

## CHROMITE OCCURRENCES IN IRAQI ZAGROS

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### ABSTRACT

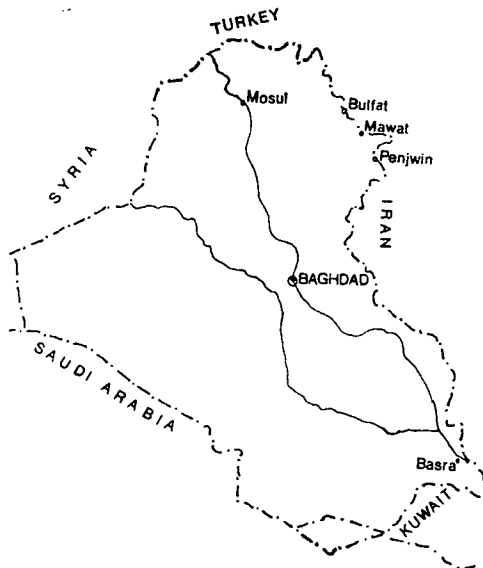
Ultrabasic rocks (harzburgite, wherlites and dunites) occurring in the northeastern Iraqi Zagros thrust zone, contain massive podiform, schlieren and accessory type chromites.

Aluminium and chromium-rich chromites have been distinguished in the ophiolitic complexes of Mawat and Penjwin Mountains. The first variety was probably originated as cumulate whereas the second one was residuum after partial melting of rising mantle. Fe-rich accessory-type chromite have been found in Bulfat formed as a differentiated product of a large gabbro intrusion.

Alteration of chromite is widespread and probably was formed simultaneously with the serpentinization. Reaction between chromite and host rock, initiated by water, resulted the formation of iron-rich rim around chromite grains and chlorite or serpentine, depending on the chromite composition.

### INTRODUCTION

Chromite-bearing ultramafic rocks located at Penjwin, Mawat and Bulfat areas in northeast Iraqi Zagros thrust zone (*Fig. 1.*). The former two localities belong to the ophiolitic complexes and have very similar petrological characters whereas the latter one may be a differentiated product of a large gabbroic intrusion.



*Fig. 1.* Location map.

H-1088 Budapest, Múzeum krt. 4/A Hungary.

Complete ophiolitic rock sequences occur in Mawat. The ultramafic rocks are mostly serpentized harzburgite, wherlite and dunite (olivine  $Fo_{93-97}$ ) with chromite (BUDA *et. al.*, 1977). The upper part of the ultrabasic body contains olivine websterite (Fig. 2., Table 1.) which forms dikes in the peridotite, too. Above the ultrabasic rock there is an about 1000 metre thick gabbroic body emplaced tectonically. Two types of gabbro can be distinguished: a strongly sheared, banded, and foliated amphibole- and a coarse-grained pyroxene gabbro. Small plagiogranite and diorite intrusions occur along the main tectonic zones probably as leucocratic differentiates of the gabbroic body. The upper part of gabbro grades into diabase which was metamorphosed under the conditions of the greenschist facies together with the basalt which occurs above the diabase. The chemical composition of basalt is oceanic tholeiite or sometimes spilitic. Pillow structure can be observed. The Penjwin ophiolitic complex has same suite but the volcanic sequences are completely missing. The ultrabasic rocks are mostly harzburgite (olivine  $Fo_{95-97}$ ), dunite and wherlite (Fig. 2. Table 1.). The two ophiolitic complexes are emplaced tectonically without any contact metamorphism. The only thermal contact which occurs at Penjwin (Asnawa) is due to a later dioritic intrusion after the emplacement of the ophiolitic complex.

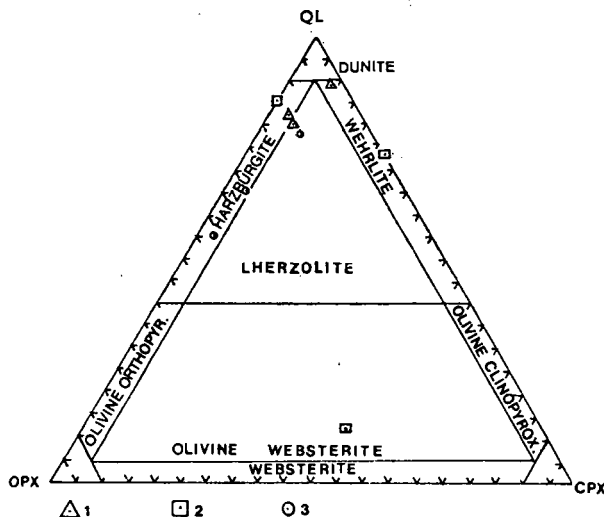


Fig. 2. Classification of ultrabasic rocks from Mawat, (1) Penjwin (2) and Bulfat (3)

