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MICROPROBE ANALYTICAL DATA ON CHROMITITES FROM THE MUSLIMBAGH OPHIOLITE, BALUCHISTAN, PAKISTAN

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ABSTRACT

Thirteen chromitites associated with ultramafic rocks of Muslimbagh consist of high chromium Al-chromite + serpentine ± chlorite ± magnetite ±Mg-Fe carbonate±olivine. Ultramafic tectonites cannot be distinguished from ultramafic cumulates on the basis of chromite composition in the chromitites. However, chromitites associated with the tectonites tend to have zoned and those in the cumulates unzoned chromite. The outer zones have developed during the alteration (principally chloritization) of the rocks and are enriched in $Fe''/(Fe''+Mg)$ *and, in some cases,* $Cr/(Cr+Al)$. *One analyzed olivine is highly magnesian* (Fo_{96}) *due possibly to an exchange of* $Fe \rightleftharpoons Mg$ *with the associated chromite at 700–800°C.*

INTRODUCTION

The Zhob Valley Ophiolite Belt of NW Baluchistan is the largest (> 5000^2 km) and best known occurrence of its type in Pakistan. It extends intermittently in a WSW–ENE direction for about 250km between the Chaman transform fault to the west and the Indo-Pakistan shield to the east. It belongs to the Tethyan belt of ophiolites, especially those of the Indus suture (Gansser, 1964). The best exposures in the Zhob Valley are in the Muslimbagh-Nasai area where some of the larger hills are entirely made up of these rocks (Bilgrami, 1964a). The Zhob ophiolites have been studied by many workers (see Ahmad, 1974; Moore *et al.*, 1980 for bibliographies). The following account of the ophiolite is mainly from Moore *et al.* (1980).

The Muslimbagh ophiolite consists of two principal tectonic massifs, the Saplai Tor Ghar-Nasai and the Jang Tor Ghar (Fig. 1), which are surrounded by melange containing blocks of pillow lava, diabase, serpentine, limestone marble, and clastic sediments. Serpentine slivers in the melange contain exotic blocks of sedimentary rocks, including radiolarite and marble, basalt and gabbro. Slivers of metamorphic rocks occur at several places immediately below the ophiolite masses. The Muslimbagh ophiolite tectonically overlies Maestrichtian and older rocks of the Indo-Pakistan plate and is overlain unconformably by shallow marine limestone of Eocene age. Ahmad and Abbas (1979), and Allemann (1979) consider that it was emplaced during the Paleocene.

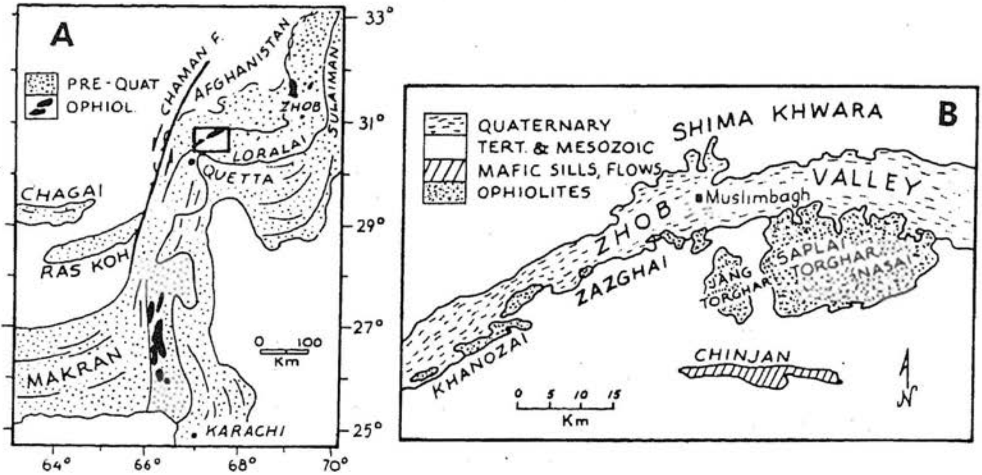

Fig. 1. Schematic geological map of Pakistan (A) showing general location of ophiolites and other major tectonic features. Area in rectangle is enlarged in B. (After Moore *et al.,* 1980).

The ophiolite complex consists of ultramafic tectonites, mafic and ultramafic cumulate rocks, a dyke complex, and a dolerite dyke swarm. Pillow lavas do not occur in the main mass; they are found as slivers in the melange. The tectonites are serpentinized to different degrees, and consist of about 70% peridotite (mainly lherzolite) and 30% dunite. The structures and layering of the tectonites generally plunge and dip southeastwards. Their prime area of exposure is the Jang Tor Ghar.

Southwest of the tectonite there is a thick sequence of cumulate rocks with several cyclic units from a few to several tens of meters thick. Commonly, these are olivine cumulates at the base and pass upwards through a thin layer of wehrlite into clinopyroxenite cumulate. The contact between the tectonite and cumulate ultramafic rocks appears to be planer and parallel to the attitude of the overlying cumulate rocks. Plagioclase appears locally but in some of the uppermost cumulates there are anorthosites as well as gabbros, which are well-layered with an igneous lamination.

The mafic to trondhjemitic dyke complex intrudes gabbro or diorite screens. A few trondhjemitic dykes cut all pre-existing rocks. A characteristic feature of the ophiolite complex is the large number of dolerite (**tholeiitic) dykes**. They reach up to 15m in thickness, intrude all the preexisting rocks, and some are composite and display chilled margins.

