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GEOLOGY AND PETROLOGY OF THE MALAKAND GRANITE, GNEISS AND METASEDIMENTARY COMPLEX

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ABSTRACT

The Malakand granite intrudes a series of low grade metasediments and granitic gneisses. It appears to be Calc-alkaline in characters. A temperature range of c. > 875–650°C and PH_2O of c. 5 – < 5 Kb has been suggested for the development of various phases in the granite. The chemical features and age relationship also indicate that the Malakand granite is not genetically related to the alkaline igneous complex of the Peshawar plain.

Three types of gneisses have been distinguished; (a) siliceous gneiss, (b) silica-rich granitic gneiss and (c) normal granite gneiss. Among these only the normal granitic gneiss seems to be genetically related to the Malakand granite.

The metasediments indicate several episodes of regional metamorphism ranging from lower green-schist facies to upper green-schist facies environments. The presence of garnet in schist at the contacts of granite has been related to the thermal effects of the intruding granitic magma.

INTRODUCTION

The Malakand granite is one of the well known granites of the north-western Himalayas occurring at longitude 34°–36′ E and latitude 70°–52′ N (Toposheet 38 N/14, Survey of Pakistan), along main Mardan-Swat road. Several workers have investigated the various aspects of this granitic body (Khan, 1965; Chaudhry *et al.*, 1974, 1976). The granite has intruded gneisses and metasediments of possible Cambrian and Precambrian age (Kempe, 1983; Shams, 1983).

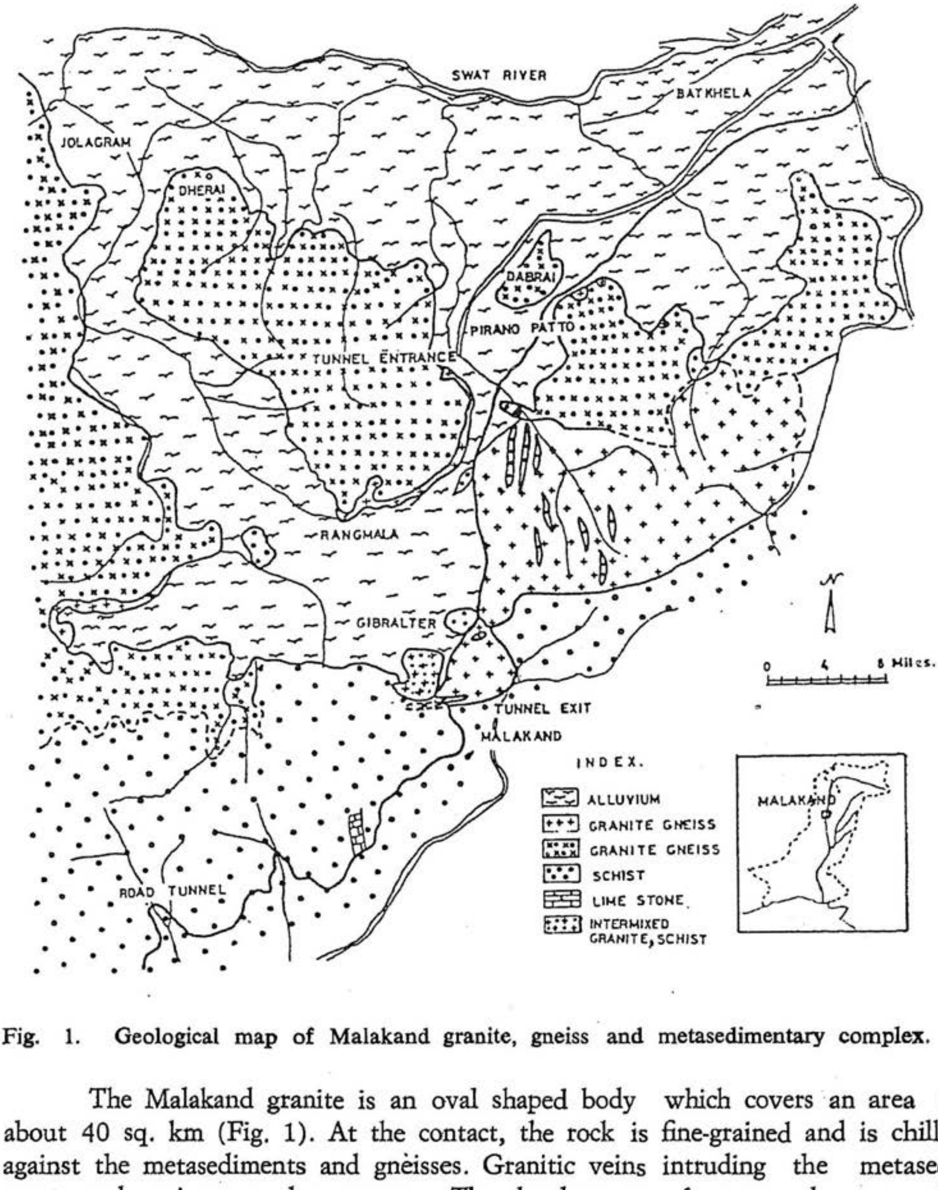


Fig. 1. Geological map of Malakand granite, gneiss and metasedimentary complex.

