Geol. Bull. Univ. Peshawar, Vol. 33, pp. 29-38, 2000

Petrography and mineralogy of the Ahingaro serpentinites, Kabal (Swat), NW Pakistan: Implications for their tectonic setting and timing of emplacement

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ABSTRACT: *A small (~6 x 1 km), lens-shaped body predominantly consisting of ultramafic rocks, occurs at the Ahingaro Banda Kandao near Kabal, Swat. This body is enclosed within the Kamila amphibolites that constitute the basal part of the intra-oceanic Kohistan island arc. The ultramafic rocks are highly fractured and almost completely serpentinized. They consist of abundant fine-grained serpentine, varying amounts of a variety of bastites after orthopyroxene, veins and stringers of magnetite, invariably altered disseminated grains of chrome spinel, trace amounts of relict clinopyroxene and traces of rather sparsely disseminated granules of sulphide (pentlandite). Some of the samples also contain thin veins of calcite.*

The Ahingaro serpentinites display both pseudomorphic and non-pseudomorphic textures. The serpentine predominantly consists of the lizardite and chrysotile varieties, whereas the antigorite occurs rarely. The chrysotile is mostly distributed as veins. A detailed petrogrphic and mineralogical comparison with the serpentinized rocks of the Indus suture melange zone suggests that the Ahingaro serpentinites most probably represent the original Tethyan lithosphere that served as a substratum or platform for the construction of the KIA. These rocks were emplaced together with the enclosing amphibolites along the Kohistan fault during post-Early Oligocene.

INTRODUCTION

The amphibolites and minor coarse-grained hornblendites of the Kohistan arc contain a small (~6 x 1 km) lenticular body of ultramafic-mafic rocks at the Ahingaro Banda area of Kabal, Swat, northwest Pakistan (Fig. 1). The petrographic and mineralogical details about these rocks are currently lacking. Published reports on these rocks include a discussion of their tectonic setting, which is largely based on outcrop observations and field relationships (Rehman & Zeb, 1970; DiPitero & Ahmad, 1995). The highly fractured and tectonized nature of these rocks has been taken to suggest their emplacement along a brittle zone within the Kohistan arc (Rehman & Zeb, 1970). More recently, it has been suggested that the dominantly ultramafic rocks of the Ahingaro Banda area represent a sliver of the Indus suture zone melange that was imbricated with the Kohistan arc during brittle emplacement of the latter above the Indus suture zone (DiPitero & Ahmad, 1995).

This report describes the petrographic and mineralogical characteristics of the Ahingaro serpentinites. Results from the present studies are compared with the corresponding published details about the seemingly similar serpentinized ultramafic rocks from the ophiolitic member of the Indus suture melange group with the major objective to elucidate the tectonic setting of the Ahingaro serpentinites.

GENERAL GEOLOGY

The central Swat area essentially consists of three major tectonostratigraphic units (Fig. 1). From south to north, these include: 1) the Indo-Pakistan plate sequence that consists of granitic gneisses and metamorphosed sedimentary rocks, 2) the Indus suture melange zone (ISMZ), which contains buleschist, greenschist and rocks of ophiolitic affinities, and 3) the intra-oceanic Kohistan island arc. The southern contact of the middle unit (Indus suture zone) with the Indo-Pakistan plate rocks is the Main Mantle Thrust (MMT) whereas its northern contact with rocks of the Kohistan island arc is marked as the Kohistan fault. The style of deformation associated with the MMT is largely ductile whereas that accompanying the Kohistan fault is mainly brittle (DiPietro & Ahmad, 1995).

The area around Kabal in the west-central part of Swat dominantly consists of amphibolites and minor hornblendites belonging to what is known as the Kamila amphibolite belt that constitutes the basal part of the intra-oceanic Kohistan island arc (KIA). Here, at the Ahingaro Banda Kandao, the KIA amphibolites contain a small lensoidal body of serpentinites. Both the amphibolites and enclosed serpentinites are fractured, crushed and granulated particularly along their contact zones. Quartzo-feldspathic veins and dykes, some of which are pegmatitic, traverse the amphibolites as well as serpentinites. The serpentinites are locally bordered by fuchsite-bearing quartz-carbonate assemblages that are apparently similar to the ones locally containing emerald deposits elsewhere in the region, e.g. near Mingora, ~2 Km north of Saidu Sharif (Fig.1).

