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Chromites from ultramafic rocks of northern Evia (Greece) and their geotectonic significance

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Abstract

Small bodies of nodular chromitites enclosed by serpentinites occur 200–300 m below amphibolitised layered metagabbros near the town of Mandoudi in northern Evia, Greece. This ophiolite complex occurs along the western ophiolite belt of Greece. Microprobe analyses of chromites taken from the northern Evia occurrences indicate that they are typical, Al-rich, podiform chromites. They are similar to the Al-rich podiform chromites from Pindos, Othris, Skyros, Rodiani, Rhodos and eastern Chalkidiki, which occur along the western ophiolite belt of Greece *(main ophiolite belt)*. In contrast, the chromites of western Chalkidiki, Vermion, eastern Thessaly and Vourinos are Cr-rich. The latter occur along the eastern ophiolite belt of Greece *(Vardar zone)*.

Based on compositional similarity between the chromites of the western ophiolite belt (including the northern Evia chromites) and those occurring in abyssal basalts and peridotites from present-day mid-ocean ridges, we propose that the western ophiolite belt is dominated by ophiolites formed in mid-ocean ridges. On the contrary, the chromites of the eastern ophiolite belt show similarities to Cr-rich chromites occurring in island arcs (in boninitic rocks). Consequently, we propose that the majority of the eastern ophiolite belt ophiolites were formed in island arcs.

Keywords: Ultramafic rocks, chromite, ophiolite, geotectonics, Evia, Greece.

Introduction.

The mafic to ultramafic rocks of northern Evia geotectonically belong to the western ophiolite belt of Greece, originally known as the "*main ophiolite belt*" (DIETRICH, 1979). The common interpretation for the ophiolites of this belt is that they represent oceanic crust obducted onto a continental margin. However, the type of oceanic crust (marginal basin, including island arcs, or open ocean as part of the Tethys) is still debatable for most of the ophiolites of this belt. A second ophiolite belt occurs to the east and is referred to as the eastern ophiolite belt of Greece. The latter is known as "*Vardar zone*". Similar problems concerning the type of oceanic crust present exist in the Vardar zone as well.

Chromitite occurrences are generally linked with crystal fractionation, together with olivine, having been the first phases to have formed on the liquidus. Therefore, chromitites are mainly associated with dunites. The chemistry of the chromites is dependent on the composition of the primary melt, which reflects the degree of partial melting and the composition of the peridotitic mantle (DICK and BULLEN, 1984). In mid-ocean ridge environments, as well as in marginal basins, the primitive olivine-basalt melts closely match a pyroxenitic komatiic composition as it has been suggested by DIETRICH et al. (1981). These compositions contain Al_2O_3 up to 13 wt.%, and thus the chromian spinels fractionating from such a melt are expected to have high Al-contents and lower Cr/Cr + Al ratios, respectively.

In island-arc environments, the primary melts are commonly of picritic island-arc tholeiitic or boninitic composition. They are regarded as partial melts of depleted spinel lherzolites and harzburgites. Thus, these partial melts are generally lower in aluminium. Chromian spinels in the volcanic rocks (e.g. boninites), as well as in dunitic cumulates that crystallised from such melts, are expected to have lower Al-contents and higher Cr/Cr + Al ratios.

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In this sense, the mineral chemistry of the chromian spinels in dunitic rocks and in the chromitites can be used as an excellent geotectonic indicator.

So far, chromitite occurrences in northern Evia have not been reported by any worker.

This paper deals with the chromitite occurrences in northern Evia, mainly with their chemical characteristics as determined by electron microprobe analysis. Accessory chromites occurring in harzburgites and dunites have been analysed as well. Furthermore, a correlation is attempted with the chromitites found in other ophiolitic complexes in Greece. The ultimate purpose is to discriminate different geotectonic environments within the Greek ophiolite complexes and -belts.

Geotectonic setting

The northern part of Evia Island geotectonically belongs to the westernmost unit of the internal Hellenides (the nonmetamorphic, western part of the Pelagonian Zone), a passive continental margin during the Early Mesozoic (Fig. 1). A geological sketch map of northern Evia, including a lithostratigrafic section, is shown in figure 2.