The Malakand granite is an oval shaped body which covers an area of about 40 sq. km (Fig. 1). At the contact, the rock is fine-grained and is chilled against the metasediments and gnèisses. Granitic veins intruding the metasediments and gneises are also common. The development of garnet due to the thermal effect of granite has been noticed in the large metasedimentary block occurring within the granitic body at Tor Mor Rest House, at Malakand proper (main granite-schist contact) and in granitic gneisses intruded by small granitic veins near Jolagram. The Malakand gneisses make an anticlinal outcrop with the nose plunging approximately ESE and the Malakand granite intrudes the core of this anticlinal structure (Shams, 1983). The gneisses generally trend

NE–SW and dip SE. The contact between the granite and gneisses is generally sharp but near the entrance of hydraulic tunnel (Fig. 1) gneisses have equilibrated with granite during the emplacement of the latter type and can only be distinguished on the basis of the presence of garnet in gneisses and the high proportion of amphibole in granite. The gneisses are variably mixed with schistose rocks at the back of Gibralter (Fig. 1).

We present here a detailed map and petrography of the Malakand granite, gneiss and metasedimentary complex, the major element chemistry of the Malakand granite and the associated gneisses and possible petrogentic interpretations based on these data.

PETROGRAPHY

The petrography of the schistose rocks, gneisses and Malakand granite has been described by Chaudhry *et al.* (1974, 1976) and Jabeen *et al.* (1985). The important petrographic features studied by previous workers and during the present investigation are as follows :

Metasedimentary Rocks

Members of the metasedimentary sequence are chlorit-epidote schist, calcareous schist, garnet-mica schist, quartz-mica schist, graphitic schist, and siliceous schist.

Chlorite-epidote schist is exposed near the road tunnel. This is light grey to dark grey, and commonly contains calcite and quartz veins which show ptygmatic folds and boudinage structures. The rock is fine to medium grained, hypidioblastic and is dominantly composed of amphibole (actinolite, actinolitic-hornblende), quartz, plagioclase, and chlorite. Chlorit-epidote schist is incorporated by calcareous material in the south of Malakand town (Fig. 1).

The calcareous schist is a medium to coarse-grained, hypidioblastic to xenoblastic rock, dominantly composed of calcite, quartz, biotite, and muscovite. Fine grained euhedral tourmaline of olive colour, sparingly zoned, has been found in it at Tor Mor Rest House. Its occurrence can be attributed to boron metasomatism at the granite calcareous schist contact. Calcareous schist and chlorite-epidote schist generally grade into garnet-mica schist near the granite contact.

The garnet-mica schist at Malakand proper varies in colour from greenish brown to brown and trends NE–SW. It contains garnet, muscovite, quartz, biotite, and microcline. Opaque minerals, chlorite, sphene and tourmaline are common accessories. Garnet forms large subhedral to euhedral porphyroblasts (0.7–1cm). Fractures within the garnet are filled with secondary muscovite, biotite, and plagioclase. Chaudhry *et al.* (1974) have suggested that the development of garnet has taken place due to reaction between muscovite and biotite.

A N–S trending small outcrop of quartz-mica schist (dominantly composed of quartz and muscovite) is exposed at the northern contact of the Malakand granite, about 1.6 km east of Pirano Patto (Fig. 1). Bands and blocks of quartzite (representing metamorphosed quartz veins) are interbedded with this schist.

Graphitic schist exposed south of the road tunnel varies in colour from greyish black to black. Compared with chlorite-epidote schist it has a higher biotite/chlorite ratio. Graphite occurs along the schistosity planes as thin layers, streaks, and disseminated grains in the rock. With decreasing proportion of graphite the graphitic schist near the road tunnel grades into chlorite-epidote schist.

The siliceous schist occurs to the west of Gibraltar, near Rangmala Hospital (Fig. 1). It is yellow in colour and contains abundant quartz but micaceous minerals still impart schistosity to the rock. Granitic and quartzo-feldspathic veins commonly intrude into the siliceous schist.

Gneisses

The Malakand gneisses are medium to coarse-grained rocks, greyish-white on fresh surfaces and grey to brownish on weathered ones. Deformed veins of quartz, feldspar and granitic material are common in these rocks.

The granite gneisses are composed of plagioclase, quartz, muscovite, biotite, alkali-feldspar (microcline and orthoclase) along with accessory amount of sphene, epidote, garnet, and calcite.

Plaglodase (An_{45-28}) occurs as large crystals which are generally replaced by muscovite along cleavages and margins. Alkali feldspar exhibits myrmekitic intergrowth of quartz. Both plagioclase and alkali feldspar contain epidote and quartz.

Muscovite has irregular flakes containing quartz inclusions. Greyish brown biotite replaces muscovite along the margins and cleavages, indicating its development at the expense of muscovite. Garnet is colourless and forms subhedral grains commonly associated with calcite and biotite. Subhedral grains of calcite replace plagioclase. Amphibole is green to greenish-brown and is not common.

