Geol. Bull. Univ. Peshawar, 1986, Vol. 19, pp. 83—100

PETROLOGY OF THE SWAT AMPHIBOLITES AND THE DEVELOPMENT OF A "LESSER HIMALAYAN" BASIN

MUNIR HUMAYUN
Department of Geology, University of Peshawar, Pakistan.

ABSTRACT

A geochemical study of amphibolites from the lower Swat valley, Lesser Himalayas, identifies a suite of continental flood basalts erupted over a gneissic basement of probable Late Cambrian age. Fractionation of clinopyroxene and plagioclase controlled chemical variation in the protolith. Metamorphism, retrogression and granitic intrusion strongly affected the alkali and mobile trace element contents. The magmatism was probably associated with the early rifting stage of the development of Paleotethys. Subsidence of the rifted margin followed the extrusion of the basalts, and arkosic continental sediments gave way to marine carbonates and clastics. The carbonates belong to a reefoid association of Middle Paleozoic age. The basin extended over much of present day northwestern Pakistan with probable analogues along the length of the Lesser Himalayas.

INTRODUCTION

The northern margin of the Indian plate in northwestern Pakistan is terminated by the Main Mantle Thrust (MMT), an extension of the Indus suture (Tahirkheli and Jan, 1979; Coward *et al.*, 1982, 1986). To the south of the MMT lie schists and gneisses, with marble and amphibolite intercalations (Fig. 1), that constitute part of the Indian plate. The actual margin is probably subducted deep below the suture (Malinconico, 1982), but parts of it are exposed where southward vergent thrusts have piled up slices of metamorphic rocks to form the Lesser Himalayas (Coward *et al.*, 1982, 1986; Humayun, 1985). The rocks here have been assigned ages from Precambrian to Paleozoic (Le Fort, 1975; Tahirkheli, 1982).

In the Swat Valley, a stratigraphic sequence of gneisses overlain by amphibolites, marbles and graphitic schists was recognized by Martin *et al.*, (1962). The Swat gneisses, part of a belt of augen gneisses extending along the entire Lesser Himalayas (Le Fort *et al.*, 1983), are unconformably overlain by a

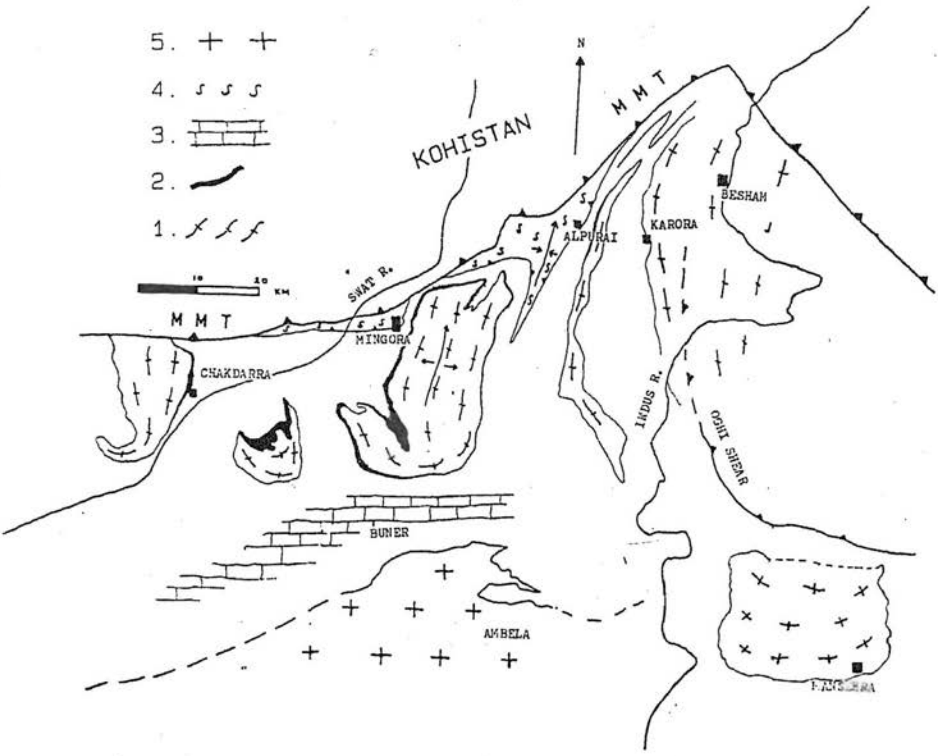


Fig. 1. Geological map of the Swat and Indus valleys, modified from Martin *et al.* (1962) and Coward *et al.* (1986). The Indian plate sequence lies to the south of the MMT, while to the north lies the plutonic belt of the Kohistan island arc. The amphibolites outcrop along the upper contacts of the gneisses, which form the cores of anticlinal folds. The blank spaces include intercalated marbles and graphitic schists. East of Alpurai, the differentiation of the basement from the overlying rocks has not been attempted. 1. Crystalline basement, 2. Amphibolite formation, 3. Massive carbonates (reef-cores), blank spaces are undifferentiated carbonates and schists overlying the amphbolites, 4. Suture melange, 5. Ambela granite.

formation of amphibolites, schists and calcsilicate marbles. These rocks are in turn overlain by dolomitic marbles and calcschists that are followed by thick graphitic schists. The gneisses and overlying rocks form a large thrust sheet, at the base of which occurs a broad mylonite zone (Humayun, 1985).

The amphibolites were previously considered to be recrystallized sediments (Kazmi *et al.,* 1984). Detailed investigations near Mingora on the amphibolites, however, indicate an igneous parentage of continental flood basalt (CFB) affinity for the protolith. This requires a reinterpretation of the available data.

