Geol. Bull. Univ. Peshawar, 1985, Vol. 18, pp. 41–52

MINERALOGY OF THE BLUESCHIST FACIES METAGRAYWACKE FROM THE SHERGARH SAR AREA, ALLAI KOHISTAN, N. PAKISTAN

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ABSTRACT

A new occurrence of the glaucophane bearing rock within the Indus suture zone is reported from the Shergarh Sar area in Allai Kohistan. Being composed mostly of quartz with small amount of white mica, glaucophane, chlorite and plagioclase, etc., the rock is described as blueschist facies metagraywacke. Constituent minerals are analysed with probe; and P-T conditions of metamorphism (about 7 k.bars and 400–450°C) are calculated. Petrographic and chemical constraints of the constituent minerals oppose any retrogression or oscillatory transition in metamorphic conditions as noted in the blueschist rocks from Ladakh, and Shangla section of Swat.

INTRODUCTION

The Main Mantle Thrust (MMT) marks the convergent plate junction where rocks of the Cretaceous Kohistan island arc are obducted onto the Indian plate (Jan and Symes, 1979; Tahirkheli *et al.,* 1979; Dewey and Burke, 1973; Molnar and Tapponnier, 1973; Bard, 1983). The origin and tectonic evolution of the Kohistan island arc are attributed to rapid convergence which resulted in the consumption of Tethyan oceanic crust and upper mantle along a northward dipping subduction zone (Tahirkheli *et al.,* 1979; Klootwijk, *et al.,* 1979; Andrew-Speed and Brookfield, 1982; Coward *et al.,* 1982; Bard, 1983; Majid and Paracha, 1980). The MMT zone is regarded as the western continuation of the Indus Zangbo suture zone and is characterized by tectonic slices.

This zone in Swat and Kohistan comprises widely distributed peridotite, their serpentinized equivalents and tectonic melanges. Beside greenschists and ophiolites which are the most abundant rocks in the melange, local occurrences of high-pressure low-temperature metamorphic rocks have been reported from the

Shangla section in Swat. Such rocks have also been found in the Indus-Zangbo suture zone in Ladakh and eastern Tibet (Jan, 1985).

Petrographic account of the blueschist facies rocks from Swat are given by Shams (1972, 1980), Jan *et al.* (1981) and Kazmi *et al.* (1984). Presence of jadeitic pyroxene (Guiraud *et al.*, in prep.) and aragonite (Davies, 1962) in these rocks suggests high-P and low-T metamorphic conditions (about 7 kbars and 380°C, Jan *et al.*, 1981) during Late Cretaceous (Shams, 1980; Kazmer *et al.*, 1983; Maluski and Matte, 1984). Zoning in amphibole grains in these rocks has been interpreted as a consequence of oscillatory transition between greenschist facies and epidote-amphibolite facies metamorphism (Guiraud *et al.*, in prep.). Beside Shangla in Swat, blueschist facies rocks were found by the authors in the Allai Kohistan section of the Indus suture zone during a field trip in summer, 1984 to Shergarh Sar area. This newly found occurrence is described in detail in this paper.

THE SHERGARH SAR AREA

The Shergarh Sar area in Allai Kohistan (340°50′ 15″N to 34°54′ 15″N & 73°1′E to 73°5′E; sheet No. 43F/1) demarcates the boundary between the Indo-Pakistan plate and the southern margin of the Kohistan island arc.

According to Shah (1985), and Shah and Majid (1985), rocks of the Indus suture melange in the Shergarh Sar area can be divided into (a) greenschist rocks characterized by light green to greenish grey colour and exhibiting granular to linear fabric; (b) a belt of island arc-type tholeiitic lavas, mostly glassy but occasionally containing phenocrysts of plagioclase, clinopyroxene and brown hornblende; (c) clinopyroxenite, peridotite and serpentinite, generally faulted, folded and in places fractured and brecciated; and (d) blueschist facies rocks. The high-P metamorphic assemblage of Shergarh Sar has developed in a metagraywacke found in the upstream section, west of Pashtu village in the studied area. The rock is described in thin section, microprobe analyses of constituent mineral phases are presented, and the results are compared with equivalent compositions from Shangla and Ladakh.

