Geol. Bull. Univ. Peshawar, Vol. 32, pp. 1-11, 1999

P-T estimates of the calc-silicate rocks and the associated scheelite mineralisation from Miniki Gol, Chitral, N. Pakistan

MOHAMMAD ZAHID[1], & CHARLIE J. MOON[2]
[1]Department of Geology, University of Peshawar, Peshawar, Pakistan
[2]Department of Geology, University of Leicester, Leicester, UK

ABSTRACT: *Co-existing calcic-amphibole and plagioclase have been used to obtain pressure-temperature estimates from the calc-silicate rocks at Miniki Gol, Chitral, N. Pakistan. The Miniki Gol calc-silicate rocks are located within the Hindu Kush range, approximately 50 km to the northwest of the Northern suture zone. Jurassic Arkari Formation hosts the calc-silicate rock, composed of clinozoisite, quartz, calcic-amphibole, plagioclase, chlorite, biotite, calcite, sphene, garnet and scheelite.*

A pair of coexisting ferro-tschermakitic hornblende and anorthite from scheelite-bearing calc-silicate quartzite and a pair of andesine and magnesio-hornblende from barren calc-silicate quartzite were selected for P-T estimates. These pairs have apparently formed under equilibrium conditions. The tschermakitic hornblende-anorthite pair yields a temperature range of 600-650°C whereas the andesine and magnesio-hornblende pair gives a temperature range between 530 ± 20°C and 490 ± 20°C. These temperatures are compatible with those of the upper amphibolite facies and greenschist facies metamorphism, respectively.

A general agreement was also observed when these estimates were checked with the criteria described for the correlation of temperature with increase in TiO_2, Na_2O and Al_2O_3 from actinolite to tschermakite. The chemistry of the tschermakitic amphibole indicates that the calc-silicate rock has formed at a pressure below 5 kbar. Keeping in view the variation of chemical composition (Al_2O_3 content) in calcic-amphibole associated with scheelite grains, it can be suggested that scheelite crystallised in a temperature range of 550°C-400°C.

INTRODUCTION AND GEOLOGY

Calcic-amphibole is considered a good indicator of pressure and temperature over a wide range of metamorphic conditions. The increasing Al-content of the calcic-amphibole fairly correlates with the grade of metamorphism. Moreover, co-existing amphibole and plagioclase are also widely used for pressure-temperature estimation in the metamorphic rocks (Spear, 1980; Plyusnina, 1982). The systematic partitioning of X_{An} / X_{Ab} in plagioclase and Ca, M_4/ Na, M_4 in amphibole is generally accounted for geothermometry (Spear, 1980; Perchuk, 1966). Such pairs have apparently formed under equilibrium conditions and the systematic partitioning of Na and Ca occurs between plagioclase and M_4 site of the co-existing amphibole with Ca enriched in the plagioclase.

The current study attempts to discuss the pressure-temperature (P-T) estimates of co-existing amphibole and plagioclase grains within calc-silicate rock. The Miniki Gol calc-silicate rocks are located within the Hindu Kush range, approximately 50 km to the northwest of the Northern suture zone (Fig.1). The Northern suture marks the zone between the Kohistan complex and Asian plate. The Hindu Kush terrane merges into western Karakoram along the Pak-Afghan border near Chitral (Fig.1). The terrane stretches southwest from the Pamirs in Russia across the north-western extremities of Pakistan and passes into Afghanistan. Based on the stratigraphical sequence and structural evolution, Pudsey et al. (1985) described the geology of Western Karakoram and Hindu Kush between the Pak-Afghan border and Northern suture in the Chitral and surrounding area. They divided the area into two tectonic units: (1) the Northwestern unit between Pak-Afghan border and the Reshun Fault and (2) the Central unit between the Reshun Fault and Northern suture (Fig.1).

Leake et al. (1989) subdivided the Northwestern unit into three fault-bounded lithostratigraphic entities, namely Sewakht Formation, Lutkho Formation and Arkari Formation. The Jurassic Arkari Formation, which hosts the tungsten mineralisation at Miniki Gol (Fig.1), is dominantly composed of garnet-mica schist, phyllite, calc-silicate quartzite and a thick unit of marble. These rocks have undergone at least two phases of deformation and metamorphism that are related to continent-arc collision. Metamorphism within the formation is highly variable, ranging from lower greenschist to amphibolite facies followed by the emplacement of leucogranite.

SAMPLES AND METHODS

The study area was sampled through a number of systematic traverses during three separate field trips. A total of about 47 samples from calc-silicate quartzite were collected. The collected samples were studied through thin sections and megascopic observations. Among these samples only two samples (ZC65 and ZC4) were chosen for pressure temperature estimation (Tables 1, 2). About 650 microprobe analyses from calc-silicate quartzite were performed on different grains of amphibole and plagioclase, from which 44 representative analyses are presented in the Tables 1and 2.