Reconnaissance visits to Buner, Malakand, Alpurai and Besham confirm the extent of the Swat sequence (Fig. 1). The sequence is best exposed in the Swat valley and becomes increasingly disturbed towards the Indus valley where the exposures are dominated by mylonitised gneisses. The structural relations of these rocks in the Indus valley were described by Coward *et al.,* (1982). The rocks are younger than the underlying Precambrian-Early Paleozoic basement, and are Middle Paleozoic in age (Martin *et al.,* 1962).

Lithologic relations were obscured during Barrovian metamorphism and deformation. The metamorphism is associated with the main Himalayan orogeny (Maluski and Matte, 1984). Metamorphism up to almandine amphibolite facies was followed by retrogression during uplift resulting in the local development of epidote and chlorite. Both staurolite and kyanite have been widely reported from the region (Coward *et al.,* 1982). Garnet-staurolite schists are intercalated with the amphibolites, refuting earlier opinion (Kazmi *et al.,* 1984) that the metamorphism of the region is upper greenschist.

AMPHIBOLITES

The rocks consist of hornblende, plagioclase, and lesser amounts of quartz, garnet, biotite, sphene, ilmenite/magnetite, rutile and apatite with local epidote, chlorite, zoisite and carbonate. Texturally the rocks are massive to schistose, and the hornblende is prismatic and aligned. Schistosity characterizes altered amphibolites (higher biotite content) which commonly grade to biotite schists. Epidote and carbonate are secondary, zoisite is euhedral but probably formed during intrusion of tourmaline granite veins. Some biotite is present in all samples in textural equilibrium with hornblende and garnet, but is developed as a major constituent in altered amphibolites, where it frequently replaces hornblende. Sphene is abundant in several rocks and generally rims ilmenite and rutile. This indicates that the rocks were equilibrated at conditions above, and subsequently cooled through, the sphene-in isograd (min. P–T : 600°C at 3 kb, 700°C at 4.5 kb) of Spear (1981).

The amphibolites occur as concordant layers several tens of metres thick (being thickest near the top of the sequence), intercalated with quartz-mica schists and marbles (Fig. 2). Feldspathic schists separate the gneisses from the adjacent marbles and amphibolites. A basal layer of grossular-quartz rock is present in several places. At one locality, coarse skarn-like rocks and garnet amphibolite occur as pods between the gneisses and a tourmaline granite body. Such pods of the amphibolite and associated metasediments have also been described from Buner (Rosenberg, 1985).

Overlying the varied basal rocks is a sequence of alternating layers of amphibolite, marble and quartz-micaschist. Contact relations between schists, marbles and amphibolites do not satisfy the metamorphic differentiation model

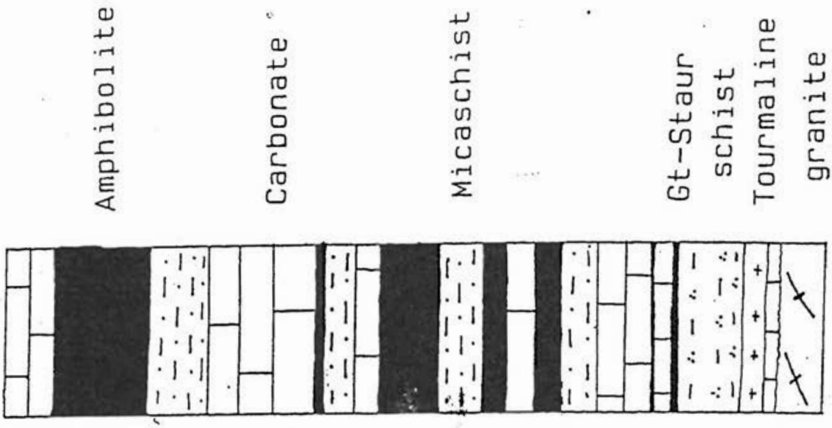


Fig. 2. Stratigraphic section of the amphibolite unit, from bottom: Swat gneisses, the amphibolite formation (200 m thick, to scale) followed by the overlying carbonate formation. The formation consists of a grossularte-quartz rock intruded by tourmaline granite, passing upward to feldspathic schists and garnet-staurolite schists. These are overlain by intercalated amphibolite, carbonate and quartz-micaschists.

of Orville (1969) for the origin of thin-layered amphibolites. Although thin layers of amphibolite are present, many of the amphibolite layers are too thick (Fig. 2) to be interpreted this way. Biotite-bearing schists required by the model occur frequently within the amphibolite layers, rather than on the contact. Such schists also contain relict hornblende and garnet and chemical analyses of these suggest an origin from amphibolite by addition of alkalies and removal of MgO, CaO and even TiO_2. A similar process has also been described from syn-metamorphic shear zones in Moine amphibolites (Floyd and Winchester, 1983).

Towards the base, the marbles are progressively replaced by calcsilicate layers containing tremolite, diopside and epidote probably formed by thermal activity during magmatism. Wollastonite is reported from one place where a basic dyke intrudes the carbonates (Shams, 1963). Basic dykes (now garnet amphibolite) intrude carbonate rocks near Alpurai and contain xenoliths of the adjacent marbles. Lead-zinc sulphide mineralization near Besham is closely associated with amphibolite (Leake and Haslam, 1984). These field relations indicate an igneous origin for the amphibolites.

Small intrusions of tourmaline granite in the amphibolites are variably metamorphosed, but tourmalinization and alteration in the adjacent amphibolites (forming zoisite-biotite schists) indicate that the granites are anatectic melts formed during the Himalayan orogeny. There is substantial evidence for hydrothermal activity adjacent to the tourmaline granite contacts, including tourmalinization of the augen gneisses and feldspathic schists, and alteration of the amphibolite to biotite-zoisite schist.

The upper contact with the dolomitic marbles is usually concordant, but locally it is sheared. Amphibolite layers occur rarely in the base of the overlying carbonates. In contrast, basic dykes are common in the underlying gneisses. These dykes, now transposed parallel to the foliation, frequently contain relict sub-ophitic textures. Since mafic rocks are uncommon above the uppermost thick amphibolite layer (Fig. 2), and absent from the calcshists and graphitic schists, it seems likely that the amphibolite dykes in the gneisses acted as "feeders" to basaltic flows overlying the gneisses.