The Bulfat ultrabasic and gabbroic complex differs from the others. It is an intrusion with high temperature contact aureole (cordierite + K-feldspar + sillimanite hornfels, predazzite, opicalcite). The ultrabasic rocks are rich in pyroxene (Fig. 2. Table 1.) and contain iron-rich chromite in small amount.

#### METHOD OF STUDY

About 40 polished ore and thin sections of chromite and chromite bearing rocks were studied in reflected and transmitted light and by microprobe. Universal stage was used for determining optical properties of silicate minerals (olivine, pyroxene,

Chemical analyses of ultrabasic rocks from Northeast Iraq

TABLE 1

	Penjwin			Mawat			Bulfat		
	1.	2.	3.	1.	2.	3.	1.	2.	3.
SiO <sub>2</sub>	35.64	40.00	39.82	40.99	42.98	49.50	40.14	38.71	38.51
TiO <sub>2</sub>	0.00	0.00	0.00	0.03	0.06	0.13	0.06	0.14	0.09
Al <sub>2</sub> O <sub>3</sub>	0.85	0.85	0.32	2.13	2.63	2.75	0.60	0.90	1.27
Cr <sub>2</sub> O <sub>3</sub>	0.21	0.17	0.13	0.86	0.88	0.00	0.08	0.14	0.33
Fe <sub>2</sub> O <sub>3</sub>	4.31	3.23	3.64	2.02	1.11	3.30	3.60	6.78	7.10
FeO	3.35	4.14	3.85	5.06	7.27	3.72	4.03	1.84	2.00
MnO	0.10	0.10	0.10	0.08	0.13	0.03	0.10	0.09	0.13
MgO	40.70	43.00	42.96	44.01	37.36	24.86	42.86	38.20	35.56
CaO	2.03	1.40	1.61	1.17	7.43	11.83	1.75	1.40	1.32
Na <sub>2</sub> O	0.10	0.15	0.10	0.09	0.15	0.24	0.10	0.15	0.10
K <sub>2</sub> O	0.04	0.04	0.05	0.02	0.03	0.03	0.04	0.04	0.03
P <sub>2</sub> O <sub>5</sub>	0.10	0.07	0.10	0.00	0.00	0.00	0.07	0.10	0.09
CO <sub>2</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H <sub>2</sub> O <sup>+</sup>	9.86	5.10	6.00	4.03	0.30	3.51	5.00	10.69	11.93
H <sub>2</sub> O <sup>-</sup>	0.60	0.16	0.12	0.25	0.22	0.26	0.21	0.43	0.88
Total	97.89	98.41	98.80	100.74	100.55	100.2	98.64	99.61	99.34

CIPW NORMS									
Or	0.27	0.25	0.32	0.12	0.16	0.18	0.25	0.27	0.20
Ab	0.97	1.36	0.91	0.79	1.28	2.12	0.91	1.43	0.98
An	2.00	1.64	0.30	5.55	6.53	6.61	1.15	1.88	3.38
Di	6.84	4.16	5.95	0.37	24.39	42.77	5.99	4.07	2.73
Hy	3.00	12.90	13.47	13.02	—	32.57	13.30	26.41	34.99
Ol	79.04	74.12	72.83	75.32	64.32	10.50	72.36	55.51	46.32
Mt	7.15	4.03	5.69	3.04	1.65	4.39	5.59	6.09	6.48
He	—	—	—	—	—	—	—	3.46	3.74
Ap	0.27	0.18	0.25	—	—	—	0.17	0.26	0.24
Il	—	—	—	0.06	0.12	0.25	0.12	0.30	0.20
Cr	0.49	0.37	0.29	1.83	1.33	—	0.18	0.32	0.78

Penjwin: 1. Dunite-wehrlite (37A)\*; 2. Harzburgite (107); 3. Harzburgite (111)

Mawat: 1. Harzburgite (average 4 analyses); 2. Wehrlite (1 analysis); 3. Olivine websterite (average 5 analyses)

