THE MODE OF DISTRIBUTION OF CHROME-ORES IN PERIDOTITES IN TURKEY

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ABSTRACT — The theories which exist on the formation of chrome-ores cannot give any satisfactory solutions in the practical mining. In this publication, it has been tried to explain the formation of Turkish chrome-ores, generally, as a magmatic injection deposit with concrete examples obtained by the author during 15 years in the field of prospecting, detailed studies and exploitation of these ore-bodies. The differentiation of the chromite magma has taken place prior to the magma intrusion according to the mineral paragenesis, the morphology of the deposits and the relation between the ore and the wall-rock. Therefore, the form and the localization of chromite deposits, grade and texture of the ore formed as a result of the flow and the movements of the differentiated magma intrusion. These deposits are distributed in three dimensions in the extension of peridotite masses, but not in their peripheries; this consideration is based on the observations and the results mentioned above. Tectonic movements following the magma consolidation have produced comparatively small deformative effects on the ore-bodies.

CHROME - ORE PRODUCTION IN TURKEY

Chrome-ore fields in Turkey can be divided into four groups with respect to the shipping ports; namely, the Mediterranean, the Aegean Sea, the Sea of Marmara and the Black Sea.

The important ports where chrome-ore is shipped for export are as follows:

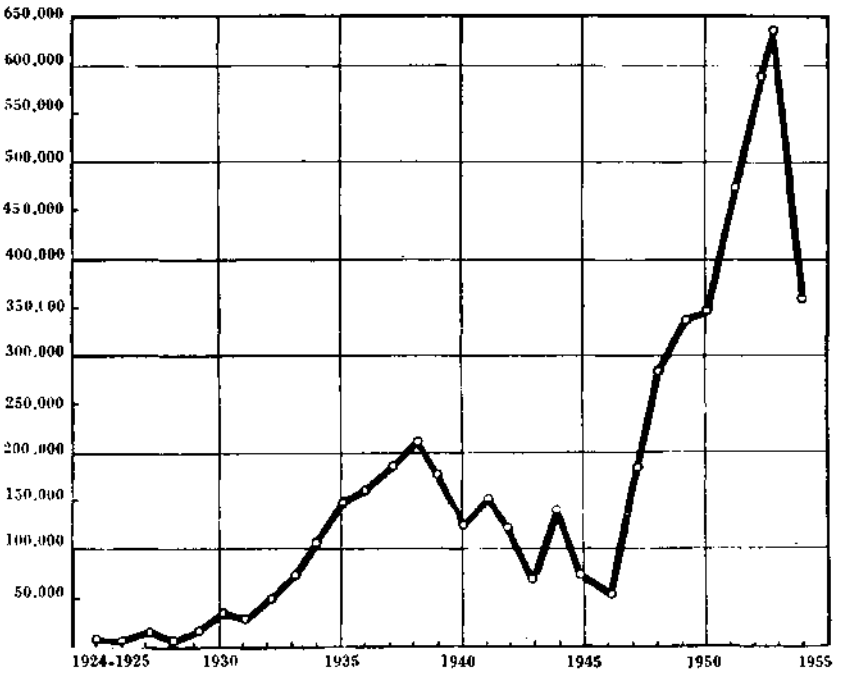
1. In the Mediterranean : İskenderun, Mersin, Antalya, Fethiye, Göcek, Marmaris, Gökova.
2. In the Aegean Sea: Izmir (Smyrna).
3. In the Sea of Marmara : Bandırma, Mudanya, Derince.
4. In the Black Sea : İnebolu, Samsun and Trabzon.

These four chromite districts have different characteristics regarding ore-reserves and metallurgical, chemical and refractory properties of the ore. The ore-fields in the Mediterranean district appear to be superior to the ones of the other three districts. At the ports of the Mediterranean group, there are better ore - loading facilities, fields of this district have deposits with large ore - reserves, and finally the chrome - ores are of excellent metallurgical grade.

The district of Marmara occupies the second place.