Malakand Granite

The Malakand granite is a medium to coarse-grained, locally porphyritic through subequigranular to equigranular and hypidiomorphic to allotriomorphic rock varying in colour from white on fresh surface to brown and brownish black on weathered surfaces. It is invariably criss-crossed by quartz, pegmatite and aplite veins. The tourmaline-flourite bearing pegmatites are reported near the Malakand Rest House by Chaudhry *et al.* (1974). On the basis of the proportion of micaceous minerals, the granite can be classified into (a) muscovite granite and (b) muscovite-biotite granite. Except for the different proportions of the two micas, the petrography of the two types is generally similar. Both are essentially composed of quartz, plagioclase, alkali-feldspar, muscovite and biotite. Epidote, sphene, apatite, calcite, amphibole and opaque ores are the common accessories.

Two types of muscovite (10–25%) occur, a primary muscovite represented by large anhedral occasionally kinked flakes with corroded margins, and a secondary muscovite replacing other phases and occupying fractures in quartz and feldspar. Biotite is generally associated with muscovite.

Quartz grains (10–30%) are highly fractured and exhibit wavy extinction. Inclusions of epidote and apatite occur in these grains. Plagioclase (An_{5-20}) occurs as subhedral to anhedral grains which are partly sericitized and kaolinized. It commonly shows exsolution lamellea of k-feldspar. Microline is the dominant alkali-feldspar together with some orthoclase. Myrmekitic quartz forming as a result of reaction between microcline and plagioclase is common. Apatite is found as inclusions in quartz and feldspars.

Epidote occurs in the form of granular aggregates as well as inclusions in quartz, muscovite, and alkali-feldspar. Compositional zoning is noticed in certain grains of epidote. A fine-grained epidote has also resulted from the alteration of plagioclase. Calcite occurs interstitially and seems to represent the final phase of primary crystallization.

Amphibole occurs as anhedral crystals with green to dark green colour. The crystals are fractured and the fractures are filled with pagioclase, muscovite, and opaque ore. Garnet, found only locally, forms subhedral to anhedral grains of pinkish colour. Orthoclase and small flakes of muscovite and biotite are generally associated with garnet. A detailed study is required to investigate the origin of the garnet.

GEOCHEMISTRY

Twenty two representative analyses of the Malakand granite, and ten from the surrounding gneisses are plotted on variation diagrams. The Malakand granite is a calcite-normative peraluminous granite. On a P *vs* Q plot of Debon and Le Fort (1983, Fig. 2a), the Malakand granite analyses plot in the field of granite, granodiorite, adamellite, and tonalite. Most of the granite gneisses occur in the adamellite field, while the siliceous gneiss does not occupy any particular field because of its high Q content.

On alkalis *vs* SiO_2 plot (Fig. 2b) majority of the Malakand granite and granite gneiss compositions occupy the field of calc-alkaline rocks. Analyses of the siliceous gneiss and certain granite gneiss which indicate much higher SiO_2

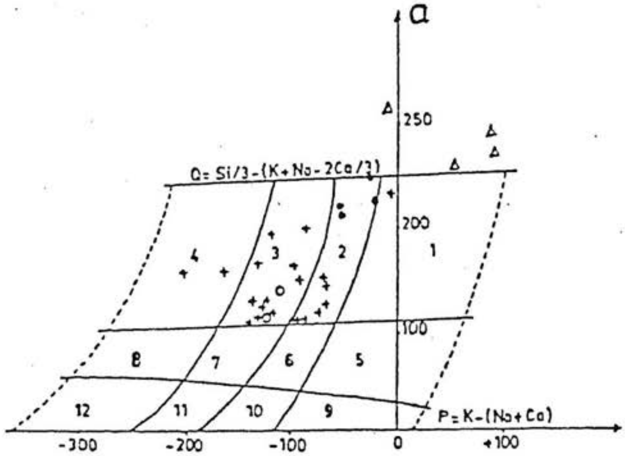


Fig. 2a. Q *vs* P diagram for the Malakand granite and gneisses with division into various fields (after Debon and Le Fort, 1983); Pluses = granite, open circles = normal granite gneisses, filled circle = silica-rich granite gneisses and triangles = siliceous gneisses. The fields are: (1) granites; (2) adamellite; (3) granodiorites; (4) tonolite (trandhjemite); (5) quartz-syenite; (6) quartz-monzonite; (7) quartz-monzodiorite; (8) quartz-diorite/gabbro/anorthosite; (9) monzonite; (10) monzogabbro; (11) Gabbro/diorite/anorthosite.

