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ON RELATIONSHIP BETWEEN THE COMPOSITION OF CHROMITES AND THEIR TECTONIC-MAGMATIC POSITION IN PERIDOTITE BODIES IN THE SW OF TURKEY *

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ABSTRACT.— From a huge belt of peridotites, situated in the province of Muğla - SW Turkey, the general tectonic setting, age relations, composition and structure are discussed.

In this belt many chromite deposits are scattered, some of them having economical importance. It is shown that differences of chromites, calculated from analyses of chromium ores, make it possible to distinguish between basal-middle and upper zone of the ultrabasic intrusion.

This observation is of practical importance inasmuch as economical chromite deposits are mostly restricted to the basal - lower middle part of the peridotites.

It also may be used to solve tectonic problems where alpine mountain building, resulting in overthrusts respectively thrust faults and posterior faulting, obliterated primary-magmatic relationship.

INTRODUCTION

This article is the result of field and laboratory work on behalf of the Mineral Research and Exploration Institute of Turkey (M.T.A. Enstitüsü). Some of the results, that are briefly discussed in this paper, were laid down by van der Kaaden-Müller (1953), v. d. Kaaden-Metz (1954) and by v. d. Kaaden in two unpublished reports. A complete list of references is included in these papers. Before these investigations, the area was briefly mentioned by Philippson (1918).

The analyses were carried out by the chemistry department of M.T.A. This paper is presented by the kind permission of the former general-director of M.T.A., Prof. Dr. Hamit Nafiz Pamir, who promoted this investigation.

GENERAL TECTONIC SETTING
(Compare Fig. 1)

In the province of Muğla, SW Turkey, situated between Datça and the Dalaman river, a huge belt of ultrabasic rocks extends without interruptions over more than 120 km. covering approximately 3,000 km^2.

On the east side of the Dalaman river the ultrabasic rocks have a wide distribution too, but were not included in this investigation. In the north this belt is separated from Paleozoic rocks by a zone of disturbance which is tectonically of primary importance. In the south the ultrabasic belt is also separated from Mesozoic rocks by an important zone of disturbance.

The Paleozoic rocks were subjected to pre-alpine regional metamorphism and are composed of graphitic slates, phyllites—which are probably of Devonian age—marbles, semi-crystalline limestones and black fossiliferous Lower Permian limestones with intercalated chloritoid and kyanite-bearing quartzites.

Some radiolarites and igneous rocks of the spilitic suite may belong to the phyllitic series.

Within this area remnants of Cretaceous limestones are preserved. These are only affected by mechanical deformation which is also characteristic of the Mesozoic formation in the south.

The Mesozoic-early Tertiary rocks in the south range from Trias to Eocene. Their total thickness is estimated at 3 km. at least. They are represented by massive limestones, and thin - bedded limestones with intercalations of radiolarites in the upper parts of the Mesozoic formations. Reef formations are known within the Triassic and Upper Cretaceous formations. Eocene is developed in flysch, reef and nummulitic facies. Jurassic and Lower Cretaceous sediments have not been established with certainty, but may be represented in parts by radiolarites and oolitic limestones. In the Upper Cretaceous and Eocene orogenetic movements are indicated by flysch facies. These sediments contain much detritus of fine decomposed ultrabasic material.

Subordinate spilitic rocks are known to occur in the Middle Cretaceous. Detritus of spilitic material is also found in sediments of the flysch facies.

In parts, within this belt, Middle Cretaceous apparently rests on top of ultrabasic rocks, which implies a pre-Middle Cretaceous age of these rocks.

Both zones of disturbance are characterized by lenses of amphibolites and quartzites from the basement of the peridotitic body, together with spilitic rocks and lenses of serpentine, radiolarites, marbles, Permian and Mesozoic limestones. Both zones are strongly tectonized. Only the zone bordering Paleozoic rocks in the north was subjected to g l a u c o p h a n i z a t i o n . The glaucophane occurrences are irregularly distributed within this zone. Main constituents of these rocks, with the exception of amphibolites and quartzites, are" albite, quartz, carbonate, chlorite, tremolite, glaucophane and crossite. Local occurrence of pistazite and pumpellyite may be mentioned. Glaucophane and crossite have been bent or broken and recemented by a younger generation of carbonate, albite and quartz. Glaucophanized amphibolites, spilitic rocks, schists and radiolarites are known from this zone. The glaucophanization seems to have been favoured by local, relatively high hydrostatic pressure, combined with moderate temperature and subordinate shearing stress, as was suggested by de Roever (1953).

In many places along these zones of disturbance, especially in the north, the base of the ultrabasic rocks is exposed. This base consists of c r y s t a l l i n e s c h i s t s o f t h e e p i d o t e - a m p h i b o l i t e f a c i e s . Main rock types are amphibolites, amphibole schists, quartzites and gneisses. Main constituents of these rocks are green amphibole, albite oligoclase, quartz, clinozoisite, epidote, chlorite, carbonate and muscovite. Furthermore the occurrence of garnet, piedmontite, prehnite and a small amount of glaucophane should be mentioned. These rocks were subjected to at least one post - crystalline deformation after the metamorphism in the epidote- amphibolite facies. Besides glaucophane and prehnite, part of the quartz, albite, chlorite, carbonate and epidote belongs to the younger minerals, which originated after the metamorphism of the epidote-amphibolite facies.

The footwall of these crystalline rocks is unknown, but the exposed thickness is at least 100 m.

A P a l e o z o i c d i s t u r b a n c e is indicated by intense NE to NNE shearing phenomena, epi-metamorphism of the phyllitic series, and by chloritoid and kyanite-bearing Lower Permian quartzites, as mentioned previously. Bearing more importance to our problem is the alpine mountain building which resulted in overthrusts and thrust faults of ultrabasic rocks on Paleozoic, Cretaceous and Eocene formations.