The analyses were performed using a Jeol Superprobe model JXA-8600 with an on-line computer for ZAF corrections. Quantitative analyses were obtained using wavelength dispersive system under the following operating conditions: 15 kV accessory voltage; 30 x 10^{-9} A probe current; 20 (2 x 10) seconds peak, 10 (2 x 5) seconds negative background and 10 (2 x 5) seconds positive background counting times. The diameter of the X-ray beam varied according to the type, nature and grain size of the analysed phase. For plagioclase and amphibole, 15 m and 5 m diameters were used respectively.

The silicate phase and some oxides were analysed for major and minor oxide such as SiO_2, TiO_2, Al_2O_3, FeO (total), MnO, MgO, CaO, Na_2O, K_2O, and Cr_2O_3. The following standards were used for these microprobe analyses: wollastonite (natural for Si, and Ca); rutile (natural for Ti); jadeite (natural for Al and Na); magnetite (synthetic for Fe); rhodonite (natural for Mn); MgO (synthetic for Mg); microcline (natural for K. Pure synthetic metal was used for Cr. The accuracy of the ZAF correction was generally better than 2 %.

TABLE 1. CHEMICAL VARIATION IN THE MINIKI GOL AMPHIBOLE FROM SCHEELITE-BEARING CALC- SILICATE QUARTZITE, (EXCEPT ZC 4 AND ZC 49, BARREN CALC-SILICATE QUARTZITE)

Sample	ZC65*	ZC65*	ZC65*	ZC65*	ZC65*	ZC65*	ZC65*	ZC65*	ZC65*	ZC4▲	ZC4▲	ZC4▲
Posit.	C	C	C	R	R	C	C	R	R	C	C	C
SiO_2	42.94	43.02	43.03	42.38	41.88	42.79	42.79	42.06	42.13	53.93	53.50	47.42
TiO_2	0.19	0.25	0.20	0.22	0.18	0.15	0.22	0.22	0.15	0.04	0.07	0.28
Al_2O_3	16.39	16.52	15.85	16.82	17.19	16.34	16.23	16.81	17.59	2.02	3.36	9.43
Cr_2O_3	0.05	0.01	0.03	0.00	0.00	0.02	0.04	0.01	0.06	0.02	0.04	0.05
Fe_2O_3	3.78	3.43	3.24	4.21	7.74	3.43	3.20	3.47	8.68	2.79	1.99	0.96
FeO	15.33	15.34	15.67	14.39	11.32	15.24	15.29	15.10	10.25	9.36	10.85	14.03
MnO	0.28	0.37	0.41	0.37	0.36	0.39	0.35	0.36	0.32	0.55	0.61	0.58
MgO	6.72	6.89	6.63	6.93	7.02	6.83	7.00	6.73	6.92	15.97	15.28	11.21
CaO	11.64	11.79	11.56	11.60	10.60	11.68	11.75	11.78	10.09	12.40	12.74	12.43
Na_2O	0.98	0.99	0.94	1.04	1.10	0.99	1.04	1.01	1.10	0.13	0.28	0.79
K_2O	0.57	0.60	0.60	0.59	0.74	0.63	0.61	0.56	0.73	0.06	0.15	0.60
Total	98.87	99.20	98.16	98.54	98.14	98.49	98.52	98.11	98.02	97.27	98.87	97.79

