

THE GEOLOGY OF THE LOWER PART OF INDUS KOHISTAN (SWAT), WEST PAKISTAN

M. QASIM JAN AND R. A. KHAN TAHIRKHELI

ABSTRACT

An area of over 450 square miles in Indus Kohistan, Swat, has been mapped and the detailed petrography of the rocks is presented. The area investigated is bounded by latitudes $35^{\circ} 15'$ to the north, and $34^{\circ} 45'$ to the south, by the Indus River to the east, and by the drainage divide of the Indus and Swat Rivers to the west. The predominant rocks in the southeast and south belong to the Lower Swat-Buner Schistose Group (Siluro-Devonian or possibly Ordovician). The Schistose Group is commonly represented by low grade quartzites, quartz-mica schists, amphibolites, marbles, calcareous schists, phyllitic schists, graphitic schists, and greenschists. These were intruded by ultramafic rocks (pyroxenites and dunites near Jijal; serpentinites near Alpurai, Jijal etc.) during the earlier phases of the Himalayan orogeny (middle to late Cretaceous). During later orogenic phases (early Tertiary), the area was intruded by the abundant Swat Granites and Granite Gneisses (generally leucocratic, two feldspar-bearing rocks) and pegmatites, and minor gneissic granodiorites near Shang and Dubair. These events were followed by overthrusting of the (?Precambrian) Upper Swat Hornblendic Group which covers the northern and northwestern part of the investigated area. The Hornblendic Group is represented mostly by diorites, metadiorites, hypersthene gabbros, and garnet-amphibole gneisses.

INTRODUCTION

The Department of Geology, University of Peshawar, conducted a field mapping programme during June and July 1968, and May 1969, to investigate the geology of the previously unmapped area of Swat Kohistan. The basic purpose of this work was to prepare a preliminary geological map and to provide some knowledge about the various rock types exposed in the area. Traverses were carried out along the Indus Valley Road and major stream courses, and about 300 rock samples were collected for further investigation. From these, some sixty thin sections have been cut. Mapping was carried out on toposheets (No. 43-A, 43-B, and 43-E, scale $1'' = 3.798$ miles enlarged to $1'' = 1$ mile) of the Survey of Pakistan Department. The accompanying map is thus based on limited information for such a complex area and will require additions and revisions, especially in the areas lying far from the main road and streams.

Location and Access: The area investigated lies roughly between the drainage divide of the Indus and Swat Rivers to the west, and the Indus River to the east. The northern and southern limits of the area do not extend beyond latitudes $35^{\circ} 15'$ and $34^{\circ} 45'$, respectively. Construction of the Indus Valley Road is in progress and the area is accessible by motor vehicles in fair weather. From this road, access on foot is possible deeper into the area along streams and footpaths.

Topography and Drainage: The terrain in general is very rugged and the relief is very high. The main valley floor is less than 2200 feet, south of Kayal village, whereas the nearby peaks may reach 10,000-12,000 feet. The valley slopes are thus very steep, and are mainly V-shaped, many of them separated by long acute ridges. The drainage in general is dendritic, but some of the subsequent streams join the major consequents at right angles, locally producing a trellised pattern.

Rainfall and Vegetation: Rainfall is moderate in the south but scanty towards the north. Dubair (taken as average) has a rainfall of about 20-25 inches per year, whereas Patan gets only ten inches. The valley is characterized by hot summers and cold winters. Summer maximum temperatures may be above 110°F and winter minima below freezing point. Much of the precipitation during winter months is in the form of snow on high peaks, many of which, and some high valleys, are glaciated.

Vegetation is sparse; common plants below 4000-5000 feet are broad-leaved *Quercus ilex* (oak), *Juglans regia* (walnut), *Aesculus indica* (bankhor), etc., and narrow-leaved trees of *Pinus* species. *Cedrus deodara* (deodar), *Abies pindrow* (palunder), *Abies webbiana* (silver fir), *Pinus gerardiana* (chalthoza), *Pinus wallichiana* (blue pine) and *Juniperus communis* (juniper), etc. are typical of higher elevations.