The thicker amphibolite layers presumably originated as single or composite lava flows, although, the possibility that some layers were dykes or sills cannot be ruled out. No chemical evidence for *in situ* differentiation, as may be expected in thick sills, has been found. Within a single thick unit texturally differing amphibolites with sharp contacts have been observed. These variations may be due to separate flows (or intrusions) since they differ markedly in chemical composition. This does not include variation in texture and chemistry caused by the presence of shear zones along which metasomatic alteration has taken place.

Geochemistry

Chemical analyses of 19 amphibolites (Table 1) were performed by XRF. Total iron, MgO, CaO, Na_2O and K_2O were repeated by Atomic Absorption Spectrometry and FeO was determined by the method of Wilson (1960) for 11 samples. The analyses were recalculated to 100% on an anhydrous basis before plotting or norm calculations were performed. Corrections for oxidation of iron in normative calculations were applied, following Irvine and Baragar (1971).

Primary chemical variation : The Swat amphibolites span a broad range of fractionation with $FeO^*/MgO = 1–3$, and maximum $MgO = 9.56$. Most of the analyses would be quartz-normative after correction for alkalies, a consequence of the generally high SiO_2 (> 50%, anhydrous). Despite excess alkalies, the rocks are subalkaline on a SiO_2 *vs.* $Na_2O + K_2O$ plot (Irvine and Baragar, 1971) and on a TiO_2 *vs.* Zr/P_2O_5 plot (Winchester and Max, 1982). They are distinguished from calcalkaline suites by higher Zr contents and Zr/Y ratio *(cf.* Tectonic setting), and a positive correlation of TiO_2 with FeO^*/MgO (Miyashiro, 1975). They show a tholeiitic trend on the AFM diagram (Fig. 3) and follow the trend of the Karroo dolerites on Niggli c *vs.* mg, 100 mg–(al–alk) c, and (al–alk) *vs.* c diagrams (Leake, 1964; Kalsbeek and Leake, 1970). These and the diagrams of Winchester and Max (1982) distinguish the Swat amphibolites from para-amphibolites, or rocks derivative from a sedimentary parentage.

Crystal fractionation has been modelled following Kalsbeek and Jepsen (1984), by plotting elemental concentration ratios with Zr as denominator against Si/Zr. This method is more reliable and less effected by alteration than oxide-oxide plots. The slopes are satisfied by the removal of calcic pyroxene and

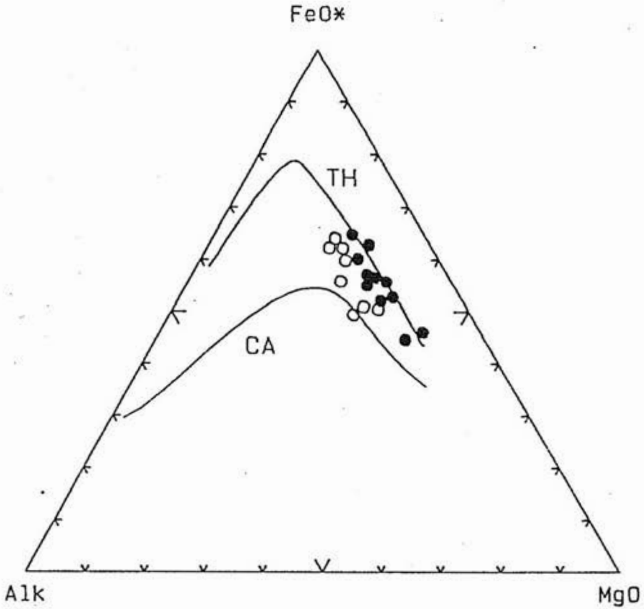


Fig. 3. AFM diagram of the Swat amphibolites. CA is the division between the calcalkaline and tholeiitic series after Irvine and Baragar (1971) and TH is the calculated Skaergaard liquid trend. Those samples having excessive alkali contents are marked by open circles. These samples deviate from the tholeiitic trend.

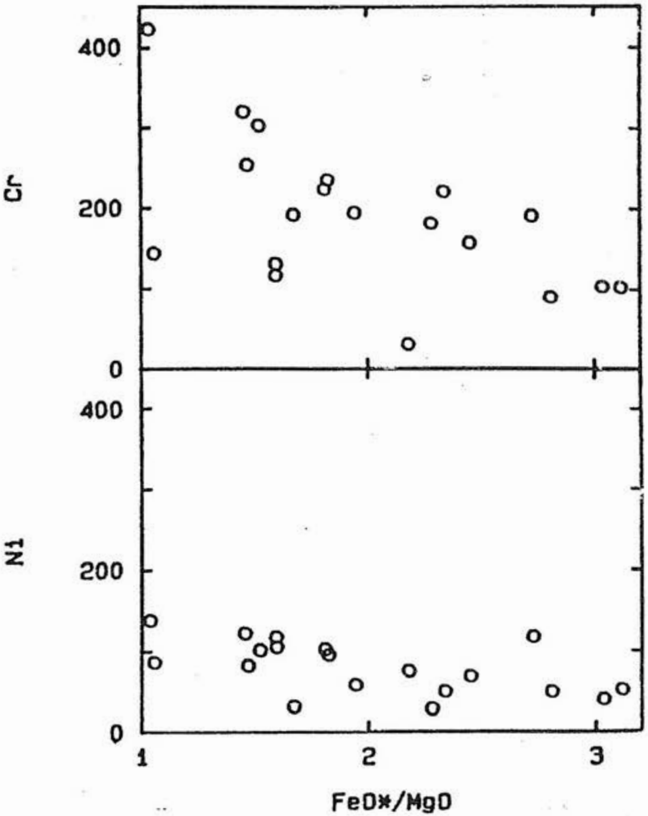


Fig. 4. Ni and Cr relations *vs.* FeO*/MgO. The much steeper decrease of Cr with fractionation indicates that clinopyroxene exerts most of the control over Ni and Cr.

