

PETROGRAPHY OF THE AMPHIBOLITES OF SWAT AND KOHISTAN

M. QASIM JAN

ABSTRACT

The amphibolites of Swat and Kohistan are mainly found in two belts. Those forming the southern belt are the prograde metamorphic products of basic to intermediate rocks which were intruded into tuffs, with some volcanic flows; the tuffs now represented by banded amphibolites. The rocks are locally migmatitic and are essentially composed of hornblende, plagioclase and/or clinopyroxene, with garnet and/or quartz in some places. Opaque minerals, rutile and/or sphene are the common accessory minerals, whilst white and dark micas, clinopyroxene, carbonate, K-feldspar, margarite, corundum, cummingtonite, zoisite, green spinel and staurolite are locally present. The amphibolites of the granulite belt are retrograde products of the pyroxene granulites, mainly due to an influx of water, and are essentially composed of hornblende and plagioclase.

INTRODUCTION

Amphibolites are amongst the most extensive rocks of Upper Swat, Kohistan, and the adjacent areas. They are principally found in a prominent southern belt of the Kohistan "sequence" and extend from Afghanistan, through Bajaur, Dir, Swat, Indus valley, Babusar (Shams, 1975; Ahmed and Chaudhry, 1976), up to Nanga Parbat (Misch, 1949). In addition, amphibolites are also found intimately associated with granulites and making up to about a third of the pyroxene granulite belt. In the following pages, the two occurrences are separately described.

Small bodies of amphibolites, which have not been considered here, are also found in other parts of Swat and Indus Kohistan. Those "associated" with the diorites of Deshai area, northern Swat, have been briefly described elsewhere (Jan and Mian, 1971; Khalil and Afridi, this volume).

THE AMPHIBOLITES OF THE SOUTHERN BELT

Amphibolites are the main rocks of this belt although some other rock-types also occur locally. The former are generally medium-grained but some are fine- or coarse-grained. Most of them are well-foliated, homogeneous or banded. Foliation in the latter is mostly parallel to the banding which, in turn, is in general conformity with the E-W to NE-SW trend of the amphibolite belt. Rehman and Zeb (1970) classified and mapped the amphibolites and associated rocks of the Shah Dheri-Kabal area into two types: (a) banded and associated homogeneous amphibolites of sedimentary origin, and (b) coarse-grained dioritic (igneous) rocks. Although detailed mapping of the rocks has not been carried out elsewhere, a three-fold mapping of the rocks into banded (striped or streaky inhomogeneous), fine- to medium-grained homogeneous, and coarse-grained homogeneous types may prove fruitful in clarifying the structure and petrology of the belt.

The banded rocks occupy at least 25% of the southern belt. The banded aspect of these rocks is due to variations in the proportions of the amphibole and plagioclase \pm quartz in alternate layers; however, in rare cases, quartz-epidote- or garnet- rich bands also occur. The quantity of the amphibole in the extreme types may be less than 10% or more than 90%. In the south of Timurgara (Jan *et al.*, 1969), and around Sahibabad, Dir (Chaudhry *et al.*, 1974), and to the northwest of Matta (Swat), a green epidote is a dominant mineral in some of the bands that alternate with epidote amphibolitic ones. Bands and patches rich in biotite/muscovite have also been noticed in a few places in the Indus valley.

The bands range from streaks to over half a metre in thickness; most of them, however, are less than two centimetres thick and usually have sharp megascopic contacts. The banded amphibolite outcrops "are from a few to several hundred feet thick and may extend for many miles" (Rehman and Zeb, 1970). Most of them are veined, tongued, wedged, distorted and folded (the associated quartz veins, at places, pygmatically) and the term 'hornblende migmatite' would best describe such cases (Jan and Kempe, 1973). Some of

these features are presented in the accompanying plates (Pl. 1 a, b, c; see also Jan and Kempe, Plate 1b) and are not discussed further. In general appearance, the Swat rocks resemble the banded amphibolites described from other areas, such as Connemara (Evans and Leake, 1960).

