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GEOCHEMISTRY OF MINOR ELEMENTS OF THE CHROMITES FROM THE VERMION-VORA AND VOURINOS AREAS (GREECE)

by
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Abstract: *A Geochemical study of the minor elements Ti, Mn, V, Co, Ni and Zn of ten Greek chromite samples, which were determined with the method of atomic absorption, is made. The samples come from deposits or occurrences of the chromiferous Vermion-Vora and Vourinos areas, which belong to the podiform type. The results of all analyses give an exceptional low titanium content, below 100 p. p. m., for all samples. This was expected, because of the podiform type of the deposits, but not in a such low level. The comparison of the determined vanadium values and the* Al_2O_3 *values, in the samples where we have data of chemical analysis of the major elements, reveals an interesting relation between them. The decrease of the vanadium content in p.p.m. is a linear function with the increase of the* Al_2O_3 *content in wt %. This is nowhere cited, and the data of the chromite analyses from the Bushveld critical zone, show a rather opposite trend. However, the generalization of this relation, as well as its interpretation, requires the publication of more data of analyses from all over the world. Any other relation or analogy between the investigated minor elements does not occur. Only a trend of coincidence between the minimum and maximum values of manganese and zinc exists. The fluctuation of the manganese values is considerable and the chromites found in more metamorphosed rocks, show the highest content. Finally, a detailed comparison is made between the values of the determined minor elements and the corresponding values (available from literature) of chromites coming from: podiform and stratiform deposits, eruptions of lava, ultramafic xenoliths in kimberlites, a progressively metamorphosed environment, drawn up basalts from oceanic crust, diamonds, meteorites and lunar samples. Also, a comparison is made between the determined values of the minor elements and those of the same elements which have been recently determined in basalts, eclogites and the members of the ophiolite suite.*

INTRODUCTION

Chemical analyses of chromites with data of minor elements are very rare or missing in previous literature. Chemical analyses performed on mined massive chromites or chromitic concentrates for technological purposes, were including data of only the major elements Cr, Fe, Al, Mg, where rarely ferrous and ferric iron were distinguished. In some analyses, mainly on chromites from big ore deposits (i.e. Bushveld), sometimes titanium has been determined. The classification of the chromite deposits in genetical categories became possible, on the base of a large number of such analyses. Thus, with chemical criterions and defining the genetical conditions, i.e. oxygen fugacity, chromite deposits are classified into stratiform and podiform deposits (Irvine 1967, Thayer 1970, Dickey 1976).

However, as it is known, (Donath 1962, Kern 1968) the chromites contain also minor elements in a considerable proportion which sometimes exceeds 1% by weight. These elements, except the above mentioned Ti are Mn, V, Co, Ni and Zn. These elements, which belong to the rare elements of the rocks, are recently studied systematically with rare earths in order to solve petrogenetic problems (Montigny et al 1973, Coleman 1977). During the last years a research of the above mentioned elements began, on chromite found in ultramafic rocks as an unessential mineral (except its deposits). There are publications, including data of chemical analyses of all or part of the above elements, on chromites from: different known deposits (de Waal 1972, 1975a, Chakraborty 1973, Hedlung et al 1974, Cameron 1975, Wazny and Substyk 1975, Henderson 1976, Saho and v. d. Kaaden 1976), basaltic extrusions (Evans 1972), xenoliths in diatreme (Wallace 1975), xenoliths in kimberlites (Basu and MacGregor 1976), diamonds (Meyer 1975), basalts which have been drawn up from oceanic crust (Freu et al 1974) as well as on chromites from meteorites, usually chondrites, (Bunch et al 1967, Bence and Bornet 1969, Allen and Mason 1973, Bunch et al 1976) and lunar samples (Nehru et al 1974). There are also studies on the alteration of chromites with data of chemical analyses on the above elements (de Waal 1975b, Onyeagoha 1974) and data from analyses on chromites formed during progressive metamorphism (Evans and Frost 1976).

In some of the papers a relation between the values of the major and minor elements occurs. Thus, de Waal (1975b) recognizes in the chromites from the Bushveld stratiform deposit a decrease of MgO and Cr_2O_3 accompanied by an increase of FeO, Al_2O_3, Fe_2O_3, TiO_2, V_2O_3, NiO and ZnO in the different horizons upwards, while CaO, MnO and CoO remain constant. Wazny and Substyk (1975) showed that the content of chromites in Ti, V and Mn is directly depended on the Fe content, while Ni is exclusively depended on Mg. Evans (1972) shows that a decreasing trend of Cr_2O_3 in chromites from two eruptions of the Kilauea volcano, Hawaii is accompanied by an increase of Fe_2O_3, FeO, TiO_2 and V_2O_5.

From all the above results that more experimental work is still required for the solution of many problems. The study of the minor elements of chromites, in combination with their major elements, shows a significant interest.

In the present work a geochemical study of the minor elements of Greek chromites from deposits of known genetical conditions (podiform type) is performed.