Chromite Deposits

The Muslimbagh complex has been mined for chromite since the beginning of this century. Chromite occurs as pods, lenses, layers, stringers, transgressive veins and as disseminated grains. The host rocks are serpentinized dunites of the ultramafic tectonites and cumulates. However, some layers are also associated with harzburgite. Textural varieties include banded, massive, globular, grape-shot, some have pull-apart and other features commonly found in alpine-type occurrences; several subvarieties are described in detail by Bilgrami (1964a, 1964b, 1968, 1969). The chromite bodies are isoclinally folded (Moore *et al.*, 1980) and most mineable ore is found at the hinges of isoclinal folds. In the ultramafic cumulates tabular ore bodies are more regular, persistent along strike, and are only locally folded. Annual production has been estimated at 25,000 to 30,000 long tonnes of metallurgical grade ore and a few hundred tonnes of chemical grade ore in the Zhob valley (Ahmad, 1975).

MICROPROBE ANALYSES

Chromite

At least 57 wet chemical analyses of cleaned chromites from the Zhob Valley have been published (Asrarullah, 1960; Bilgrami and Ingamells, 1960; Bogue, 1962; Bilgrami, 1963, 1968, 1969; Shams and Ahmad, 1972; Ahmad, 1976). Wet analyses are appropriate to determine the average composition of chromite and, in monomineralic rocks, give an idea of economic potential. However, recent data obtained on some other chromites indicate significant chemical variation within and between grains. For these reasons we collected thirteen samples of chromitites from the ultarmafic rocks of the Muslimbagh ophiolite for microprobe investigation. Samples GA–2, 3 and 10 are hosted by ultramafic cumulates and the remainder by ultramafic tectonites. Microprobe analyses of 26 chromites in the samples are presented in Table 1. Chromite deposits of economic significance do not occur above the horizons we sampled.

Various aspects of the chemistry of the Zhob Valley chromites have been discussed at length in the papers cited above. Bilgrami (1969) found variation in Cr, Mg, and total iron in chromites from different localities, and a general decrease in Cr/Fe ratio from W to E. Our samples, however, were not collected for this kind of study. A comparison of the wet and microprobe analyses of the Zhob chromites is made in Table 2. The Zhob data do not include chromitite whole-rock analyses presented by Bilgrami (1964b). The table shows that the wet chemically analysed chromites have a wider range for many oxide percentages and cation ratios probably due to their greater number than the microprobe analyses.

All the samples investigated by us contain alumino-chromtie with high Cr_2O_3 content (55.5 to 62.3%). Although the chromite modal content of the samples ranges from ~ 15% (GA–5) to ~ 90% (GA–10), no significant chemical

TABLE 1. MICROPROBE ANALYSES OF CHROMITES FROM MUSLIMBACH CHROMITE-RICH ROCKS

	G.A. 13 (11)	G.A. 1 (6)	G.A. 2 (6)	G.A. 3 (6)	G.A. 4 Centre (6)	G.A. 4 Local Margin (1)	G.A. 5 (6)	G.A. 6 (6)	G.A. 7 (6)	G.A. 8 (9)	G.A. 9 Grain IV Brown Centre (1)	G.A. 9 Grain IV Brown Margin (1)	G.A. 9 Grain IV Black Periphery (1)
SiO_2	0.30	0.22	0.30	0.33	0.27	0.28	0.33	0.44	0.23	0.46	1.33	0.48	0.42
TiO_2	0.19	0.15	0.24	0.23	0.21	0.17	0.18	0.27	0.17	0.17	0.17	0.31	0.23
Al_2O_3	10.81	8.95	9.73	11.04	10.52	8.05	8.98	12.09	11.84	7.93	9.20	9.19	4.87
Cr_2O_3	59.27	61.60	59.49	57.93	58.13	61.79	60.13	55.51	58.26	61.74	60.06	60.70	57.76
Fe_2O_3	2.67	1.86	2.80	3.25	4.11	2.51	3.61	4.01	2.56	2.93	1.01	1.78	6.52
FeO	12.30	12.17	12.32	11.65	12.18	12.66	11.57	12.50	13.44	11.18	14.50	17.22	20.16
MnO	0.33	0.15	0.38	0.31	0.30	0.28	0.39	0.15	0.19	0.25	0.21	0.29	0.60
MgO	14.17	13.88	13.85	14.51	14.18	13.49	14.32	14.28	13.61	14.62	13.52	11.31	8.03
TOTAL	100.04	98.98	99.11	99.26	99.90	99.23	99.51	99.25	100.30	99.28	100.00	101.29	98.59
NUMBER OF IONS ON THE BASIS OF FOUR OXYGENS													
Si	0.010	0.007	0.010	0.011	0.009	0.009	0.011	0.014	0.007	0.015	0.043	0.016	0.015
Ti	0.005	0.004	0.006	0.006	0.005	0.004	0.004	0.007	0.004	0.004	0.004	0.008	0.006
Al	0.408	0.344	0.373	0.418	0.398	0.311	0.343	0.456	0.445	0.304	0.350	0.352	0.200
Cr	1.500	1.589	1.528	1.471	1.475	1.600	1.539	1.406	1.470	1.586	1.532	1.558	1.588
Fe'''	0.064	0.046	0.069	0.079	0.099	0.062	0.088	0.097	0.061	0.072	0.024	0.044	0.171
Fe''	0.329	0.332	0.335	0.313	0.327	0.347	0.313	0.335	0.359	0.304	0.391	0.468	0.587
Mn	0.009	0.004	0.010	0.008	0.008	0.008	0.011	0.004	0.005	0.007	0.006	0.008	0.018
Mg	0.676	0.675	0.671	0.695	0.679	0.659	0.691	0.682	0.648	0.708	0.650	0.547	0.416
Z	1.987	1.990	1.986	1.985	1.986	1.986	1.985	1.980	1.987	1.981	1.953	1.978	1.980
Y	1.014	1.011	1.016	1.016	1.014	1.014	1.015	1.021	1.012	1.019	1.047	1.023	1.021
$100\ Mg/(Mg+Fe'')$	67.3	67.0	66.7	68.9	67.5	65.5	68.8	67.1	64.3	70.0	62.4	53.9	41.5
$100\ Cr/(Cr+Al)$	78.6	82.2	80.4	77.9	78.8	83.7	81.8	75.5	76.8	83.9	81.4	81.6	88.8
$100\ Fe'''/(R''')$	3.2	2.3	3.4	4.0	5.0	3.1	4.5	5.0	3.1	3.7	1.3	2.3	8.7
$100\ Al/(R''')$	20.7	17.4	18.9	21.2	20.2	15.8	17.4	23.3	22.5	15.5	18.4	18.0	10.2

