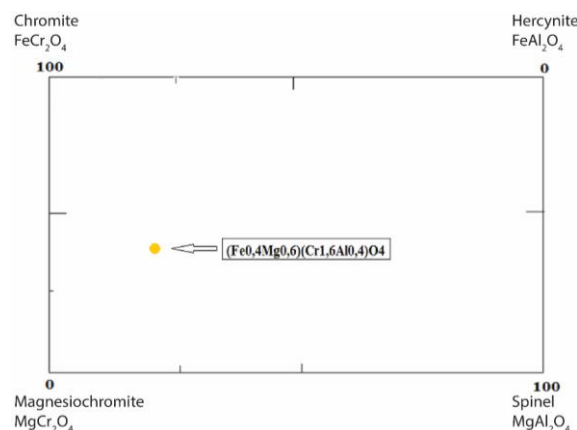


Figure 12. Quadratic Solid Solutions Series of chromite with the indication of computed average chemical formula of the magnesium chromite examined according to SEM-EDS results

Assuming the ideal magnesium chromite stoichiometry ($MgCr_2O_4$), the divalent magnesium ion (Mg^{+2}), according to the SEM-EDS results (Tables 5 and 6) is partially replaced by the divalent ferrous ion (Fe^{+2}) by more than 40 at % in the solid solution series chromite-magnesium chromite ($Fe_{0.4}Mg_{0.6}$). Simultaneously, a partial replacement of the trivalent chromium ion (Cr^{+3}) by the trivalent aluminum ion (Al^{+3}) by more than 20 at % also occurs. These chemical processes are indicative of a geochemical environment rich in magnesium and aluminum in aluminosilicates, such as serpentine, chlorite and tremolite. Apparently, there are several natural solubility solid-state geochemical systems with up to 100% substitution of chromite by magnesium chromite and vice versa ($Fe^{+2} \leftrightarrow Mg^{+2}$) in tetrahedral positions of the lattice, magnesium chromite by spinel ($Cr^{+3} \leftrightarrow Al^{+3}$) in octahedral positions, spinel by hercynite and hercynite by chromite. These successive substitutions are mainly due to the similarity of the ionic radii of the divalent and trivalent cations in-

involved, in the tetrahedral and octahedral crystallographic sites respectively, but also to the actual formation conditions of temperature and pressure. It is worth noting that the average stoichiometric chromite formula for the SEM-EDS analysis result is $(\text{Fe}_{0.4}\text{Mg}_{0.6})(\text{Cr}_{1.6}\text{Al}_{0.4})\text{O}_4$ (Fig. 12). Moreover, according to the SEM-EDS Point & ID analysis results of the A1 and B1 chromite samples (Tables 5 and 6), Cr/Fe ratios reveal mean values 3.18 and 3.73 for sample A1 and sample B1 respectively. In accordance with relevant literature findings [6], [12], these values underline the considerable presence of metallurgical type of chromite.

5. Conclusions

XRD results indicate that all the samples in the research area (Aetorachi, South Vourinos) contain mainly magnesium- and aluminum- chromite (“aluminum-picrochromite”) along with forsterite (magnesian olivine), serpentine and chlorite occurrences; also, occurrences of the hydrotalcite group (pyroaurite/stichtite). These minerals appear in the dunite/diorite/harzburgite/ peridotite association as the main components of the ophiolitic complex that host the chromite ore.

The above results are also confirmed by semi-quantitative elemental analyses using SEM-EDS: from the chemical elements that are present in chromite, chromium is present in all samples in relatively high amounts, along with variable magnesium, aluminum and iron amounts. The indicative average chemical formula of this specific chromite type is calculated to be: $(\text{Fe}_{0.4}\text{Mg}_{0.6})(\text{Cr}_{1.6}\text{Al}_{0.4})\text{O}_4$. It is worth noting that, since the Cr/Fe ratio is higher than 2.8/1, the chromite of the Aetorache sampling area can be classified as metallurgical chromite.

The LOI of the samples with higher content of chlorite/serpentine/tremolite/pyroaurites paragenetic accessory minerals in the chromite deposits is comparatively much higher at relatively low temperatures (11.04 and 12.96%) than the samples where the chromite predominates quantitatively (3.86 and 4.23%) with lower volatile phase contents (hydrates and carbonates).

The TG/DTG results indicated weight losses in the range of 4.4 to 14.36%, at temperatures between 600 and 750°C, where the decomposition of some hydroxyl-rich silicate minerals (serpentinite, chlorite) occurs, followed by formation of metal oxides. These findings are quite comparable to LOI (%) results.

The results of the current research can be useful for the ongoing and future exploitation of chromite ore in the Vourinos complex, which is situated in Region of Western Macedonia, Greece, an area with high unemployment and rather slow economic growth.