Metagraywacke from the Shergarh Sar area

The rock is medium- to coarse-grained with a greenish white colour in handspecimens. It is mainly composed of quartz, white mica, chlorite and glaucophane, with small amount of plagioclase, epidote, carbonate, and traces of apatite and magnetite. The rock is inequigranular, porphyroblastic and schistose. The quartz grains (60% by volume) are highly fractured and cataclasized, showing undulose extinction and pressure shadows. Chlorite and white mica flakes and laths swirl and wind around quartz porphyroclasts, thus imparting a gneissic character to the rock in parts. Glaucophane grains (2mm to 5mm long) are commonly zoned from pinkish blue core to dark blue margin. Alteration to chlorite along the margins is common. Epidote and apatite occur mostly as inclusions within the quartz grains and mica flakes. Similar mineral assemblages have been reported from the Shangla area (Jan *et al.*, 1981) and eastern Ladakh (Virdi *et al.*, 1977).

MINERAL CHEMISTRY OF THE METAGRAYWACKE

Grains of amphibole, chlorite, epidote and white mica are analysed in a polished thin section with a Jeol Superprobe Jcx–703 using wave length dispersive system and 15 kv. voltage. Suitable laboratory standards were used and ZAF correction was applied through a computerized programme.

a. *Amphibole*

Thirteen analyses of amphibole with oxides total lying between 95 and 98 per cent are presented in Table 1. These represent six zoned grains from core to margin. Total Fe as FeO from the probe analyses was partitioned into FeO and Fe_2O_3 through a calculation procedure suggested by Leake (1978). Number of ions on the basis of 23 oxygens and other useful ratios are also included in Table 1. In some of the analyses the occupancy of T site is slightly more than 8.00, suggesting an overestimation of Si. There is a complete lack of K ions except in analysis No. 1 GL (0.05 k). Total C is mostly equal to theoretical value 5.00, while a small deficiency in the ionic content at B site and completely unoccupied A site are typical of the analyses. $(Na)_{M4}$ is always greater than 1.34 (average 1.80). The $(Ca/Ca+Na)_M$, values of the analyses are generally between 0.03 to 0.08, with a maximum~0.1 and are consistent with sodic amphibole analyses from elsewhere (Dobrestov *et al.,* 1971).

Following the nomenclature scheme of amphibole (Leake, 1978), eleven point analyses classify as glaucophane. Some of the glaucophane compositions have 100 $Fe^{+2}/Fe^{+2}+Mg$ ratio over 45 and plot close to the boundary line of ferro-glaucophane (Fig. 1). Zoning is common from glaucophane interior to crossite margin. Seven points were analysed from the crossite margins in six zoned amphibole grains. These are also plotted in Fig. 1 and connected with their respective glaucophane cores. Both glaucophane and crossite have higher Fe^{+2}/Mg ratio and plot outside the field of sodic amphiboles from Ladakh (cf. Jan, 1985).

Al^{vi} is always greater than Al^{iv} and in general nearly 90–100% of total Al in the analyses is Al^{vi}. The deficiency of Al^{iv} and high Al^{vi} in the formulae of these amphiboles points to high P/T conditions during metamorphism (cf. Jan and Hawie, 1982). Prevalence of high pressure conditions is indicated also by the clustering of data points around a pressure line of 7 Kbar in a plot of Na_{M4} vs Al^{iv} (cf. Fig. 10 of Brown, 1977).

b. *Chlorite*

Three representative analyses of chlorite are given in Table 2 along with the number of ions on the basis of 28 oxygens. All the chlorite compositions are very similar and show approximately 60 per cent of total Al as Al^{iv} which replaces Si in the tetrahedral coordination with values of $Si_{5.55}$, $Al^{iv}_{2.45}$ **Y site totals** are constantly less than 12.00 with a substitution of Fe^{+2} for Mg in the ratio of 0.6:1 resulting in a constant $Fe^{+2}/(Fe^{+2}+Mg)$ values of 0.41. This ratio is slightly higher than those reported in the chlorites of Ladakh (i.e. 0.35, Jan, 1985).

