

FORMATION, GEOLOGY AND GEOCHEMISTRY OF CHROMITE DEPOSITS OF TRIADION THESSALONIKI (GREECE)

By
A. PAPADAKIS

(Laboratory of Mineralogy and Petrography University of Thessaloniki)
(Received 18.10.77)

Abstract: *The formation, geology and geochemistry of Triadion chromite deposits (Thessaloniki) are studied. From the bibliographic data doubts arise whether these deposits belong to the «stratiform» or «podiform» type of deposits. The geochemical research of the chromites of the whole series of the Chalkidiki mafic-ultramafic complexes, to which the Triadion chromites belong, gives a $Fe^{++}:Mg$ ratio between 0.75-1.35. This ratio corresponds to the district of maximum frequency of chromites from podiform deposits, but this is not a sufficient criterion, because the existence of chromites from stratiform deposits within the same district of $Fe^{++}:Mg$ ratio, is not excluded. The $Cr:Cr+Al$ ratio varies between 0.528-0.754 i.e., it covers partly the district of chromites from podiform and partly the district of stratiform deposits. The $Fe^{+++}:Cr+Al+Fe^{++}$ ratio varies between 0.014-0.067 and shows a low oxygen fugacity during the crystallization of chromites.*

The geochemical research of the minor and rare elements of the Triadion chromites proves an exceptionally low titanium content, lower than 20 p.p.m. This means that these chromites belong to the podiform deposits. The manganese content (av. value 1483 p.p.m) and vanadium (av. value 367 p.p.m) is much lower than the corresponding values in chromites from the known stratiform deposits of the world. Also the vanadium value is almost equal with that one of chromites from the podiform deposits of Bourinos. Generally, the geochemical research of the minor and rare elements of the Triadion chromites proves their subjection to the podiform type of deposits. It shows also their origin from the same initial magma with the gabbros of mount Lanari.

The geological research shows that the Triadion chromites appear in two districts of deposits. In the first district the ore appears scattered in the form of schlieren with clear movings during its formation. In the second district the ore appears in preference, as massif in the form of plates, which are often curved or become vertical. Sometimes in the first district appears also ore in the form of nodules in schlieren. The conclusions from the geochemical research of the minor and rare elements, as well as those from the formation research leave no one doubt that the chromite deposits of Triadion belong to the podiform type. Consequently, the

complex gabbro-dunite of the Panorama mount Lanari area belongs to the alpine - type ophiolite complexes. The same conclusions can be extended to the rest mafic - ultramafic rocks complexes of Chalkidiki which are situated on the NW to SE series: Height 465 (Exochi of Thessaloniki) - Triadion - Vasilica - Galarinos - Vavdos - Ormilía - Nikiti (except the Gomation area).

INTRODUCTION

During the last 15 years it was established and was generally accepted the distinction of chromite deposits into two great categories: the stratiform deposits with typical examples the Bushveld deposits of S. Africa, the Great Dyke of Rodesia and the Stillwater of N. America and the podiform with typical examples the Gulleman deposits of Turkey, the Coto of Philippines, the Camagüey of Cuba e.t.c. (Thayer, 1962, Kern, 1968). The first are always connected with mafic intrusions which are characterized as layered or «non orogenic» gabbro-peridotite complexes. The second are always connected with ophiolite complexes which are characterized as alpine - type intrusions. As ophiolite complexes were recently characterized only the alpine - type intrusions (Dickey, 1976) which consist of marine sediments, pillow - lavas, gabbro and tectonite peridotidore (in descending order) when the whole suite is preserved. Small amounts of diorite or albite-granite may also be present in the upper part of the suite. These associations have been found in alpine - type orogenic belts, in island arcs (Davies, 1968) and in dredge hauls from the see floor (Bonatti et al., 1971). Many authors consider that ophiolite complexes are fragments of oceanic crust, which have been tectonically placed in continental margins (Maxwell, 1969. Moores and Vine, 1971). Except the ophiolite complexes, at least other two kinds of gabbro - peridotite complexes are recognized: the layers in which, as we have said, the stratiform chromite deposits occur, and the concentric in which the ore mineralization consist mainly of magnetite and platinum (Jackson and Thayer 1972).

Especially, for the Greek chromite deposits, Panagos (1965) was the first one who was occupied with the problem of their distinction, according to the new ideas. He came to the conclusion that the Greek mafic - ultramafic formations belong to the ophiolite complexes (or alpine - type as it was elucidated above) and consequently, all the chromite deposits belong to the podiform type. In the same category he classifies the gabbro - peridotite complexes of Chalkidiki as well as the related chromite deposits, with the deposits of Triadion Thessaloniki

included. *Kern* (1968), relying on the relative bibliography, considers that the chromite deposits of Ormilía Chalkidiki and Xerolivádon of Bourinos belong to an intermediate category between the stratiform and the podiform. *Jackson* and *Thayer* (1972) consider the complex of mount Troodos (Cyprus) as alpine - type. *Papadakis* and *Trontsios* (1974) consider the chromite deposits of the Vermion - Bora area as podiform.

Doubts arise from bibliography concerning the type of Chalkidiki chromite deposits and especially the deposits of Triadion Thessaloniki. These deposits are in fact found in dunites underlying the mount Lanari gabbros. This gabbro-dunite complex shows the following characteristics, (from bibliography) which after *Jackson* and *Thayer* (1972), constitute the basic criteria for their classification into the layered complexes:

- 1) Age over than 1.200 million years (*Sapountzis* 1969).
- 2) Cumulate texture of the rocks (*Sapountzis* 1973).

3) Existence of a norite gabbro horizon enriched in magnetite with exsolutions of ilmenite (*Sapountzis* and *Katagas* 1975)

To the above main characteristics we can add, the considered by *Sapountzis* (1973) as probable, second unit of rocks overlying the first one i.e., a circular layering which characterizes the layered complexes. Likewise the *Panagos* (1965) description of the Chalkidiki chromite as partly massif ore in the form of plates surrounded by scattered ore type, consists rather an indication for the stratiform type. The appearance of only the gabbro-dunite complex in the area of mount Lanari, and generally the lack of the whole suite of rocks of the ophiolite complex (marine sediments, pillow - lavas e.t.c.) from Chalkidiki area, consist also an indication for the stratiform type, but not a sufficient one, because it is possible the higher numbers of the ophiolite suite to have been removed by corrosion.

The present work treats with the elucidation of this problem, i.e., the definition of the genetical type of the Triadion Thessaloniki chromite deposits. For this purpose the known from bibliography chromite analyses of Chalkidiki are used. To these chromites belong the Triadion chromites which are elaborated with the modern methods (*Irvine* 1965, 1967, *Dickey* 1976). The data of new analyses exclusively made on Triadion chromites are also used to define the minor and trace elements of them. The geological study and the form of ore mineralization follows at the end.

ON THE CHEMISM OF CHALKIDIKI CHROMITES

The chemism of the chromites of one deposit or a group of deposits which occur in a gabbro-peridotite complex constitutes a significant criterion for the classification of the deposit into the stratiform or into the podiform type. The chromites of the podiform deposits are, as a rule, more magnesian and in the histogram of the $Fe^{++}: Mg$ ratio (atomic proportions) they show a maximum of frequency in the district between 0.3 and 0.7. On the contrary the chromites of the stratiform deposits show the maximum of frequency in the district between 0.7 and 1.0. Except these two maxima there are chromite samples from both categories which cover all the width between 0.3 and 2.3 and consequently, the value of this ratio does not constitute a safe criterion. The $Cr: Al+Cr$ ratio (also in atomic proportions) shows a great dispersion in the chromites of the podiform deposits, ranging from 0.4 to 0.9 with a small gap in the district from 0.55 to 0.62, while in the chromites of the stratiform deposits it shows a smaller dispersion limited between 0.58 and 0.7. The TiO_2 content of the chromites constitutes also a decisive criterion. In the chromites from podiform deposits the content is below the 0.3% in weight while from stratiform is over this limit. *Dickey's* (1976) results are based on 117 new analyses of chromites, from different deposits of the world from both categories and agree with *Thayer's* (1970) results as regards the $Cr: Al+Cr$ ratio.