In this period the splitting up of the ultrabasic complex in two large tectonic units was also accomplished. These units represent the upper-middle and bottom-middle parts of the ultrabasic intrusion respectively. The first unit — with the higher tectonic position — is situated between the two zones of disturbance mentioned previously. The second unit — -with the lower tectonic position — is partly exposed south of the southern zone of disturbance. Such a splitting up of ultrabasic complexes was first described by Hiessleitner (1952) from the Balkan peninsula. In our case, distinction is substantiated by chemical differences in chromites of these units and will be discussed later.

Nappes arc indicated respectively by Eocene and Cretaceous flysch under older Mesozoic strata at Bayır köy, south of Marmaris—as was already suggested by Philippson (1918) — and at Dalyan, south of Köyceğiz. In the north two remnants (Klippe) of the ultrabasic overthrust sheets are situated on a line that is parallel to the zone of disturbance, described before, and are now isolated from the main body at a discance of more than 10 km. They are flat-lying bodies of serpentinized peridotites with tectonized lenses of amphibolites, quartzites and strongly cataclastic Eocene flysch. In the south, Eocene flysch and Mesozoic formations— the former rich in detritus of decomposed ultrabasic material — were overridden to the south, along a low-angle fault plane, by the ultrabasic sheets.

In the area investigated by the author, Lower and Middle Miocene were not involved in the overthrusts and thrust faults. The age of these thrusts is therefore probably Oligocene. In strong contrast with the metamorphism afore-mentioned, the metamorphism of the overthrusts is purely mechanical, resulting in zones of intense shearing, but with little or no recrystallization. In Pliocene and early Pleistocene strong block faulting with displacements of more than 1000 m, and more or less independent of older tectonic directions, affected the area and complicated the solving of tectonic problems.

AGE RELATIONS OF METAMORPHIC PHASES AND ROCKS

The metamorphism in the epidote-amphibolite facies is considered to belong to a pre-varistic orogenetic cycle; therefore the rocks may be early-Paleozoic or older.

The metamorphism of the phyllitic schists, marbles and Lower Permian is considered to belong to the vanstic orogenetic cycle. The Lower-Permian quartzites, with the combination of chloritoid-kyanite, represent the biotite-chlorite subfacies. The Cretaceous sediments in the immediate vicinity are not affected by this metamorphism. Turner and Verhoogen (1951) pointed out that the combination of chloritoid - kyanite is rare and represents perhaps incomplete equilibrium. As the tectonic picture of the Paleozoic disturbance in this area is not properly understood, no opinion can be offered.

The metamorphism in the glaucophanite subfacies is older than the pure dynamic metamorphism, which accompanied the overthrust movement. It is younger than the amphibolites, radiolarites, spilitic rocks and phyllitic schists. This metamorphism probably belongs to the alpine orogenetic cycle.

Generation of igneous rocks of the spilitic suite may have taken place during the varistic orogenetic cycle and certainly during the alpine orogenetic cycle. Quantitatively they are of minor importance. The exact age of the ultrabasic intrusions is difficult to establish, but they are older than the main period of alpine cliastrophism. For the following reasons it seems probable that this age is from late-Paleozoic to early-Mesozoic.

1. Endogenetic or exogenetic contact metamorphism of ultrabasic rocks in connection with Mesozoic or Eocene formations could not be proved.
2. The NE-NNE shearing directions that are typical for the Paleozoic disturbance are also characteristic in the ultrabasic complex itself.
3. Somewhat younger gabbroic dike rocks, which belong to the ultrabasic cycle, are never intrusive in the Mesozoic formations. In one place it could be proved as being intrusive in the phyllitic series.
4. In some places along the contact with the phyllitic series, transitions from peridotites to tremolite schists might be explained as the result of regional metamorphism older than the glaucophanization. Schurmann (1956) suggests a magnesium metasomatism in connection with the ultrabasic intrusions.

However, the possibility indicated by Bowen and Tuttel (1949) and, among others, supported by du Rietz (1956), that the peridotites represent mobile masses of crystalline olivine, that have been separated from a peridotite substratum of the earth's crust and pushed up from this substratum by orogenetic forces, should not be eliminated. It accounts for the absence of thermal metamorphism, for the close association with old crystalline rocks, and for the negligible amount of spilitic extrusives in comparison with the huge belt of ultrabasic rocks. In that case we cannot speak of the time of intrusion, but only of the time of tectonic emplacement. This emplacement may have been started in a pre-alpine orogenetic cycle and accomplished during alpine mountain building.

COMPOSITION AND STRUCTURE OF ULTRABASIC AND GABBROIC ROCKS

The ultrabasic belt is more than 120 km. in length; the width varies between 3-30 km., the thickness is estimated at 2.5 km. at least, and the general strike is NNE-SSW. Furthermore the ultrabasic rocks have also a wide distribution east of the investigated area. In parts of the belt that were not affected by zones of disturbance, massive-magmatic bedding is more or less preserved. Low-angle dipping of this bedding is common, with NNE-SSW to NE-SW strike and a dip towards WNW-NW.

The composition of the ultrabasic rocks is rather monotonous. More than 95% consist of peridotites. The bulk of these peridotites has the composition of harzburgites. Lherzolites are extremely rare and seem to be limited to the upper parts of the ultrabasic intrusion. The content of the orthopyroxenes of these harzburgites, however, changes from place to place. In general, the content of orthopyroxenes in the harzburgites varies between 5-40 %. vol. The massive-magmatic bedding that is visible in the belt is the result of these slight changes in composition. Although transitions to dunites are known, the pure dunites are restricted to the immediate vicinity of chromite occurrences. On the other side, there are transitions to pyroxenites in the upper zone of the ultrabasic complex, though pure pyroxenites are also present as small veins in the vicinity of chromite deposits, cutting the surrounding peridotites.

The olivine of the peridotites is rich in magnesium. Its composition varies between Fo_{95-80} - Fa_{5-20}. The orthopyroxene is enstatite, rich in magnesium. Only in the rare transitions to pyroxenites, hypersthene may be observed.