Thin to thick bands and 'beds' of undoubted sedimentary origin are locally associated with the banded amphibolites. Amphibole-bearing quartzitic bands have been noticed near Kedam and Asrit (Swat valley), Kiru (Indus valley), and in Jandul, Dir (Kakar *et al.*, 1971), whilst thin to thick bands of biotite \pm garnet gneisses are also present locally. Along Patan stream, a few metres thick calcareous horizon (composed mainly of quartz, plagioclase, grossular garnet and calcite) is associated with the amphibolites. Towards the north of the amphibolite belt along the Swat river and Parao stream, horizons of similar thickness but doubtful sedimentary origin occur. The one along the river is composed mainly of epidote and garnet whilst that along the stream of quartz, garnet, and plagioclase. The banded aspect and the association of the metasedimentary rocks led the previous workers to regard the banded amphibolites of the area to be metasedimentary.

The medium- to coarse-grained and non-banded amphibolites, on the other hand, clearly seem in many cases to be of igneous parentage, probably basic intrusions in main, because: (a) in places they contain xenoliths of fine-grained amphibolites, (b) they locally cut across the banded types, and (c) their outcrops are 'irregular' in outline; although some of them are concordant, they may or may not extend for long distances along the general trend of the banding despite their large sizes in some cases. Most of these rocks are gneissose (Pl. 2a) and dioritic-looking but a few are melanocratic or leucocratic. Included in this group of amphibolites are many of the so called diorites of central Dir (Chaudhry and others, 1974; Kakar *et al.*, 1971) and Thak valley (Shams, 1975).

Some of the Swat amphibolites are porphyroblastic with up to 3 cm large crystals of garnet and, rarely, hornblende or plagioclase. In a road-cut along the Indus, a small pegmatite in the epidote amphibolites contains up to 30 cm long crystals of clinozoisite with a subordinate quantity of smaller grains of plagioclase and hornblende. Granitic rocks, hornblende-plagioclase pegmatites, and minor ultramafic rocks, olivine gabbros and various types of veins

containing one or more of plagioclase, quartz, amphibole, epidote, chlorite, and, in some, garnet, are common throughout. In the Indus valley, some of the thin veins of quartz also carry garnet (Jan and Tahirkhelt, 1969). In some places, abundant plagioclase has grown into large crystals up to a few centimetres in length and locally having parallel alignment (Pl. 1d). Wintsch (1975) has suggested deformation to be an essential cause of feldspathisation and at least in some places the formation of large feldspars in the Swat amphibolites may have been facilitated by deformation.

AMPHIBOLITES ASSOCIATED WITH THE PYROXENE GRANULITES

Throughout the Indus and Swat valleys, amphibolites are intimately associated with the noritic rocks and probably occupy up to a third of the granulite terrain. They are more common in the southern part of the granulites, particularly in the Swat valley; they tend to preserve the gneissose texture and coarse grain size of the granulites around Fatehpur (Pl. 2b). There are unequivocal indications of a gradual passage between the two rocks without any break, twisting or shearing in the foliation at a number of places. The amphibolites may form large masses of many hundred metres extension, or they may be in the form of patches, veins and streaks, at places entirely composed of hornblende (Pl. 2c, see also Jan and Kempe, Plate 1 a). In the Indus valley, islets of norite relics, similar to those of the Scourian granulite-amphibolite terrain (Beach, 1974), have also been found.

Between Madyan and to the south of Fatehpur, the amphibolites make at least 50% of the 15km broad area. Here they are intermixed with the pyroxene granulites of similar coarse and gneissose aspect. They gradually increase towards the south until a zone is reached where the norites are in the form of local lenses, finally giving way to pure amphibolites. Although Jan and Kempe (1973) have drawn a boundary between the two rock-types in the south of Fatehpur, it is arguable whether such a distinction should or not be made. This belt of rocks extends to the east beyond the drainage divide between the Swat and Indus valleys; however, coarse-grained norites and the associated amphibolites have not been found along the Indus river.

Some of the amphibolites in the Indus valley have a very high proportion of hornblende, at places to the near exclusion of other minerals. Some of these rocks are coarse-grained (with up to 4cm long crystals), usually

occurring in bodies of various shapes and sizes within the 'normal-looking' amphibolites. It appears that metasomatism has played an important role in the development of such hornblende-rich rocks here as well as elsewhere in the region. Some of the Indus amphibolites were called diorites by Jan (1970) due to their comparatively low amphibole content (20–40%). While some of these rocks may be dioritic in chemistry (equivalent of the intermediate granulites), it appears that they have undergone amphibolite grade metamorphism and use of the term diorite is avoided in the present work.