Two relative papers have been published up to now concerning the Greek chromites. Panagos (1967) has studied semiquantitatively the minor elements Pt, Ga, V and Ir of the Vourinos chromites and Papadakis (1977) studied quantitatively the minor elements Ti, Mn, V, Co, Ni and Zn of the Triadion, Thessaloniki chromites. On the base of their titanium content and other geological data the last investigator classified the Triadion chromite deposits into the podiform type. As it is known, (Dickey 1976, Coleman 1977) these deposits always appear in alpine-type ophiolite complexes e.i., in ancient fragments of oceanic crust.

EXPERIMENTAL MATERIAL

For the research of the minor elements and the finding of relations between their values as well as between their values and those of the major elements, ten samples of Greek chromites were analyzed. Seven of them belong to the relatively extensive Vermion and Vora area, and the rest numbered 5, 6 and 7 to the known chromiferous Vourinos area. The Vermion-Vora chromite deposits are found in serpentinized dunites and harzburgites (Papadakis and Trontsios 1974) which are characterized by a different grade of serpentinization, fracturing and generally metamorphism. They constitute a significant number of deposits and occurrences with disseminated to massive type ore. They present a great variety of forms but generally belong to the podiform type. According to Dickey (1976) and Coleman (1977) the chromites from podiform deposits belong to two dinstinct categories from which one is richer in chromium and the other in magnesium. This is intensively observed in the chromites of the Vermion-Vora deposits where the rich in Al_2O_3 group of Giannakohori has values ranging from 14.32% to 15.10% Al_2O_3

by weight, while the group of the rest occurrences from 7.52% to 10.33% (Papadakis and Trontsios 1974). The Vourinos chromite deposits are found in unaltered or slightly serpentinized duuites (Moores 1969). Thry appear in schlieren, plates-schlieren and other forms and belong to the podiform type of deposits too (Panagos 1965).

The chromite samples were firstly crushed in a mill up to 200 mesh, they were screened and then they were separated from the coexisting gangue (serpentine or dunite) by the superspanner method. The already pure chromitic material was analyzed in an atomic absorption apparatus to determine the minor elements. All the experimental part of the present study was performed in the laboratory of Mineralogy and Petrography of the University of Heidelberg (W. Germany).

RESULTS - CONCLUSIONS

Table I shows the results of the analyses.

TABLE I

Chemical analyses of the minor elements of chromites (p.p.m.)

Number of sample	Ti	Mn	V	Co	Ni	Zn
1	<100	700	280	200	500	<100
2	<100	900	300	300	400	<100
3	<100	4.500	190	300	800	150
4	<100	1.400	465	300	900	740
5	<100	1.000	225	400	900	540
6	<100	1.000	220	500	800	460
7	<100	1.000	260	600	800	500
8	<100	4.000	580	600	800	570
9	<100	8.000	300	600	900	640
10	<100	5.400	250	300	800	640

Localities: 1. Polykarpi (Edessa), 2. Koukouli (Naousa), 3. Giannakohori (Naousa), 4. Fytia (Veria), 5. Scoumtsa (Grevena), 6, 7. Xerolivado (Grevena), 8. Kerasia (Edessa), 9. Kremenirtsa (Edessa), 10. Lyki (Edessa)

For the best presentation of the results and the finding of relations or proportions between their values, the simple values (not the logarithmic, because a great confusion might occur) were placed on the Y axis and the elements on the X axis.

Because of the very low titanium values, which in all samples are lower than 100 p.p.m., this element was not included in the diagram. Also, three values of Mn, higher than 1.000 p.p.m., lie outside of the diagram.