Three major formations (disregarding the Neogene and Quaternary deposits) can be distinguished (KATSIKATSOS, 1977, GARTZOS, 1986):

1. Triassic – Upper Jurassic limestones and dolomites, usually more than 1000 m thick and deposited in a neritic environment. This formation passes upwards into a transitional unit of coarse, turbiditic limestones and fine-grained, pe-

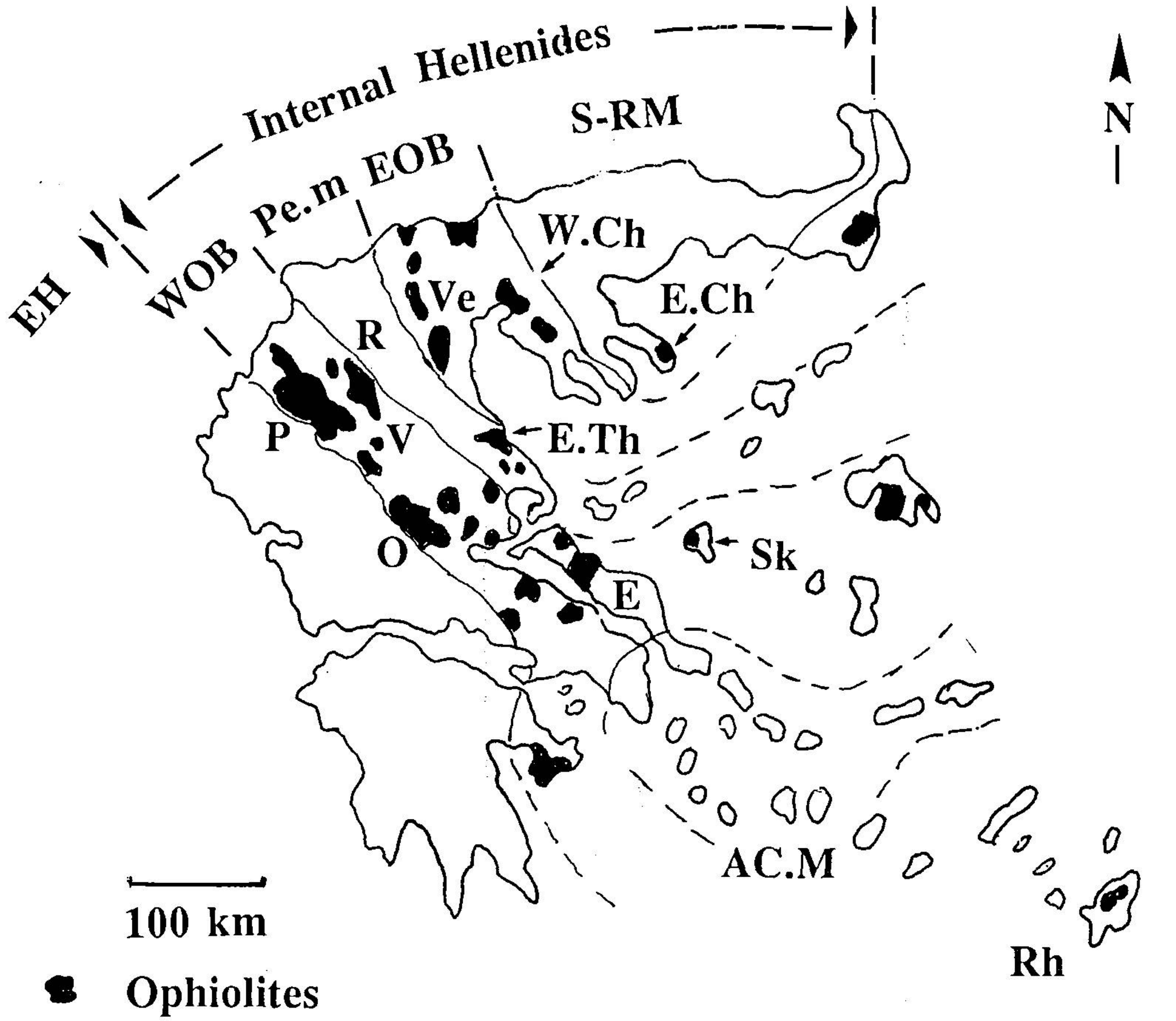

Fig. 1 Localities with ophiolites hosting chromitites and their distribution between the eastern (Vardar Zone) and western ophiolite belts of Greece. EH: External Hellenides, IH: Internal Hellenides, S-RM: Servomacedonia-Rhodope Massif; Pe. m: Pelagonian metamorphosed; AC.M: Atticocycladic Massif; E.Ch: Eastern Chalkidiki; W.Ch: Western Chalkidiki; Ve: Vermion; E.Th: Eastern Thessaly; V: Vourino; R: Rodiani; P: Pindos; O: Othris; Sk: Skyros; E: Evia; Rh: Rhodes.