For the study of the chemism of Chalkidiki chromites, 11 analyses known from bibliography were used (*Donath* 1968, *Panagos* 1967a). In these analyses titanium, which plays such a decisive role in the distinction of the two categories, has not been calculated. The calculation of titanium and other minor and rare elements was made in individual analyses only on the Triadion chromites, as it is mentioned in the next chapter.

The chemical composition of the Chalkidiki chromites is given in table I.

Their high Ca content causes an impression at once. But, given that the high calcium values are accompanied with corresponding high silicon values, it is very probable the high calcium values to be due to impurities of secondary dolomite with SiO_2 , which sometimes appears in ultramafic rocks, or besides to Ca-rich pyroxene. In the number 1 analysis, which concerns a chromite from Triadion, the high calcium value ($CaO=2.5\%$) is not accompanied with high silicon ($SiO_2=1.45\%$) and at least part of this high percentage exists in the chromite.

TABLE I

Chemical analyses of Chalkidiki Chromites

	1	2	3	4	5	6	7	8	9	10	11
SiO ₂	1.45	3.71	4.18	4.90	5.09	6.60	4.90	3.92	5.94	11.86	9.13
Cr ₂ O ₃	52.65	51.05	38.75	51.69	52.10	45.15	48.09	48.36	51.45	42.33	46.16
FeO		16.80	15.10	15.45	11.31	14.24	16.40	14.21	12.98	13.27	12.11
Fe ₂ O ₃	19.90*	5.21	1.69	1.94	1.57	2.57	1.32	1.69	1.25	1.07	3.27
Al ₂ O ₃	12.32	12.03	23.21	13.11	14.02	14.76	13.69	13.56	13.89	9.28	14.53
CaO	2.5	0.22	1.37	2.60	1.82	2.07	2.60	2.29	1.36	2.03	0.87
MgO	10.85	10.47	12.96	10.20	13.62	12.98	13.96	15.02	13.34	17.55	14.26
Sum	99.67	99.55	97.25	99.89	99.53	100.37	100.96	99.05	100.23	97.39	100.33
MgO fin.	9.40	7.66	8.78	5.30	8.53	6.38	9.06	11.10	7.40	5.69	5.13

* It is evidently about the total iron which was determined in the analysis number one as Fe₂O₃. From this, after calculations (on the stoichiometric basis of 32 oxygen atoms, 8 atoms of bivalent and 16 atoms of trivalent metal) results FeO=15.84 and Fe₂O₃=2.24.

Localities:

1. Triadion 2, 3, 5: Ormilía 4, 6, 7, 8: Galarinos 9, 10, 11: Vavdos

Sourche:

1: Donath (1962)

2-11: Panagos (1967)

This is in agreement with *Sapountzis* (1973) results that the magma of the gabbroic rocks of the area was very rich in calcium.

From the data of the chemical analyses of table I we calculate the atomic proportions (percentage) for the main components of the Chalkidiki chromites. The results are given in table II.

TABLE II.

Atomic proportions (percentage) calculated from Table I.

	1	2	3	4	5	6	7	8	9	10	11
Fe ⁺⁺	6.93	8.32	7.02	8.88	6.11	7.95	7.20	5.97	7.09	8.09	8.20
Mg	7.36	5.97	7.27	5.41	8.18	6.34	7.09	8.32	7.20	6.20	6.09
Cr	20.58	19.74	14.77	20.20	20.02	18.54	19.77	19.77	20.08	21.22	18.59
Al	7.19	6.93	13.18	7.63	8.07	9.04	8.37	8.16	8.10	6.92	8.73
Fe ⁺⁺⁺	0.81	1.91	0.63	0.73	0.49	1.00	0.44	0.64	0.4	0.44	1.25
O	57.14	57.13	57.13	57.15	57.13	57.13	57.13	57.14	57.13	57.13	57.14

From the data of table II the $Fe^{++}:Mg$ and $Cr:Cr+Al$ (Dickey 1976) as well as the $Fe^{++}:Mg+Fe^{++}$, $Mg:Mg+Fe^{++}$ and $Fe^{+++}:Cr+Al+Fe^{+++}$ (Irvine 1967) ratios were calculated. The results are given in table III. From them the following conclusions result, as regards the chromites of Chalkidiki:

1. The $Fe^{++}:Mg$ ratio varies between 0.72 and 1.35, i.e. it coincides with the district of maximum frequency for the chromites from stratiform deposits. But as it was emphasized before, this value does not constitute a sufficient criterion.
2. The $Cr:Cr+Al$ ratio varies between 0.528 and 0.754, i.e. it covers partly the district of the chromites from stratiform and partly the district from podiform deposits with a greater divergence to the second
3. The $Fe^{+++}:Cr+Al+Fe^{+++}$ ratio varies between 0.014 and 0.067 i.e it is exceptionally low which shows a low oxygen fugacity. This is in agreement with Sapountzis and Katagas (1975) same conclusions for the gabbros of mount Lanari.

From the above results that the chemism of Chalkidiki chromites does not give clear indications for the type of the chromite deposits.

TABLE III.

Ion ratios for the Chalkidiki chromites (atomic proportions)

	1	2	3	4	5	6	7	8	9	10	11
$Fe^{++}:Mg$	0.94	1.39	0.97	1.64	0.75	1.25	1.01	0.72	0.98	1.30	1.35
$Fe^{++}:Mg+Fe^{++}$	0.485	0.582	0.491	0.621	0.428	0.556	0.504	0.418	0.496	0.566	0.574
$Mg:Mg+Fe^{++}$	0.515	0.418	0.509	0.379	0.572	0.444	0.496	0.582	0.504	0.434	0.426
$Cr:Cr+Al$	0.741	0.740	0.528	0.726	0.713	0.672	0.703	0.708	0.713	0.754	0.680
$Fe^{+++}:Cr+Al+Fe^{+++}$	0.028	0.067	0.022	0.026	0.017	0.035	0.015	0.022	0.014	0.016	0.044

GEOCHEMISTRY OF THE MINOR AND RARE ELEMENTS OF THE TRIADION CHROMITES

For the study of the chemism of the minor and rare elements of the Triadion chromites, chemical analyses for the elements Ti, Mn, Co, Ni, V and Zn were carried out on six chromite samples. The chemical analyses were carried out in the mineralogical Laboratory of Heidelberg (W. Germany) using the method of atomical absorption. The results are given in table IV.

TABLE IV.

Chemical analyses on chromite samples from Triadion, Thessaloniki

	Ti p.p.m.	Mn p.p.m.	Co p.p.m.	Ni p.p.m.	V p.p.m.	Zn p.p.m.
1	<20	1400	300	600	480	440
2	<20	1400	500	700	460	500
3	<20	1300	300	1,000	240	200
4	<20	1700	300	600	350	210
5	<20	1700	500	500	310	245
6	<20	1400	300	600	360	245

Chemist who performed the analyses: E. Krouzed. Heidelberg (W. Germany).

From table IV the following conclusions result:

Titanium: The Triadion chromites are exceptionally poor in titanium. Their titanium content is below the sensitivity limit of the used apparatus (20 p.p.m.). The low titanium content of the chromites ($\text{TiO}_2 < 0.3\%$) constitutes, after *Dickey* (1976), a safe criterion for their classification in the category of the chromites from podiform deposits which are always connected with alpine - type ophiolite complexes.

It must be noted that the overlying gabbros of mount Lanari, show also a relatively low titanium content which varies between 0.01 and 0.73% in TiO_2 with an average value, from 36 analyses of 0.178% in TiO_2 (*Sapountzis* 1973). In these gabbros titanium is found in the form of ilmenite exolved in magnetite. Any way, the value of 0.178% TiO_2 is very high in comparison with that of the chromites.