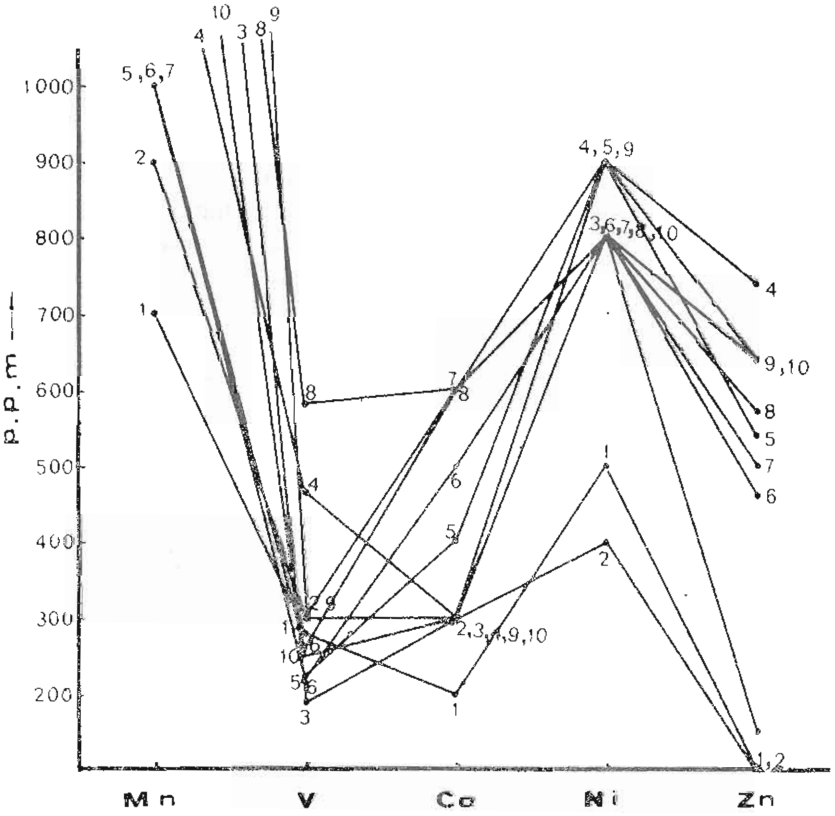

Fig. 1. Minor elements content of chromites from the Vermion - Vora and Vourinos areas (Enumaration of samples as in table I).

Fig. I shows that, although we generally observe maxima in the values of Mn and Ni and minima in the values of V, Co and Zn, a correlation or a constant analogy between the values of minor elements cannot exist with certainty.

From Table I the following conclusions result:

TITANIUM

This minor element was found in all samples in exceptionally low values below 100 p.p.m. As it is known (Dickey 1976), low values of Ti in chromites, below 0.3% in TiO_2 or 1,800 p.p.m. in Ti respectively, constitute a criterion of classifying the chromite deposits into the podiform type. The values which were found confirm the classification of the Vermion-Vora and Vourinos chromite deposits, into the podiform type, after Papadakis and Trontsios (1974) and Panagos (1965) respectively.

Anyway, these very low titaninm values were an exception because, even in podiform deposits Ti usually appears in higher values. Thus, the chromites from the ophiolites of Bay of Island contain 0.11 - 0.51% in TiO_2 (0.37% in TiO_2 as average of 5 analyses, e.i. 2,220 p.p.m. in Ti) when they are found in dunites, 0 - 0.15% in TiO_2 (0.09% in TiO_2 as average of 10 analyses, e.i. 540 p.p.m. in Ti) in harzburgites, and 0 - 0.1% in TiO (0.05% in TiO_2 as average of 2 analyses, e.i. 300 p.p.m. in Ti) in lherzolites (Malpas and Strong 1976). Also, the chromites from the alpine-type dunite of Twin Sisters, Washington contain 0.03 - 0.08% in TiO_2 with 0.67% in TiO_2 as average of 9 analyses, e.i. 4,020 p.p.m. in Ti (Onyeagocha 1974).

Reratively low titanium values, but anyway higher that tnose of Table I, are observed in the chromites of the ultramafic xenoliths in kimberlites with 0.040% in TiO_2 e.i. 240 p.p.m. in Ti (Basu and MacGregor 1976) and in chromites which form inclusions in diamonds with 0.16% in TiO_2 as average of 2 analyses or 960 p.p.m. in Ti (Meyer 1976). Higher values have been determined on the chromites formed during a progressive metamorphism with TiO_2 from 0.08% to 1.17% and 0.26% in TiO_2 as average of 8 analyses e.i., 1,560 p.p.m. in Ti (Evans and Frost 1976) and in chromites of drawn up basalts from oceanic crust with 0.295% in TiO_2 as average of 2 analyses e.i., 1,770 p.p.m. in Ti (Frey et al 1974).

In the chromites from stratiform deposits, as it is mentioned above, the titanium values are higher. Thus, the chromites of the Marico, Bushveld stratiform deposit contain 0.36% in TiO_2 e.i., 2,160 p.p.m. in Ti as average of 2 analyses, the chromites from Kalrangi, Orissa (India) 0.55% in TiO_2 e.i., 3,000 p.p.m. in Ti (average of 4 analyses) Chakraborty 1973) and the chromites of the critical zone of Bushveld from 0.43% to 2.7% in TiO_2 with 1.08% in TiO_2 e.i., 6,480 p.p.m. in Ti as average of 12 analyses (Cameron 1976). In the chromites from Kilauea, Hawaii lavas, the average of 4 analyses is 2.34% in TiO_2 e.i., 14,040 p.p.m. in Ti (Evans 1972). The titanium values of chromites from meteorites are very high too. Thus, the average value of 7 analyses on chromites from different meteorites gives 1.33% in TiO_2 e.i., 7,980 p.p.m. Ti (Bunch and Olsen 1976), the average value of 350 analyses on chromites from chondrites gives about 2% in TiO_2 e.i., 12,000 p.p.m. in Ti (Bunch et al 1967) the chromite of Guarena meteorite 13,000 p.p.m. in Ti, of Modoc meteorite 17,000 p.p.m. in Ti (Allen and Mason 1973) and the chromite of Kodaikanal meteorite 30,000 p.p.m. in TiO_2 or 18,000 p.p.m. in Ti (Bence and Bornett 1969). The highest values of Ti have been determined on chromites from lunar samples of Apollo 15 where in 15 samples TiO_2 ranges from 3.2% to 9% with an average value of 5.9% in TiO_2 e.i. 35,400 p.p.m. in Ti (Nehru et al 1974).