As accessory constituent in the dunites, harzburgites and Iherzolkes, up to 0.5 % chromite is present. In the pyroxenites it seems to be picotite. Protoclastic effects in the olivines and orthopyroxenes are not uncommon. According to Chudoba and Frechen (1950) this phenomenon might be explained by assuming differential movement in a rather viscous medium at still elevated temperature. The chromite occurrences are genetically related to the peridotites. Younger, but belonging to the same magmatic cycle, are stocks and dikes of coarse to finely-grained gabbroic to dioritic rocks and diabases. They are crystallized within the ultrabasic belt after consolidation of the peridotitic magma. The dikes and diabases are rapidly cooled; chilled border zones were often observed. No more than 5 % of the belt consists of these rocks. They are more frequent in the upper-middle parts of the peridotites than in the bottom zones.

As accessory minerals ilmenite and magnetite are to be mentioned. Chromite was never observed in these rocks The gabbroic - dioritic rest - melts were already devoid of chromite.

Serpe'ntinization is generally poor. Within the belt, zones of differential tectonical movements are strongly serpentinized. This is also the case along the two major zones of disturbance as mentioned previously. Microscopical and field observations make it clear that the serpentinization was a post-magmatic process, initiated by a tectonic movement. The necessary water for the process might have easily been supplied by surrounding geosynclinal sediments.

Primary water of the peridotitic magma seems to have been concentrated in the immediate surroundings of chromite concentrations. Here pneumatolitic-hydrothermal action is indicated by the occurrence of minerals as chromium - bearing tremolite and kammererite, and perhaps by local strong serpentinization phenomena within these ore bodies.

POSITION OF CHROMITE DEPOSITS

In the investigated area approximately 100 chromite occurrences and deposits — some of them having economical importance — were visited. As internal zoning is only indicated by primary magmatic bedding, but not by lithological differences that can be used in the field, it is rather difficult and sometimes impossible to make a distinction between basal, middle and upper zone as was done by Hiessleitner (1952).

Still a rough estimation is possible. The bedding gives us a tool to judge the general strike and position of the undisturbed areas of the ultrabasic belt. It was obvious that in general the more finely - grained disseminated ores were limited to the upper-middle parts, and the coarsely-grained massive ores to the lower parts of peridotites. The «leopard» ores were mainly restricted to the upper-middle parts, but sometirhes clouds of this ore-type were surrounding massive ores in the lower parts. However, exceptions to these rules are possible. Tabular «schlieren» - banded ore bodies, often thin - sheeted, were more or less restricted to the middle zone. Especially the ore deposits in the neighbourhood of both zones of disturbance, mentioned before, were strongly tectonized. Mylonitic chromium ore could often be observed.

The intrusive shape of some massive ore bodies in this area, and their steep-inclined position with respect to magmatic bedding, suggests a relative mobility of chromium-rich rest-solutions in a stage in which the surrounding peridotitic magma was already highly viscous.

The protoclastic effects in olivines and pyroxenes, mentioned before, also give the impression of differential movements in largely crystalline material. Furthermore, two main directions of ore bodies could be distinguished. They are approximately in the direction of NNE-SSW and E-W respectively. These directions might be interpreted as tension cracks, developed in the end stage of cooling. When the rock was subjected to stress, they were favoured by still mobile chromium-rich rest-solutions. As was suggested by Prof. Borchert (oral communication), in this stage remelting of crystalline chromite seems improbable. Besides gravitational concentration of chromite in a solid state, the possibility of this kind of concentration in a liquid state, during the magmatic factional crystallization, should therefore not be eliminated. In the field, distinction was made between peridotites with different tectonic positions, which was discussed previously. Also within the tectonic units, as far as possible distinction between the lower and upper parts of the peridotites was made. In order to examine the possibility of relationship between composition of chromites and their position in the tectonic units, 56 analyses of chromium ores, representing 32 different deposits or occurrences were carried out. From three deposits five or more analyses are available.

CHEMICAL COMPOSITION OF CHROMITE ORES

Table I gives the result of 56 analyses of chromium ores. Oh the tectonical map (fig. 1.) the position of the respective chromium deposits or occurrences are indicated by the same numbers as are used in this table. In order to obtain comparable values, the chromite formulas had to be calculated from these analyses. Var der Kaaden-Müller (1953) pointed out how these calculations were accomplished. As this paper is difficult to acquire, an outline will be given.

Example

	Chemical analysis No. 20	*calculated at 100 %*
Cr_2O_3	48.45 %	50.35 %
Fe_2O_3	14.67 %	15.25 %
SiO_2	4.54 %	4.72 %
Al_2O_3	10.53 %	10.94 %
CaO	0.62 %	0.64 %
MgO	17.19 %	17.86 %
MnO	0.04 %	0.04 %
NiO	0.19 %	0.20 %
	96.23 %	100.00 %

Mineral Content

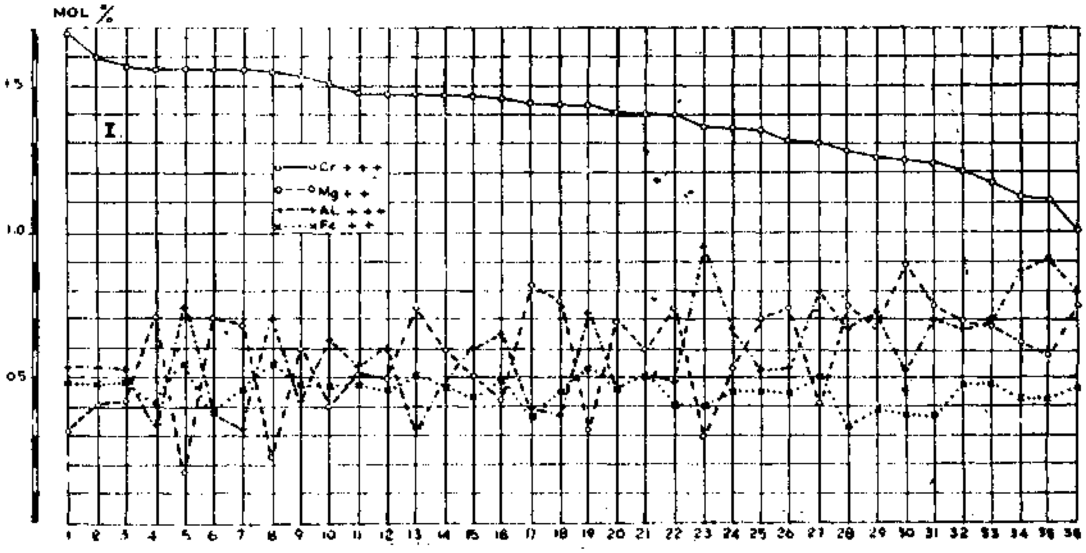
Chromite, serpentine, and calcite.