SAMPLES AND METHODS

A total of twelve samples representing serpentinites and associated lithologies from the study area were collected and cut and made into polished thin sections. All the thin sections were studied petrographically through both reflected and refracted light microscopy. Most of the phases in selected samples of serpentinites were analysed through Jeol Superprobe model JXA-8600 with an on-line computer for ZAF corrections. Quantitative analyses were conducted using wavelength dispersive system and natural and synthetic standards. The analyses were performed with a 15 Kv accelerating voltage, 30×10^{-9} A probe current, and 20 (2 x 10) S peak, 10 (2 x 5) S negative background and 10 (2 x 5) S positive background counting times. The accuracy of the ZAF correction is generally better than 2 %.

PETROGRAPHY

The investigated small, lens-shaped rock body dominantly consists of serpentinites. The serpentinites display both pseudomorphic (i. e. hourglass) and non-pseudomorphic (e. g. isotropic) textures (cf. Wicks & O'Hanley, 1988). Besides abundant fine-grained serpentine, the studied rocks contain variable proportions of a variety of bastites, veins and stringers of magnetite, disseminated grains of chrome spinel, relict clinopyroxene, and traces of rather sparsely disseminated granules of sulphide(s). Some of the samples also contain thin veins of calcite.

The serpentine is dominantly lizardite, however, thin magnetite-free veins of chrysotile also traverse the magnetite-bearing matrix serpentine in some of the studied rocks. Besides, textural features (bladed habit) reveal the occurrence of antigorite as a minor serpentine polymorph in some of the studied samples. The XRD data confirm this petrographic observation. Samples containing both lizardite and antigorite display what can be termed as the lizardite-antigorite interlocking texture (cf. Wicks & O'Hanley, 1988).