Bulfat: 1. Harzburgite (213); 2. Harzburgite (166); 3. Harzburgite (212)

\* Sample number

stc.) and Leitz MPV2 microscope photometer was applied for measuring the reflectivity of chromite using different wave lengths (542 nm, 584 nm, 640 nm). The chromite and olivine were separated by heavy liquids and were investigated by X-ray powder methods. The chromite cell sizes were measured following STRAUMANIS method and the forsterite content of olivine was determined by using the (130) reflection (YODER *et al.*, 1957) and by 2V determination. Cameca microprobe was used for quantitative chemical analysis of chromite applying the MBXCOR computer software introduced at the 3th International Conference of X-ray Optics and Microanalysis held at Boston in 1977. FeO was re-expressed as FeO and Fe<sub>2</sub>O<sub>3</sub> on the assumption that RO=R<sub>2</sub>O<sub>3</sub> in spinel structure (Ti and Si were assumed to occupy trivalent sites). Some altered grains were selected and Fe, Cr, Al and Mg distribution were determined across these grains.

## MINERALOGY AND PETROGRAPHY OF THE CHROMITE OCCURRENCES

At Penjwin and Mawat three types of chromite occurrences have been distinguished (1) accessory-type chromite (chromite content 2—5 V%). (2) schlieren-type chromite (chromite content 20—25 V%). (3) massive chromite ore (chromite content is more than 80 V%).

In Bulfat only euhedral or subhedral accessory-type chromite have been found.

### 1. Accessory-type chromite

The ultrabasic rocks usually contain about 2—5 V% chromite which is mostly euhedral or subhedral, corroded and it normally has an altered iron-rich rim. The host rocks are strongly sheared, foliated and serpentinized. Besides serpentine, talc, Mg-chlorite, brucite and magnetite are also present. Magnetite is mostly secondary, originated by serpentinization of olivine. Talc and Mg-chlorite formed from Al-bearing pyroxene and from chromite altered during the serpentinization.

Before the complete or partial serpentinization the ultrabasic rocks were harzburgite, dunite in Penjwin, wherlite, harzburgite, dunite in Mawat and pyroxene-rich harzburgite in Bulfat (original compositions were estimated from chemical analyses).

*1.1. Penjwin.* The chromite is subhedral transected by cracks and altered along the rims and cracks into iron-rich chromite. The chromites in dunite are somewhat richer in Cr which contain a lower amount of Al (Table 2.). The reflectance is low ( $R_{542\text{ nm}}\% = 12.5\%$ ) which indicates a lower iron content, too. The grains are surrounded by serpentine. Increasing pyroxene content of the rocks resulted in a relative enrichment of aluminium.

*1.2. Mawat.* The same alteration phenomenon can be recognized in Mawat but differences between chromite compositions occurring in different rock types are more obvious. The chromite in dunite has high chromium content and in pyroxene-bearing rocks the chromite is aluminium-rich and the grains are surrounded by Mg-chlorite (Table 3.).

*1.3. Bulfat.* The chromite grains are always euhedral without any alteration rim and are surrounded by chromium-bearing Mg-chlorite and by magnetite. The chromite is rich in iron. (Table 2.). Under reflected light, it shows high reflectance  $R\%_{542\text{ nm}} = 16,9$ ) due to the high iron content.

### 2. Schlieren-type chromite

This type occurs around the massive chromite lenses or scattered irregularly in peridotite. The grains are mostly rounded subhedral, corroded and reddish brown in transmitted light. The host rock is always dunite which is frequently altered to serpentine. The forsterite content of olivine is high (Penjwin =  $\text{Fo}_{98}$ , Mawat =  $\text{O}_{93}$ ). The chemical composition of chromites are very similar in both occurrences, so called subferrichromite with high  $\text{Cr}_2\text{O}_3$  content. (Table 2, 3).