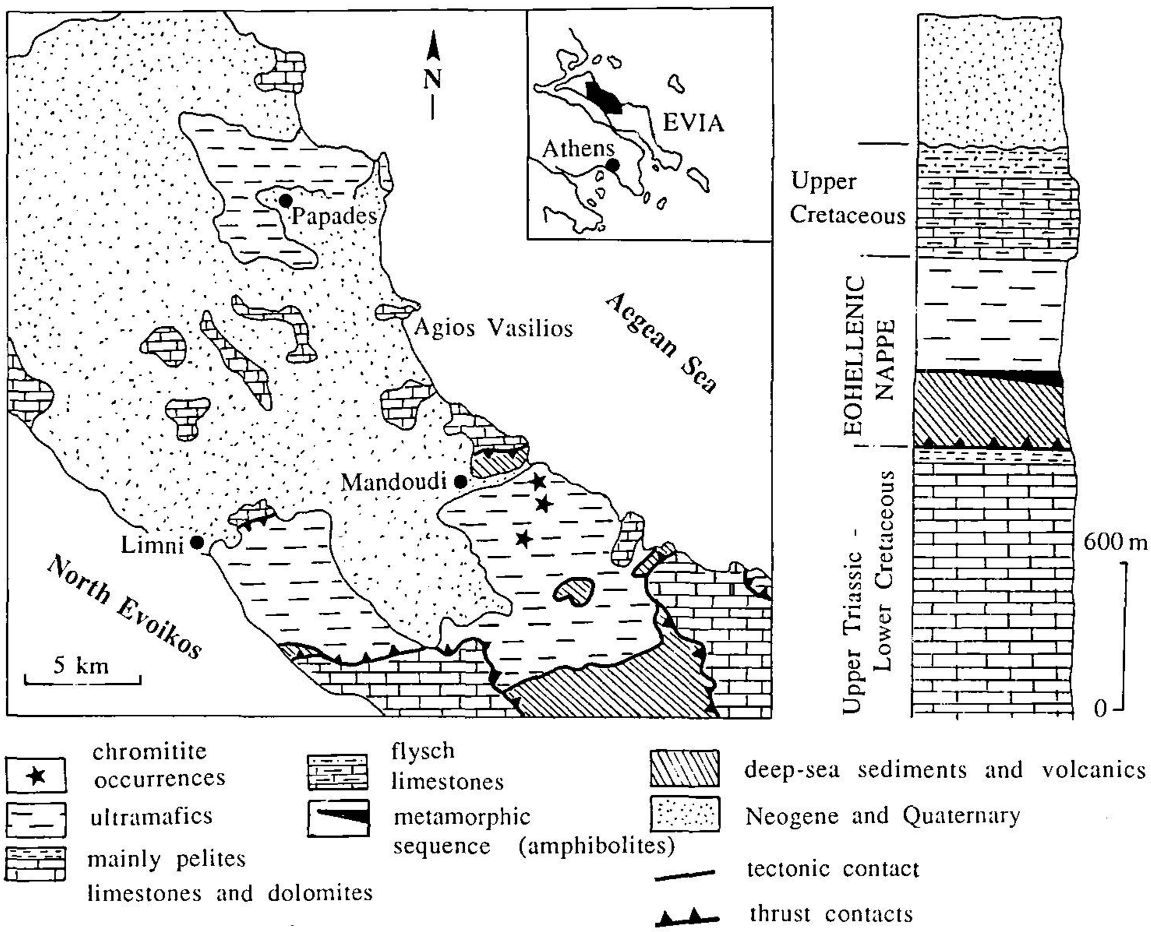

Fig. 2 Sample localities and ditribution of the ultramafic rocks in northern Evia.

lagic sediments, with radiolarian mudstones of Berriasian to Valanginian age (BAUMGARTNER and BERNOULLI, 1976).