TABLE 1. WHOLE-ROCK MAJOR AND TRACE ELEMENT ANALYSES OF THE SWAT AMPHIBOLITES.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	49.74	50.70	49.69	50.43	51.63	50.87	53.46	49.34	49.13	47.11	51.57
TiO_2	1.98	1.47	2.00	1.59	1.17	2.39	1.00	1.12	1.17	1.35	1.14
Al_2O_3	12.08	12.91	13.01	13.03	15.02	12.11	13.58	13.65	15.89	12.26	10.20
FeO*	12.60	11.75	13.40	12.14	10.70	14.70	11.27	11.27	11.36	9.57	9.93
MnO	0.25	0.27	0.23	0.24	0.18	0.24	0.20	0.21	0.22	0.17	0.21
MgO	6.91	6.05	5.47	5.58	4.58	5.24	6.75	7.14	7.13	6.58	9.56
CaO	11.56	11.79	11.15	10.39	14.05	10.02	9.92	12.01	9.70	13.95	12.12
Na_2O	2.27	2.31	3.01	2.82	1.43	2.36	1.86	2.59	2.64	1.64	1.65
K_2O	0.53	0.48	0.52	1.21	0.32	0.40	0.35	0.37	1.20	1.20	0.44
P_2O_5	0.32	0.26	0.14	0.16	0.14	0.20	0.15	0.13	0.09	0.13	0.13
FeO	10.32	7.71	9.26	9.68	5.63	10.51	8.78	7.43	8.45	6.77	7.77
Rb	4	8	7	35	6	4	4	6	36	21	7
Sr	118	275	173	190	333	179	111	148	147	143	198
Ba	159	132	147	203	24	133	44	56	425	176	95
Y	23	22	25	34	20	31	22	20	32	23	19
Zr	186	137	150	178	140	194	147	101	101	119	143
Ni	95	58	69	75	50	50	31	101	105	122	138
Cr	235	194	156	30	220	89	192	303	130	320	422
Co	73	56	68	63	82	77	69	67	65	48	49
V	420	380	492	327	348	535	292	344	266	317	313

Samples 1 to 11 are mean of XRF and AAS readings, with FeO* = total iron as FeO, and FeO = ferrous iron determined by titration against ammonium metavanadate. Trace elements determined for all samples by XRF on 10g pressed powder pellets, using 12 USGS standards for calibration.

	12	13	14	15	16	17	18	19
SiO_2	47.53	50.43	49.40	48.81	51.56	54.80	51.74	50.84
TiO_2	0.92	1.81	1.11	1.72	3.29	1.06	0.81	1.08
Al_2O_3	12.03	12.14	11.78	13.63	12.28	14.22	13.39	13.79
FeO*	11.34	13.50	10.98	14.22	13.30	10.80	8.28	11.34
MnO	0.19	0.23	0.19	0.23	0.20	0.17	0.13	0.25
MgO	6.27	4.45	7.48	5.22	4.27	4.74	7.83	7.12
CaO	13.21	9.95	13.02	10.50	9.67	10.26	13.53	9.61
Na_2O	2.51	3.34	1.74	2.82	2.21	2.04	2.16	3.55
K_2O	0.49	0.40	0.63	0.61	0.97	0.38	0.32	0.97
P_2O_5	0.06	0.24	0.06	0.23	0.45	0.12	0.07	0.14
	—	—	—	—	—	—	—	—
Rb	—	2	2	—	—	—	—	23
Sr	145	82	196	133	67	151	326	180
Ba	—	51	106	112	129	—	—	71
Y	23	29	18	35	35	26	16	26
Zr	83	150	111	163	208	153	136	129
Ni	102	40	82	118	52	28	86	117
Cr	223	103	254	191	102	181	143	116
Co	54	78	56	73	85	87	33	56
V	336	418	293	311	512	288	202	282

plagioclase in approximately equal amounts, probably with some olivine. Normative Di, CaO, MgO, Ni and Cr decrease with increasing FeO*/MgO. The Ni and Cr fractionation pattern (Fig. 4) suggests a dominant control by clinopyroxene. The compatible behaviour of Ni and Cr. typical of mafic igneous rocks, cannot be duplicated by pelite-dolomite mixtures (para-amphibolite).

Alteration: Plots of oxide and element abundances against stable elements such as Zr and TiO_2 show that concentrations of generally mobile elements have been affected by secondary processes, including redistribution and metasomatic addition. In Fig. 3, those samples which have excess alkalies for given values of FeO*/MgO and TiO_2, are marked by open circles. These eight samples have higher normative Ab/An ratios and deviate from the tholeiitic trend towards the A apex.

Plots of major elements divided by TiO_2 *vs.* SiO_2/ TiO_2 and TiO_2 (Fig. 5) are expected to give well-defined trends for chemical variation during fractional crystallization, following the principle of Pearce (1970). The elements correlate in order of decreasing field strength as SiO_2, Al_2O_3, FeO, CaO and MgO, the deviation probably caused by redistribution of these elements. This is reflected by both mineralogy and texture. The proportions of biotite, epidote and calcite, and schistosity or cataclasis generally indicate the degree of alteration. The development of sphene rims around ilmenite and rutile indicates the small scale of Ti diffusion during retrogression. The conversion of amphibolite to biotite schist accompanying mylonitic shearing results, however, in a loss of TiO_2 compared to Zr and Y.