Another distinct feature of the Indus amphibolites is the presence, in some, of garnet, in places in porphyroblasts or in thin 'bands'. Garnet has not been found in the amphibolites associated with the Swat valley granulites; its development is attributed here to changes in the bulk chemistry accompanying amphibolitisation rather than to difference in the grade of metamorphism in the two areas. It may, however, be mentioned that garnet has been found in some of the amphibolites in the upper reaches of Kana stream which may be an extension of those of the Fatehpur area. Here is also seen fine-grained amphibolitic and felsic material included in, or associated with, the amphibolites and contamination could be a cause of garnet development.

In addition to these rocks, thick sheets of banded amphibolites have also been found in the granulites near Asrit, in Kedam valley, and, locally, along the Madyan (Bishigram) stream. The former two contain local quartzitic bands and epidote, and are very similar to the banded amphibolites of the southern belt. Their presence here may be due to folding, faulting, xenolithic incorporation, or an extension from Dir area. Those of the Madyan stream are fine-grained, in places banded and, like the above two, may be representing the country rocks or, more probably, are sheared and amphibolitised granulites.

FEATURES OBSERVED IN THIN SECTION

The rocks are generally medium-grained, 'hypidioblastic' to xenoblastic, and locally contain porphyroblasts; foliation and gneissose structures are common. The banded varieties are usually finer grained than the homogeneous types some of which are coarse-grained and look like diorites. Variations in texture and mineral proportions are common. Some of the coarse-grained amphibolites associated with the granulites in the Madyan-Fatehpur area are

TABLE 1. MODAL COMPOSITION OF SOME AMPHIBOLITES

Sample	No. of points counted	Thin section(s)	Plg	Qz	Amph	Epi	Bio	Ore	Rt	Sph	Ap	Cpx	Others
US 4	7288	2	25.8	7.4	59.3	4.9	...	Tr.	...	2.4	0.2	...	...
US 8	5227	1	57.6	Tr.	40.7	0.1	0.1	0.3	0.4	Tr.	0.8	...	...
US 12	5482	1	41.1	0.6	40.3	10.4	...	4.5	...	Tr.	...	3.0	...
SI 177	4724	2	27.2	...	65.9	2.9	...	2.8	...	...	1.2	...	*
SI 261	7844	1	...	3.5	67.6	26.8	...	0.2	0.1	...	...	1.2	0.6
SI 347	10777	1	2.6	0.3	93.2	1.0	...	0.1	0.5	0.3	0.1	...	2.0
SI 355	6615	1	26.4	0.6	55.9	16.0	...	0.3	...	0.9	...	...	...
SI 363	12730	2	47.6	10.7	32.8	6.2	0.2	1.3	0.3	0.2	0.3	...	0.4
SK 462	7509	1	34.1	0.2	42.6	8.2	5.3	...	...	0.6	0.7	7.1	1.2
SK 504	7210	1	64.7	0.4	32.9	0.7	0.3	0.7	...	0.1	0.3	...	...

* Although none in the section, the sample contains about 2% garnet.

Samples prefixed by US are from Upper Swat (south of Fatehpur), SI from the Indus valley and SK are from Swat Kohistan (north of Fatehpur).

Samples US 8 and SK 504 are retrograde amphibolites of the granulite belt whilst the remaining ones are prograde types from the southern amphibolite belt.

medium-grained under the microscope; their coarse-looking amphibole is an aggregate of small grains probably developed after pyroxene.