### 3. Massive chromite

The shape of chromite bodies are variable occurring mostly as lens-like or podiform surrounded by dunite halos. The sizes of these bodies are larger in Mawat (thickness 0,5 m up to 2,7 m) than in Penjwin (0,1 m up to 0,5 m). In Mawat two types of ore can be distinguished: in the first one the main gangue mineral is tremolite ( $\gamma/\text{C} = 19^\circ$ ,  $2\text{V} = -83^\circ$ ) and the ore is slightly crushed and the grains are mostly sub-

TABLE 2

## Chromite analyses

wt %	Penjwin					Bulfat				
	Accessory-type chromites				Schlieren-type chromite	Massive chromite	Accessory-type chromite			
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Cr <sub>2</sub> O <sub>3</sub>	46.43	48.10	42.40	41.87	59.26	54.59	58.10	54.06	46.92	48.39
Al <sub>2</sub> O <sub>3</sub>	19.23	16.67	19.91	23.62	10.35	10.77	9.59	9.22	6.58	10.61
Fe <sub>2</sub> O <sub>3</sub>	2.92	4.39	6.69	3.22	4.11	7.43	3.86	8.18	14.66	9.70
TiO <sub>2</sub>	0.04	0.23	0.26	0.03	0.15	0.15	0.15	0.09	0.18	0.12
SiO <sub>2</sub>	0.13	0.01	0.01	0.47	0.08	0.60	0.00	0.35	0.08	0.32
FeO	19.44	20.75	22.14	19.77	10.23	11.70	17.18	18.79	23.06	21.54
MgO	9.26	8.65	7.75	9.81	15.14	14.07	10.42	9.30	5.60	7.37
MnO	0.30	0.26	0.63	1.21	0.11	0.80	0.32	0.84	0.35	0.26
ZnO	0.87	0.28	0.84	—	0.06	—	0.03	—	0.31	0.30
Total	98.62	99.34	100.62	100.00	99.49	100.11	99.65	100.83	97.74	98.61
Numbers of ions on the basis of 4 (0)										
Cr	1.187	1.241	1.075	1.033	1.501	1.381	1.523	1.416	1.320	1.299
Al	0.733	0.642	0.753	0.869	0.391	0.406	0.375	0.360	0.276	0.425
Fe <sup>3+</sup>	0.071	0.108	0.162	0.076	0.099	0.179	0.096	0.204	0.393	0.248
Ti	0.001	0.006	0.006	0.001	0.004	0.004	0.004	0.002	0.005	0.005
Si	0.004	0.000	0.000	0.015	0.003	0.019	0.000	0.012	0.003	0.017
Fe <sup>2+</sup>	0.526	0.567	0.594	0.516	0.274	0.313	0.476	0.521	0.686	0.612
Mg	0.446	0.421	0.371	0.456	0.723	0.671	0.515	0.459	0.297	0.373
Mn	0.008	0.007	0.017	0.032	0.003	0.022	0.009	0.024	0.011	0.008
Zn	0.020	0.007	0.020	—	0.001	—	0.001	—	0.008	0.008
Cr/Cr + Al + Fe <sup>3+</sup>	0.59	0.62	0.54	0.52	0.75	0.69	0.76	0.71	0.66	0.65
Al/Cr + Al + Fe <sup>3+</sup>	0.37	0.32	0.38	0.44	0.20	0.20	0.19	0.18	0.14	0.21
Fe <sup>3+</sup> /Cr + Al + Fe <sup>3+</sup>	0.04	0.05	0.08	0.04	0.05	0.09	0.05	0.10	0.20	0.12
Mg/Mg + Fe <sup>2+</sup>	0.45	0.42	0.37	0.45	0.72	0.67	0.51	0.46	0.30	0.37

1. Chromite core (with altered rim) from serpentinized dunite (No. 37B); 2. Chromite core (with altered rim) from serpentinized dunit (No.82); 3. Chromite core (with altered rim) from serpentinized dunite (No.28A); 4. Chromite core (with altered rim) from peridotite (No. 82); 5. Chromite from olivine chromitite (No. 77); 6. Chromite from olivine chromitite (No. 78); 7. Chromite from olivine chromitite (No. 79); 8. Massive chromite with pyroxene gangue (No. 80); 9. Chromite from peridotite (No. 166B); 10. Chromite from peridotite (No. 131).

hedral with corroded rims. The colour is yellowish brown with reddish brown rim under transmitted light. These grains are slightly altered to Fe-rich chromite along their cracks and margins and are coated by thin layer of Mg-chlorite. According to the chemical composition, this type of ore is a slightly oxidized aluminochromite (RO/R<sub>2</sub>O<sub>3</sub>=0.96). The second ore type is a very strongly crushed and oxidized (RO/R<sub>2</sub>O<sub>3</sub>=0.79) reddish brown (under transmitted light) aluminochromite (Table 3). The only gangue mineral is Mg-chlorite.