Previous Work: Although much has been written about the geology of the Himalayas, little of it contributes directly to the area under discussion. The main source of information hitherto is a paper containing geological and structural maps by Martin, Siddiqui and King (1962). They divide the rocks of the region immediately to the south into the following six units:

1. The Upper Swat Hornblendic Group
2. The Lower Swat-Buner Schistose Group
3. The Swat Granitic Gneisses
4. The Swabi - Chamla Sedimentary Group
5. The Ambela Granite
6. The Shewa Formation

Of these, the first three are exposed in Swat Kohistan. In order to keep uniformity in nomenclature, the present authors have retained the names used by Martin *et al.*

In 1964, M. Abu Bakr of the G.S.P., and R.O. Jackson of the U.S. G.S. compiled the geological map of Pakistan but only the rocks exposed immediately to the south of the area investigated are shown on this map. Davies (1965) gives a brief account of the Upper Swat Hornblendic Group.

FIELD RELATIONS AND PETROGRAPHY

The rocks of Swat Kohistan can readily be grouped into five broad units, as follows:

5. The Shang Granodiorite Gneiss
4. The Swat Granitic Gneisses
3. The Jijal Ultramafics
2. The Lower Swat - Buner Schistose Group
1. The Upper Swat Hornblendic Group

The relative ages of some of these groups are speculative because of lack of positive evidence.

1. The Upper Swat Hornblendic Group.

These rocks occur in the north and northwest of the area, with a general NE trend, and extend into Dir State to the west (Davies, 1965). The name 'Hornblendic Group' was applied to these rocks by Martin *et al.* (1962) because of the ubiquity and abundance of hornblende.

The rocks range in composition from garnet-amphibole schists to gneissic diorites, diorites, and quartz - hypersthene gabbros. Davies mentions the presence of associated granites and syenites, and Martin *et al.* report associated dunites. The present authors did not see such associates of the Hornblendic Group in Indus Kohistan.* The predominant rocks in this area are hornblende - gneisses, followed by less gneissic intermediate and basic rocks of plutonic character; less abundant metasediments are found to the south, north of Patan Village.

The Hornblendic Group is flanked to the south by a special group of rocks, the garnet-amphibole gneisses, described at the end of this section.

Foliation, compositional banding, and microfolding (in the more schistose rocks) are common. The rocks are cut by thin pegmatites and quartz veins. Most of the pegmatites are less than five feet thick and very coarse grained, containing different combinations of quartz, feldspar, hornblende and tourmaline, etc. Some pegmatites may carry perfectly euhedral crystals of hornblende up to nine inches long (Martin *et al.*, 1962). Garnet is commonly associated with the quartz veins, especially the narrow ones.

* Granitic rocks and peridotites occur north of the area.

The metamorphosed sediments of the Hornblendic Group are fine-grained schistose rocks that generally grade into gneissic and apparently plutonic non-gneissic rocks, although some may have sharp contacts with the latter. Many of them have well preserved sedimentary layering indicated by the changing composition of different layers, although this might be probably due to migmatization and/or metasomatism. Texturally the metasediments are porphyroblastic, and most of the grains exhibit some crystal faces, and parallel arrangement. Based on a study of three thin sections, they are composed of hornblende (45 per cent);* andesine - labradorite (25 per cent); clinozoisite (10 per cent); quartz (10 per cent); pinkish (? almandine) garnet (6 per cent); and minor rutile and opaque minerals, (one section only contains 5 per cent biotite). Much of the garnet is in "bands" or "pods", though some may be dispersed throughout the rock.

The gneisses are medium- to coarse - grained, ranging from normal hornblende diorites to metamorphosed amphibolites. They are composed of abundant hornblende, followed by plagioclase, quartz, pyrite and magnetite/ilmenite. Pyrite is rimmed by opaque iron oxide and hornblende has light green rims of more sodic amphibole. Hornblende may be rimmed by mica (Martin *et al.*, 1962, p. 2) in some cases. The rocks contain xenolithic inclusions that are metamorphosed to garnet-amphibole assemblages. As previously mentioned, weakly gneissic norites** are also associated with these rocks. These are medium-grained, sub-equigranular rocks composed of 55-60 per cent labradorite (with both albite and pericline twinning); 14-16 per cent each of strongly pleochroic hypersthene, and light green, weakly pleochroic diopsidic - augite (both with exsolved lamellae); 5 per cent each of quartz and iron ore; and minor hornblende. Some rocks may have up to 10 per cent quartz.