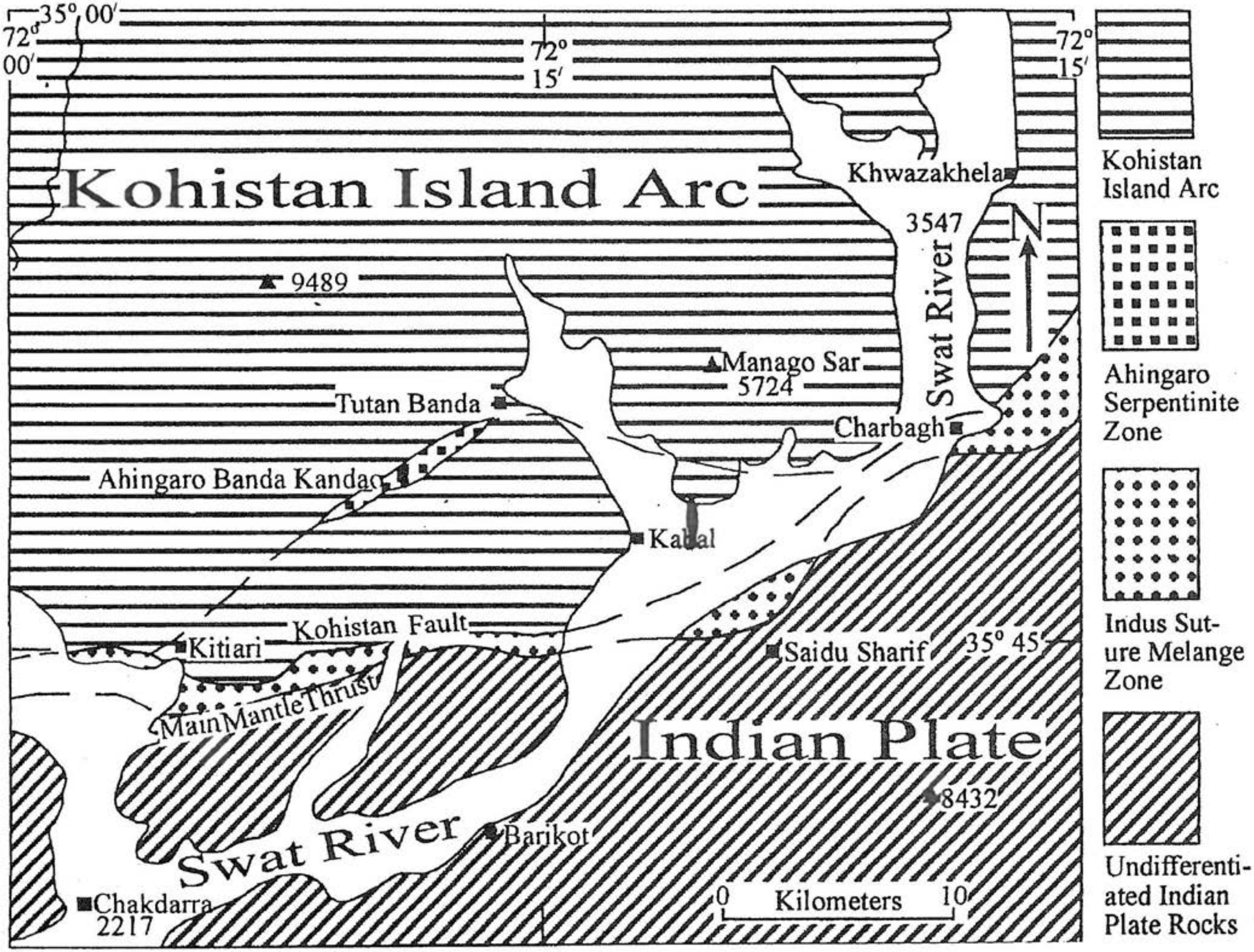

Fig. 1. Geological map of the central Swat area showing major tectonics units including the Ahingaro serpentinite zone. Elevations are in feet (afte DiPietro & Ahmad, 1995).

Bastites, i.e. grains with bronze-like metallic lustre and formed by the complete transformation of orthopyroxene (Deer et al., 1992), from the studied rocks include domainal, patchy, shaggy as well as indistinct types. Some of the bastite grains display undulose extinction. Wicks and O'Hanley (1988) have defined and distinguished five different types of bastite. These, arranged in the order of increasing degree of crystallization, include uniform, domainal, patchy, shaggy and indistinct. Therefore, it follows that bastites from the Ahingaro serpentinites might have undergone a moderate to high degree of crystallization.

Texturally, opaque minerals in the studied rocks are distinguishable into granular or skeletal and lamellar types. Petrographic observations and chemical analyses reveal that whereas the lamellar ore invariably contains lamellae of a sulphide of Ni and Fe (pentlandite) alternating with those of the non-sulphide (i.e. oxide) ore(s), the skeletal ore exclusively consists of oxide(s) of Cr and/ or Fe, i.e. chromite, ferritchromite and chrome magnetite. In most cases, the granular ore consists of chromite cores/ patches that are surrounded by zones/ rims of ferritchromite and/ or chrome magnetite. The latter two phases most probably represent products of serpentinization-related alteration of chromite. Some of the ferritchromite/ magnetite zones contain granules of pentlandite. However, sulphide granules in some of the studied samples lie close to but not within the zones of ferritchromite/ magnetite around chrome spinel cores. Furthermore, sulphide also occurs as granules disseminated in the serpentine matrix of some of the studied samples.

PHASE CHEMISTRY

Serpentine

Serpentine was analysed in five samples. Representative analyses are listed in Table 1. In addition to SiO_2 and MgO as essential major constituents, the analysed serpentine contains notable amounts of (wt %): FeO (1.10-4.39), Al_2O_3 (0.07-2.07) and NiO (0.03-0.62). The abundance of MnO is inavriably low (0.02-0.17 wt %), however, some of the analyses contain relatively high amounts of Cr_2O_3 (ranging up to 0.91 wt %). The high amounts of Al_2O_3 and Cr_2O_3 in some of the analyses are probably a result of alteration of the original chrome spinel grains to ferritchromite and/ or magnetite.