2. *Eohellenic tectonic nappe formations.* This nappe has been divided by KATSIKATSOS (1977) into two groups of formations on the basis of their lithological composition, origin and inferred tectonic emplacement: a) the volcanosedimentary formations and b) the masses of ultramafic to mafic rocks.

3. *Upper Cretaceous transgressive limestones* which pass in the uppermost part into flysch sediments of Maastrichtian age.

The ultramafic rocks of the Eohellenic nappe in the studied area exhibit substantial thickness (up to 500 m) and are mainly represented by partially or completely serpentinized harzburgites and dunites, which enclose small chromitite bodies. Layered metagabbros are rare, the most important outcrops occur to the SE of Mandoudi, very close to the area where the chromitites crop out (Fig. 2).

Northern Evia Chromites – Generalities

Chromite occurrences have been found at three localities to the SE of Mandoudi (Fig. 2). The outcrops are rather small in size (4 × 5 m) and are enclosed in serpentinites. They occur in a narrow zone striking in a northeasterly direction, approximately parallel to the outcrops of amphibolitised layered metagabbros occurring further to the SE.

The chromitites occur, roughly estimated, 200–300 m stratigrafically lower than the amphibolites. They are severely tectonized, exhibiting a cataclastic texture. However, individual chromite grains appear homogeneous in colour under the microscope. This could be verified with the electron microprobe (Tab. 1). Cores and rims were found chemically homogeneous.

Accessory chromite was found in harzburgites and dunites. The chromites in the dunites (analyses No. 6–7, Tab. 1), as well as the dunites themselves, have been altered by fluids related to the

Tab. 1 Chemical analyses of chromites from northern Evia.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Al_2O_3	26.65	26.90	26.40	25.85	26.35	6.25	6.85	9.00	21.75	21.35	22.70	14.60	27.75	23.55	30.00	31.30	16.50
TiO_2	0.09	0.10	0.07	0.07	0.07	0.05	0.03	0.10	0.06	0.08	0.05	0.05	0.00	0.05	0.02	0.05	0.07
SiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.65	0.03	0.06	0.05	0.04
MgO	13.60	13.80	13.45	13.80	13.95	7.15	6.40	6.60	12.35	11.90	12.75	9.95	11.55	12.03	12.13	14.16	9.82
CaO	0.05	0.07	0.03	0.05	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.01
MnO	0.20	0.19	0.02	0.18	0.25	0.00	0.00	0.53	0.00	0.60	0.00	0.00	0.00	0.33	0.29	0.29	0.40
FeO_{tot}	17.75	17.30	18.20	18.90	17.60	22.75	24.20	26.50	16.40	17.00	16.20	19.25	18.80	17.11	18.23	15.20	20.70
Cr_2O_3	41.03	41.45	40.60	40.75	40.70	61.75	60.25	54.30	47.05	46.70	45.90	53.05	37.20	46.70	37.80	38.05	51.10
NiO	0.13	0.15	0.09	0.20	0.17	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.20	-	-	-	-
Total	99.50	99.96	99.04	99.80	99.11	97.95	97.73	97.21	98.28	97.63	97.60	96.90	96.15	99.80	98.57	99.12	98.64
$\frac{Cr}{Cr+Al}$	0.51	0.51	0.51	0.51	0.51	0.87	0.86	0.80	0.59	0.60	0.50	0.71	0.47	0.57	0.46	0.45	0.67
$\frac{Mg}{Mg+Fe^{+2}}$	0.61	0.62	0.60	0.61	0.62	0.37	0.25	0.33	0.58	0.57	0.60	0.49	0.54	0.56	0.54	0.63	0.49

1-5: Chromites from chromitites; 6,7: accessory chromites in altered dunites; 8: small chromite inclusion in olivine; 9-13: accessory chromites in harzburgite; 14-17: accessory chromites in harzburgite (from CAPEDRI, 1976).

magnesite deposits occurring in this area (GARTZOS, 1986).

Chemical characteristics

Chromite grains occurring in chromitites and accessory chromite from the unaltered harzburgites and from altered dunite were analysed for their Cr, Al, Fe, Mg, Mn, Si, Ti, Ca, Na, K, and Ni contents (Tab. 1). Na and K are not shown in table 1 because they were below the detection limit. An A.R.L. (type SEMQ) electron microprobe was used, equipped with four motor-driven X-ray spectrometers and two fixed X-ray monochromators (set for SiKα and MgKα, respectively). Natural silicates and oxides provided reference intensities. Counting times were used that yielded a standard deviation < 1% for the minor elements. Correction procedures for X-ray absorption, atomic number effects, and X-ray fluorescence were based on the EMMA correction program written at the ETH Zürich. The proportions of Fe^{+2} and Fe^{+3} have been calculated on the basis of spinel stoichiometry.