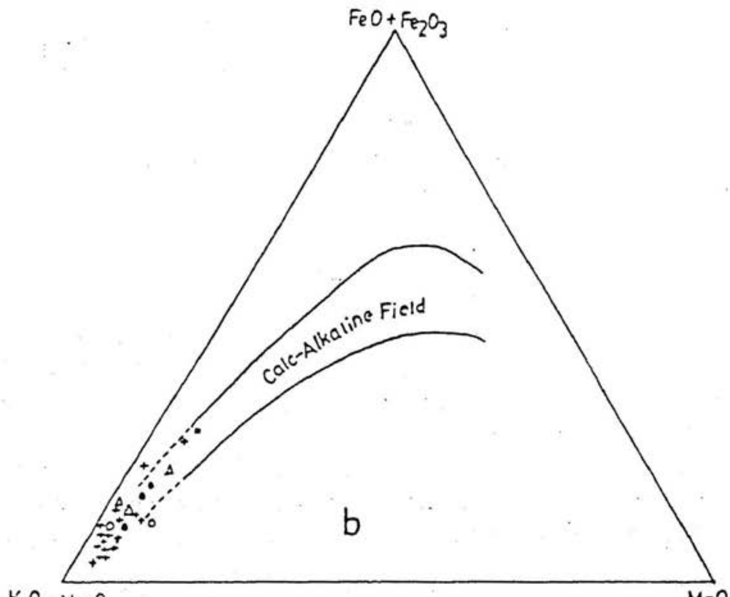


Fig. 2b. Alkali *vs* SiO_2 diagram for the Malakand granite and gneisses with division into various fields after Schwarzer and Rogers (1974).

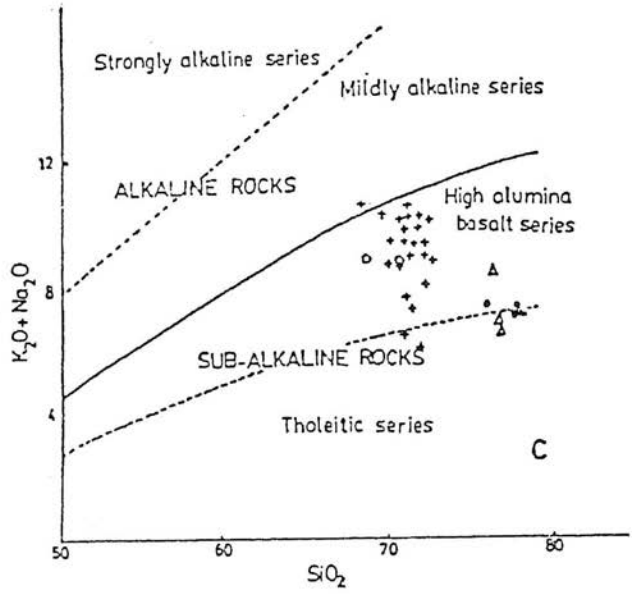


Fig. 2c. AFM plot of the Malakand granite and gneisses.

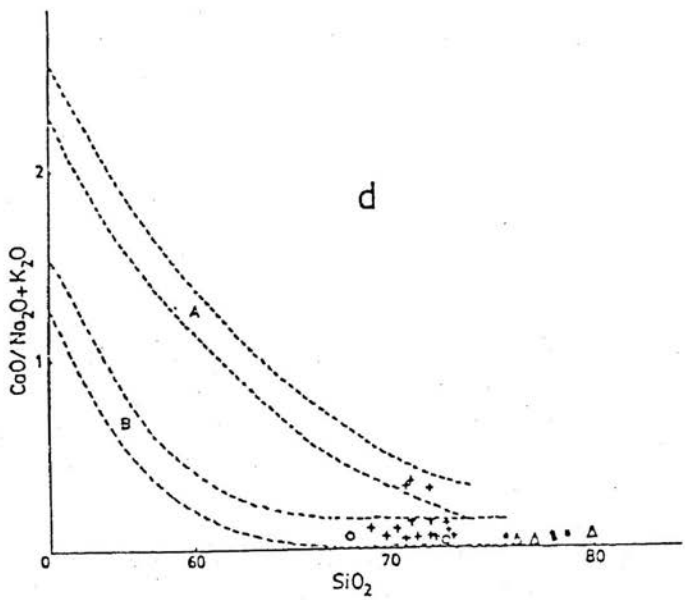


Fig. 2d. $CaO/Na_2O + K_2O$ *vs* SiO_2 diagram for the rocks of Malakand area; A = compressional environments, B = extentional environments; fields after Petro *et al.* (1980), and Jan and Asif (1983; pers. commun.).

content (> 75%) than the Malakand granite, straddle the boundary between the fields of calc-alkaline and tholeiitic rocks. On AFM plot (Fig. 2b) majority of the Malakand granite and granite gneisses compositions also plot in the extrapolated field of calc-alkaline rocks. In addition, on a $CaO/Na_2O + K_2O$ *vs* SiO_2 plot of Petro *et al.* (1980, Fig. 2d), the Malakand granite indicate development in extentional environments.