Cations per 23 oxygen atoms

Si	6.318	6.307	6.381	6.246	6.163	6.320	6.318	6.240	6.174	7.742	7.609	6.970
Ti	0.021	0.028	0.022	0.024	0.020	0.017	0.024	0.025	0.017	0.004	0.007	0.031
Al	2.842	2.855	2.770	2.922	2.982	2.845	2.825	2.940	3.038	0.342	0.563	1.634
Al4	1.682	1.693	1.619	1.754	1.837	1.680	1.682	1.760	1.826	0.258	0.391	1.030
Al6	1.160	1.161	1.151	1.167	1.144	1.164	1.143	1.180	1.212	0.084	0.172	0.603
Cr	0.006	0.001	0.004	0.000	0.000	0.002	0.005	0.001	0.007	0.002	0.004	0.006
Fe^{3+}	0.418	0.378	0.362	0.466	0.857	0.381	0.355	0.388	0.957	0.301	0.213	0.106
Fe^{2+}	1.886	1.880	1.944	1.773	1.393	1.883	1.889	1.873	1.256	1.124	1.290	1.725
Mn	0.035	0.046	0.052	0.046	0.045	0.049	0.044	0.045	0.040	0.067	0.073	0.072
Mg	1.474	1.506	1.466	1.522	1.540	1.504	1.541	1.488	1.512	3.418	3.239	2.456
Ca	1.835	1.852	1.837	1.832	1.671	1.848	1.859	1.873	1.584	1.907	1.941	1.958
CaB	1.835	1.852	1.837	1.832	1.671	1.848	1.859	1.873	1.584	1.907	1.941	1.958
Na	0.280	0.281	0.270	0.297	0.314	0.284	0.298	0.291	0.313	0.036	0.077	0.225
NaB	0.165	0.148	0.163	0.168	0.314	0.152	0.141	0.127	0.313	0.036	0.059	0.042
NaA	0.115	0.133	0.107	0.129	0.000	0.132	0.157	0.163	0.000	0.000	0.019	0.183
K	0.107	0.112	0.114	0.111	0.139	0.119	0.115	0.106	0.136	0.011	0.027	0.113
Mg #	0.439	0.445	0.430	0.462	0.525	0.444	0.449	0.443	0.546	0.753	0.715	0.587
$Ca+Na_B$	2.000	2.000	2.000	2.000	1.985	2.000	2.000	2.000	1.897	1.943	2.000	2.000
$(Na+K)_A$	0.222	0.245	0.221	0.240	0.139	0.251	0.272	0.269	0.136	0.011	0.046	0.296

Table 1 (contd.)

Sample	ZC4ˆ	ZC4ˆ	ZC4ˆ	ZC41	ZC41	ZC49	ZC49	ZC49	ZC49	ZC43	ADIT 3	ADIT 3
Posit.	M	M	R	M	R	C	R	C	R		C	R
SiO_2	47.39	47.34	47.10	44.01	43.48	50.80	51.85	47.48	49.64	50.65	42.38	49.23
TiO_2	0.29	0.27	0.30	0.25	0.32	0.06	0.07	0.17	0.09	0.13	0.31	0.22
Al_2O_3	9.85	10.11	9.42	18.04	16.32	5.91	4.60	9.99	7.61	7.09	16.48	14.34
Cr_2O_3	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.02	0.03	0.01	0.04	0.00
Fe_2O_3	0.72	2.18	0.65	0.00	1.37	0.42	0.77	2.01	1.37	2.09	0.79	0.00
FeO	13.43	12.37	13.98	13.28	13.03	13.21	12.78	12.82	13.07	9.63	15.68	14.69
MnO	0.63	0.61	0.53	0.40	0.40	0.48	0.48	0.46	0.48	0.62	0.37	0.28
MgO	11.57	11.67	11.26	7.58	8.85	12.89	13.55	10.89	12.27	14.55	7.16	6.22
CaO	12.46	12.33	12.32	11.93	11.98	12.33	12.38	11.71	12.34	12.48	11.93	10.55
Na_2O	0.89	0.85	0.89	1.34	1.08	0.46	0.34	0.75	0.57	0.70	1.02	0.84
K_2O	0.62	0.61	0.61	0.56	0.44	0.27	0.20	0.56	0.38	0.31	0.52	0.43
Total	97.88	98.38	97.07	97.42	97.30	96.87	97.07	96.86	97.85	98.26	96.68	96.80
Cations per 23 oxygen atoms												
Si	6.938	6.885	6.969	6.485	6.391	7.434	7.554	6.994	7.222	7.239	6.350	7.265
Ti	0.032	0.030	0.033	0.028	0.035	0.007	0.008	0.019	0.010	0.014	0.035	0.024
Al	1.700	1.733	1.643	3.133	2.828	1.019	0.790	1.734	1.305	1.194	2.910	2.494
Al4	1.062	1.115	1.031	1.515	1.609	0.566	0.446	1.006	0.778	0.761	1.650	0.735
Al6	0.638	0.618	0.612	1.618	1.219	0.454	0.343	0.728	0.527	0.434	1.260	1.759
Cr	0.003	0.005	0.002	0.003	0.003	0.005	0.005	0.002	0.003	0.001	0.005	0.000
Fe^{3+}	0.080	0.238	0.072	0.000	0.151	0.046	0.085	0.223	0.150	0.224	0.089	0.000
Fe^{2+}	1.644	1.505	1.730	1.636	1.602	1.617	1.558	1.580	1.590	1.151	1.965	1.813
Mn	0.078	0.075	0.066	0.050	0.050	0.060	0.059	0.057	0.059	0.075	0.047	0.035
Mg	2.525	2.530	2.484	1.665	1.939	2.812	2.943	2.391	2.661	3.100	1.599	1.368
Ca	1.955	1.921	1.953	1.883	1.887	1.933	1.933	1.848	1.924	1.911	1.915	1.668
CaB	1.955	1.921	1.953	1.883	1.887	1.933	1.933	1.848	1.924	1.911	1.915	1.668
Na	0.253	0.240	0.255	0.383	0.308	0.131	0.096	0.214	0.161	0.194	0.296	0.240
NaB	0.045	0.079	0.047	0.117	0.113	0.067	0.067	0.152	0.076	0.089	0.085	0.240
NaA	0.207	0.161	0.209	0.266	0.195	0.064	0.029	0.062	0.084	0.105	0.212	0.000
K	0.116	0.113	0.115	0.105	0.083	0.050	0.037	0.105	0.071	0.057	0.099	0.081
Mg #	0.606	0.627	0.589	0.504	0.548	0.635	0.654	0.602	0.626	0.729	0.449	0.430
$Ca+Na_B$	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	1.908
(Na+K)	0.323	0.274	0.324	0.371	0.278	0.114	0.066	0.167	0.155	0.162	0.311	0.081