Associated garnet-amphibole gneisses: Massive, generally coarse-grained and gneissic rocks of the almandine-amphibolite facies are well exposed along the southern limits of the Hornblendic Group; the best exposures are southwest of Patan Village. Concentration of various minerals in distinct bands is very characteristic of these rocks. In hand specimen, they appear to be composed of about equal amounts of garnet, amphibole, and white minerals, with subordinate muscovite in some, towards the south. Some of these rocks are non-porphyroblastic, others have large crystals of garnet (up to 2 inches across, and sometimes aligned in trains), surrounded by a narrow rim or corona of felsic or mafic minerals. Veins of calcite, epidote, and quartz are common along fractures. Thin veins of garnet and rare intrusions of pegmatite also occur.

* All percentages in this paper are based on visual estimates.

** Recent investigations to the north of the area suggest that hypersthene-gabbros (norites) are predominant.

Pink garnet, calcic plagioclase, and hornblende make more than 80 per cent of the rocks in thin section. The remainder consists of clinozoisite, quartz, rutile, and iron ore in decreasing quantity. Chlorite and extensive epidote appear after garnet, hornblende and plagioclase in many of these rocks. The muscovite-bearing rocks have more clinozoisite and less garnet than the rest. Muscovite, as coarse flakes, generally forms less than 15 per cent. The rocks vary in texture from fine- to coarse-grained, gneissic to non-gneissic. One of the sub-equigranular amphibole-rich parts has crystals of hornblende 3 inches long. The grain size may change gradationally or abruptly across a plane.

Some of these rocks are very rich in one mineral, and there are "sheets" up to 120 feet thick that contain more than 80 per cent garnet or amphibole. Similarly, there are pods (up to several feet across) of hornblende and/or garnet, incorporated in normal garnet - hornblende - felsic assemblages. A garnet - rich rock in thin section has 80 per cent garnet, 10 per cent each of plagioclase and hornblende, and minor iron ore. A hornblende - rich rock contains only 18 per cent of pink garnet and traces of ore and rutile, besides predominant hornblende.

The mineralogy and abrupt variations in texture and composition of the garnet-amphibole gneisses within themselves indicate that they were a series of basic intrusions that have been metamorphosed to their present assemblages.

Martin *et al.* (1962) think that the Hornblendic Group is older than the Swat-Buner Schistose Group. The latter, according to them, is younger than the Salkhala Series (Precambrian), and older than the Chamla quartzites (? Devonian). Bakr and Jackson (1964) have tentatively placed the rocks, exposed south of Kalam along the Swat River, in the Precambrian. These rocks are part of the Hornblendic Group under discussion.

2. The Lower Swat-Buner Schistose Group.

Most of the rocks south of Jijal village belong to this group of, generally, low grade metasediments. Martin *et al.* divide them into five subdivisions, namely: (1) Siliceous Schists, (2) Amphibolite Horizon, (3) Marbles and Calcareous Schists, (4) Phyllitic Schists, and (5) Greenschists. The present authors have not extended this subdivision in the north, where the above sequence is seen in the area. Common rocks east of Churlandai village are pyrite-bearing quartz-mica schists and quartzites (probably equivalent to the Siliceous Schists of Martin *et al.*), whilst those to the west of Alpurai village are greenschists and associated serpentinites. Between these types are marbles (some containing fuchsite and tourmaline) and calcareous schists, and phyllites, with minor but persistent quartzites and quartz-mica schists (like those to the east), and graphitic schists.