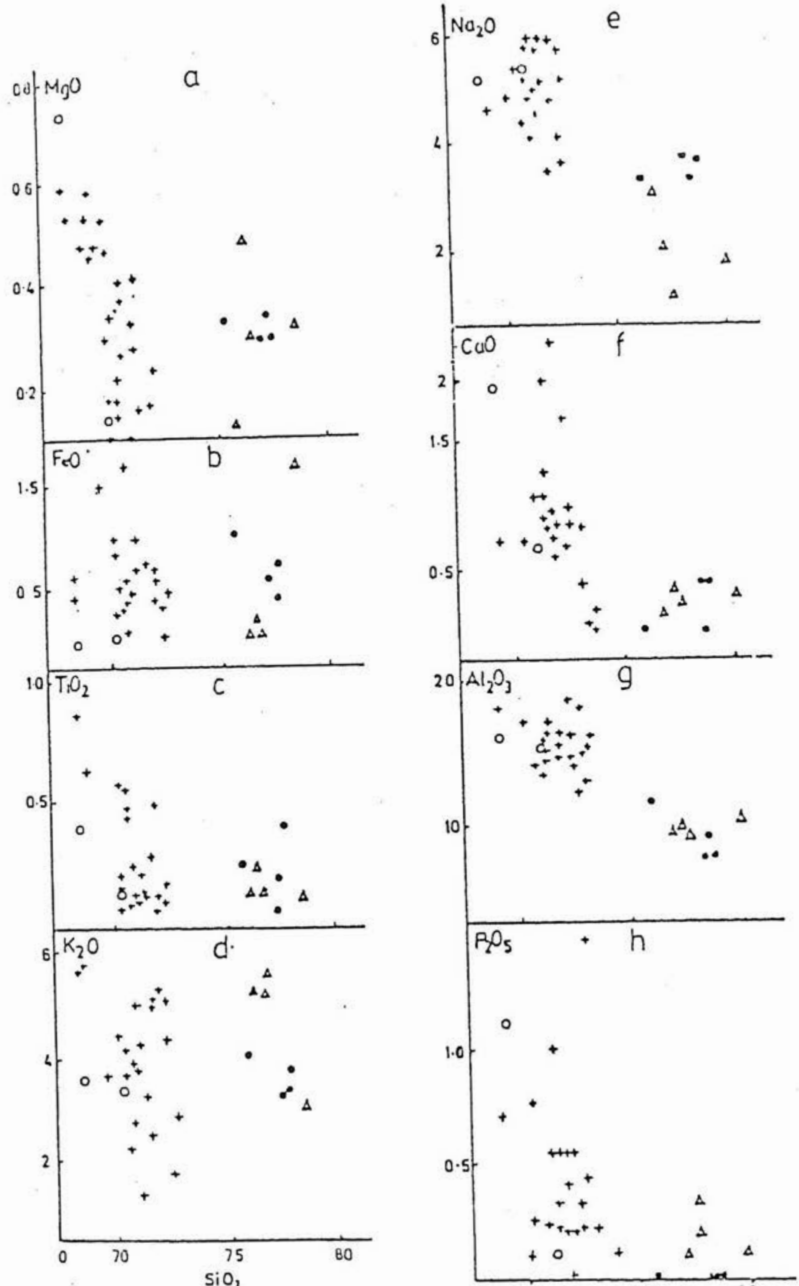
Variation in major element chemistry of Malakand granite and associated gneisses is represented on oxide *vs* SiO_2 plots. MgO, FeO and TiO_2 *vs* SiO_2 plots for Malakand granite indicate crystallization differentiation and some control of mafic minerals like biotite, amphibole and iron-titanium oxides on the liquidus (Figs. 3a–c). The relatively high content of $FeO+Fe_2O_3$ (1.72%) and TiO_2 (0.82%) in certain granites is related to the high proportion of femic minerals and oxides (Table 1).

The correlation of K_2O and Na_2O against SiO_2 is not very clear and both the former elements show a considerable variation at more or less constant SiO_2 (Figs 3d, e). CaO and Al_2O_3 *vs* SiO_2 plots (Figs 3f, g) show an overall negative correlation with some scatter. Such feature can be related to a dominant feldspar fractionation. A negative correlation can also be noticed on a P_2O_5 *vs* SiO_2 plot indicating apatite fractionation along with other phases. No phosphorous-bearing phase has been noticed in the calcarious metasediments at Tor Mor Rest House. The granitic vein material, however, reflects a high content of CaO and P_2O_5, corresponding to a high apatite content. Therefore, the formation of the high proportion of apatite can be attributed to the metasomatic introduction of CaO from metasediments and the provision of appropriate P_2O_5 from the granitic magma.

On the basis of SiO_2 content the granite gneisses are distinguished into two groups: a) the silica-rich granite gneiss (SiO_2 > 75%) from Dabrai (Table 1. 27, 30, 31, 32) and b) the normal granite gneiss (SiO_2 < 75%) from Jolagram and Jalal Kot (Table 1. 16, 23).

On oxide *vs* SiO_2 diagram the normal granite gneiss generally plote along Malakand granite analyses which indicates some genetic relationship between the two types. The siliceous gneiss and silica-rich granite gneiss are different in terms of chemistry from the Malakand granite and the normal granite gneiss (Figs 3a–h).

Analyses of the Malakand granite and gneisses were also ploted on oxides *vs* D.I. diagram (not represented). Majority of the variation diagrams confirm the differentiation processes operating during the development of the Malakand granite reflected on oxide *vs* SiO_2 plots. The granitic vein material from the Tor Mor Rest House, however, shows significantly lower D.I. (< 85)



Figs. 3a–h. Oxide *vs* SiO_2 plots for the Malakand granite and gneisses; symbols as in Fig. 2a.

as compared to the main Malakand granite due to its high Ca-content and thus does not follow the trend of the Malakand granite on any of the oxides *vs* D.I. plots. This feature confirms that these veins have been metasomatized during their intrusion into the sediments.