Mg # = Mg / (Mg + Fe^{2+}); C = Core; M = Middle; R = Rim; *ferro-tschermakitic horblende co-existing with anorthite (used in Fig. 4.6 C); ˆ Magnesio-hornblende containing andesine inclusion (used in Fig. 4.6 C).N. B. The various positions within a single grain are underlined together.

TABLE 2. CHEMICAL COMPOSITION OF INVESTIGATED PLAGIOCLASE FROM BARREN CALC-SILICATE QUARTZITE (ZC27 AND ZC4), SCHEELITE-BEARING CALC-SILICATE QUARTZITE (ZC65), AND MARBLE (ZC56)

Sample	ZC65*	ZC65*	ZC65*	ZC65*	ZC65*	ZC65*	ZC65*	ZC65*	ZC4^	ZC4^
Posit.	C	C	C	C	M	M	R	R	Inc	Inc
SiO_2	45.28	46.18	45.22	46.02	45.63	46.35	45.84	46.18	58.46	56.75
TiO_2	0.01	0.00	0.02	0.04	0.01	0.00	0.01	0.01	0.04	0.02
Al_2O_3	35.08	34.14	35.35	34.23	35.31	34.50	32.37	32.99	24.82	26.75
FeO	0.08	0.08	0.03	0.07	0.09	0.12	1.28	0.29	0.24	0.84
MnO	0.02	0.00	0.00	0.03	0.01	0.01	0.03	0.01	0.02	0.04
MgO	0.00	0.01	0.01	0.01	0.00	0.00	0.38	0.04	0.00	0.35
CaO	19.15	17.73	18.94	17.98	18.55	17.63	16.02	16.63	7.35	7.62
Na_2O	0.85	1.18	0.82	1.05	0.95	1.35	1.47	1.52	7.30	6.26
K_2O	0.02	0.43	0.02	0.57	0.03	0.03	0.38	0.10	0.17	1.00
Total	100.49	99.75	100.41	100	100.58	99.99	97.78	97.77	98.4	99.63
Cations per 32 oxygen atoms										
Si	8.324	8.529	8.307	8.493	8.361	8.521	8.655	8.672	10.618	10.262
Ti	0.001	0.000	0.003	0.005	0.001	0.000	0.001	0.001	0.005	0.003
Al	7.602	7.432	7.654	7.446	7.626	7.476	7.204	7.302	5.313	5.701
Fe^{2+}	0.013	0.013	0.005	0.010	0.014	0.018	0.202	0.046	0.036	0.127
Mn	0.003	0.000	0.000	0.005	0.001	0.001	0.005	0.001	0.003	0.006
Mg	0.000	0.003	0.003	0.003	0.000	0.000	0.108	0.012	0.000	0.095
Ca	3.772	3.508	3.729	3.556	3.642	3.473	3.241	3.346	1.431	1.476
Na	0.303	0.422	0.292	0.376	0.338	0.481	0.538	0.553	2.572	2.195
K	0.005	0.101	0.005	0.134	0.006	0.006	0.092	0.024	0.040	0.230
Total	20.023	20.008	19.997	20.028	19.990	19.977	20.046	19.958	20.017	20.095
An•	92.44	87.02	92.62	87.44	91.36	87.69	83.73	85.29	35.4	37.83