The rocks are strongly schistose, medium - to fine-grained, and some are banded. Banding is particularly well displayed by the quartz-mica schists. Some of the rocks, especially the greenschists, are very deformed, faulted and micro-folded. The most common rocks are quartz-mica (biotite/muscovite) schists, quartz-mica-garnet(-ore) schists, quartz-chlorite-albite schists, quartz-carbonate-(mica-ore) schists, quartz-carbonate-garnet-mica schists, carbonate-talc schists, marbles, quartz-chlorite schists, epidote-albite schists, actinolite-talc-quartz schists, and fine-grained phyllitic schists, some of which also have garnet and/or graphite. Martin *et al.* have also found kyanite in some of the calcareous rocks. An interesting member of the group is a metaconglomerate (<300 feet thick) exposed in Chaman Nala, and to the south of Bhesam Qala. It has a fine-grained phyllitic matrix, enclosing boulders (up to one foot long) and pebbles of igneous and metamorphic rocks, elongated parallel to the schistosity. These may be interlayered with thin, equigranular schistose rocks.

The Schistose Group is intruded by abundant pegmatites, squeezed lenses and veins of quartz, granite and granodiorite gneisses, and a few amphibole-bearing rocks. The latter are composed of hornblende and plagioclase, with minor iron ores (sulphides and oxides), quartz, and traces of sphene. Alteration in these has commonly lead to partial chloritization of the hornblende, saussuritization of the plagioclase, and oxidation of the ores. Intrusions of granites and pegmatites are so abundant in some places that they cannot be shown on the map as separate bodies. The quartz-mica schists on the contact of these intrusions are feldspathized (some have 60 per cent feldspar) and some may appear "gneissic". Some of the schists close to these intrusions may also contain sulphides, which on alteration impart a yellowish-green colour to the rocks.

Martin *et al.* (1962) place the rocks of the Lower Swat-Buner Schistose Group below the Chamla Quartzites of (?) Devonian age. According to them, the presence of fossil remains in the marbles indicates that the rocks are younger than similar rocks of the Precambrian Salkhala Series. Bakr and Jackson (1964) give these rocks a Siluro-Devonian or possibly Ordovician age.

3. The Jijal Ultramafics.

A NW trending and northerly dipping body of ultramafic rocks, over three miles wide and at least seven miles long, occurs between the villages of Serai and Chopra to the north, and Jijal and Jaba to the south. It separates the Hornblendic Group from the Schistose Group, but to the northwest is probably terminated by the Hornblendic Group, which from then on is in direct contact with the Schistose Group. Immediately to the south of the main ultramafic body are concordant sills and lenses of serpentinite, intruding the Schistose Group. The main mass is composed of

massive, hard, brown to green pyroxenites, incorporating a smaller greenish, resinous body of dunite towards the upper part.

The rocks are medium-to coarse-grained, hypidiomorphic to allotriomorphic; some of the pyroxenites have ophitic textures. All the rocks, particularly the dunites, have cataclastic textures. Colourless to faintly pleochroic diopsidic augite is the most common mineral of the pyroxenites. It has rod-shaped inclusions of iron oxide and exsolved lamellae of another clinopyroxene. In some cases it is partially altered to serpentine along grain boundaries. In one section, completely serpentinized grains, apparently of pyroxene, are seen among unaltered grains. This selective alteration is not clearly understood. Hypersthene is also present in some of the pyroxenites. It is generally more altered than the associated clinopyroxene and, in one section, all of it (forming about four per cent of the rock) is altered to brownish material, with the exception of a few fresh, pleochroic cores. Some types carrying more hypersthene (up to 35 per cent) may form hypersthene-rich bands. In these, hypersthene has inclusions of iron ore and about one quarter is altered to talc or serpentine. Greenish pleochroic diallagic diopside takes the place of diopsidic augite in the hypersthene-rich rocks. Diopside is only slightly altered and contains abundant, thin exsolved lamellae. It is interesting that the hypersthene-bearing rocks carry minor amounts of interstitial garnet. Iron ore is a constant but minor accessory in all the pyroxenites.

The authors do not know of any alpine peridotite or pyroxenite containing hypersthene. On the other hand, the latter is common in pyroxene granulites. It is therefore considered that some of the pyroxenites of Swat Kohistan may have undergone metamorphism, whereby hypersthene - garnet - diopside assemblages were produced at the expense of the original pyroxenites. Another possibility, suggested by S.F.A. Siddiqui (personal communication, 1969), is that the Jijal ultramafics might derive from a basaltic magma.