MANGANESE

This minor element, in the studied chromite samples, ranges rom 700 to 8,000 p.p.m. with 2,790 p.p.m. in Mn as average of 10 analyses. Consequently, manganese shows a considerable fluctuation of values, the highest of all the analyzed minor elements. No one parallelism, relation or analogy has been found with the values of the rest minor elements. However, it was found that the manganese content of the chromites, depends on the grade of serpentinization and generally the grade of metamorphism of the surrounding the chromitic occurrences rock. Thus, the Vourinos chromites show the lowest manganese values while the adjacent rock is an unaltered dunite, at least in the analyzed samples. The highest values of Mn have been determined on the chromites from Giannakohori, Kremenitsa and Lyki of the Edessa area, where the surrounding the chromitic occurrences rock is intensively serpentinized and the ore usually appears mylonitized.

Anyway, we accept this dependence with a precaution, because we have only determined the grade of metamorphism from petrographic observations and without data of chemical analyses on the adjacent rock. It is remarkable that in the chromites formed during a progressive metamorphism, manganese shows about the same fluctuation in 8 analyses from 0.11% to 0.75% in MnO e.i. 814 - 5,805 p.p.m. in Mn and an average value of 0.4% in MnO e.i., 3,096 p.p.m. in Mn (Evans and Frost 1976). Also, in the chromites from the alpine-type dunites of Twin Sisters, Washington, manganese ranges from 0.23 % to 0.58% in MnO in 2 analyses, with an average value of 0.37% in MnO e.i., 2,864 p.p.m. in Mn (Onyeagocha 1974), a similar value with the average found in the chromites of the present study.

Lower values have been determined on the chromites of the drawn up basalts from oceanic crust with 0.17% in MnO e.i. 1,316 p.p.m. in Mn as an average value of two analyses (Frey et al 1974), on the chromites of the Kairangi, Orissa (India) stratiform deposit with 0.177% in Mn or 1,370 p.p.m. in Mn as an average value of 4 analyses (Chakraborty 1973), on the chromitic inclusions of diamonds with 0.18% in MnO or 1,393 p.p.m. in Mn as an average of 2 analyses (Meyer 1976), on the chromites from the lavas of two eruptions of the Kilauea, Hawaii volcano with 0,18% Mn or 1,393 p.p.m. in Mn as an average of 4 analyses (Evans 1972) and on the chromites from the Marico area of Bushveld with 0.25% in MnO or 1,935 p.p.m. in Mn as an average of 2 analyses (de Waal 1975a). In the chromites from lunar samples of Apollo 15, manganese ranges from 0.26% to 0.43% in MnO with an average value of 0.34% in Mn or 2,632 p.p.m. in Mn (Nehru et al 1974).

Higher values appear in the chromitic concentrates of the Campo Formose (Brazil) stratiform deposit with 0.5% in MnO or 3,870 p.p.m. in Mn (Hedlund et al 1974), in the chromites from: xenoliths in diatremes of South Westland New Zealand with 0.39% - 0.60% in MnO and 3,974 p.p.m. in Mn as an average of 3 analyses (Wallace 1975), the Guerena meteotite with 5 - 8,000 p.p.m. in Mn and Modoc with 6,000 p.p.m. in Mn (Allen et Mason 1973), the Kodaikanal meteorite with 8,000 p.p.m. in MnO or 6,208 p.p.m. in Mn (Bence and Bornett 1969) and in the chromites from chondrites with 0.9% in MnO or 6,960 p.p.m. in Mn as an average of 350 analyses (Bunch et al 1967).

In the chromites of Triadion, Thessaloniki, manganese ranges from 1,300 to 1,700 p.p.m. with an average value of 1,483 p.p.m. in Mn (Papadakis 1977), e.i. it is considerably lower than the values of the chromites from the Vermion - Vora area. It must be noted that the surrounding the deposits rock is a slightly serpentinized dunite. Thus, the above mentioned dependence of the manganese content on the grade of metamorphism of the surrounding rock is confirmed.

VANADIUM

This minor element, in the studied samples, ranges from 190 to 580 p.p.m. with an average value of 307 p.p.m. in V. Also, the fluctuation of the vanadium values showed none correlation with the values of the rest minor elements. However, an interesting correlation with the aluminium values is observed. Thus, in all samples where we had also data of chemical analyses on the major elements (e.i. samples 1, 2, 3, 4 and 7), a linear function exists between V in p.p.m. and Al_2O_3 in weight per cent. This is clearly shown in table II and even better in Fig. 2, where the values of Al_2O_3 in wt % were placed on the X axis and the values of V in p.p.m. on the Y axis. Vanadium in p.p.m. livearly decreases with the increase of Al_2O_3 in weight per cent. All the points on the diagram lie almost on a straight line except the number 2 analysis which diverges.