DISCUSSION

The Malakand granite, gneiss and metasedimentary complex represents rocks of highly variable lithology which have presumably passed through a complex pattern of evolutionary processes. Based on petrographic observations of the Malakand graphite, the order of the appearance of various phasses is biotite-amphibole pair, plagioclase and alkali-feldspar, muscovite, and calcite, respectively. The geochemistry of granite also indicates the dominant control of feldspar fractionation on the liquidus together with the fractionation of the ferromagnesian minerals. Biotite, amphibole, Iron-titanium oxides and sphene represent the earliest association on the liquidus, while feldspars followed this assemblage. Considering the granite crystallization under a PH_2O of 5 kb (*cf.* Fig. 4),

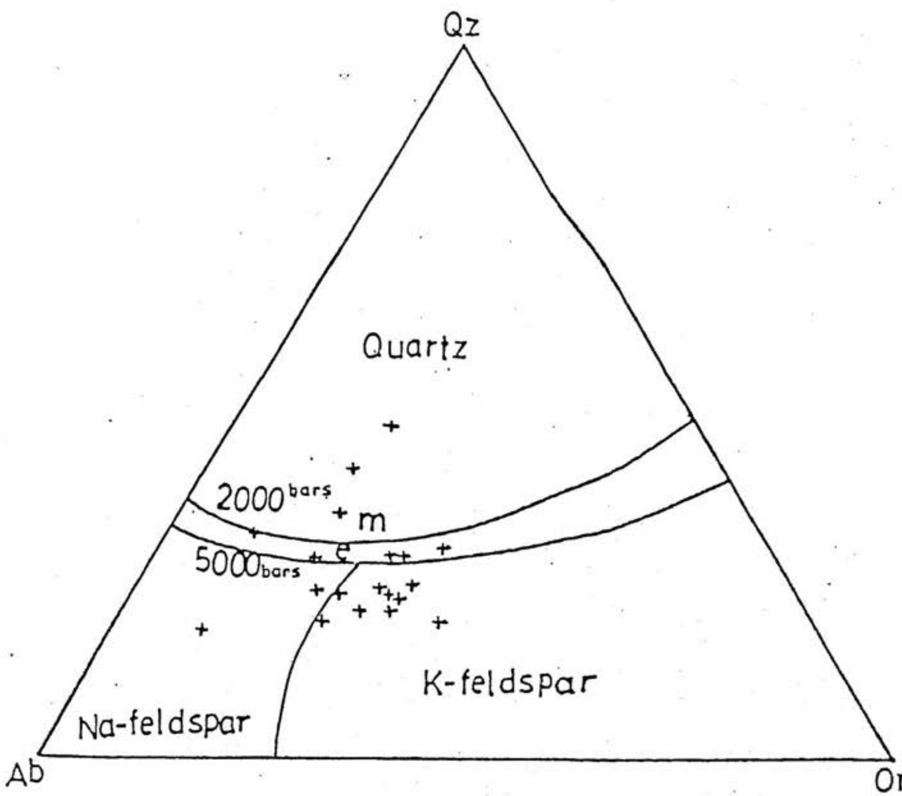


Fig. 4. Compositional plots of the Malakand granite in the Q–Or–Ab diagram of Bowen and Tuttle (1958); symbols as in Fig. 2a.

majority of the granite analyses show a temperature range of **800–850°C** on Ab–An–Or (normative) plot of Yoder *et al.* (1957; not represented). This temperature range can be related to feldspar crystallization. Muscovite seems to be appeared on the liquidus at temperature lower than that suggested for feldspar. As suggested earlier that biotite-amphibole pair appeared on liquidus before the appearance of feldspar. Thus, a temperature greater than **85°C under similar** PH_2O is suggested for the ferromagnesian minerals. The association of primary sphene with amphibole and biotite is consistent with this interpretation (*cf.* Hamidullah, 1983, p. 98). The maximum temperature under a PH_2O of 5 kb for the appearance of two feldspars (albite and orthoclase) in albite orthoclase system is about 700°C (Yoder *et al.,* 1957). However, albite, orthoclase have not crystallized simultaneously in the Malakand granite but the presence of perthite indicates that exsolution of plagioclase and K-feldspar has occurred (Jabeen *et al.,* 1985) probably at a temperature below the solidus in albite-orthoclase system. A temperature of < 650°C and a PH_2O of 5 kb are suggested for such phenomenon in the Malakand granite (*cf.* Bowen and Tuttle, 1950). Quartz and calcite are interstitial to feldspar in Malakand granite and are of magmatic origin. Therefore, their crystallization may have occurred at a temperature higher than 650°C (i.e. feldspar exsolution temperature). Apatite is generally associated with plagioclase. Therefore, P–T condition similar to those suggested for the crystallization of plagioclase are also proposed for the development of apatite.

The Malakand gneisses also represent highly variable lithology. The normal granite gneiss of Jolagram, and Jalal Kot corresponds to Malakand granite on the basis of their chemistry, and considered to be of igneous parentage and are genetically related to the Malakand granite. On the other hand, the silica-rich granite gneiss of Dabrai and siliceous gneiss of Jolagram, and near tunnel entrance (*cf.* Map 1) contain much higher quartz content. Therefore, these gneisses may be metasedimentary in nature, originally containing a large proportion of quartz with some feldspar and ferromegnesian minerals or the products of partial melts from a deep source. Except the garnet, developed locally in the vicinity of granitic veins, the gneissose rocks have generally passed through the biotite zone of green schist facies metamorphism. For example, brown biotite has developed at the expense of muscovite and opaque minerals (Jabeen *et al.,* 1985).