In Penjwin the gangue mineral of massive chromite is clinopyroxene and small amount of amphibole together with Mg-chlorite. The chromite is frequently euhedral, corroded and slightly crushed with dark reddish brown colour under transmitted light. Iron content is high (FeO=18.79 wt% Fe<sub>2</sub>O<sub>3</sub>=8.18 wt%) and the aluminium

TABLE 3

## Chromite analyses

	Mawat				
	Accessory-type chromite		Schlieren chr.		Massive chromite
	1.*	2.*	3.*	4.	5.
Cr <sub>2</sub> O <sub>3</sub>	46.50	65.50	56.50	48.43	49.06
Al <sub>2</sub> O <sub>3</sub>	20.75	—	10.00	18.80	18.76
Fe <sub>2</sub> O <sub>3</sub>	4.94	6.66	5.83	2.96	8.70
TiO <sub>2</sub>	—	—	—	0.21	0.06
SiO <sub>2</sub>	—	—	—	0.71	0.90
FeO	11.21	15.85	13.91	14.23	8.80
MgO	15.50	10.20	12.60	12.60	13.60
MnO	—	—	—	0.15	0.16
ZnO	—	—	—	0.48	—
Total	98.90	98.17	98.84	98.57	100.04
Numbers of ions on the basis of 4 (0)					
Cr	1.132	1.824	1.468	1.195	1.186
Al	0.754	—	0.388	0.692	0.676
Fe <sup>3+</sup>	0.115	0.176	0.144	0.069	0.200
Ti	—	—	—	0.005	0.001
Si	—	—	—	0.020	0.020
Fe <sup>2+</sup>	0.289	0.465	0.382	0.372	0.225
Mg	0.712	0.535	0.618	0.586	0.620
Mn	—	—	—	0.040	0.005
Zn	—	—	—	0.011	—
				Ni 0.004	
Cr/(Cr+Al+Fe <sup>3+</sup> )	0.67	0.91	0.73	0.60	0.60
Al/(Cr+Al+Fe <sup>3+</sup> )	0.38	—	0.20	0.19	0.32
Fe <sup>3+</sup> /(Cr+Al+Fe <sup>3+</sup> )	0.05	0.35	0.07	0.06	0.10
Mg/(Mg+Fe <sup>2+</sup> )	0.71	0.54	0.62	0.59	0.73
a <sub>0</sub>	8.267±0.007	8.336±0.007	8.301±0.004	8.268±0.004	8.272±0.003
R % 542 μm	11.9±0.15	core rim 14.9 17.0	13.3±0.16	12.2±0.10	12.3±0.1
Fo content of olivine	93	92	90	—	—

1. Chromite from peridotite (No. 161, 201); 2. Chromite from dunite (No. 160); 3. Chromite from olivine chromitite (No. 211); 4. Massive chromite with tremolite gangue (No. 64); 5. Massive chromite with pyroxens gangue (No. 272)

\* Determined by physical properties

content is low (Al<sub>2</sub>O<sub>3</sub>=9.22 wt%) (Table 2). The ore is subferrichromite according to PAVLOV (1949) nomenclature.

The matrix of the first chromite ore type of Mawat was also clinopyroxene but altered to tremolite. Local reactions between tremolite and chromite resulted, through diffusion of Al, the formation of Mg-chlorite. The matrix of the second ore type was originally olivine which was altered to serpentine and then to Mg-chlorite.

## CHEMISTRY OF CHROMITE

On the basis of the chemical composition of chromites, four groups (Fig. 3) can be distinguished:

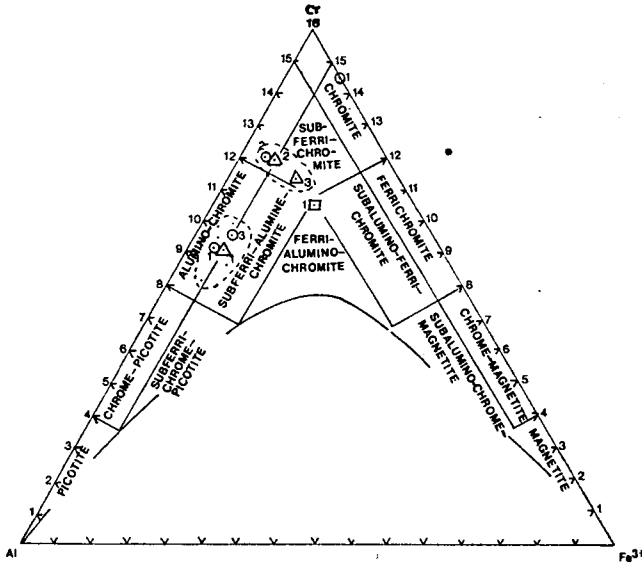


Fig. 3. Atomic proportions of Cr, Al and  $Fe^{3+}$  of chromites from Mawat, Penjwin and Bulfat