TABLE 1. REPRESENTATIVE ANALYSES OF SERPENTINE

No.[a]	1	2	3	4	5
SiO_2	43.87	42.77	42.48	44.64	42.00
TiO_2	0.01	0.02	0.01	0.01	0.03
Al_2O_3	0.51	0.65	2.07	0.24	0.28
Cr_2O_3	0.02	0.19	0.47	0.17	0.91
FeO*	1.51	3.35	2.79	2.07	4.29
MnO	0.07	0.12	0.07	0.08	0.09
MgO	41.23	39.68	39.6	40.31	39.55
CaO	0.01	0.02	0.01	0.02	0.02
NiO	0.12	0.16	0.09	0.08	0.14
Total	87.35	86.96	87.59	87.62	87.31
Cations on the basis of seven (O, OH)					
Si	2.027	2.007	1.972	2.056	1.981
Ti	0.000	0.000	0.000	0.000	0.002
Al	0.028	0.037	0.114	0.012	0.016
Cr	0.000	0.007	0.018	0.007	0.033
Fe^{2+}	0.058	0.131	0.109	0.081	0.170
Mn	0.004	0.005	0.004	0.004	0.004
Mg	2.839	2.776	2.742	2.769	2.781
Ca	0.000	0.002	0.000	0.002	0.002
Ni	0.005	0.005	0.004	0.004	0.005
Total	4.961	4.970	4.961	4.935	4.995

[a] 1 = vein serpentine; 2-5 = matrix serpentine

Chrome spinel

Spot composition of chrome spinel grains was determined in five of the studied samples (Table 2). The amounts of almost all the components vary between wide limits from

TABLE 2. REPRESENTATIVE ANALYSES OF CHROME SPINEL

No.	1	2	3	4	5	6	7	8	9
SiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.01
TiO_2	0.40	0.02	0.05	0.10	0.90	0.00	0.02	0.03	0.01
Al_2O_3	0.35	29.78	27.89	7.75	4.05	30.17	27.28	3.28	1.16
Cr_2O_3	33.02	34.55	37.08	37.99	48.39	36.44	38.79	22.04	12.11
Fe_2O_3	29.84	4.18	3.98	19.87	12.01	3.63	4.29	36.10	43.55
FeO	31.79	20.39	18.97	27.84	28.83	17.28	17.69	31.23	37.37
MnO	0.57	0.34	0.37	0.51	1.31	0.27	0.35	3.24	2.05
MgO	1.88	10.44	11.17	3.74	1.92	12.72	12.14	1.96	0.68
CaO	0.02	0.00	0.01	0.01	0.01	0.03	0.00	0.05	0.03
NiO	0.22	0.03	0.11	0.25	0.06	0.08	0.07	0.10	0.12
ZnO	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.09
Total	98.28	99.73	99.63	98.06	97.48	100.62	100.63	98.29	97.18
Cations on the basis of four oxygens									
Si	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000
Ti	0.012	0.000	0.001	0.003	0.025	0.000	0.000	0.001	0.000
Al	0.016	1.069	1.005	0.330	0.177	1.058	0.972	0.147	0.055
Cr	1.002	0.832	0.897	1.084	1.422	0.858	0.927	0.663	0.384
Fe^{3+}	0.861	0.096	0.092	0.540	0.336	0.081	0.098	1.034	1.314
Fe^{2+}	1.020	0.519	0.485	0.840	0.896	0.430	0.447	0.994	1.252
Mn	0.019	0.009	0.010	0.016	0.041	0.007	0.009	0.104	0.070
Mg	0.108	0.474	0.509	0.201	0.106	0.564	0.547	0.111	0.041
Ca	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.002	0.001
Ni	0.007	0.001	0.003	0.007	0.002	0.002	0.002	0.003	0.004
Zn	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.003
Total	3.049	3.001	3.002	3.021	3.007	3.001	3.001	3.070	3.123
Cr #[1]	98.44	43.77	47.14	76.68	88.91	44.76	48.82	81.84	87.51
Mg #[2]	9.54	47.73	51.22	19.32	10.61	56.75	55.03	10.06	3.14
Fe^{3+} #[3]	45.85	4.80	4.60	27.63	17.36	4.07	4.89	56.06	74.97