Serpentine is calculated as $2SiO_2$. $3MgO.2aq$ and subtracted from the analysis (4.72 % SiO_2 bind 4.75 % MgO). CaO is subtracted as calcite NiO replacing partly MgO in chromite or serpentine or partly contained in sulfides is not considered.

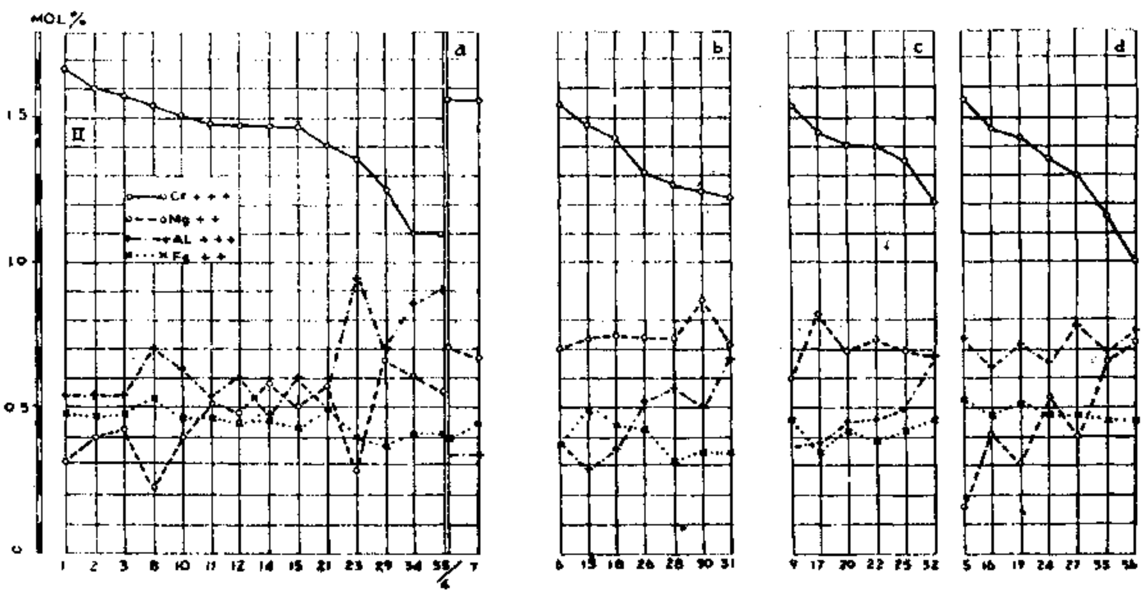
For the calculation of chromite the formula remains :

Cr_2O_3	50.35 %	56.14 %
Fe_2O_3	15.25 %	17.00 %
Al_2O_3	10.94 %	12.20 %
MgO	13.11 %	14.62 %
MnO	0.04 %	0.04 %
		100.00 %

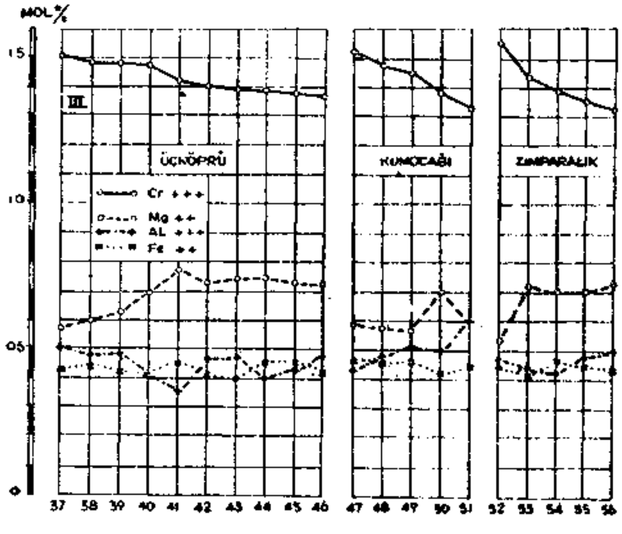
I



II



III



Graphs I, II, III

	Weight %	Molecular %
Cr	38.41 %	0.739
Fe	13.21 %	0.237
Al	6.46 %	0.240
Mg	8.82 %	0.363
Mn	0.03 %	0.0005
O	33.07 %	2.067

Weight percentages of anions and kations are computed, and from these weight percentages, the molecular percentages were derived.

From this the formula :

$$Cr^{+++}_{0.739}\ Fe^{++}_{0.237}\ Al^{+++}_{0.240}\ Mg^{++}_{0.363}\ Mn^{++}_{0.0005}\ O^{--}_{2.067} \text{ results.}$$

Calculated at R_3O_4 the formula besomes:

$$(Cr^{+++}_{1.430}\ Fe^{++}_{0.459}\ Al^{+++}_{0.464}\ Mg^{++}_{0.702}\ Mn^{++}_{0.001}).\ O_4 = R_{3.056}\ O_4.$$

Theoretically the total sum of the metals should be three. Small deviations might be expected, in asmuch as minor simplifications were necessary. As these deviations are small they are neglected. In order to obtain uniform results the formula was adjusted to :

$$R_3 = Cr^{+++}_{1.404}\ Fe^{++}_{0.451}\ Al^{+++}_{0.455}\ Mg^{++}_{0.689}\ Mn^{++}_{0.001}$$

The results were tabulated according to decreasing mol.% Cr^{+++} in Table II. In this table occurrences were included of both tectonic units with the exception of three deposits, of which more analyses were available, and therefore, listed in Table III. The figures in these tables were used for the construction of different graphs.