- |             |   |   |
|-------------|---|---|
| ○ 1 Mawat   | } | Average composition of accessory chromite |
| △ 1 Penjwin |   |   |
| □ 1 Bulfat  | } | Average composition of schlieren chromite |
| ○ 2 Mawat   |   |   |
| △ 2 Penjwin | } | Average composition of massive chromite   |
| ○ 3 Mawat   |   |   |
| △ 3 Penjwin |   |   |

1. *Aluminochromite*. This group is rich in aluminium (average  $Al_2O_3 = 19.01$  wt%) and in ferrous iron (average  $FeO = 15.99$  wt%). In Mawat, it forms both the accessory and massive-type of chromites ( $a_0 = 8.267 - 8.272 \text{ \AA}$ ,  $R\%_{542nm} = 11.9 - 12.3$ ), whereas in Penjwin it constitutes accessory-type chromite only. The host rock usually contains orthopyroxene in addition to olivine.

2. *Subferrichromite*. Chromites of this group contain a rather high amount of chromium (average  $Cr_2O_3 = 56.6$  wt%) and magnesium (average  $MgO = 12.35$  wt%). They form the so-called schlieren-type chromitite in Penjwin, Mawat and the massive ore-type of Penjwin. The unit cell parameter of subferric chromite is larger than that of aluminochromite ( $a_0 = 8.296 - 8.306 \text{ \AA}$ ).

3. *Chromium-rich chromite*. These chromites ( $Cr_2O_3 = 65.5$  wt%) occur in small amount in dunitic rocks of Mawat ( $a_0 = 8.336 \text{ \AA}$ ,  $R\%_{542nm} = 14.9$ ).

4. *Ferrichromite*. This chromite contains high amount of ferric and ferrous iron ( $Fe_2O_3 = 12.10$  wt%,  $FeO = 22.3$  wt%); and is found only in the pyroxene-rich (harzburgite) rocks of Bulfat. The reflectance is strong ( $R\%_{542nm} = 17$ ) due to the high iron content.

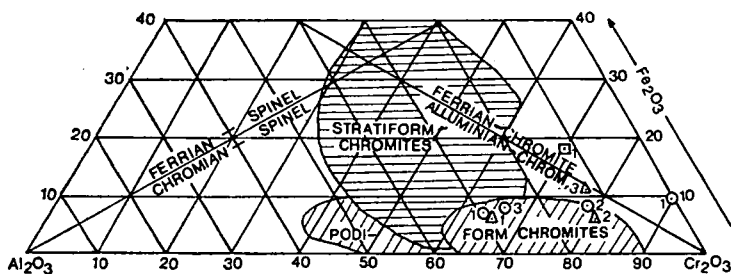


Fig. 4.  $\text{Cr}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  variation in chromites from Mawat, Penjwin and Bulfat (after THAYER, 1964).

- |             |   |
|-------------|---|
| ○ 1 Mawat   | } Average composition of accessory chromite |
| △ 1 Penjwin |   |
| □ 1 Bulfat  |   |
| ○ 2 Mawat   | } Average composition of schlieren chromite |
| △ 2 Penjwin |   |
| ○ 3 Mawat   |   |
| △ 3 Penjwin |   |

The  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{Cr}_2\text{O}_3$  contents of chromites were plotted in THAYER's (1964) triangular diagram (Fig. 4) which show that the composition of Mawat and Penjwin chromites are similar to the composition of Alpine-type podiform chromites. The aluminium-rich chromites are very near or in the field of stratiform chromites where two compositional fields overlap. The subferrichromites are little far but also in or near to the field of podiform chromite. Dunitic accessory chromite of Mawat is on the  $\text{Fe}_2\text{O}_3$ - $\text{Cr}_2\text{O}_3$  line. The accessory ferrichromite of Bulfat is far from the fields of stratiform and podiform chromites indicating a different origin.