Manganese: The manganese content of the Triadion chromites varies between 1300 and 1700 p.p.m. with an average value of 1483 p.p.m. in Mn or 0.188% in MnO. Manganese consequently, appears in relatively constant proportion or with a small fluctuation. The found average manganese content is lower than of the chromites from the Fiskenaesset stratiform deposit of Greenland where the average content amounts 4,120 p.p.m. (*Ghisler* 1976). It is also lower than that of other chromites with 0.8 - 0.58% in MnO (*Berger* 1968) and slightly lower than the average content of peridotites with 0.21% in Mn (*Nockolds* 1959) and of the mafic rocks generally, i.e. basalts, diabases, gabbros and norites with 0.22% in MnO (*Vinogradov* 1956). It must be noted that the overlying gabbros of mount Lanari contain 0.1 to 0.18% MnO with average value of 0.13% in MnO (*Sapountzis* 1973) i.e., they are also poorer in Mn than the mafic rocks of other localities as was noted before.

Cobalt: The cobalt content of the Triadion chromites varies between 300 and 500 p.p.m. with an average value of 367 p.p.m. Cobalt consequently, appears in relatively constant proportion or with a small fluctuation. The found average cobalt content is 2.5 times higher than that of the dunites with 148 p.p.m., 3 times than that of peridotites with 127 p.p.m. (Kuhn 1968) and nearly 9 times than that of the tholeiitic basalts with 42 p.p.m. (Wedepohl 1963). Unfortunately, we have not data on the cobalt content of the overlying gabbros.

It must be noted that the chromites from the Fiskenaasset stratiform deposit (Greenland) have an average cobalt content of 250 p.p.m. (Ghisler 1976), i.e., about $\frac{2}{3}$ of the Triadion chromites content. *Nickel:* The nickel content of the Triadion chromites varies between 500 and 1000 p.p.m. with an average value of 667 p.p.m. It consequently shows a perceptible fluctuation in the different samples. For comparison, we state that the chromites from the stratiform deposit of Bushveld have an average NiO content of 1.3%, or 10.216 p.p.m. in Ni (Donath 1962), i.e., an amount 15 times higher than that of Triadion.

The overlying gabbros of mount Lanari have a Ni content varying between 11 and 283 p.p.m., with an average value of 148 p.p.m. (Sapountzis 1975). This value is low in comparison with the average value of norites with 300 p.p.m., gabbros with 222 p.p.m. and basalt with 220 p.p.m. (Kuhn 1968). Boldt and Quenean only (as Prokop 1975 states on p. 13) give an average Ni content of 160 p.p.m. for gabbros. The average Ni content of the ultramafic rocks is very higher. Thus, dunites have an average Ni content of 2,187 p.p.m., peridotites 1,167 p.p.m. and pyroxenites 607 p.p.m. (Kuhn 1968). Dunites of the ophiolite complex of Vourinos contain 0.35% NiO or 2,765 p.p.m. Ni, while the harzburgites 0.28% NiO or 2,200 p.p.m. Ni (Moore 1969). The Ni content of dunites from the layered complex of Muscox (Canada) changes in a circle with depth, varying between 1,400 to 2,300 p.p.m. to a depth from 800 to 1,000 ft, 1,100 to 2,700 p.p.m. for the depth 1,100-1,500 ft, 1,700 - 3,100 p.p.m. for the depth 1,520-1,850 ft and 1,500-2,800 p.p.m. to a depth from 1,900 to 2,000 ft (Irvine and Smith 1967). Given that the Ni slips especially in the olivine structure (Burns and Fyfe 1966), the great difference in content between mafic und ultramafic rocks as well as between dunites and pyroxenites, is justified.

Vanadium: The Vanadium content of the Triadion chromites varies between 310 and 480 p.p.m. with an average value of 367 p.p.m., i.e., it shows a rather small fluctuation. For comparison we mention the

semiquantitative analyses for vanadium which were carried out on the chromites from the podiform deposits of Vourinos (*Panagos 1967b*) by the spectroscopic method. From these analyses an average content results, for 35 samples, equal to about two crosses (++) , where one cross (+) corresponds to 0.01% V and 4 crosses (++++) to 0.1% V. If we accept an analogous change of the content with the number of crosses, a content results expressed with two crosses, equal to 0.04% V or 400 p.p.m. V, a value very similar with that for the Triadion chromites. On the contrary, the V content of the chromites from the stratiform deposits rises to 2070 p.p.m. for the chromites of Fiskenaeset (*Ghisler 1976*) and 0.8% in V_2O_5 (*Donath 1962*) or 4521 p.p.m. V, for the chromites of Bushveld. These values are almost sixfold and tenfold than those of Triadion chromites correspondingly.

The content of the overlying gabbros of mount Lanari varies between 87 and 569 p.p.m. with an average value, of 164 p.p.m. This value is clearly lower than the mentioned by *Upton and Wadsworth (1972)* average vanadium value for the cumulate gabbros (200 to 215 p.p.m.) as well as the mentioned by *Bose (1973)* average vanadium value for the olivine gabbros (180 to 320 p.p.m.) and the tholeiitic basalts (230 p.p.m.) as stated by *Wedepohl (1963)*.

Zinc: The zinc content of the Triadion chromites varies between 2 and 500 p.p.m. with an average value of 307 p.p.m., i.e. it shows a perceptible fluctuation. The zinc content of the overlying gabbros of mount Lanari varies between 1 and 47 p.p.m. with average value of 17.5 p.p.m. This value is very low in comparison with the stated by *Upton and Wadsworth (1972)* average value of 200 to 215 p.p.m. Zn for the cumulate gabbros and the stated by *Bose (1973)* average value of 180 to 320 p.p.m. for the olivine gabbros. Exceptionally high zinc contents of chromites are stated by *Pearre and Heyl (1960)* from the Woods Mine deposit of Maryland (U.S.A) with 5000 p.p.m. Zn and by *Thayer et al (1964)* for the Outocumpu deposit of Filland with 2.62 to 5.82% in ZnO. *Weiser (1967)* states a zinc content 9.6% within zonal chromite from the same deposit. However, it must be noted that the Outocumpu deposit contains mainly sulphide ores.

From the above mentioned the following conclusions result, for the geochemistry of minor and rare elements of the Triadion chromites:

1. The titanium content is exceptionally low (<20p.p.m. Ti) and classifies the deposits of Triadion into the podiform type.
2. The manganese and vanadium content are lower than the corresponding contents of the same elements in the chromites of the known

stratiform deposits of Fiskenaasset and Bushveld. This confirms the conclusion 1.

3. The nickel content is very lower than the corresponding in the chromites from the Bushveld stratiform deposit. This also confirms the conclusion 1.

4. The vanadium content is about equal to that of the chromites from Vourinos podiform deposits. This also confirms the conclusion 1.

5. The low content of the elements Ti, Mn and V corresponds also to a low content of the overlying gabbros of mount Lanari. This shows that the chromites and the gabbros originate from the same primitive magma which is confirmed by geological observations.

GEOLOGY AND CHROMITE MINERALIZATION OF THE TRIADION AREA

The chromiferous area of Triadion Thessaloniki lies on the western slope of mount Lanari, to the east of the homonymous village and at a distance of 1 kilometer from it. Fig. 1. The mount Lanari and the south - western slopes of the mount Chortiatis till the Panorama district, consist of gabbroic rocks, i.e., gabbrochromites, olivine gabbrochromite and gabbros with clinopyroxene (*Sapountzis* 1973). These rocks at the lower part, i.e., on the western and southern slopes, change into dunite in which the ore mineralization occurs. According to our observations, the gabbroic rocks appear also near the village Exochi, on the height 465 at a distance of 1.5 km to the southwest of the village. The complex Lanari-Panorama as well as the small appearance of gabbros on the height 465 belong to the complex of mafic and ultramafic rocks of Chalkidiki, which extends from the area of Thessaloniki to the Toronean gulf as a suite with a NW to SE direction, Fig. 2. It consists of the districts: height 465, Panorama-Lanari, Vasilika, Galarinos, Vavdos, Gerakini and Nikiti after the names of the nearest mount or village (Fig. 2). Between them small appearances are interposed. This district constitutes, with the NW of Thessaloniki and till the Greek-Yugoslavian frontiers extending mafic - ultramafic suite, the eastern branch of ophiolites (*Hiessleitner* und *Clar* 1951) of the formerly Axios zone after *Kossmat* (1924). After *Mercier* (1966), this part belongs to the tectonic zone of Paeonia.