The petrography and field relationship show that the metasediments associated with Malakand granite, gneiss complex have passed through several episodes of regional and contact metamorphism. Rocks exposed south of the Malakand proper indicate a general northward increase in the grade of metamorphism. The dominant mineral assemblage near Malakand road tunnel is that of the biotite zone of the green schist facies (Turner and Verhogen, 1960), while graphite schist near Malakand proper indicate the prevailance of amphibolite facies conditions (*see* Miyashiro, 1973).

TABLE 1. MAJOR ELEMENT ANALYSES OF THE REPRESENTATIVE ROCK TYPES FROM THE MALAKAND GRANITE-GNEISS COMPLEX.

S. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Field No.	RK7	RK12	RK13A	RK14	RK15	RK17	RK21	RK28	RK30	RK31	RK33	RK35	RK39	RK32	RK45	RK46
SiO_2	73.09	71.45	72.12	72.16	71.21	72.76	72.17	71.62	71.32	71.33	71.67	72.58	70.94	72.56	77.50	69.09
TiO_2	0.09	0.13	0.12	0.12	0.13	0.12	0.11	0.24	0.46	0.44	0.13	0.46	0.20	0.27	0.13	0.36
Al_2O_3	16.00	15.52	15.28	15.08	16.32	15.45	17.46	17.23	16.15	16.49	15.75	15.59	15.53	13.85	12.28	16.00
Fe_2O_3	0.05	0.05	0.04	0.01	0	0.24	0.04	0.04	0.41	0.29	0.04	0.12	0.59	1.68	1.69	1.00
FeO	0.55	0.49	0.50	0.49	0.60	0.41	0.75	1.01	1.74	0.40	0.86	0.60	0.31	0.71	0.10	0.00
MnO	0.02	0.02	0.01	0.02	0.03	0.02	0.02	0.01	0.02	0.03	0.02	0.01	0.02	0.08	0.03	0.02
MgO	0.17	0.22	0.28	0.33	0.15	0.23	0.40	0.35	0.34	0.30	0.41	0.33	0.46	0.17	0.48	0.73
CaO	0.21	1.00	0.89	1.25	1.29	0.99	1.70	2.35	2.04	1.08	0.89	0.87	0.96	0.01	0.02	1.97
Na_2O	5.89	5.04	5.08	4.83	6.11	5.23	3.42	5.90	4.11	4.94	4.54	4.17	4.44	3.63	1.00	5.31
K_2O	2.92	5.01	5.15	5.03	3.83	4.54	2.51	1.35	2.32	2.74	4.38	5.16	4.22	5.35	5.66	3.65
P_2O_5	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.14	0.04	0.04	0.06	0.05	0.06	0.94	0.03	0.11
H_2O+	1.2	1.4	0.7	1.8	0.4	0.1	1.5	1.4	2.5	2.1	1.3	0.00	5.50	0.80	1.40	1.40
H_2O-	0.06	0.0	0.18	0.08	0.0	0.06	0.05	0.03	0.07	0.04	0.13	0.02	0.02	0.15	0.04	0.05
Total	100.27	100.36	100.38	101.23	100.11	100.17	100.18	101.67	101.52	100.22	100.18	99.96	100.26	100.20	100.36	99.69

TABLE 1 CONTINUED

S. No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Field No.	RK50	RK55	RK59	RK60	RK62	RK64	RK66	RK69	RK70	RK71	RK77	RK78	RK79	RK80	RK81	RK82
SiO_2	76.99	71.40	70.77	79.81	71.31	77.39	71.08	71.81	70.12	71.05	76.45	72.77	68.94	78.41	78.60	78.48
TiO_2	0.13	0.09	0.21	0.12	0.54	0.22	0.15	0.12	0.16	0.08	0.19	0.08	0.82	0.19	0.39	0.05
Al_2O_3	12.43	15.79	15.49	12.81	16.60	12.48	15.91	16.18	16.50	15.50	13.66	14.34	17.01	12.23	11.80	11.59
Fe_2O_3	1.14	0.13	0.05	0.00	0.71	0.88	0.84	0.10	0.14	0.09	0.53	1.04	0.29	0.97	0.15	0.15
FeO	0.10	0.51	1.00	1.71	0.09	0.21	0.05	0.70	1.51	0.55	1.02	0.05	0.41	0.43	0.75	0.75
MnO	0.02	0.03	0.02	0.13	0.02	0.03	0.04	0.02	0.02	0.01	0.06	0.03	0.02	0.06	0.05	0.05
MgO	0.13	0.17	0.52	0.32	0.32	0.36	0.39	0.27	0.58	0.18	0.33	0.14	0.52	0.34	0.30	0.30
CaO	0.39	1.03	1.14	0.34	0.67	0.09	0.71	0.73	0.78	0.89	0.20	0.42	0.78	0.05	0.44	0.44
Na_2O	3.06	6.09	5.40	1.65	5.87	1.97	5.43	6.05	4.94	5.33	3.30	5.23	4.79	3.29	3.73	3.75
K_2O	5.34	3.84	4.45	3.14	3.90	5.30	3.41	3.33	3.77	4.75	4.11	4.46	5.80	3.82	3.40	3.42
P_2O_5	0.02	0.03	0.07	0.02	0.60	0.04	0.02	0.06	0.08	0.02	0.00	0.00	0.02	0.00	0.00	0.00
H_2O+	0.50	.90	0.90	1.4	0.10	1.10	2.0	0.8	1.6	0.30	0.40	1.40	0.20	0.20	0.20	0.00
H_2O-	0.03	0.04	0.08	0.05	0.03	0.13	0.01	0.0	0.03	0.00	0.03	0.03	0.03	0.12	0.13	0.16
Total	100.28	100.05	100.11	101.50	100.76	100.19	100.04	100.17	100.25	98.75	100.28	99.99	101.43	100.12	99.94	99.93