The secondary processes (addition, removal and redistribution of elements) are related to granitic intrusions in the vicinity, or take place during amphibolite facies or later retrogressive metamorphism. The possibility of contamination during the passage of magma through continental crust (Campbell, 1985), particularly the granitic gneisses, as a cause of high SiO_2 or K_2O is ruled out by the lack of correlation between K and Si abundances. Instead, selective absorption of these elements from metamorphic fluids is likely. The alteration of some of the dolerites in the gneisses by the development of garnet-biotite schist marginal to recrystallized (muscovite) gneiss indicates the liberation of Si and alkalies during the cataclasis of the gneisses (Humayun, 1985). This process probably supplies the metamorphic fluids with these elements, and may account for the many biotite schists present, both in the gneisses and the amphibolites.

The oxidation ratio is evidently controlled by retrograde changes as it is high in epidote-bearing rocks. K and Rb are affected by tourmaline granite intrusions, as well, that have a metasomatic effect on the surrounding rocks, and account for the anomalously high values of these elements in the adjacent

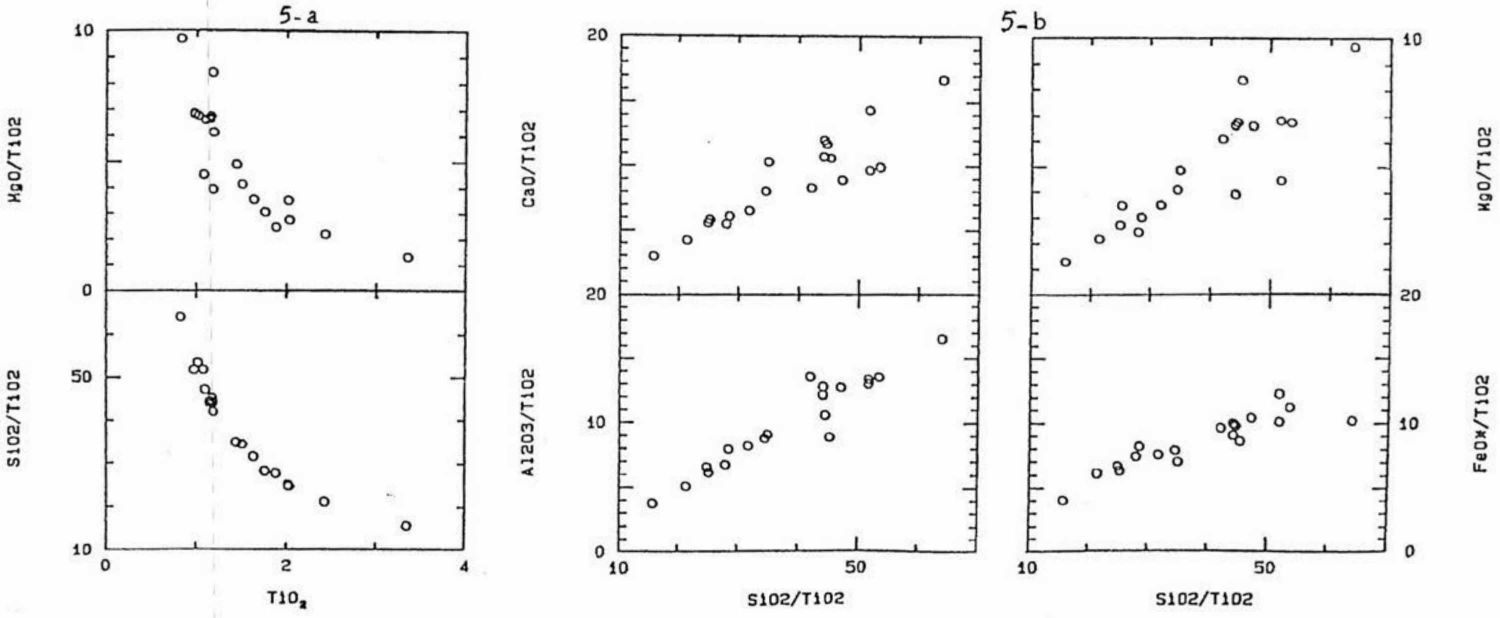


Fig. 5. Relative element stability of major elements *vs.* TiO_2. a) A comparison of SiO_2/ TiO_2 and MgO/ TiO_2 vs. TiO_2 indicating the strong correlation of SiO_2 and the marked scatter of MgO. b) Correlation of major elements *vs.* SiO_2/TiO_2. Deviation from a smooth linear trend is an indication of the degree of mobility of the element.

amphibolites. Zoisite-biotite schists, sometimes several metres thick, develop adjacent to tourmaline granite intrusions, and needles of tourmaline in amphibolite occur at one contact near Salampur village.

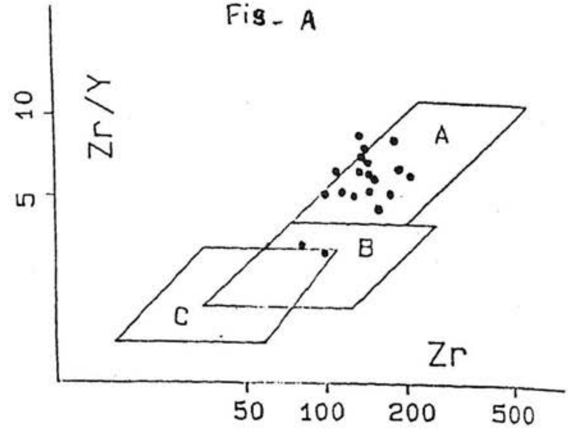
Tectonic setting: The tectonic environment of eruption is clearly supra-continental from field relations, and this is corroborated by Fig. 6 in which both altered and unaltered analyses plot in the within plate basalt field, in spite of amphibolite facies metamorphism. The stability of Zr, Y and TiO_2 has been established, both mutually and against fractionation indices. During intense alteration to biotite schist, Zr/Y remains constant but TiO_2 is considerably reduced. The Zr/Y ratio is higher than that of oceanic or subduction-related basalts in all but two samples. These samples have lower SiO_2, higher Al_2O_3 and are more olivine-normative than the other amphibolites, indicating a separate chemical suite. Zr contents are higher than those of subduction zone basalts (Pearce and Norry, 1979; Hawkesworth and Powell, 1980; Pearce, 1983) in all samples.