From the analyses presented in table 1, it is apparent that the chromites occurring in chromitites (analyses No. 1–5) exhibit little or no variation in chemical composition. Analysis No. 8 is from a small chromite inclusion in olivine, and it has the highest Cr and lowest Al content (excluding analyses No. 6 and 7). Analyses No. 6 and 7 are from chromites occurring in heavily altered dunites and show enrichment in Cr and Fe and depletion in Al and Mg. The rest of the analyses are from accessory chromites occurring in more or less serpentinized harzburgites. Four analyses (No. 14–17) have been taken from CAPEDRI (1976) and are accessory chromites in harzburgites from northern Evia.

The variations of Al_2O_3 and $FeO_{tot.}$ in relation to Cr_2O_3 are illustrated in figure 3 and are compared to variations of these same components in chromites of alpine-type peridotites. At Evia, the Cr_2O_3 content in chromites from the chromitites is about 41%, while accessory chromites from the harzburgites show a wide range of compositional variation (from 37 to 55 wt.%). All samples plot in the field of podiform chromites (Fig. 3 and 4) taken from MUSSALLAM et al. (1981). In the altered chromites, Cr_2O_3 contents increase to about 61 wt.%, whereas the Al_2O_3 contents decrease to about 6.5 wt.%, and they plot in the field of altered podiform chromites, which is shown by the dashed line in figure 3.

The range in variation in Cr_2O_3 is practically the same as that of Al_2O_3. THAYER (1970) has pointed out that an increase in Cr_2O_3 contents in podiform chromites is compensated by a decrease in Al_2O_3, whereas in stratiform chromites it is compensated by a decrease of both Al_2O_3 and Fe_2O_3. This significant relation between Cr_2O_3 and Al_2O_3 contents in podiform chromites distinguishes them from the stratiform ones; the latter plot outside of the podiform chromite field shown in figure 3.

The variation of total iron ranges from 15 to 20 wt.%. These values are characteristic for podi-

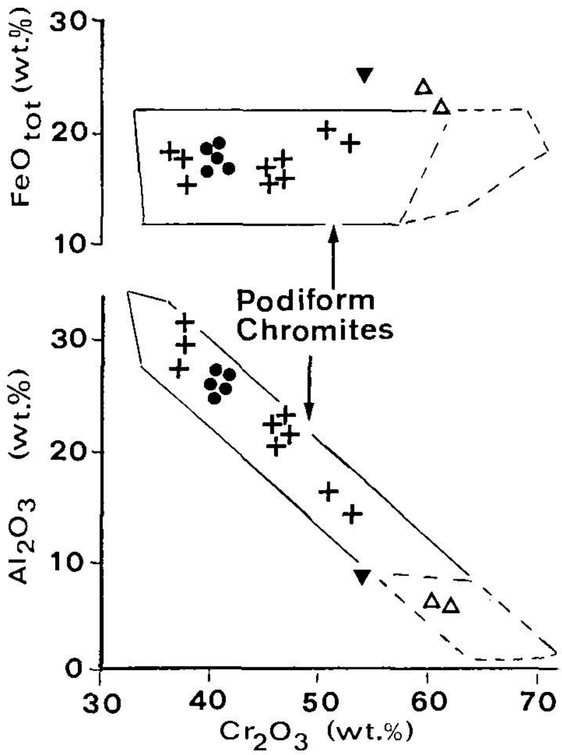

Fig. 3 Variation of $FeO_{tot.}$ (top) and Al_2O_3 (bottom) contents in chromites from northern Evia, in relation to their Cr_2O_3 content (in wt.%).