The low  $\text{TiO}_2$  content of Mawat and Penjwin chromites (0,03—0,26 wt%) is also characteristic of the podiform chromites (in stratiform chromite  $\text{TiO}_2$  content is higher than 0,3 wt%, according to DICKEY, 1975).

In Mawat and Penjwin average of the  $\text{Cr}/(\text{Cr} + \text{Al} + \text{Fe}^{3+})$  cation ratio of chromite in pyroxene-bearing rocks is 0.61 and in dunitic chromite 0.72 which indicates an aluminium enrichment in chromites occurring with pyroxenes. In Bulfat the lower Al and higher Fe content of chromite indicates a lower crystallization temperature in harzburgite with closed genetic connection of overlying gabbro.

#### TEMPERATURES OF FORMATION

Temperatures of formation of chromites can be calculated from cation distribution between coexisting olivine and chromian spinel, if equilibrium and ideal solid solution exist in the system, following the equations introduced by IRVINE, (1963) and JACKSON, (1969). The temperature of formation obtained from this equation was about 1350 °C in harzburgite and dunite in Mawat and Penjwin and 1150 °C in Bulfat. Unfortunately the host rock of massive chromite of Mawat is altered and was not possible to measure the cation distribution directly; therefore it was estimated. The range of estimated temperatures was around 1200—1250 °C. These values correspond to the temperature of formation of the Alpine-type peridotite, for example Burro Mountain (LONEY *et. al.*, 1971) and Massif due Sud, New Caledonia (RODGERS, 1973).



## ALTERATION

Alteration of ultrabasic rocks is a widespread phenomenon in all occurrences. Along the main tectonic zones the rocks are completely altered and behaved as a lubricant for advancing tectonic movement. The olivine altered to serpentine and pyroxene altered to talc, tremolite and chlorite depending on Al and Ca content of the different types of pyroxenes. The nearly equal MgO/SiO<sub>2</sub> ratios in peridotite (1.03) and in serpentinite (1.02) require larger amount of brucite formation (COLEMAN, 1971). However, only small amount of this mineral was detected due to the leaching caused by latter processes. The kink-bands and serpentinization along the cracks of deformed olivine, and alteration of the chromite along fractures suggest a deformation before and during serpentinization. The presence of other fractures in chromite without alteration indicate a further deformation after serpentinization.

A special attention was given to the alteration processes which affected chromites. Detailed microprobe traverses were carried out across different types of chromites to investigate the main element distribution in the altered rims and in the core of the crystals. One traverse was carried out across the accessory chromite of serpentinized pyroxene-poor olivine-rich harzburgite of Penjwin area and another across the accessory chromite of harzburgite from Mawat. According to these investigations the altered, strongly reflecting chromite rim is very rich in iron and poor in chromium, magnesium and aluminium in both cases. The iron content is gradually decreasing towards the core and chromium content increasing. Magnesium and aluminium contents are very low in the rim which suddenly increase at the very border of the altered and unaltered parts.

The chromite from Mawat is richer in Al (*Fig. 5*) and coated by Mg-chlorite. It is supposed that during the alteration, Al-rich chromite released aluminium by diffusion to form Mg-chlorite from the surrounding Mg-silicates. Accordingly, relative enrichment of iron took place in the rim, indicated by its strong reflectance. The relatively aluminium poor chromite from Penjwin (*Fig. 6*) had not released enough aluminium to form chlorite, therefore the altered chromite grains surrounded by serpentine, only. Along the cracks, inside the crystals iron enrichment also occurs. This phenomenon supports the theory of the simple alteration. According to this theory the volatiles caused the alteration of chromite and the silicates, too. However, the possibility of secondary chromite overgrowth as suggested by ULMER, (1974) could not be excluded.

Well developed alteration rim did not formed around the euhedral iron-rich Al-poor chromite in Bulfat. However, in few cases a very narrow magnetite rim occurs. The grains are surrounded by sometimes Mg-chlorite which can be found in other parts of the rock, too, without any connection with the chromite but attached to the altered parts of pyroxenes. Therefore chlorite most probably formed from Al-containing orthopyroxene. The sources of water which was needed for the alteration are obscure because ultramafic melts do not contain enough water for extensive serpentinization (BOWEN *et al.*, 1949). Therefore, excess water could have been derived either from the mantle (HESS, 1962) or from the wet sediments.