[1] Cr # = 100 x Cr/ (Cr+Al), [2] Mg # = 100 x Mg/ (Mg+Fe^{2+}),
[3] Fe^{3+} = 100 x Fe^{3+}/ (Cr+Al+Fe^{3+})

sample to sample, grain to grain in a given sample and spot to spot within individual grains. This extreme variability in composition most probably reflects variation in the degree of alteration. The analyses with high values of Fe^{3+} # [100 x Fe^{3+}/ (Fe^{3+}+Cr+Al)] (≥ 20) and Cr # [100 x Cr/ (Cr+Al)] (> 70) but low Mg #s [100 x Mg/ (Mg+Fe^{2+})] (≤ 20) represent the products of alteration, which display high reflectance (ferritchromite) (Fig. 2). Some of these analyses also contain relatively high amounts of NiO (0.06-0.39 wt %) and MnO (0.42-3.24 wt %) that are derived from the original olivine during its serpentinization.

In contrast to zones of alteration, the least altered cores / patches within the chrome spinel grains, show low reflectance (grey to dark grey in reflected light).

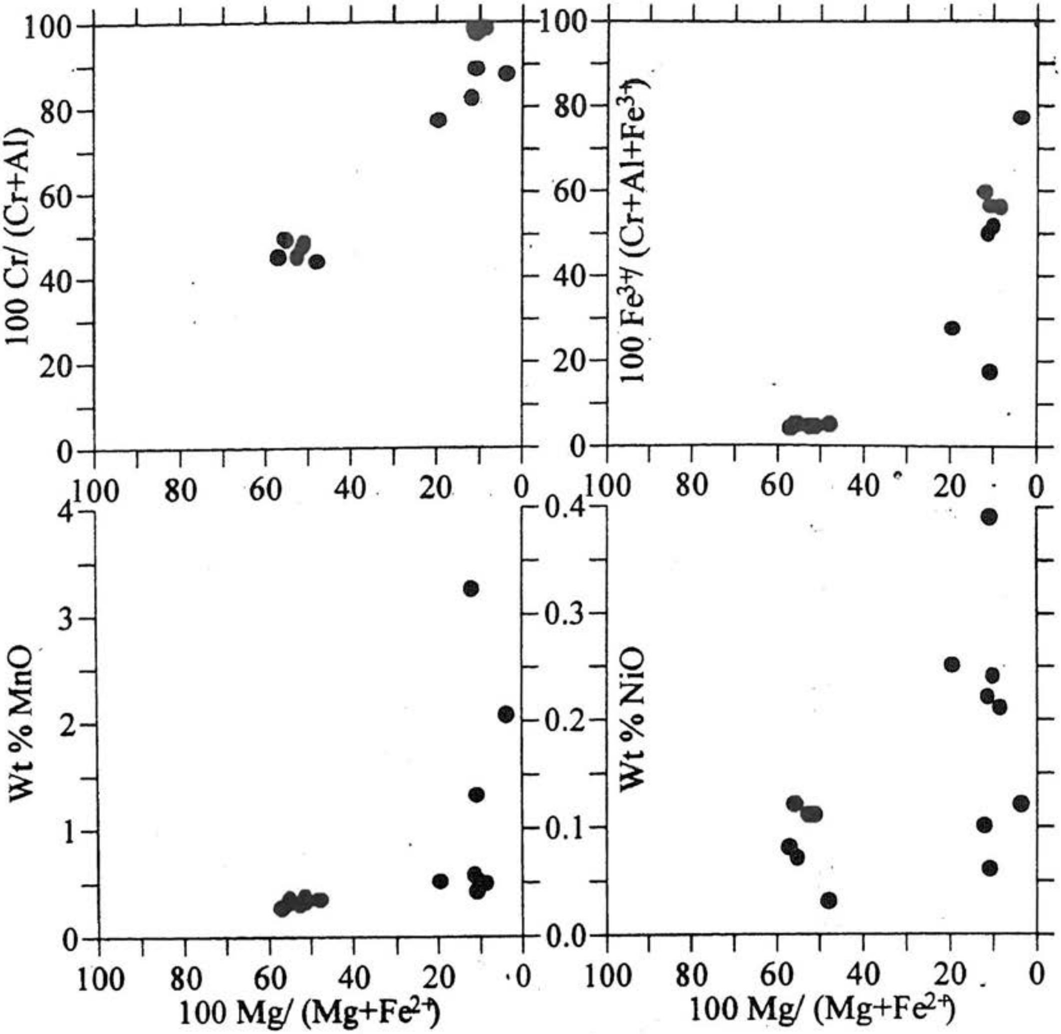

Fig. 2. Compositional characteristics of chrome spinel from the studied serpentinites.