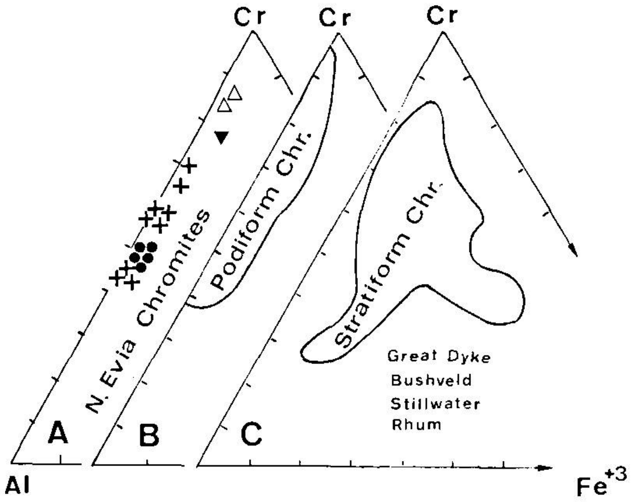

Fig. 4 Northern Evia chromite compositions in the Al–Cr–Fe^{+3} diagram (A). The fields of podiform (B) and stratiform (C) chromites, defined by MUSSALLAM et al. (1981), are shown for comparison.

form chromites and plot in the podiform chromite field. According to MUSSALLAM et al. (1981), in the majority of podiform chromites, the total iron content rarely exceeds 20 wt.%, whereas in stratiform chromites it is higher than 20 wt.%. In addition, most of the iron in the investigated chromites is in the ferrous state, as is the case with the podiform chromites.

The position of the examined chromites within the Cr–Al–Fe^{+3} diagram is shown in figure 4A. In this diagram, the main variation occurs along the Cr–Al join. All analyses plot very close to the Cr–Al join, as is the case with podiform chromites. The fields of podiform (Fig. 4B) and stratiform (Fig. 4C) chromites, taken from MUSSALLAM et al. (1981), are shown for comparison. The above chemical characteristics of the northern Evia chromitites indicate that they are typical, Al-rich podiform chromites.

Discussion

The ultimate goal of this investigation was to discriminate different geotectonic environments within the Greek ophiolite complexes and -belts using spinel chemistry. In the Cr/(Cr + Al) vs. Mg/(Mg + Fe^{+2}) ratio-diagram (Fig. 5), the chromites of northern Evia are compared to the chromites from ultramafic rocks from Othris, Pindos, Skyros, Rhodos, Rodiani and eastern Chalkidiki. With the exception of eastern Chalkidiki, these ophiolites geotectonically belong to the *western ophiolite belt* of Greece (Fig. 1). Figure 5 additionally contains chromite data from the *eastern ophiolite belt* of Greece (Vardar Zone, e.g. Chalkidiki, Vermion, and eastern Thessaly).

The distributional pattern within the ratio-diagram is very distinctive. The more Al-rich chromites mainly occur along the *western ophiolite belt*, whereas the more Cr-rich spinels predominantly occur along the *eastern ophiolite belt.* In comparison with modern geotectonic environments, figure 6 shows the fields for chromites in mid-ocean ridge basalts (solid line) and for Tertiary boninites occurring in island-arc environments of the Western Pacific (dashed line). The dotted line encircles the field of chromspinels occurring in boninitic rocks from Troodos (Cyprus), Othris and Aegina (Greece). There is a clear distinction between the more Al-rich chromites occurring in mid-ocean ridge systems and the more Cr-rich ones from boninitic rocks in island-arcs.

Under mid-ocean ridge and marginal basin environments, partial melting of spinel lherzolite or slightly depleted lherzolite produces a primary melt that is fairly high in Al, leaving a refractory harzburgitic upper mantle behind. The melt forms cumulates (e.g. dunites) with chromian spinels comparatively high in Al and low in Cr.

In an island-arc environment, partial melting probably starts with depleted lherzolite or harzburgite producing boninitic melts low in Al and Ca. Cumulate rocks (dunites) with Cr-rich chro-