Turkish chrome-ore production in the last decade is as follows :

Year	*Production (Metric Tons)*	*Shipped Tonnage (Metric Tons)*	*F.O.B. Total Sale Price in Turkish Liras*
1945	148,069	78,303	5,889,776
1946	103,059	49,120	3,123,094
1947	156,603	182,157	9,910,010
1948	285,725	285,505	17,229,894
1949	451,566	334,520	23,135,845
1950	422,529	346,536	24,409,676
1951	619,420	476,954	36,185,366
1952	806,911	586,801	46,301,251
1953	912,523	630,230	53,463,324
1954	561,549	357,178	31,136,081



Shipped tonnage of Turkish chrome-ore in the years 1924 - 1955

The superior qualities of Turkish chrome-ores can be seen in the following table :

Locality	*Cr_2O_3%*	*FeO%*	*SiO_2%*	*Al_2O_3%*	*MgO%*
Gölalan (Elâzığ Province)	52.40	14.20	4.20	10.80	17.20
Tosinler (» »)	51.00	14.70	4.40	11.50	17.50
Dağardı (Eskişehir »)	53.42	15.35	2.88	7.52	17.63
Tekirova (Antalya »)	51.26	14.60	0.76	17.02	15.65
Kündikan (Elâzığ »)	49.30	14.50	5.70	9.10	19.40
Baysınlar (» »)	49.20	14.90	3.90	12.80	16.70

In 1954, 418,000 tons of chrome-ore were produced and 256,000 tons sold from the ore-fields of the Mediterranean district. These figures show clearly the importance of this ore-district.

Break-down of the production by various firms is shown in the following table (in metric tons) :

Name of the Firm	*1954*		*1953*		*1952*		*1951*	
	Production	*Shipped Tonnage*	*Production*	*Shipped Tonnage*	*Production*	*Shipped Tonnage*	*Production*	*Shipped Tonnage*
Etibank	132,753	71,868	183,698	139,789	183,069	158,376	165,413	136,352
Türk Maadin	90,274	78,052	104,712	87,401	58,330	54,183	72,325	57,330
Sıtkı Koçman	37,741	37,587	48,919	41,009	48,981	38,367	22,102	20,125
Orhan Brand	19,815	13,051	45,537	20,724	44,708	18,600	42,231	28,910
Fethiye Şti.	19,510	15,066	43,301	26,875	28,494	21,791	32,324	22,853
Hayri Ögelmen	32,121	21,000	20,745	19,748	15,102	7,424	13,418	11,241
Stanley Peterson	34,472	34,133	30,630	17,272	26,140	11,887	21,909	21,166
Tekirova Ltd.	11,428	2,032	17,019	5,308	13,470	5,330	7,702	2,032

Chrome-ore production in Turkey increases or diminishes depending on the situation of the foreign market. The production diminished in the last years because of the decrease in the number of outcropping deposits. The sedimentary deposits are related to a few beds on the surface or underground in one or several horizons. Most of the magmatic occurrences are connected to a certain volume of the enclosed rock. On the other hand, chromite occurrences are distributed in three dimensions in the total volume of the enclosed rock consisting of basic or ultrabasic massive bodies. Therefore, chrome-ore exploitation has to deal with the whole district on the surface and the whole volume of ophiolitic massive body underground. There are, of course, exceptions to this. The examples are : 1) regularly stratified chrome ores of the Bushveld Complex in South Africa; 2) The Great Dyke in Southern Rhodesia. It is the aim of all chrome producers to set up fixed and central exploitation activities instead of having displaced exploitation undertakings. The development in the techniques of chromite prospecting and full enlightenment of chromite genesis will have a great bearing on the solution of this problem. The Dagardi chrome mine with a relatively long life of activity has been closed down. On the other hand, the Guleman chrome ore-field has been active for twenty years.

PRINCIPLES IN PROSPECTING

The applied method of prospecting consists of recording direct and indirect ore - indications. Direct indications are to find and to examine a part of a chromite occurrence at the outcrop. Indirect indications are to find ore-floats in the valleys. So prospecting is executed by following up ore - floats which were broken - off and carried away to short or long distances from the parent ore-body. Geochemical indications belong-also to the indirect group. Core-drilling is not an exploration tool, but may be used for the verification of an ore - body. It is possible, however, to discover large ore-reserves by following up closely the changes in the structure of chrome ore-bodies underground. It is rather vital to put stress on this point.