TABLE 1. MICROPROBE ANALYSES OF REPRESENTATIVE GLAUCOPHANE (CORE) AND CROSSITE (MARGIN) OF THE METAGRAYWACKE FROM THE SHERGARH SAR AREA.

	Ist grain	2nd grain				3rd grain			4th grain		5th grain		
	1GL	23GL	26CR	32CR	30CR	34GL	41GL	38CR	52GL	54CR	67GL	56GL	55GL
SiO_2	59.59	55.99	56.53	55.43	57.49	57.54	58.40	56.88	57.39	57.43	56.50	58.11	59.10
TiO_2	0.01	0.05	0.03	0.04	0.04	0.00	0.00	0.00	0.05	0.05	0.04	0.06	0.06
Al_2O_3	8.87	8.80	8.36	7.45	8.23	7.32	9.52	5.53	8.34	7.22	10.19	9.55	8.22
Fe_2O_3	3.11	6.00	7.33	8.89	8.22	4.11	5.22	8.89	2.33	6.11	2.22	2.56	0.33
FeO	12.46	11.83	10.97	8.19	8.16	11.90	9.71	9.76	12.44	10.37	12.16	11.93	13.31
MnO	0.18	0.08	0.10	0.23	0.17	0.22	0.13	0.26	0.29	0.29	0.05	0.13	0.22
MgO	7.22	7.04	6.57	8.86	9.39	8.79	8.17	8.97	7.77	8.98	7.64	7.93	8.61
CaO	0.15	0.33	0.38	0.84	0.93	0.56	0.41	0.42	0.14	1.19	0.58	0.50	0.27
Na_2O	5.95	6.65	6.24	6.25	6.32	6.93	6.07	6.83	7.04	6.36	6.86	6.66	7.53
Total	97.74	96.77	96.48	96.18	98.95	97.43	97.22	97.47	95.79	98.00	96.24	97.43	97.65

	1st grain	2nd grain				3rd grain			4th grain		5th grain		
	1GL	23GL	26CR	32CR	30CR	34GL	41GL	38CR	52GL	54CR	67GL	56GL	55GL
ATOMIC PROPORTIONS ON THE BASIS OF 23 OXYGEN ATOMS													
Si	8.27	7.97	7.91	7.90	7.92	8.13	8.08	8.06	8.18	8.04	8.00	8.10	8.24
Al^{IV}	0.00	0.03	0.09	0.10	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al^{VI}	1.45	1.44	1.37	1.15	1.26	1.23	1.55	0.92	1.40	1.19	1.70	1.57	1.35
Ti	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01
Fe^{+3}	0.32	0.64	0.82	0.95	0.85	0.44	0.54	0.95	0.25	0.64	0.24	0.27	0.03
Fe^{+2}	1.45	1.41	1.36	0.98	0.94	1.32	1.12	1.16	1.48	1.21	1.44	1.39	1.55
Mn	0.02	0.01	0.01	0.04	0.02	0.03	0.02	0.03	0.03	0.03	0.01	0.02	0.03
Mg	1.49	1.49	1.45	1.88	1.93	1.85	1.68	1.88	1.65	1.87	1.61	1.65	1.79
Ca	0.02	0.05	0.06	0.13	0.14	0.08	0.06	0.06	0.02	0.18	0.09	0.07	0.04
NaM_4	1.60	1.83	1.79	1.73	1.69	1.90	1.63	1.88	1.94	1.73	1.88	1.80	1.96
T	8.27	8.00	8.00	8.00	8.00	8.13	8.08	8.06	8.18	8.04	8.00	8.10	8.24
C	4.73	5.00	5.00	5.00	5.00	4.87	4.97	4.94	4.82	4.96	5.00	4.90	4.76
B	1.67	1.88	1.85	1.86	1.83	1.98	1.69	1.94	1.96	1.91	1.97	1.87	2.00
$100Fe^{+2}/Fe^{+2} + Mg$	49.3	48.60	48.40	34.30	32.75	41.6	40.00	38.16	47.28	39.28	47.21	45.72	46.41
$100Fe^{+3}/Fe^{+3} + Al^{vi}$	18.08	30.77	37.40	45.23	40.30	26.3	25.8	50.80	15.15	34.97	12.37	18.24	2.77