The ore mineralization develops especially in two discernible districts. The first occurs 500 to 700 m far from the last houses and to northeast of the village and the second at a distance of 1km to the east

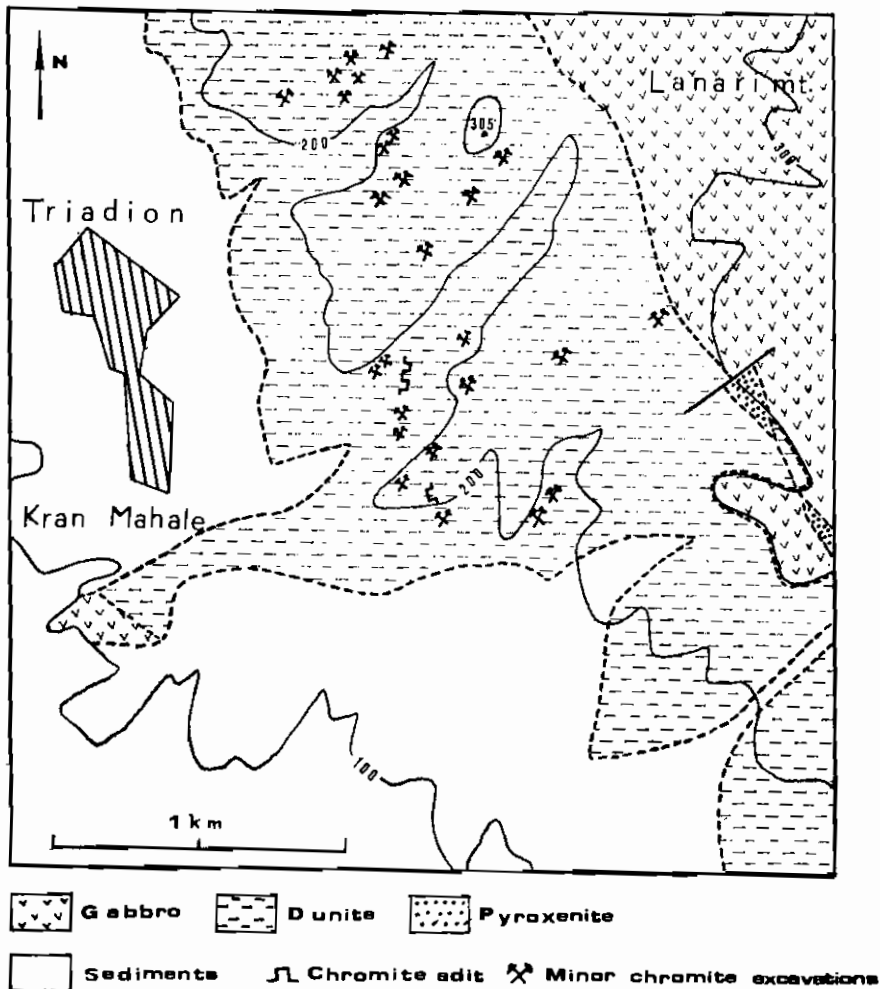


Fig. 1. Geological map of the Triadion area with chromite mineralization.

of the village. The two districts consist of dunite with chromite mineralization. The first contains the height 350 while the second extends over this height. (Fig. 1).

The metalliferous dunite appears almost unaltered in the first district. The chromite appears as scattered ore in the form of schlieren. (Fig. 3, 4, 5, 6). Eleven such schlieren, overlying one another, have been counted, but probably there are more in the depth. These schlieren are almost parallel, (Fig. 3) they have a thickness of 15 to 20 cm and

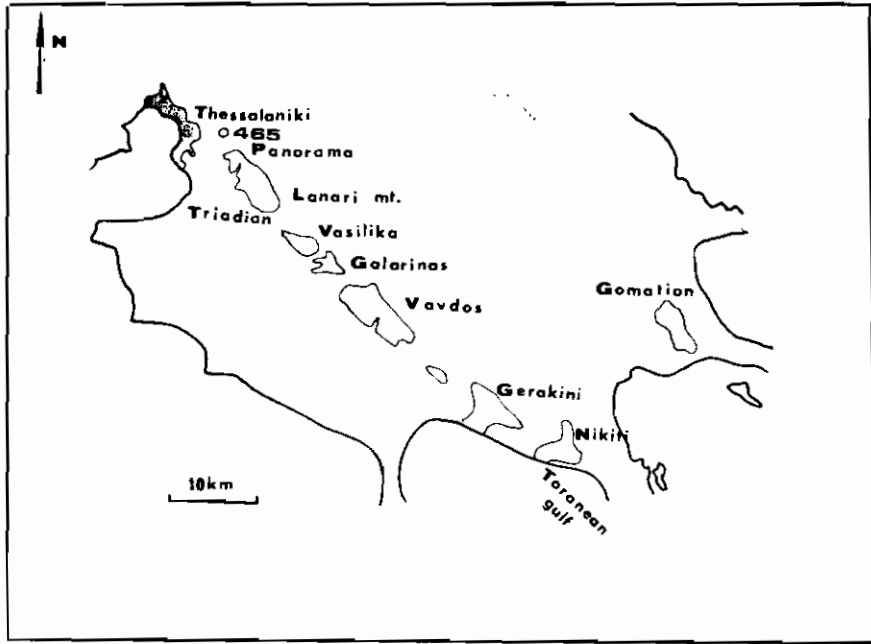


Fig. 2. A map showing the mafic and ultramafic rocks complex.

they are 1m far from each other. They have a constant SE - NW attitude and dip 27° to SW. In this area 13 ancient galleries, shafts or surface excavations have been enumerated. According to the oral informations from the villagers, the last exploitation in both the metaliferous districts refers to the period of German occupation (1941-44)

Microscopically examined the ore appears in the form of euhedral and intensely magmatically corroded crystals inside a slightly serpentinized dunite. (Fig. 7, 8, 9). This magmatic corrosion shows a re-equilibration which is characteristic for the ophiolite complexes of alpine type (Jackson and Thayer 1972). Measurements of the optic axial angle $2V$ on the unaltered olivine of dunite have always given $2V=90^\circ$. Consequently, it is about an olivine with $Fo_{80} - Fa_{10}$ (Tröger 1971). The difference which appears in the olivines of the overlying gabbros with Fo_{81-39} to Fo_{70-13} (Sapountzis 1973) is justified, because, as it is known the olivine of the initial stages of crystallization is more magnesian. The serpentinization appears as beginning under the microscope (Fig. 1) and often advances within the fractures of the chromite crystals, (Fig. 10, 11, 12).

In a careful observation, the ore shows clear indications of tectonic texture, which is characteristic for the ophiolite complexes of alpine type (*Jackson and Thayer 1972*). Thus, the schlieren often ap-

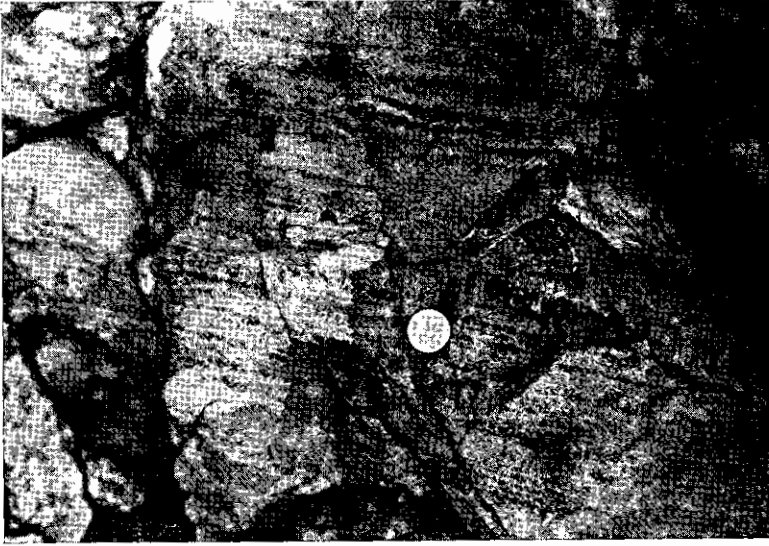


Fig. 3. Cromite crystals scattered in dunite in the form of parallel schlieren.