Graph. I. The mol. % of Cr^{+++}, Fe^{++}, Al^{+++} and Mg^{++} of Table II, including occurrences and deposits of both units and independent from their position in these units, were plotted on a graph according to decreasing mol.% O^{+++}.

Increase of Al^{+++} is compensated by a decrease of Mg^{++} and vice versa. The medium value of Mg^{++} Al^{+++} increases with decreasing Cr^{+++}. Fe^{++} seems to be almost independent from the large fluctuations in the chromite formula. Van der Kaaden - Müller (1953) already observed this fact in a limited area situated within the investigated region. Now it could be established that this observation holds true for the whole of the investigated peridotitic complex.

Graph. II. Represents graph. I. split up into four different graphs : II.a-d.

a. This graph represents occurrences and deposits of the ultrabasic unit with the higher tectonic position. In the upper part, only small chromite concentrations occur; deposits of economical value are extremely rare. In the lower part some chromite concentrations of economical value were exploited. The upper part shows Al^{+++} higher than Mg^{++}, but there are a few exceptions (No. 14 and 21) whereby Mg^{++} is higher than $A1^{+++}$, the difference being only 0.105-0.072 mol. % respectively. These occurrences have more or less a medium position. The lower part of this unit is already characterized by Mg^{++} higher than AI^{+++}. Numbers 4 and 7 both belong to the lower part and were both exploited.

Cr^{+++}	shows	variations	between	1.681 - 0.996 mol. %	= 0.685 Δ
Al^{+++}	»	»	»	0.995 - 0.228	= 0.767 »
Mg^{++}	»	»	»	0.878 - 0.158	= 0.720 »
Fe^{++}	»	»	»	0.540 - 0.318	= 0.222 »

They show Mg^{++} higher than Al^{+++} with differences of 0.370-0.357 mol. % respectively.

b. This graph represents deposits and occurrences of the ultrabasic unit with the lower tectonic position. Here, without exception, Mg^{++} is higher than Al^{+++}. The differences fluctuate between 0.032-0.450 mol. %.

c. This graph represents the lower part of the region north of Gürleyik. This is a sub-unit of the unit with the higher tectonic position. At its base lenses of Paleozoic rocks are tectonically embedded in Eocene flysch. This sub-unit is lying isolated from the main body on top of Mesozoic - early Tertiary rocks. In the lower part many deposits and occurrences arc scattered, a few of them having economical importance. Mg^{++} was higher than Al^{+++}. The differences fluctuate between 0.022-0.437 mol. %.

d. This graph represents upper parts of the sub-unit mentioned under c. These parts are somewhat characterized by transitions to pyroxenites within the harzburgites and by an abundance of younger gabbroic rocks. Though, owing to tectonic movements, magmatic relationship is nearly obliterated, these occurrences seem to belong to the upper zone of the ultrabasic intrusion. The occurrences have little or no economical importance. Furthermore they show Al^{+++} higher than Mg^{++}, which was also characteristic for the upper parts of the peridotites with the higher tectonic position.

Graph III. Thanks to the kind cooperation of Dr. Sadrettin Alpan of M.T.A., more analyses of three deposits became available. They are the deposits of Üçköprü, Zımparalık and Kum Ocağı, which have economical importance and all belong to the lower part of the sub-unit mentioned under graph II c.

Mg^{++} was always higher than Al^{+++}. Moreover, the observation of Betekhtin (1930)—that fluctuations in the composition of chromites belonging to the same deposits occur—was confirmed.

The observed maximum differences in molecular percentages of the four components Cr^{+++}, Mg^{++}, Al^{+++}, Fe^{++} are listed for the three deposits.

Üçköprü	**Cr^{+++} = 0.129**	**Mg^{++} = 0.207**	**Al^{+++} = 0.158**	**Fe^{++} = 0.067**	**mol. %**
Kum Ocağı	**= 0.183**	**= 0.133**	**= 0.173**	**= 0.044**	**»**
Zımparalık	**= 0.220**	**= 0.193**	**= 0.065**	**= 0.056**	**»**

Also here Fe^{++} shows the smallest fluctuations.

The differences between Mg^{++} and Al^{+++} change between 0.066-0.424; 0.052-0.209; 0.065-0.229 mol. % for Üçköprü, Kum Ocağı and Zımparalık, respectively.