TABLE II

Relation between the values of V in p.p.m. and Al_2O_3 in wt %

sample	V p.p.m.	Al_2O_3 wt %
1	280	10.33
2	300	8.17
3	190	14.32
4	465	7.06
7	260	11.60

Source for the Al_2O_3 values1-4 PAPADAKIS and TRONTSIOS (1974) 7 VOUTETAKIS (1970).

This phenomenon is observed for first time. From the data of the refered literature, as regards the analyses, a such correlation does not result. Even, in the chromites of the stratiform deposits of Bushveld and Orissa, India (as results from the published data) a rather opposite trend exists e.i. an increase in V with the increase in Al_2O_3 (Cameron Saho and V.d. Kaaden 1976). However, it is very early to say that this conclusion constitutes a general feature of the chromites from podiform

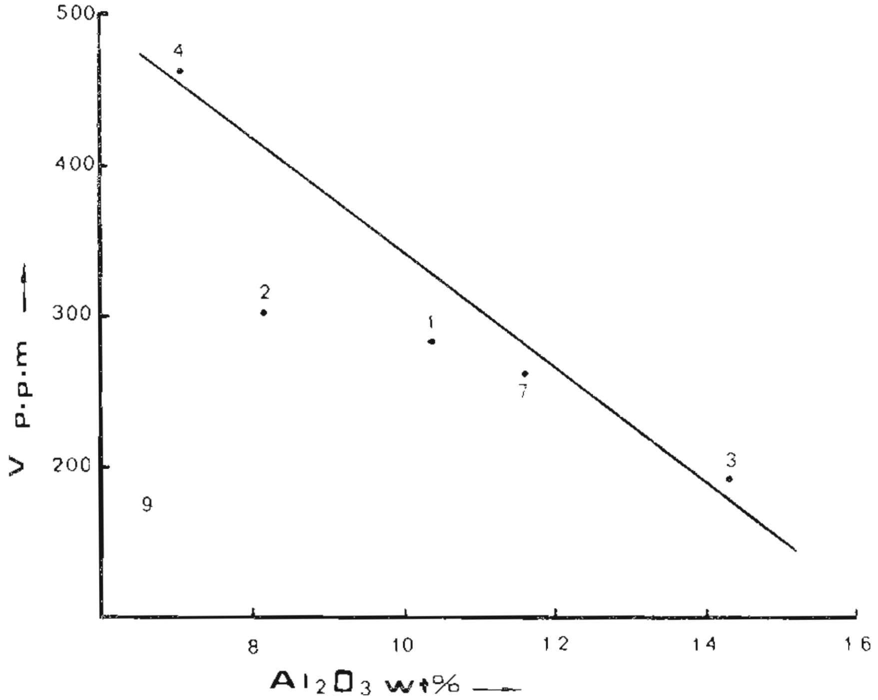

Fig. 2. Projection of V values (p.p.m.) and Al_2O_3 (wt %) of chromites from Vermion-Vora and Vourinos areas (Enumeration as in table II).

deposits. In this case it would be used as a criterion of distinction. The number of the available analyses of V from podiform deposits all over the world is still very small to make such a generalization.

Similar vanadium values have been determined only on chromitic concentrates from the Campo Formose (Brazil) stratiform deposit, with 0.05% in V_2O_3 or 340 p.p.m. in V (Hedlund et al 1974). The chromites from the alpine-type dunite of Twin Sisters, Washington, show higher values with 0.11 - 0.21% in V_2O_3 and 0.14% in V_2O_3 or 952 p.p.m. in V as average of 9 analyses (Onyeagocha 1974). Considerably higher values appear in the chromites from: the Marico area of the Bushveld stratiform deposit with 0.20% in V_2O_3 or 1,360 p.p.m. in V as average of 2 analyses, the lavas of two eruptions of the Kilauea, Hawaii volcano with 0.20% in V_2O_3 or 1,360 p.p.m. in V as average of 4 analyses (Evans 1972) and in the chromites formed during a progressive metamorphism with

0.20% in V_2O_3 or 1,360 p.p.m. in V as average of 8 analuyses (Evans and Frost 1976).

Very high values are observed in the chromites from: the critical zone of the Bushveld stratiform deposit with 0.19-0.61% in V_2O_3 and 0.42% in V_2O_3 or 2,845 p.p.m. in V as average of 12 analyses (Cameron 1976), lunar samples of Apollo 15 with 0.37-0.92% in V_2O_3 and 0.53% in V_2O_3 or 3,604 p.p.m. in V as average of 13 analyses (Nehru et al 1974), different meteorites with 0.24-0.93% in V_2O_3 and 0.62% in V_2O_3 or 4,216 p.p.m. in V as average of 7 analyses (Bunch and Olsen 1976), chondrites with 0.7% in V_2O_3 or 4,760 p.p.m. in V as average of 350 analyses (Bunch et al 1974) and in the chromites of the Modoc meteorite with 4,000 p.p.m. in V (Allen et al 1973).