1–14, 18–19, 21. 24–26, 28–29 = Granite; 15, 17, 20, 22 = Silicious gneiss; 16, 23 = Normal granite gneiss; 27, 30–32 = Silica-rich granitic gneiss.

Garnet is generally restricted to the contact of metasediments with Malakand granite (e.g. Malakand proper, Tor Mor Rest House block) although occasionally it has been noticed at considerable distance from the granite-metasediment contact, i.e. 3–4 km on road side, south of Malakand proper, (*cf.* Jabeen *et al.*, 1985). The presence of garnet in the metasediments indicates that the metamorphism in garnet zone of the amphibolite facies has occurred and was probably related to the thermal effects of the emplacement of the granitic magma, however, compositional factors controlling the development of garnet can not also be ruled out and needs further investigation. The development of garnet in the gneissose rocks in the vicinity of granitic veins is consistent with these interpretations.

In chlorite-epidote schist near Malakand road tunnel chlorite, cross cutting the general fabric of the rock occurs in equilibrium with epidote replacing amphibole. This reflects the prevailence of green schist facies conditions. Moreover, biotite has developed at the expense of chlorite which indicate a return to relatively higher metamorphic grade. All these features point to highly variable metamorphic conditions locally, and can be related to the prevailence of regional metamorphism and increase of temperature associated with the emplacement of granite.

The present investigation shows that both the Malakand gneisses and metasediments have evolved through similar metamorphic conditions at least after the emplacement of gneisses.

The Malakand granite has Rb/Sr ratios varying from 0.25–0.62. The minimum limit of this range is in accordance with that of the crustal values i.e. 0.25. The K/Rb ratio of the Malakand granite c. 123–219 is however, considerably lower than that proposed for crustal derived rocks (see Gunn, 1965). The Malakand granite is sufficiently rich in plagioclase and can be classified as Na-rich granite (cf. Fig. 3e). Therefore, the lower K/Rb ratio can be related to its richness in Na_2O, the calc-alkaline character and probably a high degree of fractionation (see Abbot, 1967).

The Malakand granite is considered to be a part of the alkaline igneous province of Peshawar plain (Kempe, 1973; Kempe and Jan, 1979; Jan *et al.*, 1981). Majority of the rock of alkaline igneous province are alkaline in character. The Malakand granite differs from most of the granitic members of the alkaline province on the basis of its lower alkalinity. In addition, Kempe (1973) has determined a 45 m.a. age for the granitic rocks of the Warsak alkaline complex and Ambella granitic complex. On the other hand Moluski and Matte (1984) have attributed an age of 23 ± 2 m.a. to the Malakand granite, on the basis of $^{40}Ar/^{39}Ar$ technique and using biotite seperates. However, similar age (23 m.a.) has been determined for the Malakand granite using zircon fission track data by

Zeitler *et al.* (1982) and thus both these dates may be representing cooling and uplift ages. The lack of deformation in the Malakand granite however, strongly supports the view of this intrusion being younger than the rocks of the alkaline igneous province of Peshawar plain. In addition the calc-alkaline character of the Malakand granite also support the view that there is not any genetic relationship between this granite and the rock of the alkaline igneous province of the Peshawar plain.

CONCLUSIONS

1. The Malakand granite intruding metasediments of probable Precambrian age is calc-alkaline in character.
2. In the Malakand granite, biotite, amphibole, sphene and iron-titanium oxides have crystallized at a temperature > 875°C and PH_2O of about 5 kb.
3. Feldspars developed at a temperature of 800–850°C and PH_2O of 5 kb.
4. On the basis of textural relationships with various phases, a temperature > 650°C and PH_2O < 5 kb are suggested for the crystallization of quartz and calcite.
5. Malakand gneisses and metasediments have been generally metamorphosed upto the upper limits of the green schist facies. Thermal metamorphism upto the garnet zone of amphibolite facies has been however, noticed both in metasediments and gneisses near the contact of the Malakand granite.
6. Among the three types of gneisses, the normal granite gneiss seems to be genetically related to the Malakand granite. In addition, on the basis of certain geochemical features and age relationships, the Malakand granite does not seem to be genetically related to the alkaline igneous complexe of the Peshawar plain.

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