The amphibolites have low values of TiO_2 and P_2O_5 for a given value of FeO*/MgO compared with basalts from other CFB provinces. Miyashiro (1975) compared the TiO_2 contents of the Columbia and Deccan plateau basalts at FeO*/MgO = 2, these being 1.5–2.7% and 1–3%, respectively. The amphibolites have TiO_2 = 1–1.5% at the same degree of fractionation, comparable to the so-called T–type basalts of the south-east Brazil margin (Fodor and Vetter, 1984). This may reflect derivation from a parental liquid formed by a high degree of partial melting (cf. Cox, 1980). Fractionation of Ti-bearing phases or depletion of these elements during metamorphism does not provide an adequate explanation since TiO_2 appears to be incompatible in the range of fractionation observed in these rocks, and the elements are considered to be stable during metamorphism (Pearce and Cann, 1973).

MARBLES AND GRAPHITE SCHISTS

Marbles and graphitic schists comprise two separate formations overlying the amphibolites. The marbles have variable composition, ranging from massive lenticular bodies to thick-bedded and thin-bedded schistose strata (defined by compositional layering). Colour variations may be conceived as a lithological change from white limestone to black shale with intermediate degrees of admixture between the two. Brown colour is due to shearing. The purest calcareous compositions are coarsely crystalline white marbles, variably dolomitic, with a fetid odour, that form large masses considered to be "bioherms" (Martin *et al.,* 1962), from which deformed fossils have been recovered yielding a probable Middle Paleozoic age (Martin *et al.,* 1962; Rosenberg, 1985).

The associated calcschists and impure marbles contain muscovite and some quartz, graphite, garnet and tremolite/actinolite in addition to calcite/dolomite.



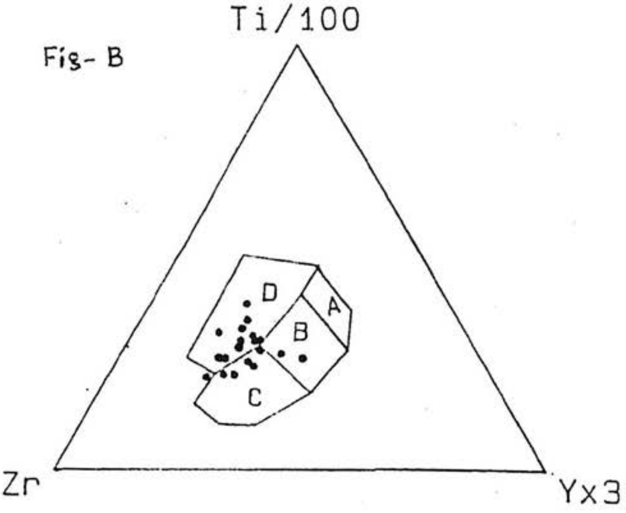


Fig 6 Tectonic environment diagrams, a) Zr, Y relations after Pearce and Norry (1979). A = within plate basalts, B = mid ocean ridge basalts, C = island arc basalts. b) Ti, Zr, Y relations after Pearce and Cann, (1973), A, B, C = island arc basalts, B = mid ocean ridge basalts (MORB), D= within plate basalts. Note that two samples consistently plot in the MORB field.

These grade upwards and interfinger with the graphitic schists, which form large mappable masses, relatively free from calcite away from the contact. The rocks are quartz-muscovite-graphite schists, with ferruginous material in places, and numerous boudinaged quartz veins. Garnet is scarcely developed. Exposures occur in most places where the Swat group is exposed, including Buner. Along the suture, tectonic slices of greenschists and ultramafic material are thrust into the schists.

To the south, the marbles tend to thicken (Fig. 1) with large massive bodies becoming more abundant, so that Rosenberg (1985) has differentiated the massive marbles as a separate formation. These rocks, however, are an integral part of the carbonate formation and their separation is not justified. The development of quartzites and a general increase in quartz-content of the clastic rocks towards the south suggests a southern source for the clastic material. The presence of pure quartzite south of the massive carbonates and the interpretation of these rocks as reef-cores is consistent with a general northward dip for the basin.

DISCUSSION

A model for the development of the basin by the rifting of continental crust and the extrusion of flood basalts over a large part of the incipient basin is proposed. Temporal constraint on this event is the 510–520 m.y. age of the gneisses (Rb/Sr whole rock isochron, Le Fort *et al.,* 1983). Also by the early Devonian, reefoid carbonates were flourishing over much of the northern Indian plate (Stauffer, 1968). Thus, during the Silurian, a widespread rifting episode probably occurred over much of the northern margin of the present Indian plate. Lithospheric cooling during extension resulted in subsidence of the rifted margin (Steckler and Watts, 1978; Royden and Keen, 1980). Extensive flood basalts preceded the gradual subsidence of the developing basin (Fig. 7). Such a process was probably operative along the length of the present Lesser Himalayas, forming the passive margin that characterizes the northern part of the Indian plate during the Middle Paleozoic (cf. the reconstructions by Klootwijk, 1979, and Rickard and Belbin, 1980).