	G.A. 9 Grain III Brown Centre (1)	G.A. 9 Grain III Brown Margin (1)	G.A. 9 Grain II Centre (1)	G.A. 9 Grain II Margin (1)	G.A. 9 Grain I Centre (1)	G.A. 9 Grain I Margin (1)	G.A. 10 (6)	G.A. 11 Centre (3)	G.A. 11 Black Margin (3)	G.A. 12 3 centres and 2 margins (5)	G.A. 12 Grain II Core (1)	G.A. 12 Grain II Centre (1)	G.A.12 Grain II Margin (1)
SiO_2	0.41	0.26	0.39	0.27	0.39	0.34	0.42	0.32	0.37	0.35	0.27	0.30	0.20
TiO_2	0.22	0.25	0.11	0.17	0.24	0.24	0.18	0.18	0.21	0.22	0.33	0.14	0.35
Al_2O_3	9.34	9.19	3.57	2.44	5.38	3.56	11.04	10.93	11.10	9.04	9.22	9.40	9.31
Cr_2O_3	61.29	59.77	62.25	59.81	59.19	62.02	58.43	59.55	59.69	58.86	59.37	61.20	59.65
Fe_2O_3	1.93	2.86	5.34	10.23	3.79	5.07	1.32	2.73	0.00	2.22	2.90	2.92	3.01
FeO	13.11	18.62	21.09	20.58	21.39	22.07	13.19	11.94	13.91	19.09	14.90	12.85	18.58
MnO	0.49	0.39	0.32	0.47	0.61	0.57	0.38	0.31	0.28	0.47	0.54	0.28	0.35
MgO	13.57	10.14	7.89	8.13	7.20	7.13	13.32	14.54	12.34	9.46	12.15	13.86	10.26
TOTAL	100.36	101.48	100.95	102.11	98.19	101.00	98.28	100.49	97.90	99.70	99.68	100.95	101.70
NUMBER OF IONS ON THE BASIS OF FOUR OXYGENS													
Si	0.013	0.009	0.013	0.009	0.014	0.012	0.014	0.010	0.012	0.012	0.009	0.010	0.007
Ti	0.005	0.006	0.003	0.004	0.006	0.006	0.004	0.004	0.005	0.006	0.008	0.003	0.009
Al	0.355	0.354	0.144	0.098	0.222	0.144	0.424	0.409	0.430	0.356	0.356	0.355	0.358
Cr	1.561	1.546	1.686	1.612	1.638	1.688	1.507	1.496	1.551	1.554	1.538	1.549	1.538
Fe'''	0.047	0.070	0.138	0.263	0.100	0.131	0.032	0.065	0.000	0.056	0.072	0.070	0.074
Fe''	0.353	0.509	0.604	0.587	0.626	0.635	0.360	0.317	0.382	0.533	0.408	0.344	0.507
Mn	0.013	0.011	0.009	0.014	0.018	0.017	0.010	0.008	0.008	0.013	0.015	0.008	0.010
Mg	0.652	0.494	0.403	0.413	0.376	0.366	0.648	0.689	0.604	0.471	0.594	0.661	0.499
Z	1.981	1.985	1.984	1.986	1.980	1.981	1.981	1.984	1.998	1.982	1.983	1.987	1.986
Y	1.018	1.014	1.016	1.014	1.020	1.018	1.018	1.014	0.994	1.017	1.017	1.013	1.016
$100\ Mg/(Mg+Fe'')$	64.9	49.3	40.0	41.3	37.5	36.6	64.3	68.5	61.3	46.9	59.3	65.8	49.6
$100\ Cr/(Cr+Al)$	81.5	81.4	92.1	94.3	88.1	92.1	78.0	78.5	78.3	81.4	81.2	81.4	81.1
$100\ Fe'''/(R''')$	2.4	3.6	7.0	13.3	5.1	6.7	1.6	3.3	0.00	2.9	3.7	3.5	3.8
$100\ Al/(R''')$	18.1	18.0	7.3	5.0	11.3	7.3	21.6	20.8	21.7	18.1	18.1	18.0	18.2

Samples 2. 3 and 10 are from the ultramafic cumulates and the rest from ultramafic tectonites. The chromite is associated with serpentine ± magnetite and (with the exception of samples 2, 3, 5, 6, 10, 12) chlorite. Olivine relics/inclusions were detected in only two samples each. The chromite shows pull-apart structure and makes 80 to > 90% of samples 1, 3, 7 and 10; about 15% of sample 5; and 50 to 70% of the rest. It is mostly brown to dark brown but black where altered. The grain-size reaches up to 2mm in 5 and 6, 3mm in 4 and 9, 5mm in 1. 11 and 12, 6mm in 3 and 7, and 7mm in 8. The grape-shot ore commonly contains 1-2cm oval chromite grapes. (Analyst : M. Q. J.)