RELATIONSHIP BETWEEN COMPOSITION OF CHROMITES AND TECTONIC-MAGMATIC POSITION

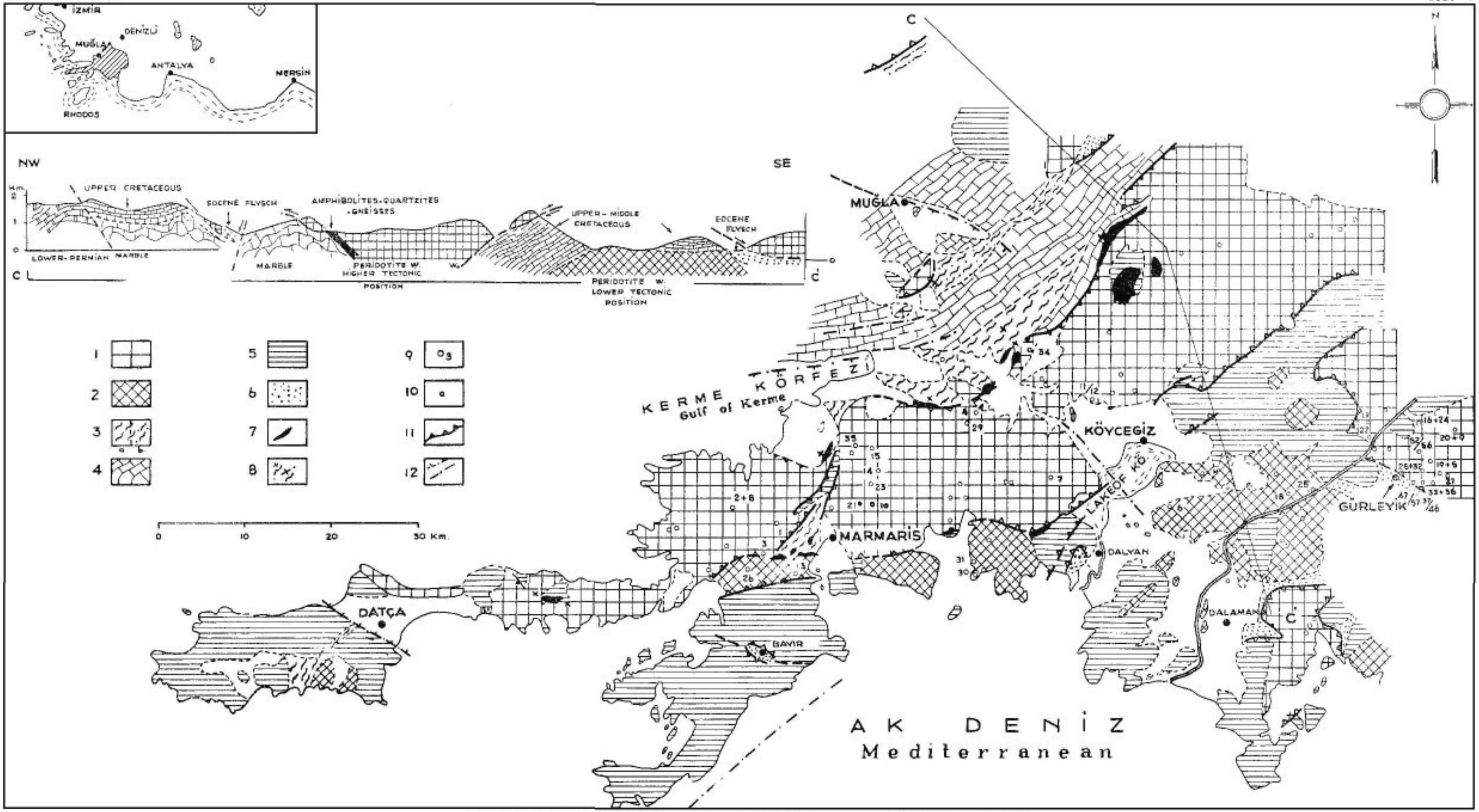
It was shown that the ultrabasic rocks in the investigated area are older than the main period of alpine diastrophism and that distinction could be made between two units of peridotites with different tectonic position. It was suggested that originally these two units were parts of one large ultrabasic body and that this ultrabasic body had been split up during alpine diastrophism along a plane of weakness. This plane of weakness seems to fall together with a transition zone in the ultrabasic body marking the boundary between the upper zone which was poor in chromite concentrations, and the bottom zone, rich in chromite concentrations. It coincides more or less with the zone of disturbance in the south, mentioned under tectonic setting. Though lithological differences between the units are shown to be small, larger concentrations of gabbroic rocks and the occurrence of pyroxenites seem to be restricted to the upper zone of the peridotites with the higher tectonic position.

The peridotites with the higher tectonic position represent the upper part and parts of the transition zone at its base. This unit is characterized in its upper parts by the fact that in chromites mol. % Al^{+++} is always higher than mol. % Mg^{++}. The peridotite with the lower tectonic position is characterized by the fact that in the chromites mol. % Mg^{++} is always higher than mol. % Al^{+++}. This unit represents the lower part of the transition zone and the bottom part of the ultrabasic intrusion. The lower part of the unit with the higher tectonic position is also characterized by mol. % Mg^{++} higher than mol. % Al^{+++}. In order to obtain a picture of the behaviour of the four elements in chromite within both tectonic units, the medium values of Cr^{+++}, Fe^{++}, Al^{+++}, and Mg^{++} are listed for the different graphs.

Medium mol. % value	Cr^{+++}	Fe^{++}	Al^{+++}	Mg^{++}
Upper part of higher tectonic unit.				
Graph IIa*	1.430	0.452	0.650	0.467
Graph IId	1.322	0.493	0.725	0.461
Unit with lower tectonic position.				
Graph IIb	1.360	0.396	0.487	0.756
Transition zone situated in basement of unit with higher tectonic position.				
Graph IIc	1.388	0.427	0.483	0.701
Üçköprü	1.429	0.434	0.447	0.601
Kum Ocağı	1.432	0.453	0.505	0.610
Zımparalık	1.410	0.445	0.466	0.680

The behaviour of the four elements in the different units can be easily understood if we assume fractional differentiation of a parent magma. A large quantity of magnesium was earlier withdrawn from the melt by crystallization of olivine, this being rich in magnesium; almost simultaneously some chromite was withdrawn from the melt by gravitational forces. This resulted in a gradual increase of the Al_2O_3/MgO and FeO/MgO ratio-in the residual liquid. This liquid, which still contained chromium, being relatively enriched in aluminium and iron, should theoretically produce chromite, which is richer in these elements than the chromite withdrawn previously. In the investigated area we see that in the upper parts of the ultrabasic intrusion the chromites are always richer in aluminium than in magnesium, as should be theoretically expected. For iron this tendency is far less striking though still recognizable. The behaviour of chromium is somewhat obscure as chromites rich and poor in mol. % Cr^{+++} are to be found in both units independent of their position within these units. The small fluctuations in composition of chromites of one and the same deposit, already mentioned under graph III, could be explained by assuming that the different chromite particles in these deposits were derived from somewhat different parts of the original magma-chamber.

The suggestion, offered by Wijkerslooth (1954), that concentration of chromite, though probably initiated by gravitational forces, might have been favoured by differential movements within the crystallizing melt, may also be considered. Particles of somewhat different composition may then have been washed together.