Modal composition of ten amphibolites is given in Table 1; in addition, Ahmed and Ahmed (1975) have presented the modes of eight garnet-bearing amphibolites and the associated gneisses from Upper Swat. The plagioclase content of the rocks studied by them is distinctly lower (0.0 to 10.6%) when compared to most of the amphibolites studied by the writer. The rocks are essentially composed of amphibole, plagioclase and/or epidote; small quantities of opaque minerals, quartz, rutile and/or sphene, and apatite occur in most of the rocks, whilst some contain biotite, white mica, garnet, and a few have margarite, clinopyroxene, carbonate and green spinel. Modal composition of the rocks from various parts of the region has been presented (Jan, 1970; 1977a; Chaudhry and others, 1974; Malik, 1974; Ahmed and Ahmed, 1975) and the rocks range from melanocratic amphibolites to leucocratic gneisses. The latter include quartz (\pm feldspar)-rich and garnetiferous bands, and some other bands of non-amphibolitic composition.

The main mineralogical difference in the amphibolites of the southern belt and those associated with the granulites is that the latter either lack epidote or, when present, is minor and usually a retrograde product after plagioclase. This led Jan and Kampe (1973) to think that the grade of metamorphism in the southern part of the complex increases northwards. However, it has already been mentioned that the banded amphibolites in the granulite terrain near Asrit and in Kadam valley have primary epidote. It is thus not certain whether the presence or absence of epidote can form a reliable criterion in establishing differences in the grade of metamorphism in all areas. In the amphibolites and granulites of the Bartica Assemblage of Guiana Shield, for example, epidote and basic auesine co-exist right up to the boundary of the granulite facies (Cannon, 1966).

An interesting boulder collected at Patan and probably derived from the amphibolite belt is worthy of mention for its unusual mineral association. It is composed of more than 3 cm long crystals of clinozoisite ($> 85\%$) and up to one centimetre long corundum ($> 10\%$), with secondary white mica, and traces of amphibole and opaque minerals. The mineral composition of this rock is very similar to some rocks of the anorthosite group ('artstone') described from Tanzania and considered by Harpum (1958) to be metamorphosed anorthosites.

The mineralogy of the Swat rock is suggestive of a chemical composition more aluminous and less silicic than even pure anorthite; the possibility of metasomatism or metasedimentary origin seems more plausible. Corundum has also been reported from the amphibolites at Timurgara, Dir, and near Shah Dheri (Jan *et al.*, 1969, 1971; Rehman and Zeb, 1970).

The amphibole is bluish green, green or brownish green but in a few rocks it is light green or distinctly brown. All of the analysed amphiboles are calciferous and fall in the general field of hornblendes; many being rather high in Al_2O_3 (up to 18.4%, average $Al_2O_3=14.6\%$). In some of the rocks the amphibole is sieved and contains abundant inclusions of quartz, less frequently rutile and opaque minerals and, in rare cases, a green spinel. In some cases these minerals occur only in the central parts of the grains, the margins being free of them. In a few rocks the hornblende may be in porphyroblasts or poikiloblasts; the latter, in rare cases, containing clinopyroxene relics. There is only one amphibole mineral in most of the studied rocks; however, a distinctly greenish blue (?) secondary variety has been noticed in a few. In the altered rocks, the hornblende is partly replaced by chlorite or, less frequently, by epidote + sphene + minor chlorite. Chaudhry and Chaudhry (1974) have reported an occasional occurrence of cummingtonite also in some meladiorites (i. e., amphibolites of this report) in Khagram area, Dir, and Shams (1975) has reported this mineral from the Thak valley.

The plagioclase is usually cloudy due to saussuritisation and kaolinisation but in some rocks it is almost fresh or completely altered. Minor biotitic mica and chlorite have also been noted in a few altered feldspars. The composition of the plagioclase determined from symmetrical extinction angles on albite twins is in the range of andesine but in rare cases it is sodic labradorite. The most common twins are according to albite law, followed by those on pericline/acline law; however, occasional combinations of Carlsbad twins with either one or both of these twins have also been found. The number of twin lamellae is much reduced compared to the igneous and the Swat pyroxene granulite plagioclases; some are poorly twinned. Straining is not uncommon whilst marginal compositional zoning is found in some.

The analysed epidote minerals belong to the clinozoisite-epidote series with $100 Fe^{3+}/(Fe^{3+} + Al)$ ranging from 10 to 28. Much of the epidote is primary in origin but traces of a secondary type also occur in many rocks.