The dunites are composed of Mg-rich olivine and minor ore (about 2 per cent). Most of the olivine grains are sheared, have undulose extinction, and a 2V of about 90°. Some of the sections are fresh with little or no serpentine, whereas others may be one third antigorite with minor exsolved ore. The alteration is selective and within one section some grains may be almost fresh whilst others are entirely altered. The alteration, however, is more intense along grain boundaries and shear planes.

It is evident from the thin sections that the pyroxenites and dunites have been only partially serpentinized. Large scale serpentinization is very selective, being more intense along sheared and deformed zones, and on mountain peaks and ridges. The latter were not seen closely, the observation being based on the greenish colour of the

cliffs along ridges, and the serpentinite pebbles and boulders in the streams. The serpentinitization in general increases towards the lower (southern) part of the body, probably due to the availability of water from the intruded rocks. This may have been the case with the upper (northern) part of the body as well, but here the serpentinites were probably obliterated by the overthrust Hornblendic Group.

A thick lenticular mass and other minor bodies of serpentinite occur west of Alpurai village; these were previously mentioned by Martin *et al.* (1962). The rocks are fractured and fairly weathered. Some thin sections show that they are composed predominantly of antigorite serpentine with subordinate ore and carbonate. One section, with a cataclastic texture, has about 40 per cent carbonate along fractures and grain boundaries. Mineralogically, these serpentinites are very similar to those occurring south of the main ultramafic complex near Jijal; the two masses are thought to be closely related in time also. Since the rocks near Alpurai are more deformed and are much smaller, it would appear that they altered more readily to serpentinites when compared with the more massive and thick ultramafic body north of Jijal.

It is the opinion of the present authors that the ultramafic rocks of the area were intruded during the earliest phases of the Himalayan orogeny (middle to late Cretaceous). This belief is based on the occurrence of other such rocks in the Himalayas (Krishnan, 1956, p. 79).

4. The Swat Granites and Granite Gneisses.

Abundant intrusions of leucocratic granites and granite gneisses occur in the Schistose Group. These are mostly concordant bodies, less than a few tens of feet thick, although some may be larger or smaller. Many of the intrusions could not be shown on the map because of their small size; such is the case especially near Shang village where half the rocks are granites and pegmatites. Xenoliths are not common but some of the granitic rocks may incorporate "islands" of country rock. The granitic rocks exposed east of Karora differ slightly in mineralogy from the Swat Granite Gneisses. They also look different in hand specimen, the former generally being more reddish on weathered surfaces. All the granitic rocks, however, are grouped together because of lack of detailed knowledge.

Most of the outcrops are gneissic and some have very distinct bands of light and dark minerals. The latter in general are uncommon but some samples contain abundant mica which may be due to assimilation of the country rocks; such intrusions have a more gneissose foliation. Some outcrops are reddish due to weathered iron oxide; where sulphides are present, sulphur incrustations are common along fractures. Epidote and some chlorite are common along fractures forming veins less than an inch thick, although some may attain four inches in thickness. Pegmatites and quartz

veins are also common and, in some cases, these and epidote veins may extend into the country rocks.) Because of the abundance of these intrusions in Swat District, a detailed petrographic account (based on the study of 18 thin sections from Indus Kohistan) is given below.