SIMPLIFIED GEOLOGICAL MAP AFTER v. d. KAADEN-METZ (1954) AND v. d. KAADEN

1. Peridotite with higher tectonic position; 2. Peridotite with lower tectonic position; 3. Epi-dynamometamorphic early-Paleozoic schists; 3ᵇ. Chloritoid-bearing schists and quartzites; 4. Marbles and semi-crystalline limestones, 6. Eocene; 7. Crystalline-rocks (amphibolites, gneisses); 8. Glaucophane-crossite-bearing rocks; 9. Chromite occurrences — analysed; 10. Cromite occurrences — not analysed; 11. Major thrust faults — hanging wall is hachured; 12. Major faults.

Table I.

No.	Cr_2O_3	FeO	SiO_2	Al_2O_3	CaO	MgO	MnO	NiO
1	52.14	13.89	4.98	11.19	0.22	9.99	0.13	0.19
2	50.89	14.02	2.36	11.60	0.25	9.01	0.21	0.15
3	49.81	14.15	5.38	11.23	0.63	12.42	0.34	0.13
4	59.28	14.20	0.85	8.50	0.15	15.04	0.30	0.18
5	39.95	13.09	12.49	12.71	1.43	17.74	0.06	0.29
6	57.91	12.73	1.06	9.24	0.24	15.00	0.29	0.21
7	53.79	14.60	5.04	7.46	0.19	17.53	0.14	0.19
8	42.96	14.14	9.23	12.92	0.08	12.49	0.07	0.21
9	49.93	14.01	4.70	9.07	0.80	15.03	0.04	0.13
10	44.17	12.76	10.49	12.32	0.93	16.64	0.13	0.24
11	45.52	13.58	9.58	11.12	0.91	18.01	0.16	0.21
12	52.61	15.01	3.37	14.31	1.24	12.51	0.14	0.05
13	53.55	17.15	2.03	7.04	0.20	16.30	0.10	0.07
14	43.40	12.90	10.72	9.50	0.40	19.95	0.15	0.18
15	52.82	14.28	2.73	14.53	1.12	12.45	0.17	0.06
16	47.70	15.05	4.40	14.33	1.17	12.45	0.07	0.20
17	53.41	12.45	3.42	9.52	0.28	19.56	0.14	0.23
18	48.25	14.00	6.05	8.28	0.38	19.50	0.19	0.23
19	36.39	13.22	12.25	12.41	0.72	16.51	0.07	0.25
20	48.45	14.67	4.54	10.53	0.62	17.19	0.04	0.19
21	39.63	13.59	12.93	9.65	0.50	21.72	0.14	0.29
22	52.52	13.78	2.84	12.01	0.15	17.43	0.17	0.20
23	46.29	12.99	5.36	21.89	0.89	10.52	0.13	0.06
24	47.84	14.97	3.86	15.68	1.47	13.84	0.17	0.20
25	45.76	14.13	3.66	11.63	0.84	16.23	0.16	0.16
26	47.57	14.89	4.08	12.97	0.32	18.29	0.10	0.08
27	43.22	15.58	3.04	17.81	1.14	10.15	0.05	0.26
28	42.54	13.57	5.52	14.75	0.62	18.78	0.19	0.24
29	45.96	12.92	2.75	17.41	0.22	15.70	0.29	0.20
30	50.97	14.14	0.84	14.10	0.37	19.96	0.20	0.21
31	47.19	12.97	3.10	17.60	0.16	17.87	0.19	0.18
32	37.07	13.78	8.35	13.58	0.40	19.49	0.06	0.32
33	43.99	16.71	2.89	17.98	1.16	16.44	0.02	0.11
34	37.33	13.56	4.75	19.63	1.06	15.58	0.35	0.24
35	39.52	14.38	3.59	22.02	1.51	14.34	0.22	0.08
36	30.41	13.77	10.60	16.12	0.82	22.64	0.05	0.21
37	46.20	12.46	6.82	10.42	0.45	16.20	0.02	0.05
38	42.56	12.15	10.70	9.20	0.50	19.80	0.02	0.10
39	45.51	12.30	9.03	9.86	0.80	19.27	0.02	0.06
40	48.28	12.94	7.10	9.17	0.84	19.10	0.02	0.10
41	47.13	13.34	5.84	7.63	0.55	19.38	trace	0.26
42	47.90	13.36	6.83	10.60	0.98	19.95	0.02	0.05
43	46.36	12.54	5.68	10.58	0.85	18.85	0.02	0.08
44	43.61	13.65	7.55	8.53	0.73	20.05	trace	0.38
45	44.16	13.01	7.64	9.21	0.65	20.00	»	0.20
46	49.04	14.38	4.52	11.50	0.82	18.30	0.02	0.06
47	48.71	14.07	6.42	9.25	0.53	16.50	trace	trace
48	45.27	12.77	10.25	9.46	0.64	19.24	»	»
49	40.82	12.45	12.05	9.80	0.60	20.55	»	»
50	48.17	13.91	4.55	11.52	0.74	17.54	»	0.32
51	40.57	12.95	10.95	12.25	0.90	20.92	0.02	0.06
52	42.13	11.50	10.36	8.56	0.98	18.14	0.02	0.08
53	48.94	13.37	4.35	10.23	0.71	16.17	0.02	0.26
54	45.69	14.49	5.96	9.53	0.62	18.36	trace	0.35
55	43.41	13.68	7.75	10.42	0.78	19.80	0.02	0.08
56	41.20	13.95	9.48	10.35	0.91	21.46	0.02	0.04