The latter may grow after plagioclase and, rarely, amphibole and garnet, or it may grow as a reaction product between the former two. In a few rocks, a small quantity of a (?) secondary, more coloured (? richer in Fe^{3+}) variety may closely be associated with the main type. Inclusions of cloudy plagioclase in the epidote and patchy growth of the latter in the former in some rocks suggests that the growth of the epidote is mainly at the expense of the plagioclase; in most rocks the proportion of one decreases as that of the other increases. In a number of rocks the epidote contains myrmekitically intergrown quartz, especially in the centres, while at places it is poikiloblastic. A $3\frac{1}{2} \times 1\frac{1}{2}$ cm thin section of SI 262 is entirely occupied by two epidote poikiloblasts containing abundant inclusions of brown hornblende, tiny grains of quartz, and a few clinopyroxene grains in one. Straining and, rarely, compositional zoning, and twinning have been noted in the epidote. Chaudhry *et al.* (1974) have reported coexisting zoisite and clinozoisite in amphibolites of Khagram and Sahibabad areas in Dir.

Biotite and white mica are present in small quantities in some rocks; however, in a few hornblende-poor bands, 'schlieren' and patches, either one of the two or both may be abundant. The former is comparatively more common, at places in the form of poikiloblasts up to 2 cm across, in the rocks along the Kayal stream, about 15 km north of Patan. Whilst in most rocks the dark mica seems to be a prograde product, in a few it is apparently secondary. Alteration to chlorite, in some accompanied by lenses of a mineral resembling prehnite, is common.

Margarite is restricted in occurrence and has been found in a few rocks only as a primary mineral. In the two corundum-bearing rocks studied by Jan *et al.* (1971), it is found as a green alteration product enveloping the corundum, itself enclosed in shells of serpentine, and chlorite + amphibole + clay mineral, and an irregular outer zone of epidote. In some cases the corundum is completely altered to the green material composed of the above-mentioned minerals, whereas, in rare cases, staurolite is found within the green envelopes instead of corundum. The system $\text{CaO} - \text{Al}_2\text{O}_3 - \text{SiO}_2 - \text{H}_2\text{O}$ has been investigated by Chatterjee (1974, 1975, 1976), and Storre and Nitsch (1974). For the reaction $\text{margarite} \rightleftharpoons \text{anorthite} + \text{corundum} + \text{H}_2\text{O}$, the equilibrium conditions are 565°C , 4 kb to 630°C , 7 kb. The presence of stable margarite in some amphibolites and corundum \pm plagioclase in others

may be suggestive of local variations in temperature and/or pressure in the amphibolite belt if the presence of the other components did not play a major role in influencing the reaction conditions. The absence of zoisite + kyanite \pm corundum (chemically equivalent to margarite + quartz) suggests that the operating PH_2O was less than 7 kb (Chatterjee, 1975) at a temperature of less than 650° C (Storre and Nitsch, 1974).

Minor quantities of one or more of magnetite, ilmenite, limonite/hematite (after pyrite) and, in rare cases, green spinel, occur along with rutile and/or sphene in the amphibolites of Swat. The latter two and leucoxene also grow at the expense of ilmenite. In one rock, ilmenite is enveloped by rutile which, in turn, is enveloped by sphene. Although tourmaline traces have been noted only in a few rocks, Ahmed and Ahmed (1975) have reported 10% of this mineral from a garnet (11.4%) - epidote (15.1%) - hornblende (39.5%) - quartz (18.9%) gneiss from Upper Swat.

Pinkish or, rarely, colourless garnet occurs (as porphyroblasts, small grains or, occasionally, as poikiloblasts) in some rocks only as an accessory constituent; however, garnet-rich 'layers' and 'horizons' have also been found in a few places. It is found in the homogeneous as well as banded amphibolites; in the case of the latter it is more frequently developed in the lighter bands (i. e. those poor in amphibole). In an amphibolite (SI 205) occurring about 10 km S of Kamila, there are distinct but irregular streaks and patches, generally < 1 cm broad, of garnet + feldspar + quartz + minor epidote and opaque mineral. Very similar rocks also occur near Timurgara. Dir, and Jan *et al.* (1969) have hinted at the possibility of the two forming the same geological horizon. It has already been mentioned that garnet does not occur in the amphibolites associated with the granulites (ignoring the banded types which are probably related to those of the southern belt) along the Swat river. Near the contact with the former mentioned amphibolites, garnet (along with epidote) becomes especially abundant in a narrow zone to the south of Fatehpur. Two garnets analysed by the writer and eight by Ahmed and Ahmed (1975) are all almandine-rich; however, the garnet of an "Mn-rich" rock is spessartine-almandine and that of a calcareous horizon seems to be rich in grossular content; both of these rocks are non-amphibolitic in mineralogy.