1GL contains 0.28% K_2O giving 0.05K.
A site is vacant and all the Na is in B site
GL = Glaucophane, CR = Crossite.

TABLE 2. MICROPROBE ANALYSES OF WHITE MICA (PHENGITE), CHLORITE & EPIDOTE FROM THE METAGRAYWACKE FROM THE SHERGARH SAR AREA.

	White Mica				Chlorite			Epidote		
	8 Mu	15 Mu	23 Mu	25 Mu	1c	2c	3c	1E	3E	4E
SiO_2	56.35	54.66	52.48	50.86	26.60	26.44	26.11	40.23	39.73	39.81
TiO_2	0.04	0.21	0.18	0.12	0.00	0.03	0.03	0.10	0.00	0.05
Al_2O_3	25.31	23.72	25.45	23.64	18.01	17.99	17.94	25.22	25.50	23.84
Fe_2O_3	—	—	—	—	—	—	—	8.59*	8.85*	9.30*
FeO	4.29†	5.32†	4.78†	6.22†	22.40†	21.52†	21.57†	—	—	—
MnO	0.04	0.11	0.10	0.09	0.87	0.96	0.86	0.17	0.41	0.41
MgO	4.31	3.09	3.45	3.74	16.20	15.94	15.46	0.15	0.08	0.04
CaO	0.04	0.35	0.10	0.14	0.08	0.10	0.23	22.47	23.35	22.65
Na_2O	0.18	0.55	0.27	0.62	0.11	0.14	0.51	0.12	0.14	0.08
K_2O	8.00	7.67	9.64	10.03	0.00	0.00	0.00	0.00	0.00	0.00
Total	98.00	95.58	95.35	95.45	83.27	83.12	82.71	97.05	98.06	96.18

	White Mica				Chlorite			Epidote		
	8 Mu	15 Mu	23 Mu	25 Mu	1c	2c	3c	1E	3E	4E
ATOMIC PROPORTION ON THE BASIS OF 22 OXYGEN ATOMS FOR WHITE MICA, 28 FOR CHLORITE & 12 FOR EPIDOTE										
Si	7.12	7.15	6.90	6.84	5.55	5.53	5.50	3.03	2.98	3.04
Al^{IV}	0.88	0.85	1.10	1.16	2.45	2.47	2.50	0.00	0.02	0.02
Al^{VI}	2.89	2.81	2.84	2.59	1.97	1.97	1.96	2.24	2.23	2.15
Ti	0.00	0.02	0.02	0.01	0.00	0.00	0.00	0.01	0.00	0.00
Fe	0.41	0.52	0.47	0.63	3.36	3.39	3.42	0.49	0.50	0.53
Mn	0.00	0.01	0.01	0.01	0.15	0.17	0.15	0.01	0.03	0.03
Mg	0.81	0.60	0.68	0.75	5.03	4.97	4.86	0.02	0.01	0.00
Ca	0.01	0.05	0.01	0.02	0.02	0.02	0.05	1.81	1.87	1.85
Na	0.04	0.14	0.07	0.16	0.04	0.06	0.21	0.02	0.02	0.01
K	1.29	1.28	1.62	1.72	0.00	0.00	0.00	0.00	0.00	0.00
Z	8.00	8.00	8.00	8.00	8.00	8.00	8.00	3.03	3.00	3.06
Y	4.11	3.96	3.35	3.99	10.51	10.50	10.39	2.77	2.77	2.71
X	1.34	1.47	1.70	1.90	0.06	0.08	0.26	1.83	1.89	1.86
100Na/NA+K	3.00	9.86	4.14	8.51	—	—	—	—	—	—
Phengite Content	8.64	8.52	8.02	10.05	—	—	—	—	—	—
$Fe^{+2}/Fe^{+2} + Mg$	—	—	—	—	0.40	0.41	0.41	—	—	—
$100Fe^{+3}/Fe^{+3} + Al^{vi}$	—	—	—	—	—	—	—	17.94	18.31	19.77