## CONCLUSIONS

The ultrabasic rocks of the ophiolitic complexes of northeast Iraqi Zagros thrust zone contain two main types of chromite: an Al-rich one (Cr/Al=1.6) occurs in pyroxene-bearing ultramafite (harzburgite) which can be a cumulite; and Cr-rich

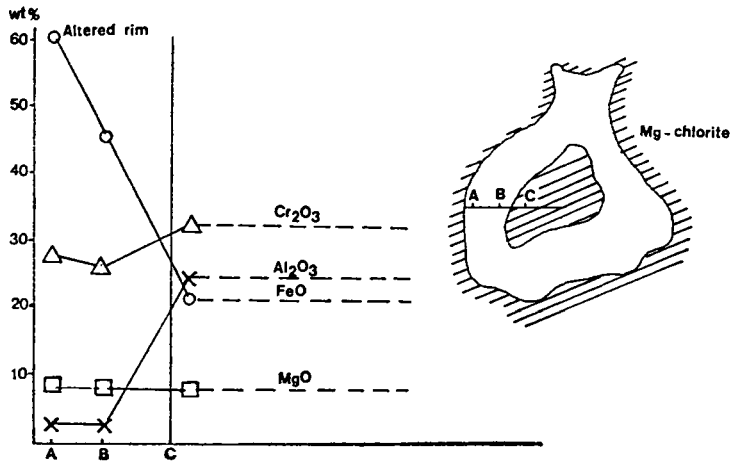


Fig. 5. Microprobe traverse across an altered accessory chromite from Mawat (surrounded by Mg-chlorite)

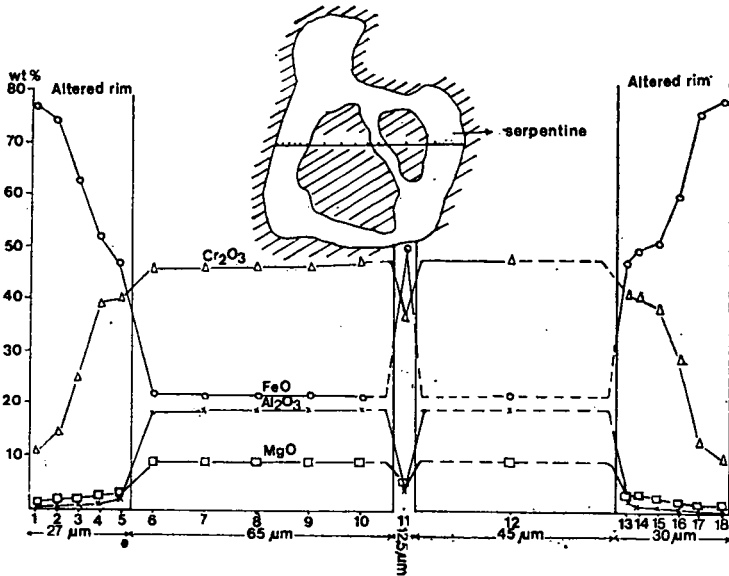


Fig. 6. Microprobe traverse across an altered accessory chromite from Penjwin (surrounded by serpentine).

one ( $Cr/Al=3.8$ ) mostly in olivine-rich rock formed as a residuum after partial melting of rising mantle material. Fe-rich chromite of the pyroxene-bearing rock of Bulfat Mountain most probably formed as a differentiated product of a large gabbroic intrusion.

The Mg-content of chromite ( $Fe^{2+}/Mg=0.8$ ) of Mawat and Penjwin is higher than of Bulfat ( $Fe^{2+}/Mg=1.97$ ) which is further confirmation of podiform (Alpine-

type) origin of the previous one and formation by differentiation of the latter one. The ophiolitic peridotite belongs to the olivine-pyroxene-spinel facies which can form at high temperature (1350 °C) and at moderately high pressure. Such conditions exist only in the upper part of the mantle (MACGREGOR, 1967).

The lenticular occurrences of massive, strongly fractured schlieren- and accessory-type chromites and kink-bands in olivine indicate a strong deformation which probably happened when the peridotite was carried up as a solid slab (no thermal contact). After the emplacement a serpentinization of the olivine and alteration of the pyroxene and chromite took place. The second phase of deformation crushed the chromite again when the igneous massif was overthrust on the sediments. In Bulfat the extensive high temperature contact of gabbro suggests a postorogenic intrusion.

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