Greenish clinopyroxene occurs only in a few rocks either as a prograde metamorphic product or as relict inclusions in the amphibole and, rarely, in

the epidote. Two pyroxene compositions determined, $Mg_{37.2} Fe_{12.6} Ca_{50.2}$ and $Mg_{35} Fe_{15.5} Ca_{49.5}$, fall in the field of salite. The appearance of clinopyroxene seems to have been controlled, like that of garnet, by the bulk chemistry.

CONCLUDING REMARKS

The amphibolites forming the southern belt are generally gneissose and can be broadly grouped into medium- to coarse-grained homogeneous, and fine to medium-grained banded varieties. The former are derived mostly from gabbros and diorites which were intruded in tuffs (now banded amphibolites). Some of the leucocratic bands in the latter may be derived from quartzofeldspathic sediments or acidic tuffs. The banded amphibolites may locally have been contaminated with sedimentary material, as suggested by the occurrence of rocks of undoubted sedimentary origin (quartzites, calc-silicate and some other rocks). The so-called leuco-amphibolites of northern Dir may have been derived from sediments, as suggested by Chaudhry and Chaudhry (1974) or from acidic tuffs but, in contrast to these authors, it is considered here that the melamphibolites of this area are tuffaceous, with some flows as suggested by pillow structure at a few places. Most of the amphibolites of Swat are basic to intermediate in composition and the homogeneous varieties show an iron-enrichment trend on $MgO-(FeO+Fe_2O_3)-(Na_2O+K_2O)$ diagram (Jan, 1977a). From various considerations it can be concluded that the rocks were mostly recrystallised between 570° to 670° C and 4 to 6 kb. The presence of pillow lavas, tuffs and other features suggests that they originally have constituted a part of the Tethyan crust.

The amphibolites of the granulite belt are intimately associated with the pyroxene granulites and seem to be retrograde products of the latter, mainly due to an influx of water, perhaps during the upward transport of the granulites. In most part there are no significant chemical changes, however, in the Madyan-Fatehpur area the granulite to amphibolite transition seems to have been accompanied by a general basification (Jan, in prep.).

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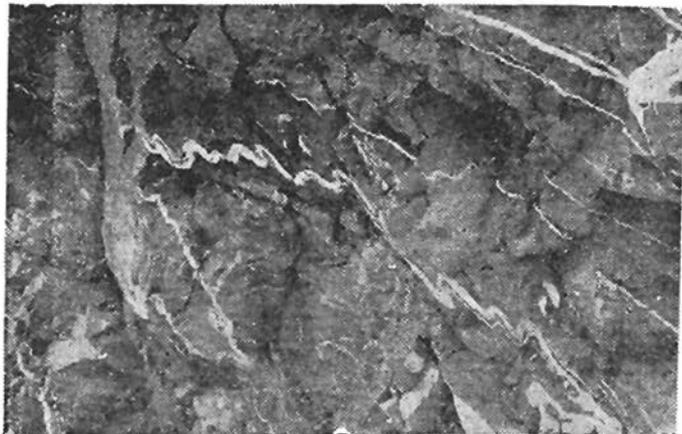
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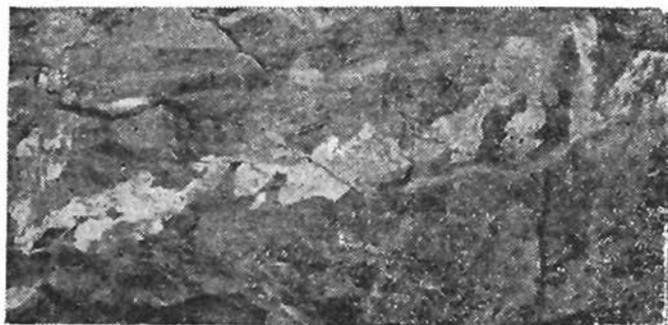
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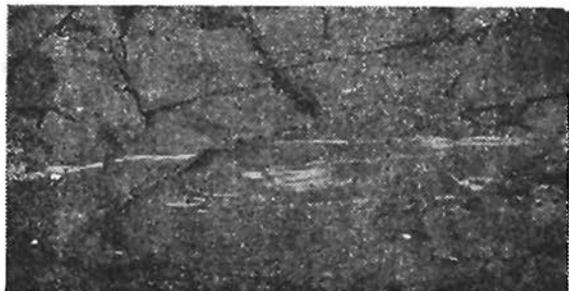
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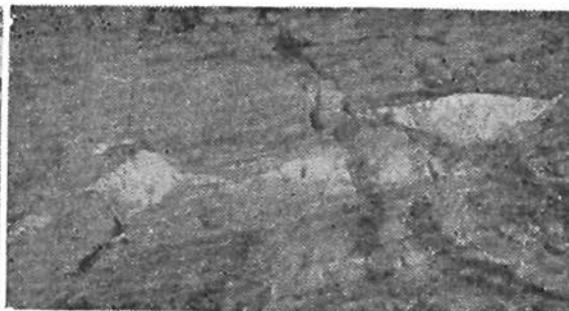
A