The analysis No. 1E was recalculated to 98% before conversion of FeO to Fe_2O_3

* = Total iron expressed as Fe_2O_3

† = Total iron expressed as FeO

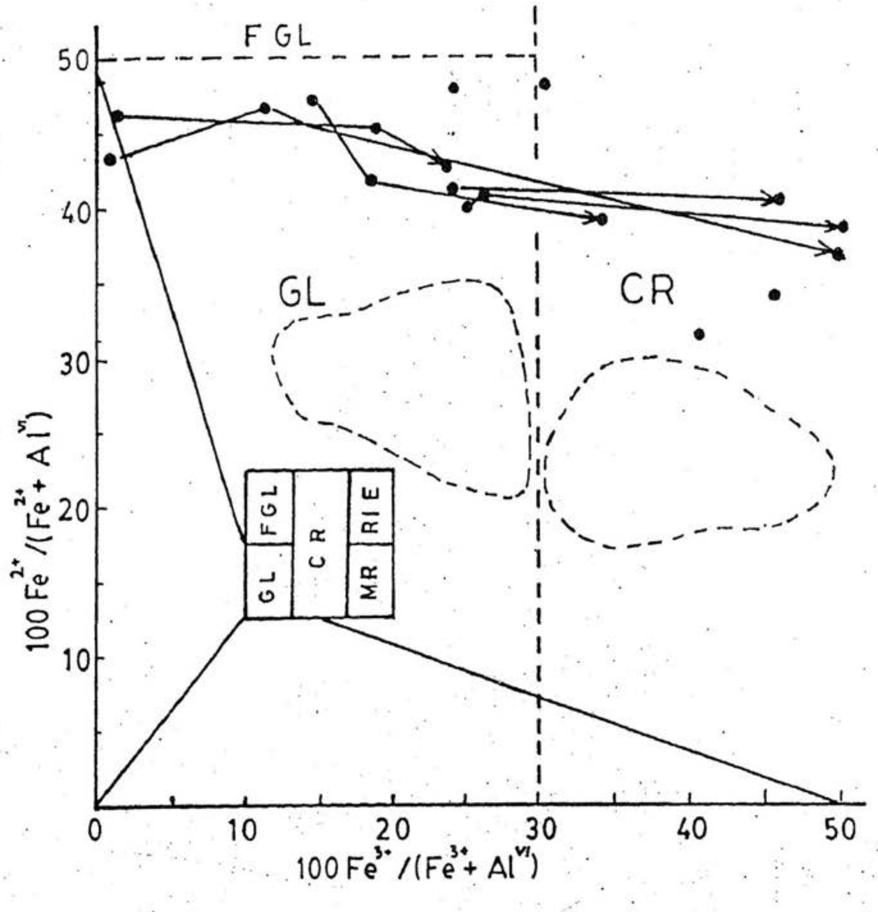

Fig. 1. Plot of sodic amphibole from metagraywacke of the Shergarh Sar area on the Miyashiro diagram. Dashes enclose the field for amphiboles from Ladakh (Jan, 1985). Arrows point to the outer zone.
GL = Glaucophane; FG = Ferroglaucophane;
CR = Crossite; RIE = Riebeckite;
MR = Magnesioriebeckite.