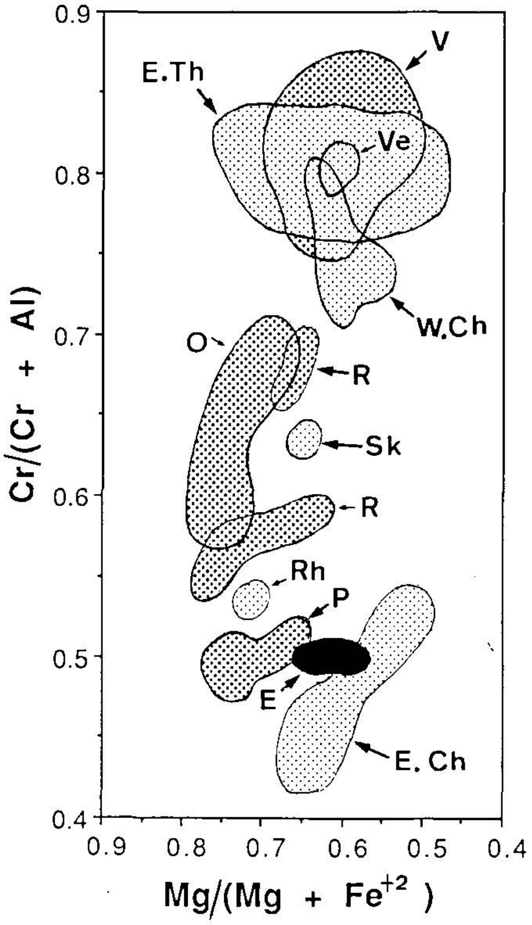

Fig. 5 Variation of Cr/(Cr + Al) ratios against Mg/(Mg + Fe^{+2}) ratios in chromite ores from Greek ophiolites. The fields were defined using data from ECONOMOU et al. (1986) and from MIGIROS and ECONOMOU (1988).

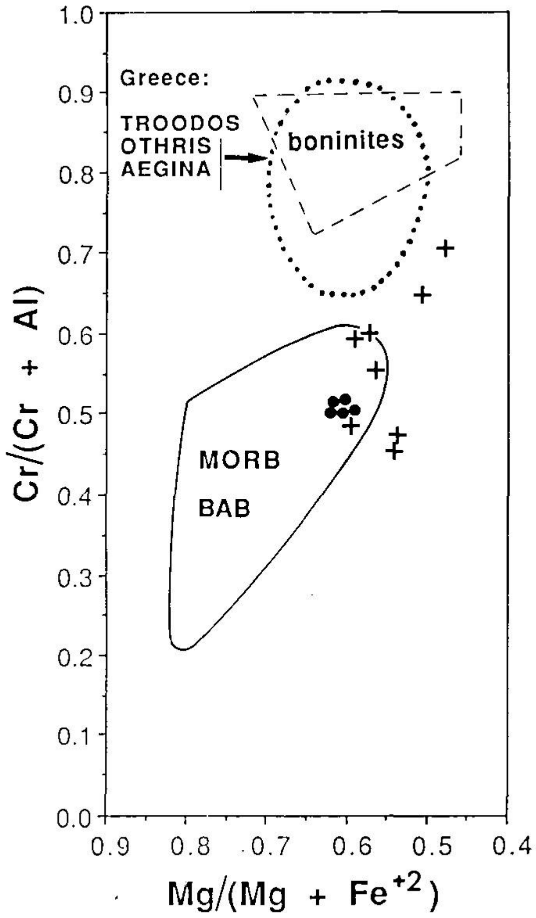

Fig. 6 Northern Evia chromite compositions expressed in terms of Cr/(Cr + Al) and Mg/(Mg + Fe^{+2}). Compositions of the chromites in altered dunites are not shown. The field for chromites occurring in ocean-floor basalts from the Mid-Atlantic ridge is shown by solid line whereas the field for chromites in Tertiary boninites from the Western Pacific and Cape Vogel, Papua is shown by dashed line. Dotted line delineates the field of chromites occurring in boninitic rocks from Troodos, Othris and Aegina (Greece). Data from DICK and BRYAN (1979), DICK and BULLEN (1984), CAMERON et al. (1979), and DIETRICH et al. (1987).

mian spinels and forsteritic olivine may crystallise from such a primary melt. According to such a generalised scheme, more Al-rich chromites should be abundant in ophiolites which were formed in a typical mid-ocean ridge or marginal basin environment and Cr-rich chromites in volcanic and plutonic rocks from island-arcs. Ophiolitic complexes, which comprise remnants of both ocean-floor rocks as well as island-arc rocks, show a large variation in Cr/(Cr + Al), ranging between the values found in mid-ocean ridges and values found in boninites. The latter case probably exists in the ophiolitic rocks of Othris, from where chromian spinels plot between the Al-rich and the Cr-rich chromites (Fig. 5).