B



E

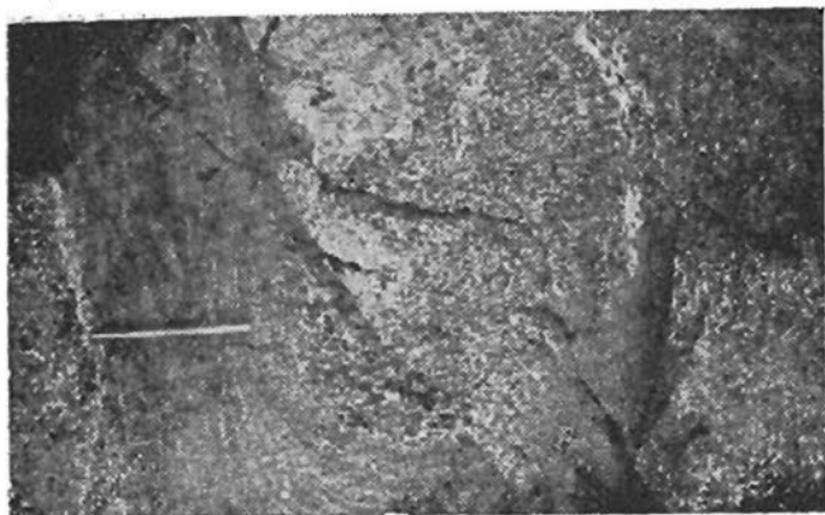


C



D

Plate 2



A



B



C

PLATE 1

- A. Banded amphibolite with folded veins and patches, and sparse porphyroblasts of felsic material. In road-cut to the south of Kamila, Indus valley.
- B. Ptygmatically folded vein in amphibolite to the south of Kamila.
- C. Folded quartz vein in amphibolite in a road-cut to the north of Kayal (Indus valley). The amphibolite seems to be finer grained in the lower than in the upper part.
- D. Abundant, large crystals of plagioclase, some with parallel arrangement, and hornblende-rich bands locally developed in amphibolites in the south of Kayal. The development of the feldspar and hornblende bands may have been facilitated by shearing before metasomatism (segregation).
- E. Lenticular (?) feldspar in banded amphibolites north of Kayal.

PLATE 2

- A. Shearing accompanying folding in a non-banded amphibolite near Kayal. The development of banded aspect in the sheared part is noticeable.
- B. Coarse-grained amphibolite associated with coarse-grained granulites in Bishigram (Madyan) stream. The bands may be preserved igneous layers or a product of metamorphic differentiation. Abundant hornblende has grown along a fracture on the right side.
- C. Amphibolitised noritic granulite with irregular patches and streaks of nearly pure hornblende. In a road-cut near Ramet, Swat valley