Chemically, they are characterized by high Mg, Cr #s and low to very low Fe^{3+} #s. These are relics of the original (magmatic) chrome spinel and, compared to ferritchromites, they contain markedly low NiO and MnO (0.03-0.12 and 0.27-0.35 wt %, respectively).

Magnetite

The composition of magnetite was determined in two of the studied samples. Besides Fe, analysed magnetite contains small amounts of MgO (0.18-0.57 wt %) and significant levels of NiO (0.10-0.18 wt %) but only traces of MnO and Cr_2O_3 (Table 3). The concentrations of Al_2O_3, TiO_2 and ZnO are around detection limits.

TABLE 3. REPRESENTATIVE ANALYSES OF MAGNETITE

No.	1	2	3	4	5	6
SiO_2	0.05	0.00	0.31	0.00	0.02	0.00
TiO_2	0.01	0.01	0.01	0.01	0.01	0.00
Al_2O_3	0.00	0.01	0.00	0.00	0.01	0.00
Cr_2O_3	0.04	0.03	0.01	0.01	0.06	0.01
Fe_2O_3	68.52	68.63	68.47	69.04	69.25	68.37
FeO	29.68	29.65	29.50	30.00	30.04	29.10
MnO	0.08	0.14	0.16	0.10	0.16	0.10
MgO	0.37	0.23	0.57	0.19	0.21	0.18
CaO	0.02	0.00	0.02	0.00	0.02	0.08
NiO	0.59	0.37	0.59	0.26	0.22	0.10
ZnO	0.01	0.02	0.02	0.02	0.02	0.02
Total	99.37	99.09	99.67	99.63	100.02	97.96
Cations on the basis of four oxygens						
Si	0.002	0.000	0.012	0.000	0.001	0.000
Ti	0.000	0.000	0.000	0.000	0.000	0.000
Al	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.001	0.001	0.000	0.000	0.002	0.000
Fe^{3+}	1.994	2.004	1.980	2.005	2.003	2.017
Fe^{2+}	0.960	0.962	0.948	0.968	0.965	0.954
Mn	0.003	0.005	0.005	0.003	0.005	0.003
Mg	0.021	0.013	0.033	0.011	0.012	0.011
Ca	0.001	0.000	0.001	0.000	0.001	0.003
Ni	0.018	0.012	0.018	0.008	0.007	0.003
Zn	0.000	0.001	0.001	0.001	0.001	0.001
Total	3.000	2.997	2.998	2.997	2.997	2.992

Pentlandite

Pentlandite was analysed in two of the studied samples. In addition to S, Fe and Ni, the investigated pentandite contains relatively high to rather high amounts of Co but only traces of Cu. Pentlandites from the two samples display significant compositional differences. Pentlandite from one of the samples contains relatively lower Ni and Fe but rather higher Co than that from the other sample (Table 4, Fig. 3).

The sulphur content ranges from 45.25 to 49.06 at %. That is some of the studied pentlandites are S-poorer and others S-richer than the stoichiometric composition M_9S_8 (47.06 at % S). Although some of the analyses under discussion appear to be higher in S than the pentlandites (45.7-47.4 at % S) reported by Misra and Fleet (1973), the S content of the studied pentlandites closely matches the range (45.7-48.5 at % S) observed by Harris and Nickel (1972).

DISCUSSION AND CONCLUSIONS

Field observations have led previous workers (DiPitero & Ahmad, 1995) to suggest that the rocks under discussion are a part of the Indus suture melange zone (ISMZ) (Fig. 1). Reports regarding petrographic and mineralogical details of serpentinized ultramafic rocks from the ISMZ are available (Arif & Jan, 1993; Arif & Moon, 1996). A detailed comparison of results from the present study with petrographic characteristics of the ISMZ serpentinized ultramafic rocks as outlined in published reports leads to the following conclusions:

(1) Whereas textures in the rocks investigated include both the pseudomorphic and non-pseudomorphic types, the ISMZ rocks display non-pseudomorphic textures and are totally free of pseudomorphic (e.g. hourglass) serpentine textures (Arif, 1994).