Sample	ZC4	ZC4	ZC27	ZC27	ZC27	ZC27	ZC56	ZC56	ZC56	ZC56
Posit.	C	R	C	R	M	R	C	R	M	R
SiO_2	57.46	61.06	50.67	48.71	48.13	46.78	45.02	45.47	57.81	44.93
TiO_2	0.00	0.02	0.03	0.01	0.01	0.03	0.01	0.00	0.00	0.01
Al_2O_3	27.15	24.64	29.78	33.13	33.69	34.88	35.11	34.50	27.56	34.20
FeO	0.01	0.04	1.61	0.33	0.03	0.04	0.01	0.10	0.05	0.12
MnO	0.01	0.03	0.04	0.03	0.02	0.03	0.02	0.03	0.02	0.00
MgO	0.00	0.00	0.19	0.01	0.00	0.03	0.00	0.00	0.00	0.01
CaO	9.17	6.13	14.67	16.93	17.04	17.67	18.90	18.32	14.88	18.19
Na_2O	6.49	8.19	2.14	2.03	2.08	1.25	0.85	1.16	0.89	1.09
K_2O	0.13	0.23	0.71	0.08	0.07	0.17	0.01	0.02	0.05	0.04
Total	100.42	100.34	99.84	101.26	101.07	100.88	99.93	99.6	101.26	98.59
Cations per 32 oxygen atoms										
Si	10.264	10.828	9.320	8.829	8.740	8.521	8.314	8.416	10.207	8.403
Ti	0.000	0.003	0.004	0.001	0.001	0.004	0.001	0.000	0.000	0.001
Al	5.716	5.149	6.456	7.078	7.210	7.489	7.643	7.528	5.736	7.540
Fe^{2+}	0.001	0.006	0.247	0.050	0.005	0.006	0.001	0.015	0.008	0.019
Mn	0.001	0.005	0.006	0.005	0.003	0.005	0.003	0.005	0.003	0.000
Mg	0.000	0.000	0.052	0.003	0.000	0.008	0.000	0.000	0.000	0.003
Ca	1.755	1.165	2.892	3.288	3.315	3.448	3.740	3.634	2.815	3.645
Na	2.248	2.816	0.763	0.713	0.732	0.442	0.305	0.416	0.305	0.396
K	0.029	0.052	0.166	0.018	0.017	0.040	0.003	0.005	0.012	0.009
Total	20.015	20.024	19.907	19.986	20.023	19.963	20.009	20.019	19.084	20.017
An•	43.52	28.88	75.68	81.82	81.57	87.75	92.41	89.61	89.9	90.01

• = Mol % An {100 Ca / (Ca + Na + K)}; * = Anorthite composition used for geothermometry in Fig. 4.6 C; ^ = Andesine composition used for geothermometry in Fig. 4.6 C; Inc = Inclusion in amphibole; C= Core; M= Middle; R= Rim; The different positions within a single grain are shown by underlining.

The Miniki Gol calc-silicate rock is composed of clinozoisite, quartz, calcic-amphibole, plagioclase, chlorite, biotite, calcite, sphene, garnet and scheelite. Some varieties of calc-silicate rocks are banded, with darker layers being mainly composed of amphibole, chlorite and clinozoisite. Amphibole is one of the dominant constituents of both the scheelite-bearing and scheelite-free calc-silicate rocks. Most of the calc-silicate rocks (such as ZC65, ZC41, ZC43, Table 1) contain scheelite grains and some of them are associated with amphibole grains, allowing pressure-temperature estimates to be made for scheelite mineralisation as well.

AMPHIBOLE

The amphibole (actinolitic hornblende) in these rocks occurs as spherulites, needles or fibrous crystals radiating from a common centre. The non-spherulitic tschermakitic hornblende occurs as laths and some are associated with scheelite, anorthite, clinozoisite and sphere. Some of thehornblende occurs, as euhedral grains whose long axes do not follow the general foliation. Some thin layers of amphibole cross-cut the main amphibole layers. The stellate form of actinolitic amphibole appears to have crystallised later than clinozoisite (Leake et al., 1989), although the tschermakitic hornblende predates the clinozoisite phase.