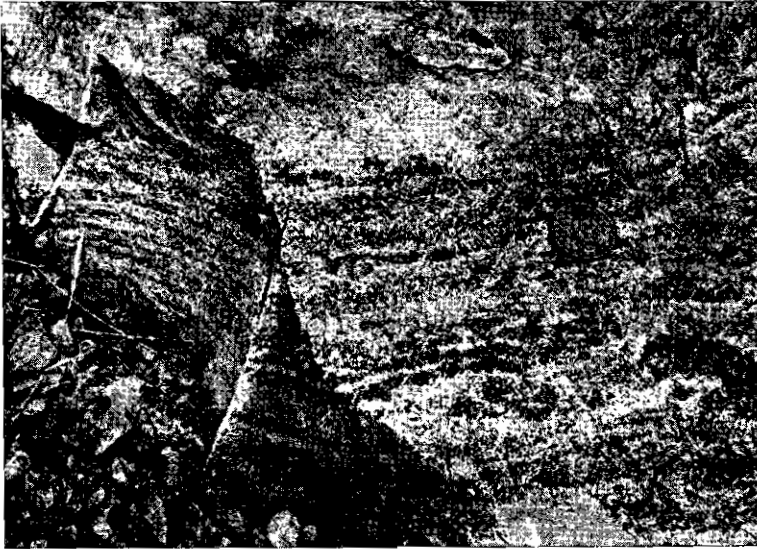


Fig. 4. Cromite crystals scattered in dunite in the form of slightly curved schlieren.

pear with varying thickness wedging at the rims, (Fig. 5). Sometimes, two systems of schlieren appear crosscutting each other in an acute angle. The curvaton and generally the distortion of the schlieren is not rare, (Fig. 4).

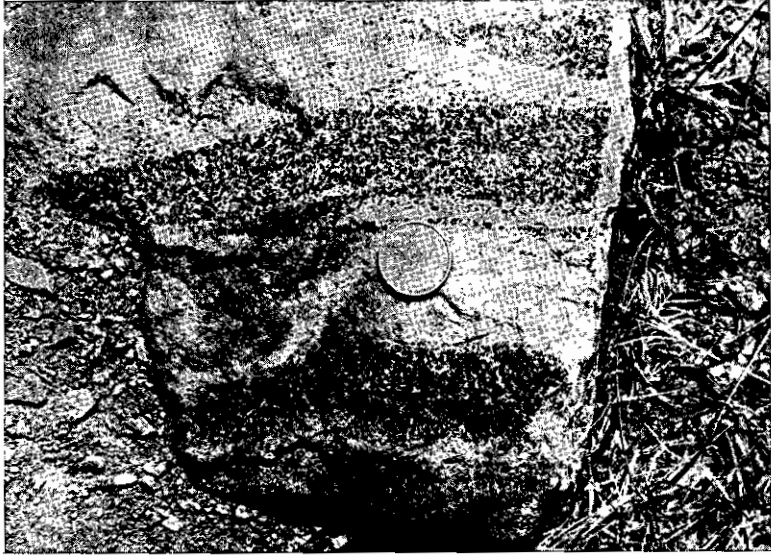


Fig. 5. Chromite schlieren wedging at the rims.

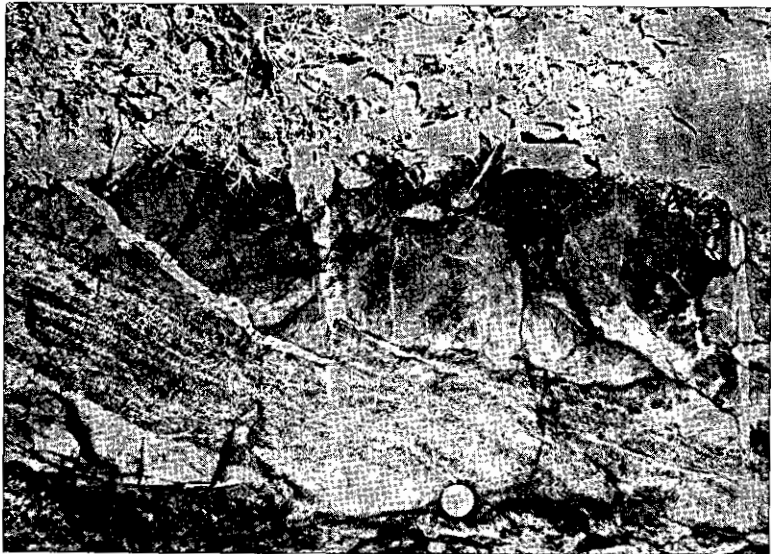
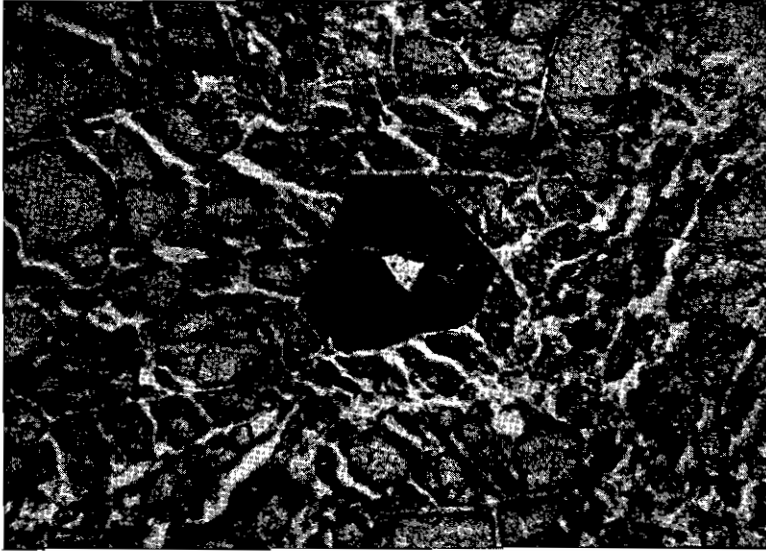
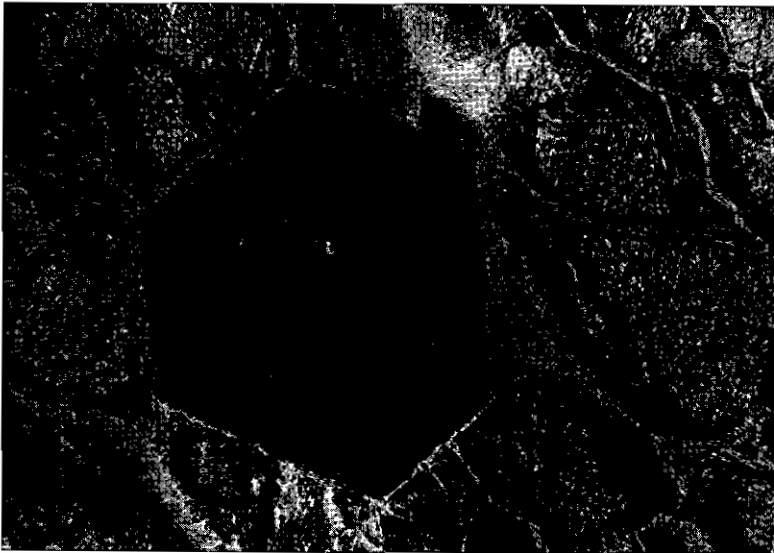


Fig. 6. Magnesite veinlets (white) crosscutting the chromite schlieren.