TABLE 2. CHEMICAL VARIATION IN THE ZHOB VALLEY CHROMITES

		Wet Analyses	Microprobe Analyses
1.	Total Number of analyses	57	26
2.	Wt % Cr_2O_3	44.7 — 60.0	55.5 — 62.3
3.	Wt % Al_2O_3	5.3 — 21.3	2.4 — 12.1
4.	Wt % Fe_2O_3	1.1 — 9.8	0.0 — 10.2
5.	Wt % FeO	8.5 — 20.7	11.2 — 22.1
6.	Wt % MgO	9.6 — 16.0	7.1 — 14.6
7.	100 Mg/(Mg+Fe″)	41.5 — 79.0	36.6 — 70.0
8.	100 Cr/(Cr+Al)	59.0 — 87.0	75.5 — 94.3
9.	100 Cr/(Cr+Al+Fe‴)	38.9 — 77.5	71.0 — 85.0
10.	100 Fe‴/(Cr+Al+Fe‴)	0.02 — 11.5	0.0 — 13.3
11.	100 Al (Cr+Al+Fe‴)	13.0 — 37.2	5.0 — 23.3

variation correlatable to modal percentage is seen in the analyses of unaltered grains. The unaltered chromites are chemically similar and the ultramafic tectonites cannot be distinguished from cumulates on the basis of the chemistry of primary chromite. However, only one of the nine analysed grains in chromitites from the ultramafic cumulates displays a slight marginal zoning. In contrast, seven of ten chromitites from the ultramafic tectonites contain chromites that are often strongly zoned. It is likely that in the tectonites the alteration processes, responsible for the zoning (discussed below), were facilitated by deformation.

Chromite in samples 2, 3, 5, 6 and 7 is unzoned (Table 1 and Fig. 2–5) and does not display grain to grain variation, whilst that in the remaining samples is varyingly zoned. In the latter the margins of grains have lower Mg/(Mg+Fe″) and, in some, higher Cr/(Cr+Al). However, only one in four grains studied per sample in 4 and 12 displays zoning. The Mn content remains unaffected, but in two cases it is distinctly higher in the margin. The most drastic variation is in sample 9 where all four analysed grains are zoned and chemically distinct. We note that only one of the five rocks with unzoned chromite contains minor chlorite, whereas six of the eight samples with zoned chromite contain variable amounts of chlorite. There is a possibility that chlorite was not detected in the remaining two samples (10 and 12). However, since only Fe-enrichment and no Al-depletion have been found in the locally developed zoning in 12, the alteration in this sample may have accompanied serpentinization instead of chloritization.

Microprobe studies of zoned chromites from different parts of the world reveal that the outer zones are generally enriched in Fe″ and depleted in Mg and Al. The variation in Cr and Fe‴ is not consistent in all cases (Bird and