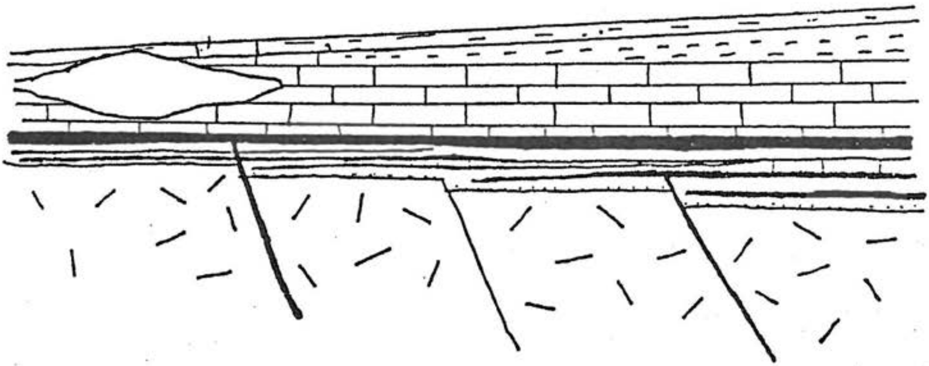


Fig. 7. A cartoon reconstruction of the Paleozoic continental margin. From below, the crystalline basement intruded by dykes which feed fissure eruptions of flood basalts. The basalts are intercalated with detrital sediments, carbonates and possibly evaporites, and are overlain by a shelf carbonate sequence. A reef-core is depicted in the southern part of the basin which presumably dips north. The carbonates contain clastic material, the content of which increases upward and outwards, interfingering with black shales deposited on the outer shelf.

The basalts were erupted on a granitic basement with a thin covering of feldspathic sediments (arkoses). Thin calcareous layers were developed in places. Quartzite and micaschist represent contemporaneous fluvial/marine activity, and the upper surface of the lavas probably underwent some erosion before it was submerged. Carbonate development began before the termination of magmatic activity in the basin, and shallow marine conditions probably alternated with continental ones.

Calcareous schists and impure marbles overlying the basalts were probably derived by the breakdown of the reefs flourishing in the basin. Actual reefs may not have developed in the Mingora area, but were present to the south. Minor igneous activity may have continued during the early phase of deposition and some dykes and sills intruded the flows and even the basal layers of the carbonates. The lime sands and muds were mixed with carbonaceous clastic mud that was being deposited further offshore. Thick calcshales were formed in this manner. Continued marine transgression resulted in the deposition of thick black shales overlying the calcareous strata. This was probably due to anoxic bottom conditions on the shelf, such as described by Leggett (1980) for Lower Paleozoic black shales of the British isles. Thin ferruginous sand layers and small pebbles have been recorded in places in the graphitic schists.

CONCLUSIONS

Geochemical analysis of amphibolites intercalated with magnesian marbles, calcsilicates and schists, indicates an igneous origin for these rocks. Recent field work near Alpurai has revealed relict intrusive features in garnet amphibolites identical to those of Mingora. The parent rocks were basalts of CFB–affinity erupted in a zone of crustal attenuation similar to basalts from Greenland (Brooks and Nielson, 1982; Kalsbeek and Jepsen, 1984), Brazil (Bellieni *et al.,* 1984; Fodor and Vetter, 1984), Deccan and Africa (Cox, 1980). This indication of rifting is accompanied by evidence of subsequent subsidence, marine transgression and passive margin sedimentation. Subject to uncertainties in the ages of the overlying carbonates, these amphibolites are evidence of Siluro-Devonian magmatism. Taken together the evidence suggests the developmnt of a Middle Paleozoic passive margin and the opening of an ocean, possibly the Paleotethys.

The extent of this basin has been traced from Malakand in the west to Besham in the east. The gneissic basement has a known extent along most of the Lesser Himalayas (Le Fort *et al.,* 1983). Le Fort (1975) has described "a remarkable lithologic control of the gneisses by quartzite, carbonaceous schist levels, and more or less dolomitic limestones that play a marker part along the 1200 km recognized". Further, he adds that the gneisses are often associated with amphibolites, which he tentatively relates to a Silurian-Devonian infilling of the Lesesr Himalaya's basin. This account is strongly reminiscent of the Swat region.

Acknowledgements : Analytical facilities were provided by the National Centre of Excellence in Geology. Irshad Ahmad and M. Tahir Shah are thanked for advice and supervision during XRF and AAS analysis, respectively. Reviews by M. Javed Khan, M. QasimJan, A.D. Saunders, B.F. Windley and an anonymous reviewer greatly improved the manuscript. M. Farooq, Alamgir, Jehanzeb and the people of Panr village, Mingora, are thanked for their hospitality during the field work.

REFERENCES

Bellieni, G., Brotzu, P., Comin-Chiaramonti, P., Ernesto, M., Melfi, A., Pacca, I.G. & Piccirillo, E.M., 1984. Flood basalt to rhyolite suites in the Southern Parana Plateau (Brazil): Paleomagnetism, petrogenesis and geodynamic implications. J. Petrol. 25, 579—618.

Brooks, C.K. & Nielson, T.F.D., 1982. The E Greenland continental margin: a transition between oceanic and continental magmatism. J. Geol. Soc. Lond. 139, 265—275.

Campbell, I.H., 1985. The difference between oceanic and continental tholeiites: a fluid dynamic explanation. Contrib. Mineral. Petrol. 91, 37—43.

Coward, M.P., Jan, M.Q., Rex, D., Tarney, J., Thirwall, M. & Windley, B.F., 1982. Geotectonic framework of the Himalaya of N. Pakistan. J. Geol. Soc. Lond. 139, 299—308.

——, Windley, B.F., Broughton, R., Luff, I.W., Petterson, M., Pudsey, C., Rex, D. & Khan, M.A., 1986. Collision Tectonics in the NW Himalayas. In: (Coward, M.P. & Ries, A.C. eds) Collision Tectonics, Geol. Soc. Sp. Publ. 19, 203—219.

Cox, K.G., 1980. A model for flood basalt volcanism. J. Petrol. 21, 629—650.

Floyd, P.A. & Winchester, J.A., 1983. Element mobility associated with meta-shear zones within the Ben Hope amphibolite suite, Scotland. Chem. Geol. 39, 1—15.