Based on the personal experiences of the author, acquired in the various chromite fields, the rules of ore - accumulations are divided into two classes :

1. The deposits of scattered lenticular or vein forms.
2. The accumulation centres of lenses or veins.

In the lenticular ore-formations, which are distributed at random, dip and strike remain identical. On the other hand, the vein accumulations form a bundle where they are localized in parallel beds. The occurrences in Islahiye (the province of Hatay) belong to the first and of Köyceğiz (the province of Muğla) to the second class. In a serpentine field, it can never be considered that all the chromite outcrops are discovered; because erosion in time produces new outcrops. Geometrical locus of the occurrences in a certain time consists of the topographic surface belonging to that particular period. The first geometrical locus moves towards the centre of Earth as the time passes. The form and accelerated movements of the consequent topographic surfaces are determined by the factors of erosion and transportation. Positive inventories were principally obtained one by one on productivities and production capacities of chromite deposits and costs of mining (in Turkey). Under the light of the above data, the time has

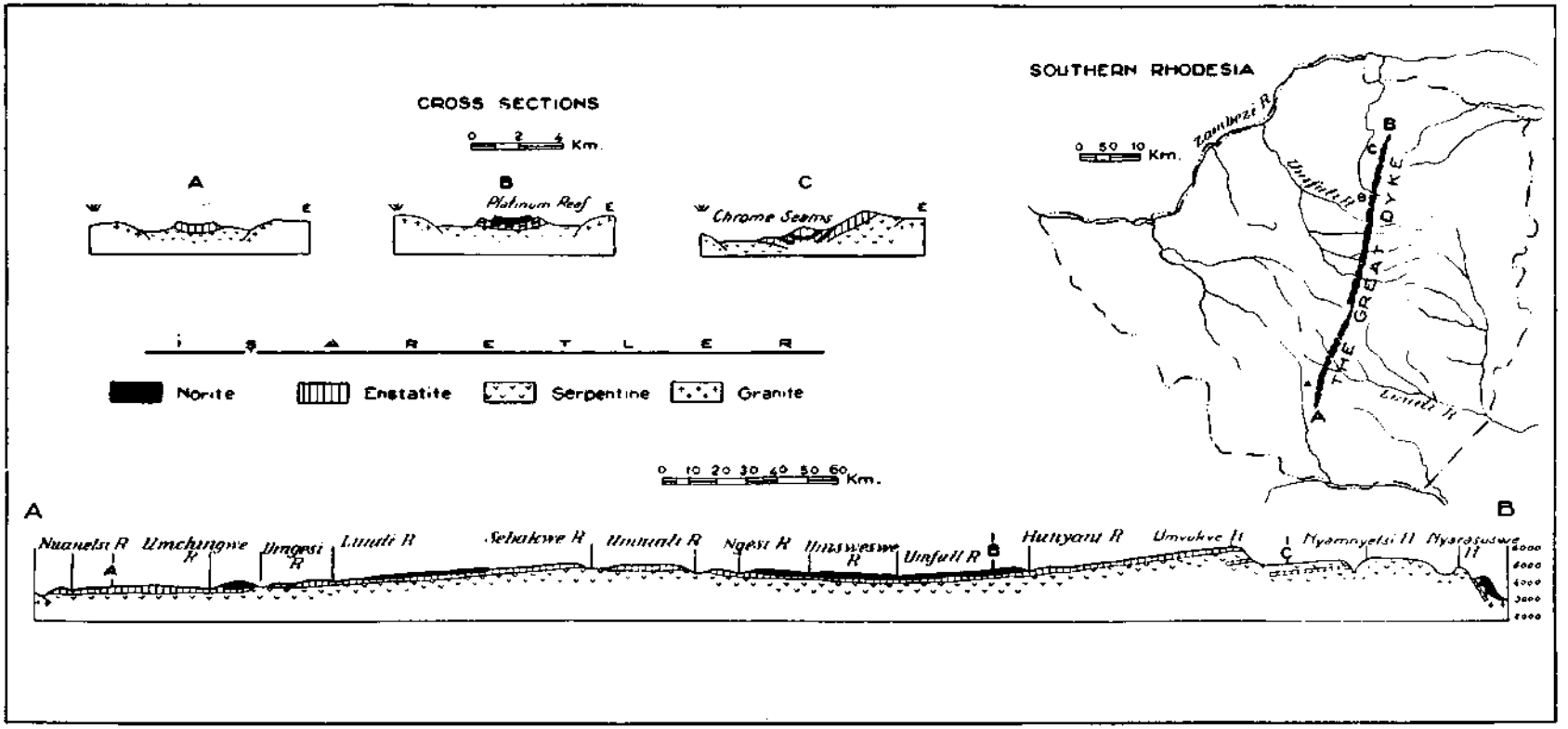


Fig. 1 - Longitudinal-section and cross-sections of the Great Dyke. (Taken from «the Mineral Resources of the World». See : References)

come for the evaluation of the Turkish chrome-ores.

MINERALOGY OF CHROMITE AND ENCLOSING ROCK

Chromite, which is a mono-mineral, is formed exclusively in peridotites or pyroxenites.

Peridotites consist of the following minerals :

1. Dunite (olivine)
2. Habsburgite (olivine + orthorhombic pyroxene)
3. Lherzolite (olivine + orthorhombic pyroxene + monoclinic pyroxene)
4. Wehrlite (olivine + monoclinic pyroxene).

Pyroxenites consist of the following minerals :