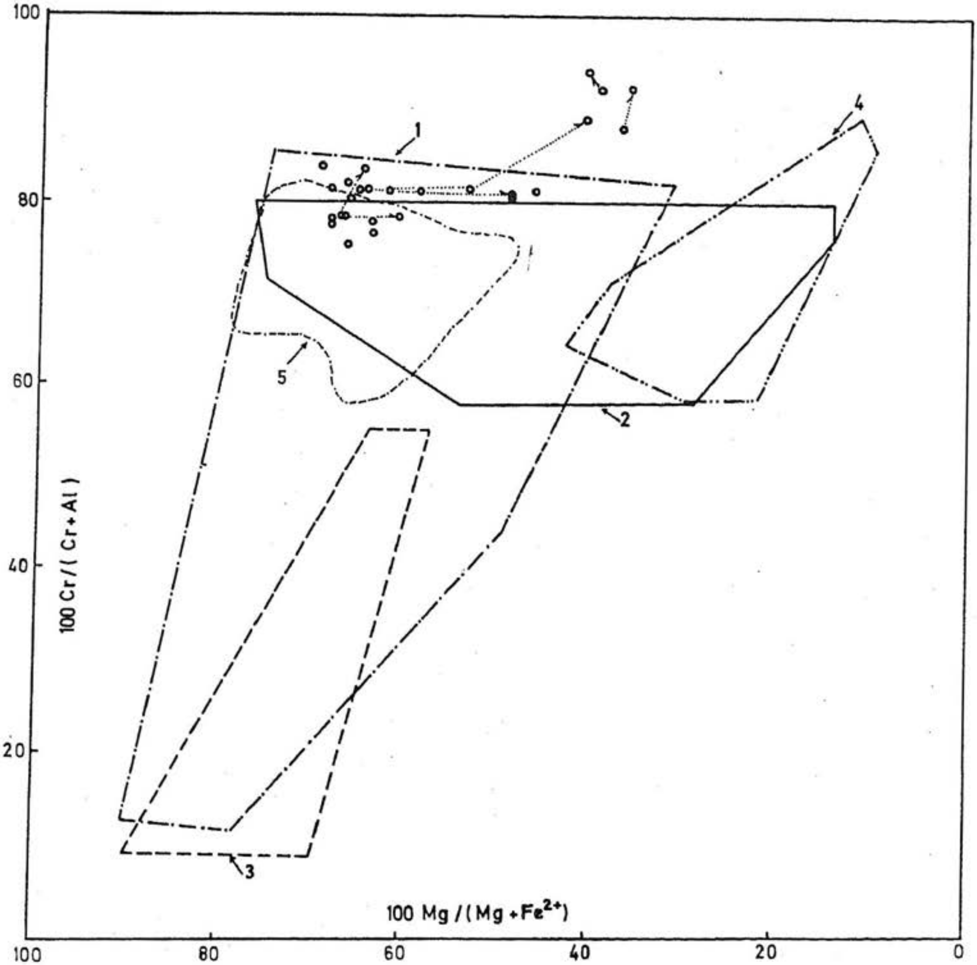

Fig. 2. 100 Cr/(Cr+Al) *vs.* 100 Mg/(Mg+Fe″) plot of the microprobe analyses of Muslimbagh chromites. Tie lines have been drawn between some chromite cores and outer zones with arrows pointing towards the outer zones. For comparison are given the fields of chromites from (1) alpine complexes, (2) stratiform complexes, (3) spinel-peridotite xenoliths, and (4) Goodnews Bay concentric complex (Data from Irvine, 1967; Irvine and Findlay, 1972; Bird and Clark, 1976). Area 5 encloses the wet chemically analysed chromites from Zhob (for source of data see references).

Clark, 1976; Oen *et al.,* 1979). Ahmed and Hall (1981) also found an increase of Mn in the outer zones of chromites from the Skhakot-Qila complex of N. Pakistan. The Fe-enriched zones have a black colour as opposed to the brown, reddish or brownish-black colour of the unaltered cores. They have a high reflectivity and are referred to as ferrit-chromit in the literature (cf. Bliss and MacLean, 1975; Bird and Clark, 1976). Such zones are produced during alteration of the rocks, especially during chloritization and recrystallization (Srikantappa and Friend, 1982).

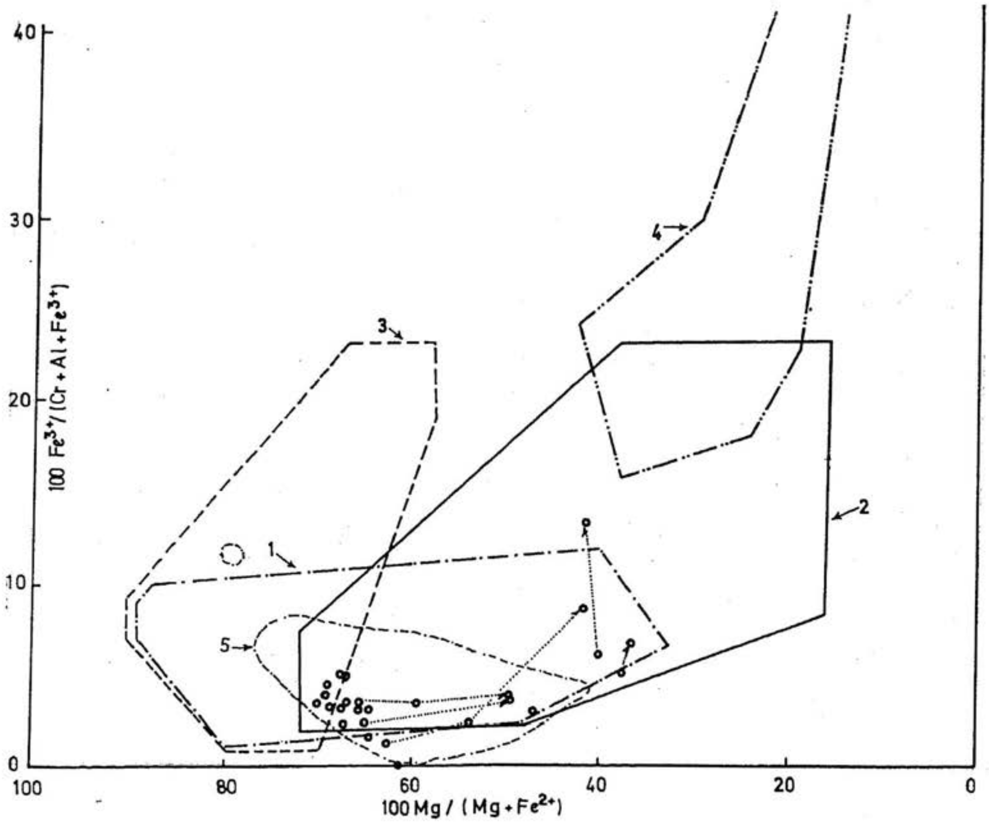

Fig. 3. Plot of 100 Fe‴ (Fe‴ + Al + Cr) against 100 Mg/(Mg+Fe″). For explanation see Fig. 2. Some tie lines have been omitted for clarity.

Enrichment in Fe, and locally Cr, in the altered margins of chromites from Muslimbagh can also be connected with late alteration (especially chloritization) of the silicate matrix. Sample 9, for example, has a higher chlorite content and the most altered chromite. In this sample, analyses of grains 1 and 2 have much higher Fe″, Fe″/(Fe″+Mg) and Cr/(Cr+Al) contents than the rest of the analyses and these grains occur along a thin fracture with abundant chlorite. Ahmed (1982), Ahmed and Hall (1981) and Jan *et al.* (1983) attributed the development of ferritchromit to chloritization in the Skhakot-Qila and Waziristan ophiolites of NW Pakistan. It seems that in all three examples in Pakistan the same process was responsible for producing variation in the chromite chemistry.