According to the recent investigations, except the chromites, vanadium slips in the composition of the high-alumina basalts in a rate of 257 p.p.m. (average of 20 analyses, Taylor et al 1971) and in the eclogite of Robert Victor Mine, South Africa with 84-461 p.p.m. in V and 240 p.p.m. in V as average of 32 analyses (Ju-Chin - Chen 1971).

In the chromites of the Triadion, Thessaloniki podiform deposits vanadium ranges from 240 to 480 p.p.m. with 367 p.p.m. in V as average of 6 analyses (Papadakis 1977) e.i., it shows slightly higher values than those of the studied in the present work chromites.

COBALT

This minor element ranges from 200 to 600 p.p.m. with an average value of 410 p.p.m. in Co. It shows none relation with the values of the rest minor elements even with those of the major elements in the analyzed samples. The values of Co always remain simply lower than those of Ni.

Lower cobalt values have been determined on the chromites from the Modoc meteorite with 28 p.p.m. in Co and the Guarena meteorite with 45 p.p.m. in Co (Allen and Mason 1973), in the chromitic concentrates of the Campo Formose (Brazil) stratiform deposit with 0.02% in CoO or 157 p.p.m. in Co (Hedlund et al 1974) and in the chromites of the Fiskenasset, Greenland stratiform deposit with 250 p.p.m. in Co (Chisler 1976).

Higher values appear in the chromites from the alpine-type dunite of Twin Sisters, Washington with 0.03 - 0.11% CoO and 0.07% in CoO or 550 p.p.m. in Co as average of 9 analyses (Onyeagocha 1974).

According to the recent investigations, cobalt is included in the high-alumina basalts in an amount of 0-200 p.p.m. and 41 p.p.m. as average of 20 analyses (Taylor et al 1971) and in the eclogites of Robert Victor Mine, South Africa with 43-105 p.p.m. in Co as average of 32 analyses (Ju - Chin - Chen 1971).

In the different members of the Pindos ophiolite suite cobalt ranges upwards as follows: in the seprentinized lherzolite 83 p.p.m., in the pyroxenite dikes 40 p.p.m., in the feldspar peridotite 83 p.p.m., in the gabbros 40 p.p.m. in the dolerites 60 p.p.m. and in the spilitic pillow lavas from 67 to 35 p.p.m. (Montigny et al 1973).

In the chromites of the Triadion, Thessaloniki podiform deposits cobalt ranges from 300 to 500 p.p.m. with 367 p.p.m. in Co as average value of 6 analyses (Papadakis 1977), e.i. it shows almost similar values with those of the chromites studied in the present work.

NICKEL

This minor element ranges from 400 to 900 p.p.m. with an average of 760 p.p.m. in Ni in the analyzed samples. Consequently, it shows a moderate fluctuation. After manganese, nickel shows the highest values but none relation with the rest minor elements even with the major elements.

Lower values than 20 p.p.m. in Ni have been determined in the Guarena meteorite, and 20 p.p.m. in Ni in the Modoc meteorite (Allen and Mason 1973). Low values of nickel were also determined in the chromitic concentrates of the Campo Formose (Brazil) stratiform deposit with 0.017% in NiO or 134 p.p.m. in Ni (Hedlund et al 1974). The nickel values in the chromites from the alpine-type dunite of Twin Sisters, Washington, range from 0.09 to 0.15% in NiO with 0.10% in NiO or 786 p.p.m. in Ni as average value of 9 analyses (Onyeagocha 1974) and they are similar with the values of the chromites of the present study. Higher values appear in the chromites from: the Marico area of the Bushveld stratiform deposit with 0.12% in NiO or 943 p.p.m. in Ni as average value of 2 analyses (de Waal 1975a), the Kalrangi, Orissa (India) stratiform deposit with 0.16% in NiO or 1,258 p.p.m. in Ni as average value of 4 analyses (Evans 1972) and in the chromites included in the dunites of the Bay of Island ophiolites with 0 - 0.47% in NiO and an average value of 5 analyses 0.19% in NiO or 1,493 p.p.m. in Ni (Malpas and Strung 1976).

Very high nickel values are finally observed in the chromites from the harzburgites of the Bay of Island ophiolites with 0.23 - 0.57% in NiO and an average value of 10 analyses 0.42% in NiO or 3,301 p.p.m. in Ni (Malpas and Strung 1976) and in the chromites formed during a progressive metamorphism with 0.31 - 0.80% in NiO and an average value of 8 analyses 0.48% in NiO or 3,373 p.p.m. in Ni (Evans and Forst 1976).