1. Websterite (orthorhombic pyroxene + monoclinic pyroxene)
2. Diallagite (diallage)
3. Bronzitite (bronzite)
4. Hypersthenite (hypersthene).

It can readily be seen that the enclosing rock consists of either mono-mineral or binary mineral. Peridotites and pyroxenites are altered into the rocks as follows as a result of metamorphism :

1. Rocks with olivine
2. Pyroxene and amphibole schists
3. Serpentine.

The mineral composition of these rocks is as follows : Olivine, pyroxene, amphibole, chlorite, talc, meerschaum, chrysotile and antigorite.

CHROMITE DEPOSITS AND THEIR FORMS

Southern Rhodesia:

They occur as continuous veins or long lenticular masses. Veins occur at 20-60 m. intervals; 10-25 cm. in thickness .and dip 25° towards the centre of the Great Dyke. Wall-rock is of pyroxenite (see fig. 1).

Russia: They occur in serpentines as lenticular, schillerian and disseminated forms.

Cuba: Deposits occur from a few tons to 100,000 tons in serpentinized peridotites as irregular masses.

Turkey: There are five kinds of deposits :

1. Lenses in the shape of a boat,
2. Schillerian veins,
3. Irregular masses,
4. A number of lenticular bodies arranged in a row from top to bottom,
5. Highly dipped beds in the shape of a sausage.

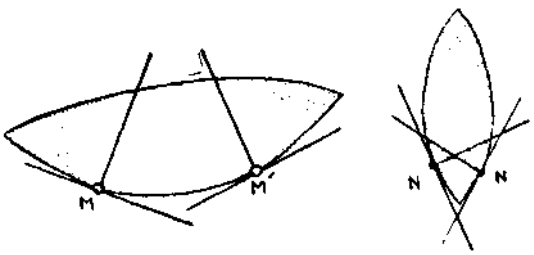


Fig. 2 - Lenticular chromite deposits

In the lenticular deposits, the ore ends suddenly at the foot • wall (see fig. 2). The centre of curvature on two faces joining at the base remains on one side of the bed. In schillerian veins, the ore does not terminate abruptly. The two concave faces close symmetrically, which is an indication for the termination of the ore. A number of schillerian veins occur in Köyceğiz (province of Muğla). There are a few sausage-shaped ore-bodies. The author has discovered Karadağ ore-body in Çayhisar (province of Muğla) for the firm called «Türk Maadin», which can be shown as an example for this type of occurrences (see fig. 3).