(2) The ISMZ ultramafic rocks mainly/dominantly consist of the antigorite variety of serpentine (Arif, 1994; Arif & Moon, 1996). In contrast, lizardite is the major serpentine in the rocks under discussion. This feature is of petrogenetic significance because the occurrence of antigorite, unlike the other two serpentines, reflects markedly high temperature conditions (>350-500 °C) (Evans et al., 1976; Coleman, 1977).

(3) The ISMZ rocks contain olivine and diopside whose mode of occurrence and textural as well as chemical characteristics are suggestive of a

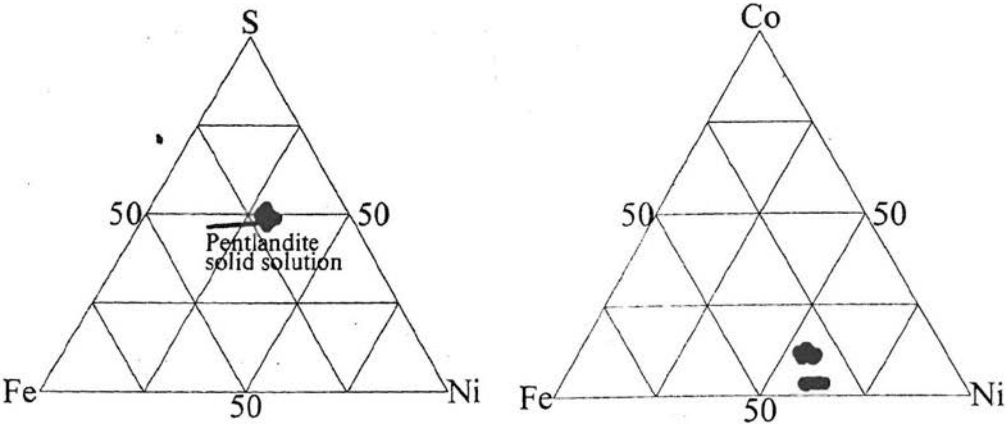

Fig. 3. Chemical characteristics of the studied pentlandite in terms of its major components. The bar in the upper plot limits the range of Fe and Ni contents in natural pentandites (after Misra & Fleet, 1973).

TABLE 4. REPRESENTATIVE ANALYSES OF PENTLANDITE

No.	1	2	3	4	5	6	7	8
S	32.67	32.49	32.5	32.57	32.39	32.16	32.54	32.83
Fe	24.79	24.64	25.57	25.51	21.14	21.94	21.34	21.33
Co	2.15	2.18	2.03	2.16	6.87	6.53	8.03	6.77
Ni	39.67	40.18	40.55	40.05	38.31	34.77	37.00	37.92
Cu	0.09	0.04	0.05	0.01	0.08	0.07	0.01	0.01
Total	99.37	99.53	100.7	100.3	98.79	95.47	98.92	98.86
Atomic Percent								
S	46.82	46.56	46.13	46.35	46.79	47.77	46.91	47.26
Fe	20.39	20.27	20.83	20.84	17.53	18.71	17.66	17.63
Co	1.68	1.70	1.57	1.67	5.40	5.28	6.30	5.30
Ni	31.05	31.44	31.43	31.13	30.22	28.20	29.13	29.81
Cu	0.06	0.03	0.04	0.01	0.06	0.05	0.01	0.01

1 = A tiny grain at the margin of a chromite grain in serpentine matrix
2 = Replacing magnetite (analysis # 3 in Table 3)
3 = Within magnetite (anlysis # 4 in Table 3)
4 and 6 = Within magnetite (anlysis # 5 and 6 respectively, Table 3)
5 = Adjacent to the altered margin of a chromite grain
7, 8 = Disseminated in serpentine matrix

prograde metamorphic origin (Arif, 1994; Arif & Moon, 1996). The rocks under discussion, on the other hand, do not contain such an olivine or diopside.

(4) Nickeliferous phases in the ISMZ ultramafic rocks (e.g. those from the Shangla area) mainly consist of heazlewoodite, millerite and awaruite, whereas pentlandite occurs rather rarely (Arif, 1994; Arif & Moon, 1994). The Ahingaro serpentinites, on the other hand, contain only pentlandite.