Recent investigations concerning the distribution of Ni in the rocks, give the following values: for the high-alumina basalts 7-200 p.p.m. with an average value of 20 analyses 27 p.p.m. in Ni (Taylor et al 1971), for the eclogites of Robert Victor Mine, South Africa 116-639 p.p.m. with an average value of 32 analyses 279 p.p.m. in Ni (Ju - Chin - Chen 1971).

In the different members of the Pindos ophiolite suite the nickel content ranges upwards as follows: in the serpentinized lherzolite 1,700 p.p.m. in the pyroxenite dikes 425 p.p.m. in the feldspar peridotite 1,120 p.p.m., in the gabbro lower 130 p.p.m., gabbro top 55 p.p.m., in the dolerite 155 p.p.m., in the slipitic pillow lavas 43 and 35 p.p.m. (Montigny et al 1973).

The chromites of the Triadion, Thessaloniki podiform deposits contain 500-1,000 p.p.m. Ni, with an average value of 6 analyses 667 p.p.m. in Ni (Papadakis 1977), e.i. they show similar to slightly lower values in comparison with the chromites studied in the present work.

ZINC

The zinc content of the analyzed samples ranges from below 100 p.p.m. to 640 p.p.m. with an average value of 440 p.p.m. in Zn. In order to find the average value we considered all the lower than 100 p.p.m. zinc contents as equal to 80 p.p.m. Consequently, zinc shows a considerable fluctuation. The comparison with the values of the rest minor elements gives an obscure correlation with the manganese values. The maximum and minimum zinc values coincide with the corresponding of manganese, with two exceptions (Giannakohori and Fytia),

Lower zinc values were observed only in the chromites of the Modoc meteorite with 86 p.p.m. in Zn (Allen and Mason 1973). Higher values show the chromites from: the Guarena meteorite with Zn>500 p.p.m. (Allen and Mason 1973), the alpine-type dunite of Twin Sisters, Washington with 0.03 - 0.27% ZnO and an average value of 9 analyses 0.01% in

ZnO or 803 p.p.m. in Zn (Onyegocha 1974), the lavas of two eruptions of Kilauea volcano (Hawaii), with an average of 4 analyses 0.11% in ZnO or 883 p p.m. in Zn (Evans 1972), different meteorites with 0.02 - 1.44% ZnO and an average value of 7 analyses 0.2% in ZnO or 1,660 p.p.m in Zn (Bunch and Olsen 1976) and the chromites formed during a progressive metamorphism with 0.05 - 0.77% ZnO and an average value of 8 analyses 0.35% in ZnO or 2,751 p.p.m. in Zn (Evans and Frost 1976). Exceptionally high zinc values were observed in some chromites from the Outocumpu deposit with 2.62 - 8.52% in ZnO (Thayer et al 1964) and 9.6% in Zn (Weiser 1967) but in this case it is a chromite of a B.P.G. deposit and was formed in an exceptionally rich in zinc environment.

In the different members of the Pindos ophiolite suite the zinc content ranges upwards as follows: in the serpentinized lherzolite 30 p.p.m. in the pyroxenite dikes 35 p.p.m. in the feldspar peridotite 35 p.p.m., in the gabbro lower 20 p.p.m., in the gabbro top 25 p.p.m., in the dolerite 40 p.p.m., in the spilitic pillow lavas 49 and 58 p.p.m.

The chromites of the Triadion, Thessaloniki podiform deposits contain 200-500 p.p.m. in Zn with an average value of 6 analyses 307 p.p.m. in Zn (Papadakis 1977) e.i. they are poorer in zinc.

From all the above in detail mentioned the following conclusions result, as regards the geochemical study of the minor elements of the chromites from the Vermion - Vora and Vourinos areas:

1. The decrease of the vanadium content in p.p.m. is a linear function with the increase of the Al_2O_3 content in wt %. This relation needs a further investigation and a confirmation on a world scale.
2. The chromite samples from more intense metamorphosed parent rocks, show higher manganese values. This element shows the more intense fluctuation from the rest analyzed minor elements.
3. High zinc values generally coincide with high manganese values and vice versa.
4. The titanium content of all the samples is exceptionally low and below 100 p.p.m.
5. The values of titanium, manganese and vanadium in the analyzed samples are very lower than the corresponding in the chromites from lunar samples and chondrites. On the contrary, the values of cobalt, nickel and zinc are very higher than the corresponding in the chromites from chondrites. For the lunar chromite samples there are not data of values on these three elements in literature for comparison.