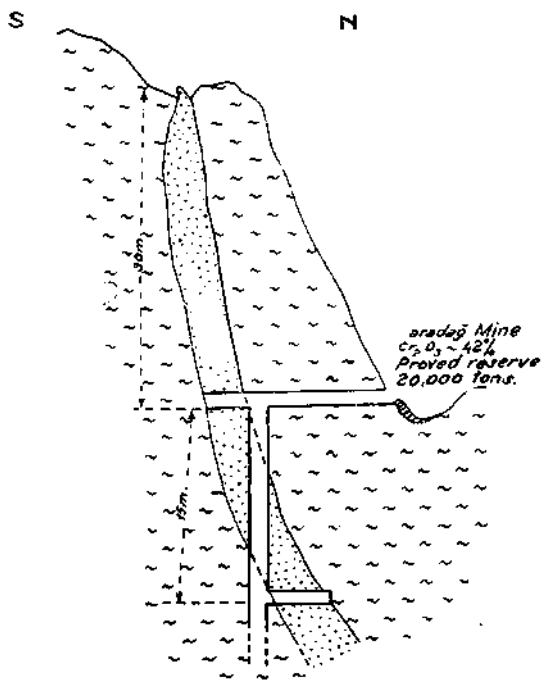


Fig. 3 - Karadağ chrome mine

DISTRIBUTION OF CROMITE DEPOSITS

At the first sigfyt, chromite deposits appear to be scattered at random in serpentines. This appearance gives the impression that they were formed as a result of segregation.

It is essential to make complete interpretation regarding the size, number, form and relative position of the deposits occurring at random in a certain field. Serpentine areas are different from the point of the density of chromite - outcrops. It is necessary to form an opinion on the metallogenetic development based on the observations. It is appropriate to set up a similarity between metallogenesis and metallurgy. Besides metallogenesis can be considered as metallurgy on the Earth Scale. It is readily understood by investigating the cataclastic texture of the ore, the morphological features of the deposits and the relation between the ore and the wall - rock that, as a rule, chromite deposits must have displaced. There is, generally, a complete coincidence between the orientation of chromite occurrences in serpentines and the elements of regional tectonic units. In Islahiye region, the orientation of the occurrences is NE to SW and they dip to the north. At the same time, the direction of mountain-range in this district extends from NE to SW. «Kundikan» and «Gölalan» occurrences appear in a similar way. The present arrangement of the deposits is composed of movements of the following two components :

1. by injection of primary magmatic concentrations,
2. by regional folding.

In this aspect, the process of injection plays the most essential part. The existence of broken-off small pieces and shining surfaces in the ore are produced as a result of rubbing of wall-rock into the ore-body.

Deformations formed as a result of injection are different from the ones mentioned above. Schillerian and banded ore - veins represent chromite injection. The bands of ore or dunite are parallel to the planes of wall - rock and dip of the former is approximately vertical. The subsequent tectonic movements produce very little deformation on ore-bodies.

TEXTURES OF THE ORE

1. The massive ore :

It is composed of crystal grains.

2. The spotted ore :

Crystal grains or crystal assemblages are cemented by the gangue material.

3. The banded ore (fig. 4&5) :

Massive or spotted-ore and dunite bands are arranged side - by - side. This type of ore - deposits shows the best traces of tectonic movements.

In a certain district, it is possible to find a few deposits different from each other in texture, structure, form, and chemical composition, or variations may occur in an individual ore - body with respect to chemical composition and mineralogical texture. Spotted-ore texture is confined and characteristic in the limited contact zones of certain occurrences with the wall - rock.