*Fig. 7. Euhedral chromite crystal in slightly serpentinized dunite. Thin section.
One nicol, 46X.*



*Fig. 8. Euhedral chromite crystal in slightly serpentinized dunite. Thin section.
One nicol, 123X.*

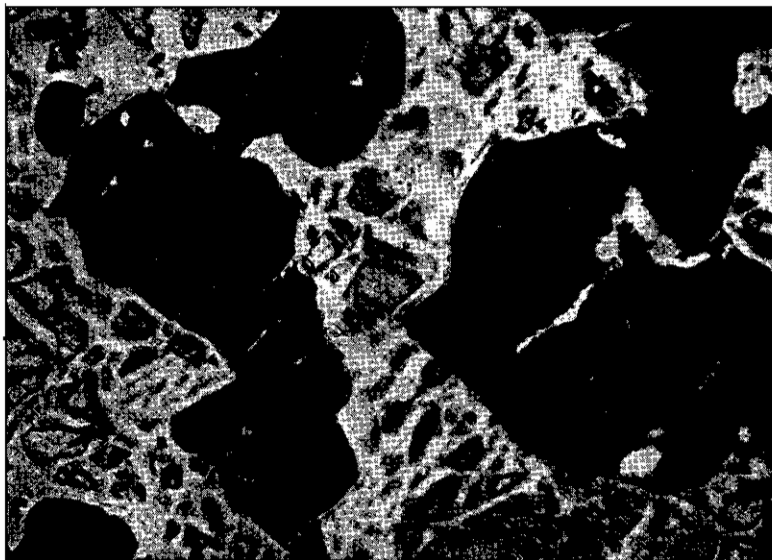
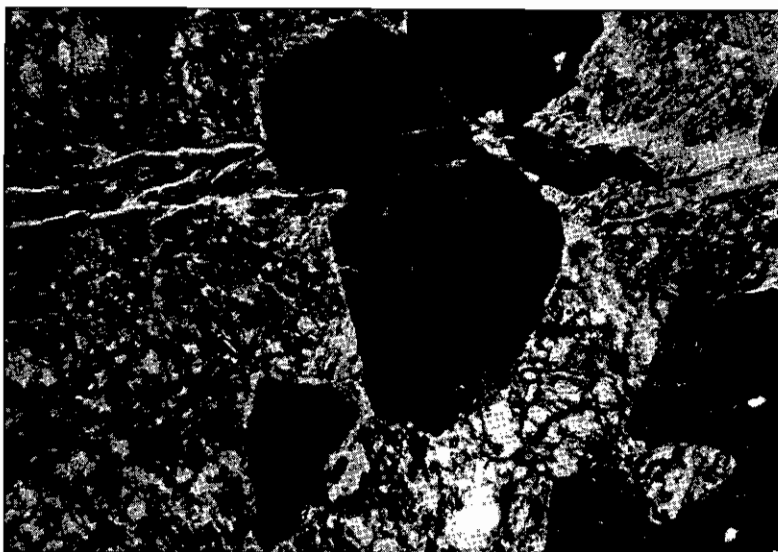


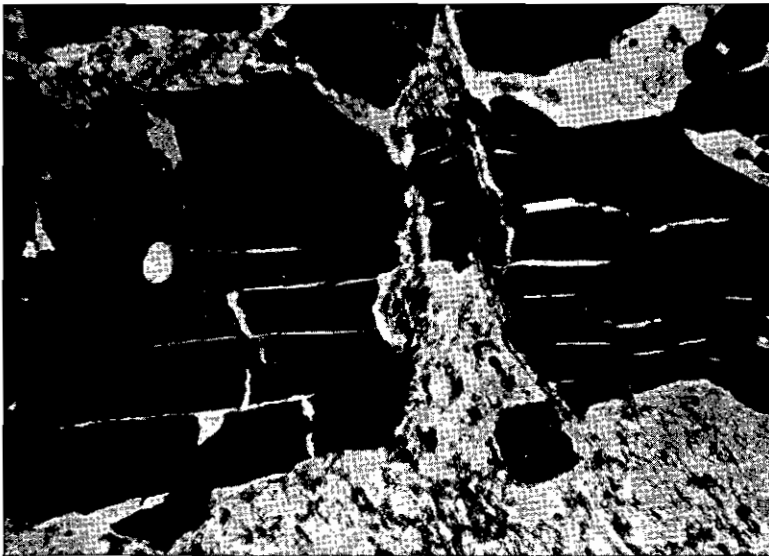
Fig. 9. Magmatically corroded chromite crystals in serpentinized dunite. Thin section. One nicol, 46X.



*Fig. 10. Advanced serpentinization within the fractures of the chromite crystals
Thin section. One nicol, 46X.*



*Fig. 11. Advanced serpentinization within the fractures of the chromite crystals.
Thin section. One nicol, 46X.*



*Fig. 12. Advanced serpentinization within the fractures of the chromite crystals.
Thin section. One nicol, 46X.*

A particular characteristic of this district is the fact that the ore appears also in nodular form to leopard type ore. In some cases chromite nodules appear surrounded by schlieren, (Fig. 13) something that

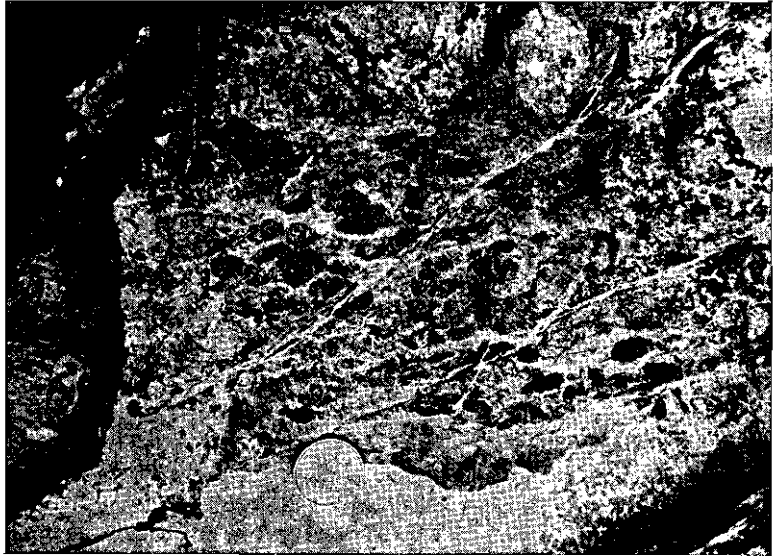


Fig. 13. Chromite nodules surrounded by schlieren.



Fig. 14. Massif chromite in the form of a plate.

is observed for the first time, at least according to the accessible for us bibliography. The appearance of chromite in the nodular form consists also a characteristic of the alpine - type ophiolite complexes (*Jackson and Thayer 1972*).

The formation of magnesite is very limited in the area of the chromiferous duites and as a rule it appears in the form of veinlets crosscutting the chromite schlieren vertically or obliquely, (Fig. 6). The formation of magnesite is very posterior as it is shown by its limitation within posterior faults of the rock and/or of the ore.

The second metalliferous district lies to the southeast of height 305. Here, 19 galleries, shafts and surface excavations have been enumerated totally. As a rule, the shafts and the galleries are deeper than those of the first district. The difference in the ore is characteristic. Here, the schlierens do not appear but instead of them rather massif ore. The thickness of the plates (Fig. 14), is over than 15cm and the distance between them over than 1m. The initially horizontal plates, often appear folded or changing in attitude and dip becoming vertical or oblique in an irregular way. The surrounding the ore dunite appears under the microscope more intensily serpentinized and sometimes changed into talc. On the unaltered parts of the olivine the optic axial angle $2V$ is also 90° and consequently, it is about an olivine with $Fo_{90} - Fa_{10}$. The chromite appears under the microscope less euhedral and also less magmatically corroded than that of the first district (schlieren type). Cataclasis of the chromite crystals is observed nowhere and consequently, the moving had taken place when the material (crystals+intercumulus liquid) was in a plastic condition.