Fodor, R.V. & Vetter, S.K., 1984. Rift-zone magmatism: Petrology of basaltic rocks transitional from CFB to MORB, southeastern Brazil margin. Contrib. Mineral. Petrol. 88, 307—321.

Hawkesworth, C.J. & Powell, M.A., 1980. Magma genesis in the Lesser Antilles island arc. Earth Planet. Sci. Lett. 51, 297—308.

Humayun, M., 1985. Tectonic significance of mylonites from Mingora, Swat. Geol. Bull. Univ. Peshawar 18, 137—145.

Irvine, T.N. & Baragar, W.R.A., 1971. A guide to the chemical classification of the common volcanic rocks. Can. J. Earth. Sci. 8, 523—48.

Kalsbeek, F. & Jepsen, H.F., 1984. The late Proterozoic Zig-Zag Dal Basalt Formation of eastern North Greenland. J. Petrol. 25, 644—664.

——, & Leake, B.E., 1970. The chemistry and origin of some basement amphibolites between Ivigtut and Frederishkhab, south-west Greenland. Gronlands Medd. Gronland 104 (4), 1—36.

Kazmi, A.H., Lawrence, R.D., Dawood, H., Snee, L.W. & Hussain, S.S., 1984. Geology of the Indus suture zone in the Mingora-Shangla area of Swat, N. Pakistan. Geol. Bull. Univ. Peshawar 17, 127—144.

Klootwijk, C.T., 1979. A review of paleomagnetic data from the Indo-Pakistani fragment of Gondwanaland. In: (Farah, A. & DeJong, K.A. eds) Geodynamics of Pakistan, Geol. Surv. Pakistan, Quetta, 41—80.

Leake, B.E., 1964. The chemical distinction between ortho- and para-amphibolites. J. Petrol. 5, 238—54.

Leake, R.C. & Haslam, H.W., 1984. Mineralisation in the area around Besham, Kohistan, Pakistan. British Geological Survey report (unpubl.).

Le Fort, P., 1975. Himalayas: The collided range. Present knowledge of the continental arc. Am. J. Sci. 275—A, 1—44.

———, Debon, F. & Sonet, J., 1983. The Lower Paleozoic "Lesser Himalayan" granite belt: Emphasis on the Simchar pluton of Central Nepal. In: (Shams, F.A. ed.) Granites of the Himalayas, Karakoram, Hindukush, Punjab Univ., 235—257.

Leggett, J.K., 1980. British Lower Paleozoic black shales and their palaeo-oceanographic significance. J. Geol. Soc. Lond. 137, 139—156.

Malinconico, L.L., Jr., 1982. Structure of the Himalayan suture zone of Pakistan interpreted from gravity and magnetic data. Thesis, Ph.D., (unpubl.) Dartmouth College, U.S.A.

Maluski, H. & Matte. P., 1984. Ages of Alpine tectonometamorphic events in the northwestern Himalaya (northern Pakistan) by $^{40}Ar/^{39}Ar$ method. Tectonics 3, 1—18.

Martin, N.R., Siddiqui, S.F.A. & King, B.H., 1962. A geological reconnaissance of the region between the Lower Swat and Indus rivers of Pakistan. Geol. Bull. Punjab Univ. 2, 1—13.

Miyashiro, A., 1975. Classification, characteristics, and origin of ophiolites. J. Geol. 83, 249—281.

Orville, P.M., 1969. The metamorphic differentiation origin of thin-layered amphibolites. Am. J. Sci. 267, 64—86.

Pearce, J.A., 1983. A user's guide to basalt discrimination diagrams. Unpubl. notes.

———, & Cann, J.R., 1973. Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth Planet. Sci. Lett. 19, 290—300.

———, & Norry, M.J., 1979. Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks. Contrib. Mineral. Petrol. 69, 33—47.

Pearce, T.H., 1970. Chemical variations in the Palisade sill. J. Petrol. 11, 15—32.

Rickard, M.J. & Belbin, L., 1980. A new continental assembly for Pangaea. Tectonophysics 63, 1—12.

Rosenberg, P.S., 1985. The structure and metamorphic petrology of the Karakar Pass area, Buner, Pakistan. Thesis, M.S., (unpubl.) Oregon State University, U.S.A.

Royden, L. & Keen, C.E., 1980. Rifting processes and thermal evolution of the continental margin of Eastern Canada determined from subsidence curves. Earth Planet. Sci. Lett. 51, 343—361.

Shams, F.A., 1963. Reactions in and around a calcareous xenolith lying within the granite-gneiss of Manglaur, Swat State, West Pakistan. Geol. Bull. Punjab Univ. 3, 7—18.

Spear, F.S., 1981. An experimental study of hornblende stability and compositional variability in amphibolite Am. J. Sci. 281, 697—734.

Stauffer, K.W., 1968. Siluro-Devonian reef complex near Nowshera, West Pakistan. Geol. Soc. Amer. Bull. 79, 1331—1350.

Steckler, M.S. & Watts, A.B., 1978. Subsidence of the Atlantic-type continental margin off New York. Earth Planet. Sci. Lett. 41, 1—13.

Tahirkheli, R.A.K., 1982. The Geology of the Himalayas, Karakorums, and Hindukush in northern Pakistan. Geol. Bull. Univ. Peshawar, Sp. Issue, 15, 1—51.

——, & Jan, M.Q., 1979. (eds.) Geology of Kohistan, Karakoram Himalaya, northern Pakistan. Geol. Bull. Univ. Peshawar, Sp. Issue 11, 1—187.

Wilson, A.D., 1960. The micro determination of ferrous iron in silcate minerals by a volumetric and colourimetric method. Analyst 85, 823.

Winchester, J.A. & Max, M.D., 1982. The geochemistry and origins of the Precambrian rocks of the Rosslare Complex, SE Ireland. J. Geol. Soc. Lond. 139, 309—319.