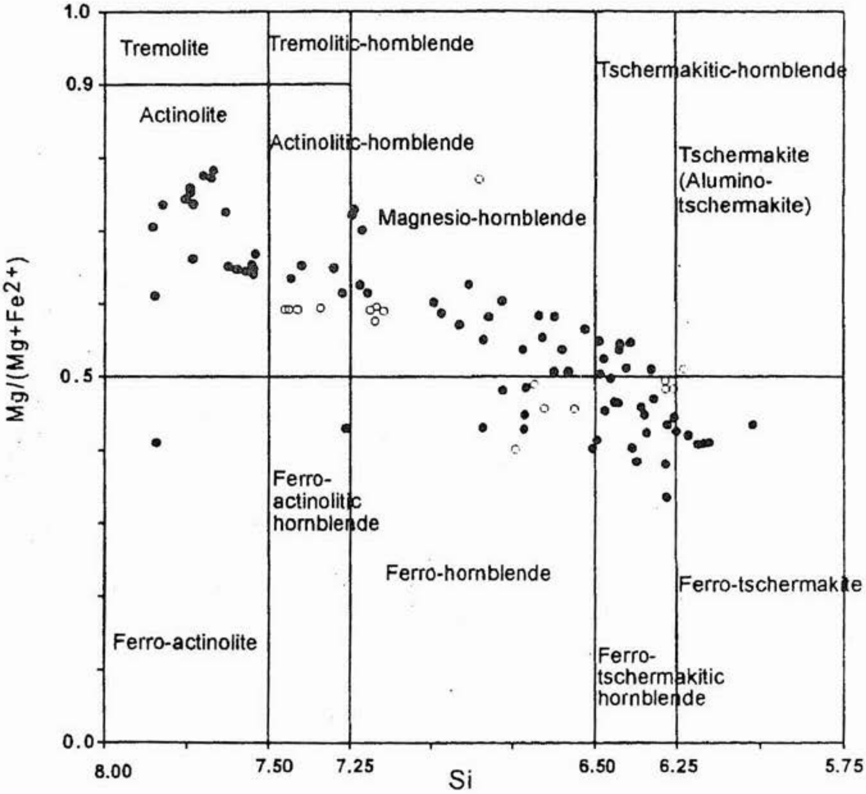

Fig. 2. Compositions of Miniki Gol amphiboles on the classification diagram of Leake (1978). The open circles indicate amphibole associated with scheelite grains whereas the filled circles show amphibole not associated directly with scheelite grains in the calc-silicate quartzite.

Twenty-four representative analyses from calc-silicate quartzite performed on different grains, are listed in Table 1. Mineral formulae calculation together with ferrous and ferric iron determination were carried out on the basis of 23 oxygen atoms and following the procedure of Leake (1978), Robinson (1982) and Robinson et al. (1982), 13 cations, that have rendered a maximum estimate of Fe^{3+} when balanced to 23 (O).

With $(Ca + Na)_B > 1.34$, $Na_B < 0.67$ and $(Na + K)_A < 0.5$ (Table 1), the amphibole is classified as calcic and can be divided into ferro-tschermakite, ferro-tschermakitic and tschermakitic hornblende, ferro-and magnesio-hornblende, actinolitic hornblende and actinolite (Fig. 2).

Compositional variation was noticed within the single grain of the calcic-amphibole. Depletion of Al_2O_3 at margins in the studied amphibole is dominant. However, the reverse is also noticed in some grains indicating the preservation of prograde metamorphic conditions in these rocks (Table 1; Fig. 3a).

PLAGIOCLASE

Plagioclase occurs almost in every lithology from the Miniki Gol and surrounding areas. Twenty representative analyses of plagioclase from 16 samples are shown in Table 2. Plagioclase in the scheelite-bearing rocks (ZC65) and marble (ZC56) varies in composition from An_{84} to An_{92} and An_{89} to An_{92}, respectively. Anorthite content of the plagioclase from Miniki Gol schist and mica quartzite ranges from An_{19} to An_{31} and An_{20} to An_{34}, respectively. Plagioclase from barren calc-silicate quartzite (ZC27), has anorthite content up to An_{88} whereas those for the barren calc-silicate quartzite (ZC4, used for geothermometry; (Fig. 3c) ranges from An_{35} to An_{38}.

According to Rambaldi (1973) and Goldsmith (1982), the increase in anorthite content in the metamorphic rocks is correlated generally with increasing metamorphic grade. However, Höy (1976) suggested that the anorthite content also greatly depends on the bulk rock chemistry and XCO_2. Therefore the high anorthite content of plagioclase from the marble in the investigated area can be correlated with this later view (ZC56, Table 2). The composition of plagioclase from schist and mica quartzite within a single grain is homogenous. However, intra-grainular compositional variation does exist in plagioclase from calc-silicate quartzite. Normal (enrichment of CaO in margins) and reverse zoning have been observed within individual grains of plagioclase from calc-silicate quartzite (ZC4, ZC27, ZC65 Table 2), indicating the preservation of both prograde and retrograde metamorphism in these rocks (Höy, 1976).