The data points in the compositional plot of Si vs $Fe^{+2}/(Fe^{+2}+Mg)$ fall within the repidolite field (cf. Hey, 1954).

c. *Epidote*

Epidote grains are mostly zoned. Three analyses from the zoned grains of epidote are presented in Table 2 for showing variations in the composition from core (IE) towards margin (3E & 4E). There appears a progressive increase in the iron content from core to margin. The iron enriched margin contains manganese approximately two times greater than in the core. Two analyses show a slight excess of Si, while analysis No. 3E exhibits some Al in the tetrahedral site. The pistacite content ($Ps=100\ Fe^{+3}/Fe^{+3}+Al^{vi}$) ranges from 17.94 in the core to 19.77 in the margin of the zoned crystals. The average Ps (18.67) is slightly lower than in the epidote from similar rocks in Shangla, Swat Kohistan (24–30, according to Guiraud *et al.,* in prep). On the basis of Ps content, the epidote is distinguished as belonging to the clinozoisite – epidote series.

d. *White mica*

The white mica is a K-rich variety, identified as phengite on the basis of abundance of $Fe^{+2}+Mg$ in the octahedral group. Phengite is a common mineral in high-P, Low-T metamorphic paragenesis (Chopin and Maluski, 1980; Frey *et al.,* 1983). Four selected analyses of white mica are presented in Table 2. A restricted range in the variation of most oxides is typical of the mica in the Allai Kohistan paragenesis which hinders a meaningful correlation with the established variation trends in the chemistry of white micas from other similar occurrences. The 100 Na/(Na+K) ratio varies from 3 to 9.86 and the phengite content (Σ FeO+MgO+MnO) from 8.02 to 10.05 (Column 3 and 4, respectively in Table 2).

DISCUSSION

The petrographic and mineral chemistry data, discussed in the previous sections, is inadequate for a precise estimation of the P-T conditions prevailing during the metamorphism of the studied rocks. Still it is helpful in pointing out some vaguely defined limits based on the following reaction boundaries (see Fig. 14, Jan, 1985) relevant to the Allai Kohistan paragenesis :

1. Jd_{25} + Qtz ⟶ Ab (Moore, 1984)
2. Ar ⟶ Cc (Johannes and Puhan, 1971)
3. Pum+Chl+Qtz ⟶ Epi+Act+Fluid (Nitsch, 1971)
4. Law+Ab ⟶ Par+Zoi (Holland, 1979; Heinrich and Althaus, 1980)
5. Plag+Mar ⟶ Par+Zoi+Qtz (Franz and Althaus, 1977)

Presence of glaucophane, epidote, quartz, plagioclase, calcite, and complete absence of pumpellyite, prehnite, paragonite, aragonite and jadeite in the studied paragenesis suggest a temperature range of about 400–450°C at 7–8 kbar pressure. The $(Na)_{M4}$ vs Al^{vi} of the glaucophane also suggests a pressure of about 7 kbar (cf. Brown, 1977). The average Si contents (7.00) of phengite analyses in Table 2, according to the method of Velde (1965), further confirm the pressure values calculated by the first two methods. Due to the complete absence of lawsonite and barroisite, the temperature range of Allai paragenesis is restricted compared to that of the Ladakh paragenesis (Compare Jan, 1985).

The absence of the barroisite and calcic amphibole development either in the successive zones around the sodic amphibole or as distinct grains, opposes any retrogression as found in eastern Ladakh, or oscillatory transition in metamorphic conditions as noted in Shangla. One possibility is that these rocks were uplifted at a very fast rate.

Acknowledgement. We gratefully thank Professor M. Qasim Jan for his assistance in the probe analysis and for his suggestions in preparing this manuscrip.

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