✓ The texture of the rocks is sub-equigranular to porphyritic, medium-grained (some fine-grained), hypidiomorphic to allotriomorphic. Some sections show a cataclastic structure and contain strained minerals. Potash feldspar, making about 35 per cent of the rocks, is the most abundant mineral.) It is mostly a perthite, of the string type, with minor microcline showing excellent cross-hatched twinning. (Plagioclase (31 per cent) is mainly albite but in some cases it is in the range of oligoclase) ✓ (with negative optic sign). In many sections the plagioclase is bent or fractured, due to straining; and, apart from a few cases, it is unzoned. In many rocks, the plagioclase is slightly epidotized or saussuritized. Much of the alteration is along grain margins and fractures, but some grains show fresh margins and altered cores. Microperthite is less altered to kaolinitic and sericitic material. The two feldspars occur side by side (in large grains as well as in the groundmass) in most rocks, but some may contain only one feldspar. Quartz, making about 23 per cent, generally occurs as small grains with undulose extinction. Biotite and chlorite make about 5 per cent but they reach 15 per cent in some rocks. Much of the chlorite is secondary after biotite so that the latter has greenish-brown pleochroism. Much of the white mica is finely divided sericite (less than 2 per cent) which is probably due to alteration. Iron ores as oxides and sulphides. (2 to 3 per cent) are frequently altered to hematite, leucoxene, etc. Yellowish-green epidote (2 per cent), and traces of sphene, tourmaline, and, in some, garnet, are other minor constituents. It is probable that much of the epidote, sphene, sericite, and chlorite occurring along fractures and grain boundaries are produced by deuteric alteration rather than simple atmospheric weathering.

Associated with these granites, along the Indus Valley, particularly near Shang village, are white coloured granites which are coarse-grained, and generally lack a gneissose structure. They are principally composed of feldspar and quartz, with subordinate sericite and chlorite. Sericite is very common along grain boundaries and fractures, developing at the expense of both plagioclase and perthite. Some of the rocks carry abundant vermiculite, sericite, and chlorite, locally forming streaks and patches. In some rocks, the feldspar is predominantly perthite (slightly kaolinized) with minor plagioclase; in others it is mainly sodic plagioclase with perthite minor or absent. Most of the feldspar is in large crystals but some small grains are also present and, along with quartz, makes the intergranular material. Some of the perthite grains are cracked, with quartz filling the cracks. Plagioclase, which is subhedral, is more altered (to a micaceous material) and locally bent or twisted. Ore

is found only in traces in some sections. The rocks in general contain less quartz than the other granites.

An interesting variant of the Swat Granite Gneisses is a coarse-grained augen-gneiss between Karora and Alpurai. It is a northeast-trending sill that is probably terminated by the Hornblendic Group southwest of Loe Kapu village in the north. This somewhat metamorphosed intrusion is characterized by abundant xenoliths and lesser sharp or gradational contacts with the country rocks. It is composed of large augen of Carlsbad-twinned potash feldspar (some up to $1\frac{1}{2}$ inches in length) in a matrix of quartz, muscovite, biotite (in distinct bands flowing round feldspar augen), and feldspar, with minor ore and garnet. This rock has a much higher proportion of ferromagnesian minerals (including garnet) than the other granites. On this, and on textural grounds, it is considered that the augen gneisses may be totally different from the granites and a subdivision of the Swat granites is therefore suggested.

The metasediments along the contacts of the Swat Granites and Gneisses are not much affected. However, as noted by Martin *et al.* (1962), as one approaches the large bodies of granite, the grade of metamorphism increases. Many of the quartz-bearing rocks have been feldspathized to varying degrees. Some of the phyllites in contact with the granites have coarser mica developed near the contacts. A thin section of a thin marble bed, along the Indus Valley Road between Dubair and Bhesham Qala, and east of Mir Ghaus Banda, shows high grade contact metamorphism. The composition of the rock is 86 per cent carbonate, 8 per cent forsterite, 4 per cent phlogopite and 2 per cent ore. Unfortunately, this bed is flanked by a 20 to 30 feet thick body of metadolerite and it is not clear whether the high grade metamorphism is due to this or to the nearby granites. In a marble xenolith lying within the Granite-Gneiss near Manglaur, Shams (1963) noted wollastonite, grossularite and idocrase, etc.

Associated Pegmatites: Abundant pegmatites intrude the granites and the schistose rocks along the Indus River Valley. The granites and pegmatites probably have a close genetic relationship because of the abundance of both in the same area. Many of the pegmatites occur as sills whilst some are dykes and squeezed lenses; they are less than 20 feet thick and not more than a few hundred yards long. Mineralogically, they are simple feldspar-quartz pegmatites with lesser amounts of mica, iron sulphides and oxides. Some of the pegmatites may also have hornblende and radiating tourmaline. Crystals of feldspar and tourmaline may reach six inches in length in rare cases. Many of the pegmatites have sharp contacts with the rocks they intrude but some have gradational or very inconspicuous contacts due, probably, to metasomatism.