Summary and conclusions

Field and laboratory investigations of the northern Evia chromite occurrences can be summarized as follows:

1) The chromitites are nodular, severely deformed and are enclosed by serpentinised peridotites.

2) They stratigraphically occur 200–300 m below layered amphibolitised metagabbros.

3) They exhibit a mineral chemistry that is typical for Al-rich podiform chromites occurring in alpine-type peridotites. Total iron contents range from 15 to 20 wt.%, and TiO_2 contents are very low (< 0.2 wt.%). They plot in the podiform chromite fields shown in the Al_2O_3 vs. Cr_2O_3, FeO_{tot}. vs. Cr_2O_3 (Fig. 3), and Al–Cr–Fe^{+3} (Fig. 4) diagrams.

They exhibit geochemical similarities with the podiform chromites from Pindos, Othris, Skyros, Rhodos and Rodiani, which are Al-rich and belong geotectonically to the *western ophiolite belt* of Greece *(main ophiolite belt)*. In contrast, the majority of the chromites occurring along the *eastern ophiolite belt (Vardar Zone)* are Cr-rich.

Based on chromian spinel compositions, it is inferred that the *western ophiolite belt (including Evia)* chromites and their host rocks (ophiolites) were formed in mid-ocean ridge systems, whereas the majority of the *eastern belt* chromitites have an island-arc origin.

References

BAUMGARTNER, P. and BERNOULLI, D. (1976): Stratigraphy and Radiolarian Fauna in a Late Jurassic-Early Cretaceous section near Achladi (Evia, Eastern Greece). Eclogae geol. Helv., 69, 3, 601–626.

CAMERON, W.E., NISBET, E.G. and DIETRICH, V.J. (1979): Boninites, komatites and ophiolitic basalts, Nature, 280 (5723), 550–553.

CAPEDRI, S. (1976): Relazione tra evoluzione geochimica e strutturale in una ultramafite di ambiente ofiolitico. Boll. Svizzero di Mineral. e Petrogr., 56, 345–359.

DICK, H. and BRYAN, W.B. (1979): Variation of basalt phenocryst mineralogy and rock compositions in DSDP hole 396B. Initial Reports DSDP, 46, 215–225.

DICK, H. and BULLEN, T. (1984): Chromian spinel as a petrogenetic indicator in abyssal and alpine-type peridotites and spatially associated lavas. Contrib. Mineral. Petrol., 86, 54–76.

DIETRICH, V. (1979): International Atlas of ophiolites, ophiolitic belts of the central Mediterranean 1:2500000, compiled by V. DIETRICH. Geol. Soc. Amer. Map and chart ser. MC-33, 5–8.

DIETRICH, V., OBERHÄNSLI, R. and MERCOLLI, I. (1987): A new occurrence of boninite from the ophiolitic melange in the Pindus-Sub-pelagonian zone S.L. (Aegina island, Saronic gulf, Greece). Ophioliti, 12, 83–90.

ECONOMOU, M., DIMOU, E., ECONOMOU, G., MIGIROS, G., VACONDIOS, I., GRIVAS, E., RASSIOS, A. and DABITZIAS, S. (1986): Chromite deposits of Greece (p. 129–159). In: CHROMITES, Unesco's IGCP – 197 project, Metallogeny of ophiolites. Ed. W. PETRASCHECK et al. Theophrastus publications, Athens.

GARTZOS, E. (1986): On the genesis of cryptocrystalline magnesite deposits in the ultramafic rocks of northern Evia (Greece). Ph.D. Thesis, unpublished 195 p., ETH Zürich.

KATSIKATSOS, G. (1977): La structure tectonique d'Attique et de l'Ile d'Eubee. VI Colloquium on the Geology of the Aegean Region. Athens, I, 211–228.

MIGIROS, G. and ECONOMOU, G.S. (1988): Chromites in the ultrabasic rocks of East Thessaly complex (central Greece). Ofioliti, 13 (2/3), 127–136.

MUSSALLAM, K., JUNG, D. and BURGATH, K. (1981): Textural features and chemical characteristics of chromites in ultramafic rocks, Chalkidiki complex (North-East Greece). Tschermaks Min. Petr. 29, 75–101.

THAYER, T.P. (1970): Chromite segregations as petrogenetic indicators. Geol. Soc. S. Africa. Special publ. 1, 380–390.

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