Consequently, the conclusions from the study of chromite mineralization of Triadion, state that the gabbro - dunite complex of the Panorama - Lanari district is an alpine - type ophiolite complex and its chromite deposits of podiform type. This conclusion may also be extended to the rest mafic-ultramafic rocks of Chalkidiki, which (except the Gomation district) belong to the same locality. A confirmation to this constitutes the fact that, nowhere in Chalkidiki have been observed (or stated in bibliography) phenomena of thermal metamorphism with the mafic rocks, a phenomenon which is also characteristic of the alpine type ophiolite complexes (*Jackson and Thayer 1972*).

REFERENCES

1. BERGER, A. (1968): Zur Geochemie und Lagerstättenkunde des Mangans, Glausthaler Hefte zur Lagerstättenkunde und Geochemie der Mineralischen Rohstoffe. Hef 7 276 p. Stuttgart G. Bornträger.
2. BONATTI, E. HONNOREZ, I. and FERRARA G. (1971): Peridotite-gabbro-basalt complex from the equatorial Mid-Atlantic Ridge. Phil. Trans. Roy. Soc. Lond A 268 p. 385-402.
3. BOSE, M. K. (1973): Petrology and Geochemistry of the Igneous complex of Mount Girnat, Gujarat, India. Contr. Min. and Petr. 39 p. 247-266.
4. BURNS, R. G. and FYFE, W. S. (1966): Behavior of Nickel during magmatic crystallization. Nature 210 1147-1148.
5. DAVIES, H. L. (1968): Papuan ultramafic belt. 23rd Int. Geol. Congr. Prague Rep. Sect. 1 p. 209-220.
6. DICKEY, J. S. (1976): A hypothesis of origin for podiform chromite deposits. In chromium (Editor T. N. IRVINE) p. 1061-1074. Pergamon Press
7. DONATH, M. (1962): Chron. Die Mineralischen Rohstoffe Band 14 Ferdinand Enke Verlag. Stuttgart. 371 p.
8. CHISLER, M. (1976): The Geology, Mineralogy and Geochemistry of the Pre-Orogenic Archaean stratiform chromite deposits at Fiskenaeset, West Greenland. Monograph Series on Mineral Deposits. No 14 156 p. Geb. Bornträger. Berlin.
9. HIESSAËITNER, G. und CLAR, E. (1951): Ein Beitrag zur Geologie und Lagerstättenkunde (chromerz - und Nickellagerstätten) basischer Gesteinzüge in Griechenland. Akad. d. Wiss, math - nat. Kl. Abt I 160 p. 679-709.
10. IRVINE, T. N. (1965): Chromian spinel as a petrogenetic indicator Part 1 Theory. Can. Journ. Earth Sci. 2 p. 648-672.
11. IRVINE, T. N. (1967): Chromian spine as a petrogenetic indicator Part 2. Petrological Applications Can, Journ. Earth Sci. 4 p. 71-103.
12. IRVINE, T. N. and SMITH, C. H. (1967): The ultramafic rocks of the Muscox intrusion northwest territories, Canada. In: Ultramafic and related Rocks (Editor P. J. Wyllie). John Willy and Sons New York p. 38-49.
13. JACKSON, E. D. and THAYER, T. P. (1972): Some Criteria for Distinguishing Between Stratiform, concentric and Alpine Peridotite - Gabbro complexes. 24 Int. Geol. Congr. Section 2 p. 289-296.
14. KERN, H. (1968): Zur Geochemie und Lagerstättenkunde des chroms und zur mikroskopie und Genese der Chromerze. Glausthaler Hefte zur Lagerstättenkunde und Geochemie der mineralischen Kohstoffe Heft 6 236 p. Geb. Bornträger. Berlin.
15. KOSMMAT, F. (1924): Geologie der zentralen Balkanhalbinsel (Die Kringschaulplätze 1914-18 geologisch dargestellt) 12 198 p.
16. KUEHN, K. (1968): Zur Geochemie von Nickel und Kobalt. Ges. f. Strahlenforschung m bH. GSF. Report T 13. München.

17. MAXWELL, J. C. (1969): <Alpine> mafic and ultramafic rocks. The ophiolite suite: a contribution to <The discussion of the paper> The origin of ultramafic and ultrabasic rocks> by P. J. Wyllie. *Tectonophysics* 7 p. 489-494.
18. MERCIER, J. (1966): Etude Geologique des zones internes des Hellenides en Macedoine centrale (Grèce). I these présenté a la faculte de sciences de l'Université de Paris..
19. MOORES, E. M. (1969): Petrology and structure of the Vourinos ophiolitic complex of northern Greece. *Geol. Soc. Am. Spec. Pap.* 118 60 p.
20. MOORES, E. M. and VINE, F. J. (1971): The Troodos Massif, Cyprus and other ophiolites as oceanic crust: evaluation and implications. *R. Soc. Lond., Phil. Truns, Ser. A* 268 p. 443-466.
21. NOCKOLDS, S. R. (1954): Average chemical compositions of some igneous rocks. *Bull. Geol. Soc. Am.* 65 p. 1007-1032.
22. PAPADAKIS, A. and TRONTSIOS, G. (1974): Contribution to the study of chromites of the Vermion-Vora area. *Sci. Annals, Fac. Phys and Mathem, Univ. Thessaloniki*, 14, p. 289-303.
23. PEARRE, N. C. and HEYL, A. V. (1960): Cromite and other mineral deposits in serpentine rocks of the Piemont upland, Maryland, Pennsylvania and Delaware-U. S. *Geol. Survey. Bull* 1082-K p. 707-833.
24. PANAGOS, A. (1965): Beitrag zur Kenntnis der griechischen chromite (griechisch mit dt. Zusammenfassung). *Ann. Geol. des Pays Hell.* 18 p. 1-42.
25. PANAGOS, A. (1967 a): Zur chemismus der Chromite von Chalkidiki (griechisch mit at. Zusammenfassung) *Prakt. Akad. Athen* 42 p. 124-134.
26. PANAGOS, A. (1967b): Die Verteilung einiger Spurenelemente in den Chromiterzen von Vourinon. (griechisch mit dt. Zusammenfassung). *Ann. Geol. des Pays Hell.* 18 p. 421-435.
27. PROKOP, F. W. (1975): The future economic significance of large lowgrade Copper and Nickel deposits. *Mon. Ser. on Mineral Deposits* 13 67 p. *Geb. Bornträger. Berlin.*
28. SAPOUNTZIS, E. (1969): Petrography and Geological position of the Thessaloniki green gneisses *Sci. Ann. facult phys. and math. Univ. Thessaloniki* 11 25-124. (in Greek, Engl. summary).
29. SAPOUNTZIS, E. (1973): Geochemical and Petrogenetic study of the gabbroic rocks of the Thessaloniki area. 1-218 (in Greek, Engl. summary).
30. SAPOUNTZIS, E. and KATAGAS, C. (1975): The iron-titanium oxides of the Thessaloniki gabbros (North Greece). *Ann. Geol. d. Pays Hell.* 26 p. 410-416.
31. THAYER, T. P. (1962): Application of structural petrology in exploration for podiform chromite deposits. *Rep. 5th Meet. Geol. of F.B.R. of Yugoslavia, Beograd.*
32. THAYER, T. P. (1970): Chromite segregations as petrogenetic indicators. *Geol. Soc. S. Africa Spec. Pube* 1 p. 330-390.
33. THAYER, T. P. MILTON, C. DINNIN, J. and ROSE, H (1964): Zincian chromite from Outokumpu, Finland. *Am. Min* 49 p. 1178-1183..
34. TREGGER, W. E. (1971): Optische Bestimmung der gesteins-bildenden Minerale Teil. 1 Bestimmungstabellen. *Stuttgart* 188 p.