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ΠΕΡΙΛΗΨΗ

ΓΕΩΧΗΜΕΙΑ ΕΛΑΣΣΟΝΩΝ ΣΤΟΙΧΕΙΩΝ ΧΡΩΜΙΤΩΝ ΑΠΟ ΤΙΣ ΠΕΡΙΟΧΕΣ ΒΕΡΜΙΟΥ - ΒΟΡΑ ΚΑΙ ΒΟΥΡΙΝΟΥ (ΕΛΛΑΔΑ)

ὑπὸ
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Γίνεται γεωχημικὴ μελέτη τῆς περιεκτικότητας 10 δειγμάτων ἑλληνικῶν χρωμιτῶν στὰ ἐλάσσονα στοιχεῖα Ti, Mn, V, Co, Ni καὶ Zn, ποὺ προσδιορίστηκαν μὲ τὴ μέθοδο τῆς ἀτομικῆς ἀπορροφήσεως. Τὰ δείγματα προέρχονται ἀπὸ κοιτάσματα ἢ ἐμφανίσεις τῶν χρωμιτοφόρων περιοχῶν Βερμίου - Βόρα καὶ Βούρινου ποὺ ἀνήκουν ὅλες στὸ λοβόμορφο τύπο. Τὰ ἀποτελέσματα τῶν ἀναλύσεων δίνουν γιὰ ὅλα τὰ δείγματα ἐξαιρετικὰ χαμηλὴ περιεκτικότητα σὲ τιτάνιο, κάτω ἀπὸ 100 p.p.m. Αὐτὸ ἀναμένετο λόγω τοῦ λοβόμορφου τύπου τῶν κοιτασμάτων, ὄχι ὅμως καὶ σὲ τόσο χαμηλὰ ἐπίπεδα. Ἡ σύγκριση τῶν τιμῶν βαναδίου ποὺ βρέθηκαν μὲ τὶς τιμὲς τοῦ Al_2O_3 σὲ ὅσα ἀπὸ τὰ δείγματα ὑπάρχουν δεδομένα χημικῆς ἀναλύσεως στὰ κύρια στοιχεῖα, ἀποκαλύπτει μιὰ ἐνδιαφέρουσα σχέση. Ἡ ἐλάττωση τῆς περιεκτικότητας τῶν χρωμιτῶν σὲ βανάδιο σὲ p.p.m. εἶναι γραμμικὴ συνάρτηση τῆς αὐξήσεως τῆς περιεκτικότητάς τους σὲ Al_2O_3 σὲ βάρος %. Αὐτὸ πουθενὰ δὲν ἀναφέρεται μέχρι τώρα καὶ τὰ δεδομένα τῶν χημικῶν ἀναλύσεων τῶν χρωμιτῶν ἀπὸ τὴν κρίσιμη ζώνη τοῦ Bushveld δείχνουν μιὰ μᾶλλον ἀντίστροφη τάση. Ἡ γενίκευση ὅμως αὐτῆς τῆς ἀναλογίας ὅπως καὶ ἡ ἑρμηνεία της ἀπαιτεῖ τὴ δημοσίευση πολλῶν ἀκόμα δεδομένων σχετικῶν ἀναλύσεων ἀπ' ὅλο τὸν κόσμο. Ἄλλη σχέση ἢ ἀναλογία μεταξὺ τῶν ἐλασσόνων στοιχείων τῶν χρωμιτῶν ποὺ ἐρευνήθηκαν δὲν προκύπτει, ὑπάρχει μόνο μιὰ τάση συμπτώσεως μεγίστων καὶ ἐλαχίστων τιμῶν τῶν στοιχείων μαγγανίου καὶ ψευδαργύρου. Ἡ διακύμανση τῶν τιμῶν τοῦ Mn εἶναι σημαντικὴ καὶ τὴ μεγαλύτερη περιεκτικότητα δείχνουν οἱ χρωμίτες ποὺ προέρχονται ἀπὸ ἐμφανίσεις ποὺ βρίσκονται μέσα σὲ περισσότερο μεταμορφωμένα πετρώματα. Γίνεται τέλος μιὰ λεπτομερὴς σύγκριση τῶν τιμῶν ποὺ βρέθηκαν γιὰ τὰ ἐλάσσονα στοιχεῖα στοὺς χρωμίτες ποὺ μελετήθηκαν, μὲ ὅλες τὶς διαθέσιμες ἀπὸ τὴ βιβλιογραφία ἀντίστοιχες τιμὲς ἀπὸ

χρωμίτες: λοβόμορφων καὶ στρωματόμορφων κοιτασμάτων, ἐκχύσεις λαβῶν, ξενολίθων κιμπερλιτῶν, χρωμίτες ποὺ σχηματίστηκαν σὲ προοδευτικὸ μεταμορφικὸ περιβάλλον, χρωμίτες ἀπὸ βασάλτες ποὺ ἀνασύρθηκαν ἀπὸ ὠκεάνειο φλοιό, χρωμίτες μέσα σὲ διαμάντια καὶ χρωμίτες ἀπὸ μετεωρίτες καὶ σεληνιακὰ δείγματα.

Γίνεται ἀκόμα σύγκριση τῶν τιμῶν ποὺ βρέθηκαν γιὰ τὰ ἐλάσσονα στοιχεῖα μὲ τὶς τιμὲς τῶν ἴδιων στοιχείων ποὺ ἔχουν πρόσφατα προσδιορισθεῖ μέσα σὲ βασάλτες, ἐκλογίτες καὶ μέλη τῆς ὀφειολιθικῆς σειρᾶς.