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Мінералогічна характеристика та оцінка хромітової руди в масиві Гревена та Козані Вурінос, Західна Македонія, Греція

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Мета. Дослідження зразків хромітової руди з рудника “Еторачес” в південній частині масиву Вурінос у Західній Македонії, Греція, з мінералого-геохімічної точки зору для оцінки можливості його промислової розробки.

Методика. Були проведені рентгеноструктурний аналіз мінеральної фази (РФА), елементна скануюча електронна мікроскопія у поєднанні з аналізом енергодисперсійної спектроскопії (СЕМ-ЕДС) та термогравіметрія/диференціальна термогравіметрія (ТГ/ДТГ).

Результати. Результати РФА показали, що всі зразки містять в основному фази хроміту магнію та алюмінію (“пикрохроміт алюмінію”), а також прояви форстериту (магнезійного олівину), серпентину й хлориту. Отримано середню хімічну формулу на основі результатів СЕМ-ЕДС, яка вказує на конкретний тип хроміта: $(\text{Fe}_{0.4}\text{Mg}_{0.6})(\text{Cr}_{1.6}\text{Al}_{0.4})\text{O}_4$. Встановлено, що втрати маси ТГ/ДТГ, виявлені в діапазоні від 4.4 до 14.36%, при температурах від 600 до 750°C, вказують на присутність силікатних мінералів, багатих гідроксидом, серпентиніту і хлориту. Мінеральні фази, виявлені в даному аналізі, присутні в основних породах дуніт/діорит/гарцбургіт/перидотит офіолітового комплексу, що вміщує хромітові руди.

Наукова новизна. Надана оцінка геохімічних аспектів хромітового масиву Вуринос, регіон Західної Македонії, Греція, особливо легкодоступних та експлуатованих хромітових родовищ рудником “Еторачес” на основі елементного, фазового та термічного аналізів.

Практична значимість. Хромітовий мінерал, особливо металургійний, має велике значення в металургійній промисловості. У цьому сенсі результати даного дослідження чистоти хроміту і мінеральної структури є передумовою для майбутньої експлуатації хромітового родовища рудника Еторачес, зокрема, і в цілому для тривалої розробки хромітової руди в масиві Вуринос. Греція – регіон з високим рівнем безробіття й досить повільним економічним зростанням.

Ключові слова: хромітова руда, масив Вуринос, рудник Еторачес, мінералогічна характеристика, геохімія, РФА, СЕМ-ЕДС, ТГ/ДТГ

Минералогическая характеристика и оценка хромитовой руды в массиве Гревена и Козани Вуринос, Западная Македония, Греция

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Цель. Исследование образцов хромитовой руды из рудника “Эторачес” в южной части массива Вуринос в Западной Македонии, Греция, с минералого-геохимической точки зрения для оценки возможности его промышленной разработки.

Методика. Были проведены рентгеноструктурный анализ минеральной фазы (РФА), элементная сканирующая электронная микроскопия в сочетании с анализом энергодисперсионной спектроскопии (СЭМ-ЭДС) и термогравиметрия/дифференциальная термогравиметрия (ТГ/ДТГ).

Результаты. Результаты РФА показали, что все образцы содержат в основном фазы хромита магния и алюминия (“пикрохромит алюминия”), а также проявления форстерита (магнезильного оливина), серпентина и хлорита. Получена средняя химическая формула на основе результатов СЭМ-ЭДС, указывающая на конкретный тип хромита: $(\text{Fe}_{0.4}\text{Mg}_{0.6})(\text{Cr}_{1.6}\text{Al}_{0.4})\text{O}_4$. Установлено, что потери массы ТГ/ДТГ, обнаруженные в диапазоне от 4.4 до 14.36%, при температурах от 600 до 750°C, указывают на присутствие силикатных минералов, богатых гидроксидом, серпентинита и хлорита. Минеральные фазы, обнаруженные в настоящем анализе, присутствуют в основных породах дунит/диорит/гарцбургит/перидотит офіолітового комплексу, вмещающего хромітові руди.

Научная новизна. Дана оценка геохимических аспектов хромитового массива Вуринос, регион Западной Македонии, Греция, особенно легкодоступных и эксплуатируемых хромитовых месторождений рудником “Эторачес” на основе элементного, фазового и термического анализов.

Практическая значимость. Хромитовый минерал, особенно металлургический, имеет большое значение в металлургической промышленности. В этом смысле результаты настоящего исследования чистоты хромита и минеральной структуры являются предпосылкой для будущей эксплуатации хромитового месторождения Эторачес, в частности, и в целом для продолжающейся разработки хромитовой руды в массиве Вуринос. Греция – регион с высоким уровнем безработицы и довольно медленным экономическим ростом.

Ключевые слова: хромитовая руда, массив Вуринос, рудник Эторачес, минералогическая характеристика, геохимия, РФА, СЭМ-ЭДС, ТГ/ДТГ