PRESSURE-TEMPERATURE ESTIMATES

In order to assess the temperature estimation in the Miniki Gol calc-silicate rocks, a pair of coexisting ferro-tschermakitic hornblende and anorthite from scheelite-bearing calc-silicate quartzite (Fig. 3c; Table 1-ZC65), and a pair of andesine and magnesio-hornblende from barren calc-silicate quartzite (Table2-ZC4), were selected for P-T estimates. The coexisting ferro-tschermakitic hornblende and anorthite have got clear grains boundaries without any reaction rims developed between them. This indicates that the two minerals have grown under equilibrium conditions. In the second pair, andesine occurs as an inclusion in magnesio-hornblende suggesting a stable coexistence. On the Spear (1980) diagram, the tschermakitic-hornblende and anorthite data plot between the contours 650 25°C and 725 25°C, whereas the andesine and magnesio-hornblende pair gives a temperature range between 530 20°C and 490 20°C (Fig.3C).

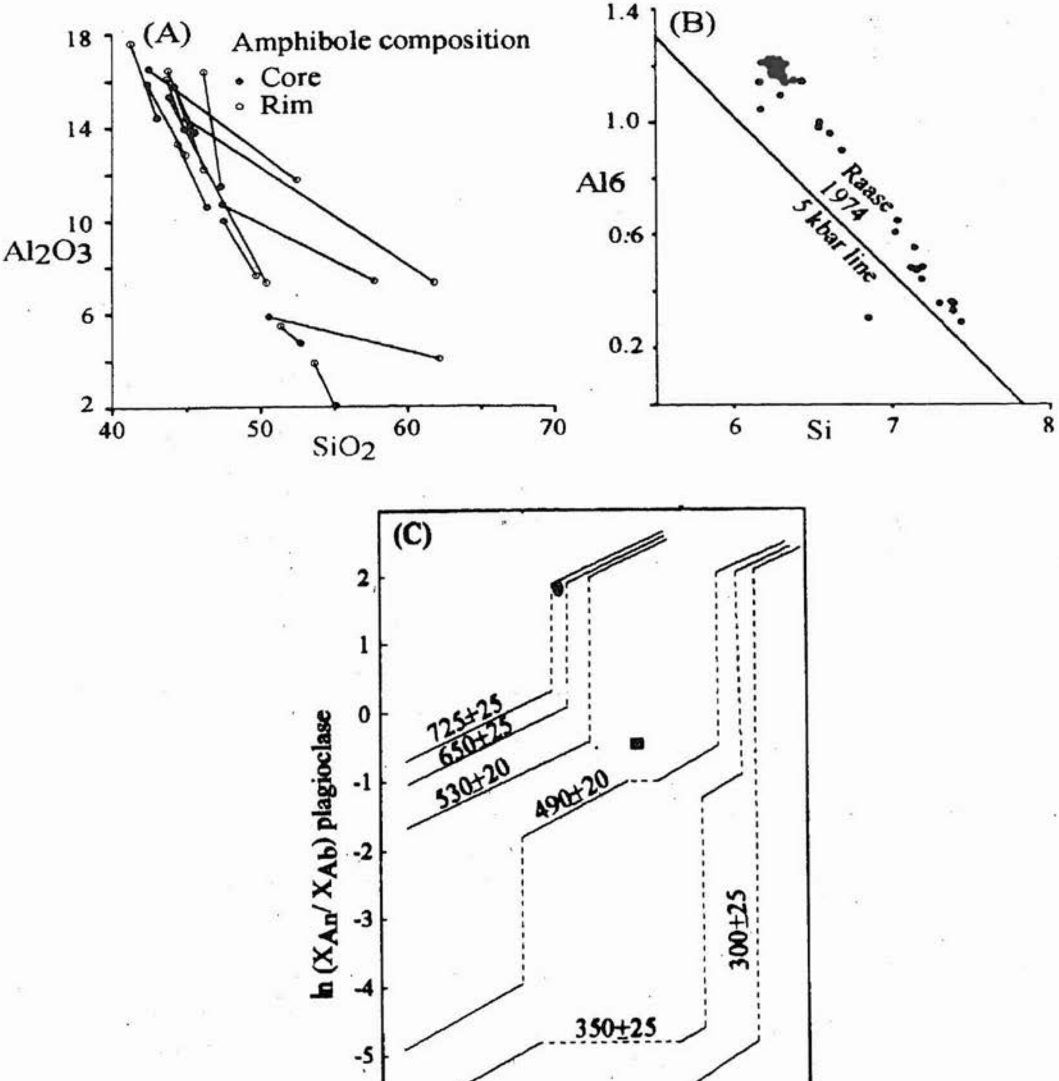

Fig. 3. (A) Relationship of wt % Al_2O_3 with SiO_2 indicating core and rim compositions of the studied amphiboles. Tie lines show core and rim compositions within a single grain. (B) Plot of Al6 vs. Si of Miniki Gol amphiboles, the line indicates an assumed pressure of 5 kbar (after Raase, 1974). (C) Plot of (Ca/Na) vs. (X_{An}/X_{Ab}) of studied amphibole and plagioclase superimposed on the Spear (1980) contours. The ellipse indicates the Miniki Gol anorthite-tschermakite composition from scheelite-bearing calc-silicate quartzite and square shows the andesine-magnesio-hornblende composition from barren calc-silicate quartzite. M4 = B-site; (X_{An}/X_{Ab}) = Ca / Na. Data taken from Table 1 and 2.