35. UPTON, B. G. and WADSWORTH, W. J. (1972): Peridotitic and Gabbroic Rocks associated with the Shield-Forming Lavas of Reunion. *Contr. Min. and Petrol.* 35 139-158.
36. VINOGRADOV, A. P. (1956): Regularity of distribution of chemical elements in the earth's crust. *Geochemistry* 1-44.
37. WEDEPOHL, K. H. (1963): Die Nickel-und Chromgehalte von basaltischen Gesteinen und deren Olivin - führenden Einschlüssen. *N. Jb. Min. Petr. Mh.* p. 237-242.
38. WEISER, T. (1967): Zink-und Vanadium - führende chromite von Outokumpu Finland *N. Jb f. Miner. Mh.* p. 234-243.

ΠΕΡΙΛΗΨΙΣ

ΣΧΗΜΑΤΙΣΜΟΣ, ΓΕΩΛΟΓΙΑ ΚΑΙ ΓΕΩΧΗΜΕΙΑ ΤΩΝ ΚΟΙΤΑΣΜΑΤΩΝ ΧΡΩΜΙΤΟΥ ΤΟΥ ΤΡΙΑΔΙΟΥ ΘΕΣΣΑΛΟΝΙΚΗΣ

Ἰπὸ

Α. ΠΑΠΑΔΑΚΗ

(Ἐργαστήριον Ὀρυκτολογίας καὶ Πετρογραφίας τοῦ Πανεπιστημίου Θεσ/νίκης)

Μελετῶνται ὁ σχηματισμὸς, ἡ γεωλογία καὶ γεωχημεία τῶν κοιτασμάτων χρωμίτου τοῦ Τριαδίου Θεσσαλονίκης. Ἐκ τῶν δεδομένων τῆς βιβλιογραφίας δημιουργοῦνται ἀμφιβολίαὶ ἐὰν ἀνήκουν εἰς τὸν τύπον τῶν στρωματοφόρων ἢ τῶν λοβομόρφων κοιτασμάτων. Ἡ γεωχημικὴ ἔρευνα τῶν χρωμιτῶν ὀλοκλήρου τῆς σειρᾶς τῶν βασικῶν - ὑπερβασικῶν συγκροτημάτων τῆς Χαλκιδικῆς, εἰς τὴν ὁποίαν ἀνήκουν καὶ οἱ χρωμίται τοῦ Τριαδίου, δίδει σχέσιν $Fe^{++}: Mg$ μεταξὺ 0.75-1.35. Ἡ σχέσις αὕτη ἀνταποκρίνεται εἰς τὴν περιοχὴν μεγίστης συχνότητος τῶν χρωμιτῶν ἐκ λοβομόρφων κοιτασμάτων, ἀλλὰ τοῦτο δὲν εἶναι ἀσφαλὲς κριτήριον διότι δὲν ἀποκλείεται ἡ ὑπαρξίς χρωμιτῶν ἐκ στρωματοφόρων κοιτασμάτων εἰς τὴν ἰδίαν περιοχὴν τοῦ λόγου $Fe^{++}: Mg$. Ἡ σχέσις $Cr:Cr+Al$ κυμαίνεται μεταξὺ 0.528-0.754, καλύπτει δηλαδὴ ἐν μέρει τὴν περιοχὴν τῶν χρωμιτῶν ἐκ λοβομόρφων κοιτασμάτων καὶ ἐν μέρει τὴν περιοχὴν τῶν χρωμιτῶν ἐκ στρωματομόρφων. Ἡ σχέσις $Fe^{+++}: Cr+Al+Fr^{+++}$ κυμαίνεται μεταξὺ 0.014-0.067 καὶ δεικνύει χαμηλὴν ἐνεργότητα ὀξυγόνου κατὰ τὴν κρυστάλλωσιν τῶν χρωμιτῶν.

Ἡ γεωχημικὴ ἔρευνα τῶν ἔλασσόνων καὶ σπανίων στοιχείων τῶν χρωμιτῶν τοῦ Τριαδίου ἀποδεικνύει ἐξαιρετικῶς μικρὰν τιμὴν τιτανίου, μικροτέραν τῶν 20 p.p.m. Τοῦτο σημαίνει ὅτι οἱ χρωμίται αὐτοὶ ἀνήκουν εἰς λοβομόρφα κοιτάσματα. Ἡ πριεκτικότης εἰς μαγγάνιον (μ.ο 1.483 p.p.m) καὶ βαναδίον (μ.ο 367 p.p.m) εἶναι πολὺ μικροτέρα τῶν ἀντιστοιχῶν τιμῶν εἰς χρωμίτας ἐκ γνωστῶν στρωματομόρφων κοιτασμάτων τοῦ κόσμου. Ἐπίσης ἡ τιμὴ τοῦ βαναδίου εἶναι σχεδὸν ἴση μὲ τὴν τῶν χρωμιτῶν ἐκ τῶν λοβομόρφων κοιτασμάτων τοῦ Βουρίνου. Γενικῶς ἡ γεωχημικὴ ἔρευνα τῶν ἔλασσόνων καὶ σπανίων στοιχείων τῶν χρωμιτῶν τοῦ Τριαδίου ἀποδεικνύει τὴν ὑπαγωγὴν των εἰς τὸν λοβομόρφον τύπον κοιτασμάτων. Δεικνύει ἐπίσης καὶ τὴν προέ-

λευσιν αὐτῶν ὡς καὶ τῶν γάββων τοῦ ὄρους Λανάρι ἐκ τοῦ αὐτοῦ ἀρχικοῦ μάγματος.

Ἡ γεωλογικὴ ἔρευνα δεῖκνυε ὅτι οἱ χρωμῖται τοῦ Τριαδίου ἐμφανίζονται εἰς δύο περιοχὰς κοιτασμάτων. Εἰς τὴν πρώτην περιοχὴν τὸ μετάλλευμα ἐμφανίζεται ὡς διάσπαρτον ὑπὸ μορφὴν schlieren μὲ σαφεῖς μετακινήσεις κατὰ τὸν σχηματισμὸν του. Εἰς τὴν δευτέραν περιοχὴν τὸ μετάλλευμα ἐμφανίζεται κατὰ προτίμησιν ὡς συμπαγὲς ὑπὸ μορφὴν πλακῶν αἱ ὁποῖαι συχνὰ καμπυλοῦνται ἢ ἀνορθώνονται. Ἐνίοτε ἐμφανίζεται καὶ μετάλλευμα ὑπὸ μορφὴν κονδύλων ἐντὸς schlieren. Τὰ συμπεράσματα τῆς γεωχημικῆς ἐρεύνης τῶν ἐλασσόνων καὶ σπανίων στοιχείων ὡς καὶ τοῦ σχηματισμοῦ οὐδεμίαν ἀμφιβολίαν ἀφήνουν ὅτι τὰ κοιτάσματα χρωμιτῶν τοῦ Τριαδίου ἀνήκουν εἰς τὸν λοβόμορφον τύπον. Κατὰ συνέπειαν καὶ τὸ σύμπλεγμα γάββρου - δουνίτου τῆς περιοχῆς Πανοράματος - ὄρους Λανάρι ἀνήκει εἰς τὰ ὄφειολιθικά συγκροτήματα ἀλπικοῦ τύπου. Τὰ ἴδια συμπεράσματα δύνανται νὰ ἐπεκταθοῦν καὶ εἰς τὰ ὑπόλοιπα συγκροτήματα βασικῶν - ὑπερβασικῶν πετρωμάτων τῆς Χαλκιδικῆς τὰ κείμενα ἐπὶ τῆς ἐκ ΒΔ πρὸς ΝΑ ἐκτεινομένης σειρᾶς: Ὑψωμα 465 (Ἐξοχὴ Θεσσαλονίκης) - Τριάδιον - Βασιλικὰ - Γαλαρινὸς - Βάβδος - Ὀρμύλια - Νικήτη (πλὴν τῆς περιοχῆς Γοματίου).