Details of chemical variation in major elements across two large grains in samples 13 (grape-shot chromite) and 8 are shown in Table 3. In both cases Mg decreases slightly and total iron (probably reflecting Fe″) increases towards the margin. Cr and Al do not show systematic variations. A survey of the wet chemi-

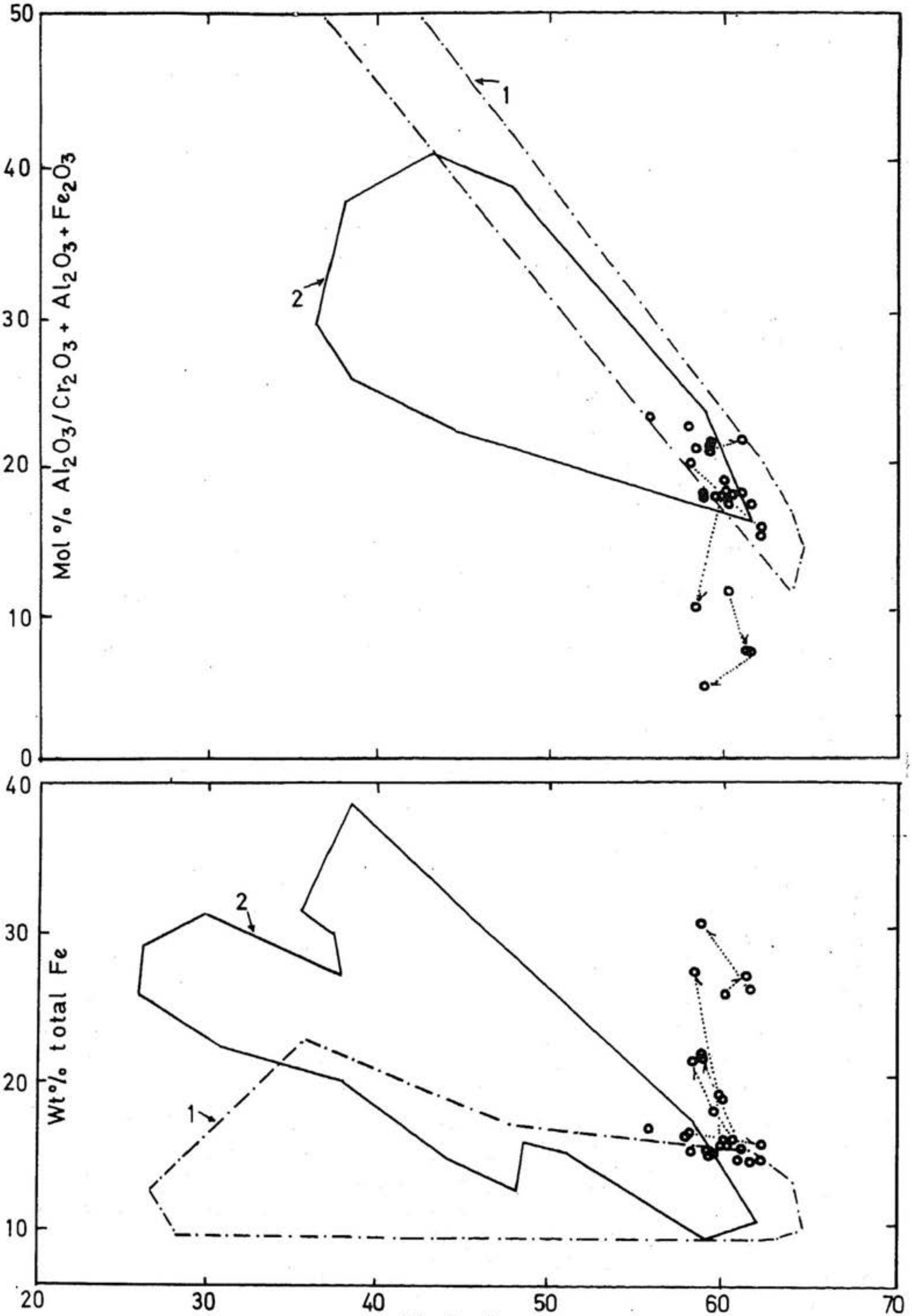

Fig. 4. Plot of mol % Al_2O_3/ (Al_2O_3+ Fe_2O_3+ Cr_2O_3) and total Fe_2O_3 against wt % Cr_2O_3. The analyses were recalculated to 100% Fields of chromites from alpine (1) and stratiform (2) complexes after Thayer (1970). Some tie lines have been omitted for clarity.