PARAGENESIS

Chromite was first consolidated in the dunite magma. Olivine or serpentinized olivine in chromite crystals is merely an inclusion. Crystal faces of crystallized chromite have lost their geometrical forms by corrosive action of dunite magma on chromite. Corrosion is a result of fusion and can be seen by the existence of contentric aureoles

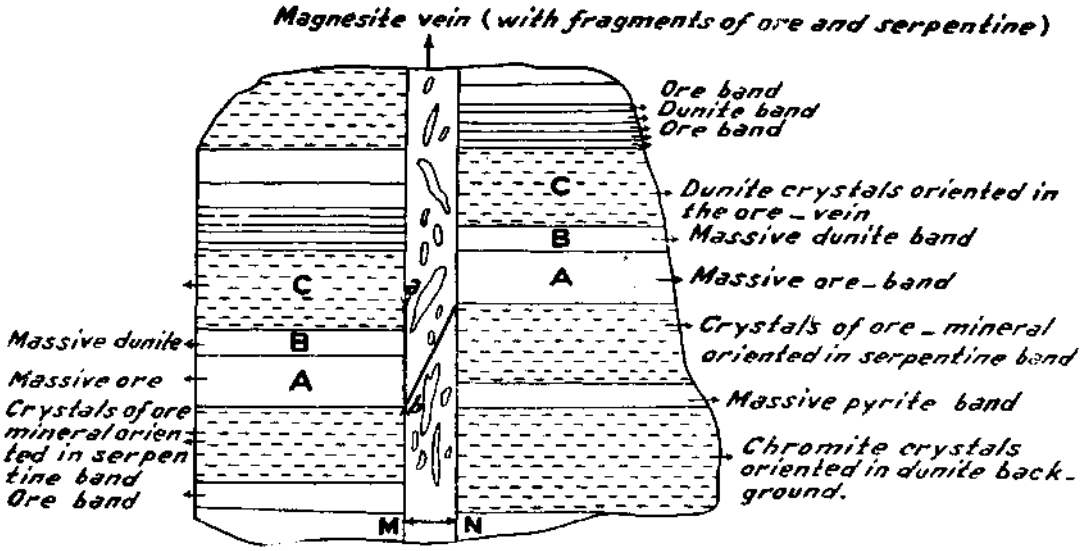


Fig. 4 - Banded ore (scale : 1/2)

Generally, chromite nodules have a shape of an ellipse and arc parallel to each other in the direction of their long-axes. The relative movement of chromite concentration resulted in the localization of chromite nodules around the contact with the wall-rock and their orientation in a certain common direction. This movement took place in magmatic stage where differentiation was completed but magma was not consolidated.

Besides, nodules in the injected chromite-veins are localized in the neighbourhood of wall-rock. With these considerations, the existence of chromite nodules is attributed to injection movements, but not to the mode of differentiation.

around crystal skeletons. Consequently, after fusion along the edges, chromite is recrystallized in smaller size and then scattered in dunite magma. The mechanical deformation is out of question here.

PRIMARY ORE - CONCENTRATION

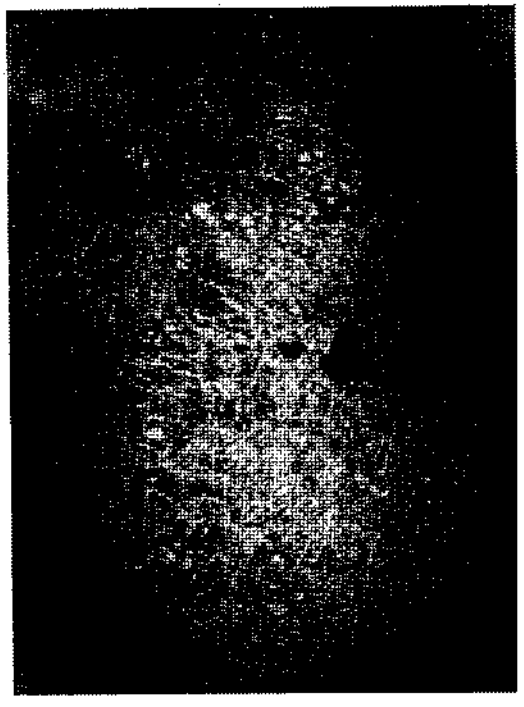
Chromite, which acquires its chemical composition in peridotite magma as a result of differentiation, accumulates in the base and middle of intrusion according to gravitation. All the chromite deposits, which are localized in various forms and horizons, derive from the first concentration centre. Therefore, all the deposits are products of injection. Injection phenomenon as a result of tectonic pressures may take