Because of these notable petrographic and mineralogical differences of petrogenetic significance, the Ahingaro serpentinites can neither be grouped with nor regarded as a part of the serpentinized ultramafic rocks constituting the ophiolitic member of the Indus suture melange group. The presence of prograde metamorphic features in the serpentinized ultramafic rocks from the Indus suture melange zone indicates that they were emplaced (along the MMT) in the late Cretaceous or early Tertiary, prior to or during the pre-Late Eocene metamorphism of the northern edge of the Indo-Pakistan crust. As the Ahingaro ultramafics lack prograde metamorphic features, they must have been emplaced long after the emplacement of the Indus suture rocks. The field features and relationships also lead to such a conclusion (DiPitero & Ahmad, 1995). However, results from the present studies do not support the thesis that the ultramafic-mafic rocks constituting the Ahingaro body are a part (sliver) of the Indus suture melange zone. On the basis of their textural and mineralogical characteristics, the Ahingaro rocks appear to be a part of the original Tethyan lithosphere, which served as a substratum or platform for the construction of the KIA. These rocks were emplaced together with the enclosing amphibolites, which constitute the basal part of the KIA, along the Kohistan fault during post-Early Oligocene. As deformation associated with the Kohistan fault is dominantly brittle, the rocks emplaced along it, including the ones under discussion, are highly fractured and tectonized in character.

Acknowledgements: The Association of Commonwealth Universities in UK financed the studies. Mr. Colin Cunnigham and Mr. Rob Wilson (Department of Geology, Leicester University, UK) helped in preparing polished thin sections and performing probe analyses, respectively.

REFERENCES

Arif, M., 1994. Studies of ultramafic rocks from Swat, northwestern Pakistan. Implications for the genesis of emerald and nickeliferous phases. Unpubl. Ph.D. thesis, University of Leicester, England, UK.

Arif, M. & Jan, M. Q., 1993. Chemistry of chromite and associated phases from the Shangla ultramafic body in the Indus suture zone of Pakistan. In: Himalayan tectonics (M. P. Searle & P. J. Treloar, eds.). Geol. Soc. London, Spec. Publ., 74, 101-112.

Arif, M. & Moon, C. J., 1994. Occurrence, chemistry and genesis of the nickel-rich phases in the ultramafic rocks from Swat, northwestern Pakistan. Geol. Bull. Univ. Pesh., 27, 29-41.

Arif, M. & Moon, C. J., 1996. Textural and chemical characteristics of olivine and pyroxenes in the ultramafic rocks from the Indus suture zone in Swat, NW Pakistan: Implications for petrogenesis and alteration. Schweiz. Mineral. Petrog. Mitt., 76, 47-56.

Coleman, R. G., 1977. Ophiolites. Springer-Verlag, New York, 229p.

Deer, W. A., Howie, R. A. & Zussman, J., 1992. An Introduction to the Rock-forming Minerals-2nd, Longman, Hong Kong, 696p.

DiPietro, J. A. & Ahmad, I., 1995. Tectonic setting of the Ahingaro serpentinite zone within the Kohistan arc complex, Swat, Pakistan. Geol. Bull. Univ. Pesh., 28, 27-29.

Evans, B. W., Johannes, J., Oterdoom, H. & Trommsdorff, V., 1976. Stability of chrysotile and antigorite in the serpentinite multisystem. Schweiz. Mineral. Petrogr. Mitt., 56, 79-93.

Misra, K. C. & Fleet, M. E., 1973. The chemical composition of synthetic and natural pentlandite assemblages. Econ. Geol., 68, 518-539.

Harris, D. C. & Nickel, E. H., 1972. Pentlandite compositions and associations in some mineral deposits. Canad. Mineral, 11, 861-878.

Rehman, J. & Zeb, A., 1970. The geology of the Shah Dheri-Kabal area, Swat. Geol. Bull. Univ. Pesh., 5, 96-110.

Wicks, F. J. & O'Hanley, D. S., 1988. Serpentine minerals: Structure and petrology. Reviews in Mineralogy, Mineral. Soc. Amer., 19, 91-167.