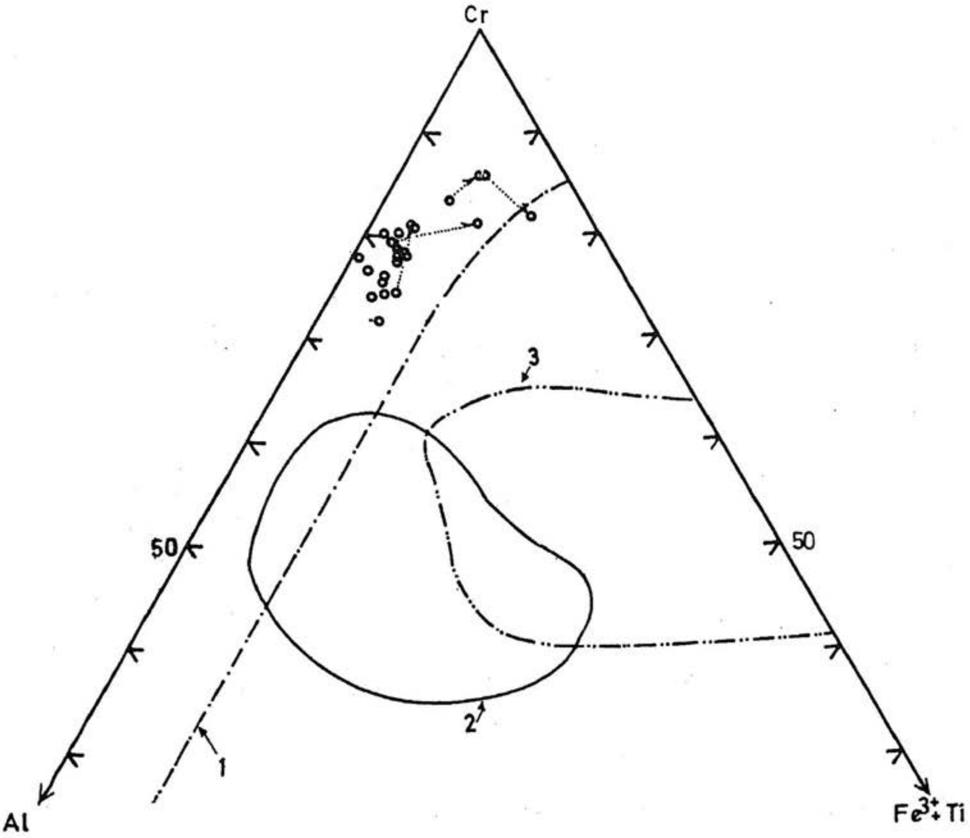

Fig. 5. Cr—Al—Fe‴+Ti plot of the analyses. Fields of chromites from alpine (1), stratiform (2) and concentric (Goodnews Bay) (3) complexes after Bird and Clark (1976) and Dickey (1975). Some tie lines have been omitted for clarity.

cal analyses from Muslimbagh fails to reveal whether cleaned chromite from the grape-shot ore has been analysed. Orbicular chromite from the Fort Sandeman area (Bilgrami, 1968; Anal. 29), however, is distinctly different in composition and contains much lower Cr_2O_3 and higher Al_2O_3 and total iron (Fe″ as well as Fe‴) than the one we analysed. Our analysis duplicates that of a chromite, with up to 5mm grains, reported from Jung Tor Ghar by Bilgrami (1969; p. 35, anal. 7).

Chemical variations in the chromites are presented in Figs. 2 to 5. On a 100 Cr/(Cr+Al) *vs.* 100 Mg/(Mg+Fe″) diagram (Fig. 2) some plot in the overlapping fields of chromites from alpine and stratiform complexes, and some only in the alpine field. Note that most analyses plot outside the field of wet-chemically analysed chromites from the Zhob Valley. The more altered chromites with high Cr/Al plot well outside the fields of those from alpine and stratiform complexes.

The relationship between 100 Fe‴/(Fe‴+Cr + Al) and 100 Mg/(Mg+Fe″) (Fig. 3) is not unusual, because most analyses fall within the field of

TABLE 4. CHEMICAL VARIATION ACROSS TWO CHROMITE GRAINS

	Grape-shot chromite GA-13. Rounded grape 1 cm across Points 1 to 4 are from left margin to centre, points 4 to 6 are from centre to bottom.						Medium-grained chromite GA-8. 7x6 mm oval grain Points 1 to 3 are from left margin to centre, points 3 to 6 are from centre to top.					
	Margin			Core		Margin	Margin		Core			Margin
	1	2	3	4	5	6	1	2	3	4	5	6
Cr	11.99	11.95	11.81	12.02	12.06	11.99	12.81	12.91	12.72	12.58	12.94	12.82
Al	3.27	3.34	3.29	3.32	3.28	3.28	2.42	2.48	2.46	2.50	2.40	2.52
Fe_T	3.18	3.18	3.14	3.11	3.11	3.23	3.20	2.92	2.87	3.05	3.09	3.00
Mg	5.36	5.36	5.47	5.47	5.38	5.37	5.48	5.68	5.79	5.78	5.58	5.59

All points analysed at about equal interval. Formulae recalculated on 32 (O) basis, with iron expressed as total FeO.
The two grains are homogeneous in composition and show only slight Fe"/(Fe" + Mg) increase towards the margins.

wet analysed Zhob chromites as well as those of alpine and stratiform complexes. The altered chromites may have higher or lower Fe'''/R''' ratios than their unaltered cores (see Table 1) and some plot outside the field of wet analyses.

Variation in total iron oxide and mol. % Al_2O_3/R_2O_3 against Cr_2O_3 wt% is shown in Fig. 4. All analyses can be classified as high Cr-chromites (Thayer, 1970). The altered chromites have been enriched in total iron oxide and depleted in the Al/R_2O_3 ratios generally, and thus tend to fall outside the fields of chromites from stratiform and alpine complexes. Despite the fact that all the analyses fall within the field of chromites from alpine complexes on the Cr-Al-Fe''' +Ti diagram (Fig. 5), there is a clear difference between the analyses of the more altered grains and the remainder.

Analyses of Associated Phases

In addition to chromite, thirteen serpentine, five chlorite, one olivine and one carbonate were also analysed in the Muslimbagh chromitites. Selected analyses are listed in Table 4. The totals of the serpentine analyses are low even when an allowance is made for 13% H_2O

The serpentines have high Mg: Si ratios and length slow orientation; features characteristic of chrysotile (cf. Page, 1968; Whittaker and Wicks, 1970; Moody, 1976). However, in most samples this variety of serpentine is accompanied by another with a very low interference colour (? lizardite). Both are usually very fine-grained and there is a possibility that some analyses represent a mixture of the two layer silicates. Minor components of the 13 analyses range as follows : Al_2O_3 0.02 to 1.4%; Cr_2O_3 0.0 to 3.1%; FeO* 1.7 to 3.2%; and NiO 0.1 to 0.8%. Chrysotile is stable at lower PT than lizardite which, in turn, has a lower stability limit than antigorite (Moody, 1976). Caruso and Charnovsky (1979) demonstrated the upper stability limit of lizardite to be 540°C at 0.5kbar to 606°C at 6kbar.