Photograph 1 - A chromite deposit of banded type (Orhaneli) Bursa

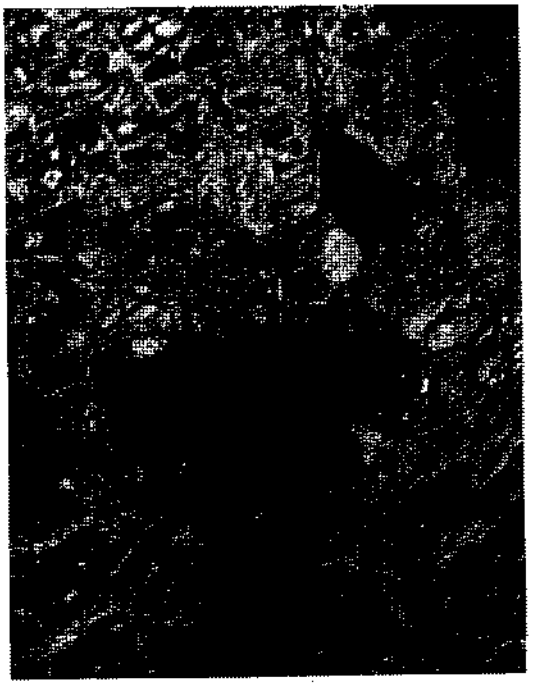
Photograph 2 - «Kırmızı Tarla» mine = injected chromite veins cutting horizontal and parallel serpentine formations

Photograph 3 - Ore with a banded structure
Scale = 1/2; (Orhaneli) Bursa

Photograph 4 - A chromite mine with banded type of ore; vertical bands are seen. (Orhaneli) Bursa



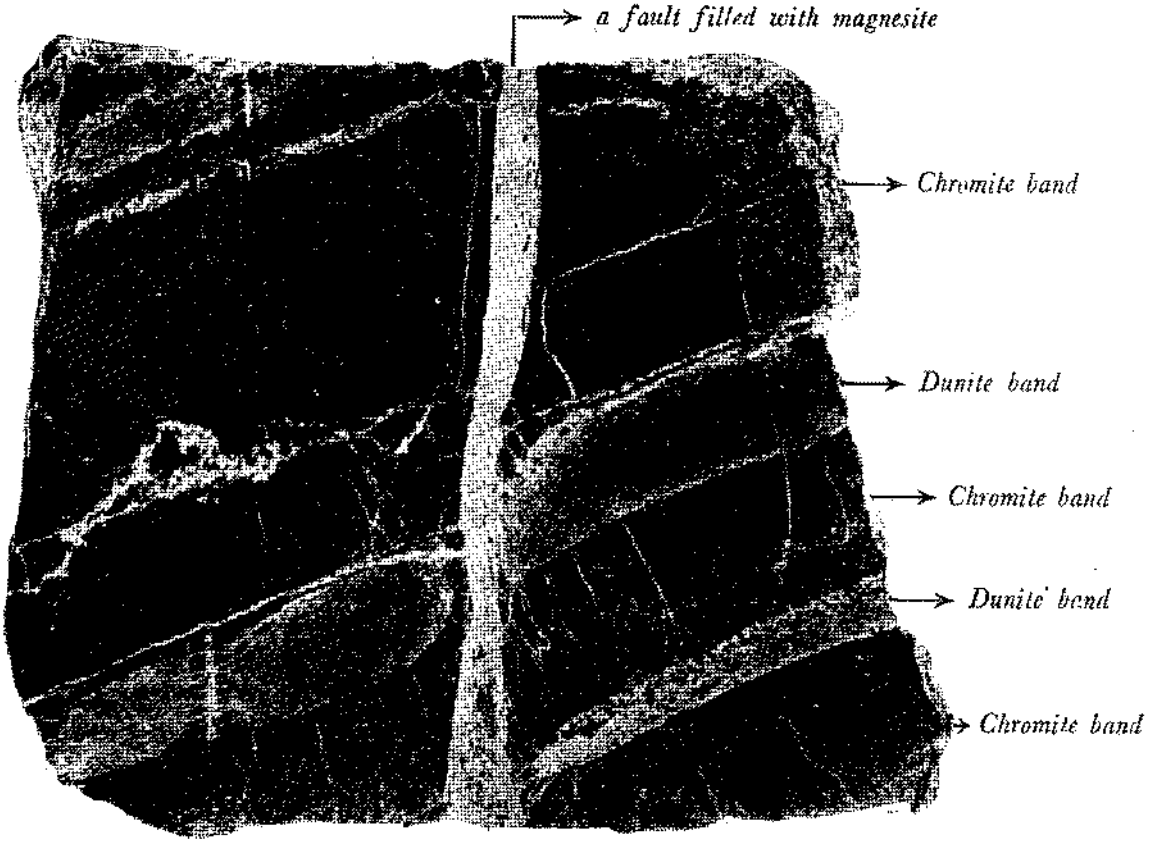
Photograph 5 - Hypidiomorphic chromite crystals in dunite; crossed nicols; magnification 26 times