Table II. Cromite Formula

No.	Cr^{+++}	Fe^{++}	Al^{+++}	Mg^{++}	Mn^{++}
1	1.681	0.474	0.539	0.302	0.004
2	1 594	0.465	0.542	0.392	0.007
3	1.572	0.472	0.529	0.416	0.011
4	1.560	0.395	0.333	0.703	0.009
5	1.560	0.540	0.740	0.158	0.002
6	1.556	0.362	0.371	0.705	0.006
7	1.551	0.446	0.321	0.678	0.004
8	1.547	0.539	0.694	0.217	0.003
9	1.533	0.455	0.416	0.595	0.001
10	1.512	0.462	0.629	0.392	0.005
11	1.478	0.466	0.538	0.512	0.006
12	1.477	0.444	0.597	0.481	0.004
13	1.472	0.499	0.288	0.738	0.003
14	1.470	0.462	0.479	0.584	0.005
15	1.467	0.420	0.601	0.507	0.005
16	1.451	0.484	0.649	0.414	0.001
17	1.439	0.355	0.382	0.819	0.005
18	1.435	0.441	0.366	0.752	0.006
19	1.429	0.536	0.725	0.308	0.002
20	1.404	0.451	0.455	0.689	0.001
21	1.400	0.507	0.508	0.580	0.005
22	1.399	0.388	0.476	0.732	0.005
23	1.356	0.402	0.955	0.283	0.004
24	1.354	0.448	0.662	0.530	0.006
25	1.348	0.439	0.513	0.695	0.005
26	1.303	0.432	0.529	0.733	0.003
27	1.301	0.496	0.799	0.402	0.002
28	1.272	0.318	0.658	0.746	0.006
29	1.251	0.371	0.706	0.663	0.009
30	1.241	0.364	0.512	0.878	0.005
31	1.230	0.357	0.683	0.725	0.005
32	1.197	0.471	0.654	0.676	0.002
33	1.164	0.469	0.691	0.676	0.000
34	1.104	0.418	0.866	0.601	0.011
35	1.098	0.423	0.912	0.561	0.006
36	0.996	0.477	0.786	0.739	0.002

Table III. Chromite Formula

	Cr^{+++}	Fe^{++}	Al^{+++}	Mg^{++}
Üçköprü				
37	1.499	0.427	0.504	0.570
38	1.482	0.448	0.477	0.593
39	1.477	0.423	0.477	0.623
40	1.475	0.419	0.417	0.689
41	1.425	0.459	0.346	0.770
42	1.401	0.414	0.463	0.722
43	1.389	0.397	0.471	0.741
44	1.387	0.460	0.405	0.748
45	1.380	0.464	0.430	0.726
46	1.370	0.426	0.479	0.725
Kum Ocağı				
47	1.518	0.464	0.429	0.589
48	1.480	0.463	0.482	0.575
49	1.447	0.467	0.517	0.569
50	1.382	0.423	0.493	0.702
51	1.335	0.450	0.602	0.613
Zımparalık				
52	1.550	0.447	0.469	0.534
53	1.423	0.411	0.443	0.723
54	1.391	0.467	0.433	0.709
55	1.357	0.453	0.485	0.705
56	1.330	0.445	0.498	0.727

SUMMARY

It was suggested that the intrusion of a large body of ultrabasic rocks took place in a highly crystalline, already differentiated condition. This differentiate originated within a substratum of the earth's crust. The same holds true for the deposits and occurrences of chromite located in these peridotites. The total absence of contact-mctamorphic phenomena, and protoclastic effects observed in olivines, support the assumption outlined above.

Gabbroic and dioritic rocks may have been still mobile during this intrusion as is indicated by a dike of gabbroic rock in Paleozoic phyllites; they are quantitavely of minor importance. The time of this intrusion, however, could not be exactly determined, but may be late - Paleozoic to early-Mesozoic. It took place before the main period of alpine diastrophism.

During alpine diastrophism the ultrabasic body was split up into two units with different tectonic position. The unit with the higher tectonic position represents the upper portion, and parts of the transition zone of the original ultrabasic body.

The unit with the lower tectonic position represents parts of the transition zone and the lower portion of this body.

During the main period of alpine diastrophism the primary relationship between these units was obliterated by overthrusts and thrust faults. After this, the region was subjected to intense faulting which made the solving of tectonic problems rather complicated.

It is shown that differences of chromites, calculated from total analyses of chromium ores, make it possible to distinguish between the different units. The method outlined above helped to disentangle complicated tectonic problems as well as the primary relationship of both units.

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REFERENCES

1 —BOWEN, N. L. and TUTLE, O. F. (1949): The system MgO-SiO_2-H_2O. *Geol. Soc. Am. Bull. 60. p. 439-460.*

2 —CHUDOBA, K. F. and FRECHEN, J. (1950) : Ueber die plastische Verformung von Olivin. *Neues Jb. Mineral. Abh. 81. p. 198.*

3 —HIESSLEITNER, G. (1952): Serpentin und Chrqmerz-Geologie der Balkanhalbinsel und eincs Teiles von Kleinasien. *Jb. Geol. Bundesanstalt. Sondtrband II. Wien.*

4 —KAADEN, G. v. d. and MÜLLER, G. (1953) : Chemische Zusammensetzung von Chromiterzen a. d. Gegend von Gürleyikköy. (SW-Türkei) u. s. w. *Bull. Geol. Sac. of Turkey. Vol. IV. p. 61-79.*

5 — KAADEN, G. v. d. and METZ, K. (1954): Beitrage zur Geologie des Raumes zwischen Datça-Muğla-Dalaman Çay (SW-Anatolien) *Bull. Geol. Soc. of Turkey Vol. V. p. 71-171.*

6 — PHILIPPSON, A. (1918) : Handbuch der regionalcn Geologie. *V. 2. Heidelberg.*

7—RIETZ, T. du (1956) : The content of chromium and nickel in the Caledonian ultrabasic rocks of Sweden. *Geol. For. Förh. Bd. 78. Stockholm, p. 235.*

8— ROEVER, W. de (1953) : Tectonic conclusions from the distribution of the metamorphic facies in the island of Kabaena, near Celebes. *Proc. Seventh Pacific Science Congress V. 2. p. 80.*

9 — SCHORMANN, H. M. E. (1956): Beitrage zur Glaucophanfrage. (3) *Neues Jb. Mineral. Abh. 89 p. 83.*

10 —WIJKERSLOOTH, P de. (1954) : Einiges über die Entstchung von Chromitlagerstattet an Hand von neuen Beobachtungen in Anatolien. *Neues Jb. Mineral. Abh. p. 190-200.*