All the analysed chlorites have rather high MgO (33.2 to 36.4%) and SiO_2 (32.6 to 37.4%) contents and Mg/Fe (43.9 to 77.4) ratios. They have a low total Fe (0.14 to 0.23) content and are unoxidized. Four plot as penninite and GA–1 as talc-chlorite on Hay's (1954) diagram. The Cr_2O_3 content of the chlorites is moderately high (2.8 to 4.1%) and two of them (especially GA–1 with 4.1% Cr_2O_3) are rather low in Al_2O_3.

The relationship between coexisting chlorite and serpentine is not clear; but chrysotile veins are usually the younger. In sample 9 most chlorite is younger than ? lizarditic serpentine in the shear zone, but it is replaced by a late chrysotile. Both the serpentine and chlorite analyses in the same section often show considerable chemical variations, suggesting a general lack of physicochemical equilibrium. Carbonate was analysed in only one sample (GA–2). Its composition $Fe_{.146}\ Mn_{.003}\ Mg_{1.842}\ Ca_{.009}\ CO_3$ suggests that it grew at the expense of olivine or orthopyroxene by the addition of CO_2.

Relics of olivine in sample GA–5 have a 100 Mg/(Mg+Fe+Mn) content of 96.0. Although such highly magnesian olivine has been reported in chromitites

TABLE 3. REPRESENTATIVE ANALYSES OF THE SILICATES IN CHROMITE-RICH ROCKS OF MUSLIMBAGH

	G.A. 1	G.A. 9	G.A. 11	G.A. 13	G.A. 6	G.A. 5	G.A. 8	G.A. 13	G.A. 4	G.A. 5
	CHL	CHL	CHL	CHL	SERP	SERP	SERP	SERP	SERP	OLIV
	(1)	(2)	(2)	(1)	(3)	(2)	(1)	(1)	(1)	(4)
SiO_2	37.38	34.11	32.62	35.92	39.02	39.27	41.50	38.80	38.16	41.52
TiO_2	0.00	0.02	0.24	0.05	0.05	0.04	0.07	0.05	0.00	0.08
Al_2O_3	5.69	11.74	15.02	8.53	1.49	0.03	0.17	0.35	1.44	0.07
Cr_2O_3	4.13	2.76	3.14	2.87	0.82	0.00	0.08	0.58	3.12	0.01
FeO_T	0.84	1.43	0.90	0.84	0.99	2.08	3.02	3.23	1.86	3.79
MnO	0.00	0.00	0.03	0.10	0.02	0.05	0.16	0.00	0.00	0.07
MgO	36.41	35.15	33.22	36.26	38.87	39.36	39.64	38.81	34.34	52.57
CaO	0.00	0.01	0.05	0.00	0.02	0.11	0.05	0.01	0.44	0.04
NiO	0.54	0.21	0.56	0.55	0.02	0.66	0.23	0.24	0.08	0.54
TOTAL	84.99	85.43	85.78	85.12	81.30	81.60	84.92	82.07	79.44	98.64
	CHLORITE ON THE BASIS OF 28, SERPENTINE ON 7 AND OLIVINE ON 4 OXYGENS									
Si	7.187	6.520	6.216	6.904	1.944	1.969	1.992	1.936	1.955	1.005
Ti	0.000	0.003	0.034	0.013	0.002	0.002	0.002	0.002	0.000	0.001
Al	1.294	2.693	3.374	2.227	0.087	0.002	0.009	0.020	0.087	0.002
Cr	0.627	0.417	0.473	0.468	0.032	0.000	0.003	0.023	0.126	0.000
Fe''	0.135	0.228	0.144	0.143	0.041	0.087	0.121	0.134	0.079	0.077
Mn	0.000	0.000	0.005	0.014	0.001	0.002	0.007	0.000	0.000	0.001
Mg	10.451	10.015	9.438	8.903	2.885	2.939	2.837	2.886	2.624	1.896
Ca	0.000	0.002	0.010	0.000	0.001	0.006	0.003	0.000	0.024	0.001
Ni	0.084	0.032	0.086	0.073	0.001	0.018	0.009	0.010	0.003	0.010

Analyst : M. Q. J.

from some alpine ultramafic complexes (Himmelberg and Loney, 1973; Arai, 1979), we suggest that the high forsterite content of the olivine may be due to an exchange of Fe⇌Mg between olivine and chromite. Olivine-spinel geothermometry suggests that the exchange took place at high temperature: 700–800°C according to the methods of Fuji (1976), Roedar *et al.* (1979), Fabries (1976), and over 950°C according to Evans and Frost (1975) and Medaris (1975).

CONCLUSIONS

1. The chromite-rich rocks from the Muslimbagh ultramafic units contain high chromium Al-chromites.

2. Chromitites from the ultramafic cumulates mostly have unzoned chromite, whereas those from tectonites tend to contain zoned chromite.

3. Seven of thirteen samples contain zoned chromites with outer margins being higher in Fe″ /(Mg+Fe″) and, in some cases, Cr/(Cr+Al).

4. The zoning appears to be related to alteration, mainly chloritization and to a lesser extent serpentinization.

5. Analyses of serpentine and chlorite within the same section may show considerable variation, suggesting a lack of physicochemical equilibrium.

6. The olivine is highly magnesian (Fo[illegible]) due probably to an exchange of Fe⇌Mg with the associated chromite at a temperature of 700–800°C.

Analytical Techniques : The analyses were performed at the University of Leicester, U.K., by M.Q.J. with a Cambridge Microscan 5 Microprobe, using an energy dispersive system. At least three chromite grains in each sample were analysed in core and margin to check for compositional zoning and variation within and among grains. Total iron was determined as FeO and a computerised programme was used to estimate the quantity of Fe_2O_3.

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