Photograph 6 - Magmatic corrosion (chromite in dunite); crossed nicols; magnification 80 times

Photograph 7 - Chromite nodules; scale = 1/2; Oval nodules are parallel to each other in the direction of their long-axes

Photograph 8 - Injected chromite veins scale = 1/2; Kırmızı Tarla (Danacık) İslâhiye



Photograph 9 - A piece of ore filled with magnesite along sliding planes

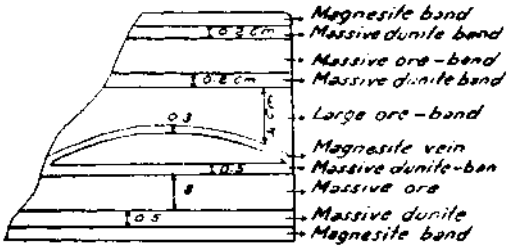


Fig. 5 - Another banded ore

place either in dunite magma, while being fluid, or may occur in the cracks which are formed in the shell of consolidated dunite magma. The first type of injections produces lenticular shaped ore-bodies. Schillerian and banded deposits are brought about by the second type of injections. Chromite lenses take shape by movements during injection. On the other hand, schillerian or banded veins take form and dip of the cracks. Tectonic pressures play the main part in the injection process because veins and lenses possess a certain common direction. The second tectonic movements after chromite injections caused fracturing of ore-bodies. At this stage, ores were subjected to silicification and carbonate inclusion.

There are indications that chromite injections occurred simultaneously with intrusion of the basic magma. A number of chromite occurrences localized in the upper parts of intrusion, but they were never observed to pass over the basic magma horizon. In Köycegiz - Fethiye district, there are schillerian veins; lenses occur in Hatay district; and banded vein deposits prevail in Orhaneli region.

CONCLUSIONS

In order to make a programme on the ore-production, it is essential to determine the ore - reserves. We have obtained some information on serpentinized pcridotite fields of Turkey taken from the recent years production activities. Some knowledge regarding the form of ore - deposits and chromite accumulation centres of every ore-field in Turkey exists in the literature and in the minds of chrome miners. It will be rather valuable to make explorations by core-drilling in the concentration centres of the important deposits by considering the main principles outlined above. Diamond drill - holes to be executed will have to be restricted to the accumulation centres of ore - bodies, so that a wastage of money and time may be avoided.

In oil - drillings, the productivity ratio is 10 to 1 (in U.S.A.). So it is necessary to carry out a similar experiment for chromite deposits in Turkey. The investigation of cores, recovered below the hydrostatic level, will reveal the origin and the nature of serpentinization. In short, prospecting, detailed studies and exploration of the important chromite occurrences exploited in the past or being active now, must be preferred to prospecting of new deposits. Because the future of chrome ore - production in Turkey is depended upon this.

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