REFERENCES

Calkins, J. A., Jamiluddin, S., Bhuyan, K. & Hussain, A., 1981. Geology and mineral resources of the Chitral-Partsan area, Hindu Kush range, Northern Pakistan. U. S. Geol. Surv. Prof. Paper, 716-G, 33.

Doolan, B. L., Zen, E. An. & Bence, A. P., 1978. Highly aluminous hornblendes: composition and occurrences from southwestern Massachusetts. Am. Min., 63, 1088-1099.

Einaudi, M. T., Meinert, L. D. & Newberry, R. J., 1981. Skarn deposits. Econ. Geol. 75th Anniv. Vol., 317-391.

Engel, A. E. J & Engel, C. G., 1962. Hornblendes formed during progressive metamorphism of amphibolites, northwestern Adirondack Mountains, New York. Bull. Geol. Soc. Am., 73, 1499-1514.

Ernst, W. G., 1972. Ca-amphibole paragenesis in the Shirataki District, Central Shikoku, Japan. Geol. Soc. Am. Mem., 135, 73-94.

Goldsmith, J. R., 1982. Review of the behaviour of plagioclase under metamorphic conditions. Am. Min., 67, 643-652.

Foster, R. P., 1977. Solubility of scheelite in hydrothermal chloride solutions. Chem. Geol., 20, 27-43.

Höy, T., 1976. Calc-silicate isograds in the Riondel area, southeastern British Columbia. Can. J. Ear. Sci., 13, 1093-1104.

Leake, B. E., 1965. The relationship between tetrahedral aluminium and the maximum possible aluminium in natural calciferous amphiboles. Am. Min., 50, 843-851.

Leake, B. E., 1978. Nomenclature of amphiboles. Am. Min., 63, 1023-1053.

Leake, R. C., Fletcher, C. J. N., Haslam, H. W., Khan, B. & Shakirullah. 1989. Origin and tectonic setting of stratabound tungsten mineralisation within the Hindu Kush of Pakistan. J. Geol. Soc. London, 146, 1003-1016.

Perchuk, L. L., 1966. Temperature dependence of the coefficient of distribution of calcium between coexisting amphibole and plagioclase. Dokl. Acad. Sci. USSR, Earth Sci. Sec., 169, 203-205.

Plyusnina, L. P., 1982. Geothermometry and geobarometry of plagioclase-hornblende bearing assemblages. Contr. Min. Pet., 80, 140-146.

Pudsey, C. J., Coward, M. P., Luff, I. W., Shackleton, R. M., Windley, B. F. & Jan, M. Q., 1985. Collision zone between the Kohistan arc and the Asian plate in NW Pakistan. Trans. Roy. Soc. Edinburgh, 76, 463-479.

Raase, P., 1974. Al and Ti contents of hornblende, indicators of pressure and temperature of regional metamorphism. Contr. Min. Pet., 45, 231-236.

Rambaldi, E. R., 1973. Variation in the composition of plagioclase and epidote in some metamorphic rocks near Bancroft, Ontario. Can. J. Ear. Sci., 10,852-868.

Robinson, P., 1982. The amphibole formula. In: Amphiboles: Petrology and Experimental Phase Relations. (D. R Veblen, & R. H Ribble, eds), Min. Soc. America, Rev. Min., 9B, 3-6.

Robinson, P., Schumacher, J. C. & Spear, F. S., 1982. Formulation of electron probe analyses. In: Amphiboles: Petrology and Experimental Phase Relations. (D. R Veblen, & R. H Ribble, eds), Min. Soc. America, Rev. Min., 9B, 6-9.

Spear, F. S., 1980. NaSi⇔CaAl exchange equilibrium between plagioclase and amphibole. Contr. Min. Pet., 72, 33-41.

Zahid, M., 1996 Genesis of stratabound scheelite and stratiform Pb-Zn mineralisation Chitral, Northern Pakistan, and its comparison with S-W England tin-tungsten deposits. Unpubl. Ph.D. thesis Univ. Leicester, U.K.