Martin *et al.* (1962) correlate the Swat Granites and Granite Gneisses with the granites of Snowy Ranges, which are not regarded as post-tectonic according to Auden.

Bakr and Jackson (1964) tentatively place them in the early Tertiary. The present authors think that the Swat Granites and Granite Gneisses were intruded during the latter orogenic phases (early Tertiary), considerably later than the ultramafic intrusions.

5. The Shang Granodiorite Gneiss.

Small bodies of coarse-grained gneissic granodiorite occur near Shang and Dubair. The intrusion near Dubair is in the form of a sheet, whereas that near Shang is probably semicircular. They differ only slightly from the Swat Granites in mineralogy and the two formations can be grouped together. However, since the granodiorite gneisses are younger than the Swat Granites (containing xenoliths of the latter), and coarser textured, they are described separately. The granodiorites are cut by fewer pegmatites, although quartz veins are common. Well developed joints in three directions, two of which are at right angles, are conspicuous. Light coloured xenoliths of Swat granite, and dark amphibolites are common. Most of these, especially the amphibolites, have sharp contacts with the host rocks. Some of the xenoliths are elongated parallel to the foliation. The rocks are composed of perthite, oligoclase-andesine (some of which is saussuritized and epidotized), strained quartz, hornblende and/or biotite, iron ore, and traces of sphene, epidote, tourmaline, apatite, zircon and calcite. Most of the secondary minerals (sphene, epidote, calcite, tourmaline) appear to be deuteric. The rocks are porphyritic with "lenses" of potash feldspar and plagioclase. Garnet is a minor accessory especially along the margins of the intrusions. Ferromagnesian minerals (30 per cent) make distinct bands that sometimes flow around large crystals.)

STRUCTURAL GEOLOGY

The general trend of the rocks is north to northeast, but near Shalal Qala it changes locally to northwest. To the west, however, the strike is persistently northeast, as indicated by the extension of the concordant augen-gneiss from Daulat Kili in the south to Balikanai in the north. Between Loe Kapu, Ranulai, Darwaza Sar, and Balikanai, the structure is highly complicated and the complete relationship cannot be seen. This might be due to abundant igneous intrusions and faulting. Martin *et al.* (1962, p. 9) interpret the regional structure thus: "The regional dip is to the northwest, which is also the direction of the dip of the minor fault planes and axial planes of the folding which are parallel to the regional trend." The general trend of the Hornblende Group is from northeast - southwest to east-west. This trend is seen not only in the area under discussion but also in the areas to the north and west, i.e. the upper part of Kohistan, and Dir (Jan *et al.*, *ibid.*).

There is a definite break in the metamorphic grade, and differences in the mineralogy between the Hornblende Group and the Schistose Group. The metamorphic assemblages found in the former are of a much higher grade than those of the latter.

There would appear to be two alternative explanations: that the Hornblendic Group was generated in situ, or that it was thrust over the Schistose Group. Martin *et al.* think that the contact between the Hornblendic Group and the other rocks is a thrust plane. Davies (1965) writes: "...evidence from the gravity survey carried out by Saleem.....supports the suggestion that this zone has been thrust-faulted over the metamorphic rocks lying to the south."

Although the present authors did not find strong evidence of thrusting, many field problems can be easily explained if such a thrust is assumed; this explanation is therefore accepted as being the most probable. The abrupt termination of the main ultramafic body west of Chopra might result from a thrust. The complicated gradational zone (of hornblende-pyroxene-garnet composition) between the pyroxenites and almandine-amphibolites along the main Indus Valley may be due to retrograde metamorphism of the pyroxenites along the thrust plane. The occurrence of the almandine-amphibolites on top of the ultramafic rocks (as indicated by boulders in the short streams that probably originate in the ultramafic rocks) may also be explained by thrusting. Such being the case, the thrust must definitely postdate the ultramafic intrusions. The presence of serpentinites (which are considered to be related to the main ultramafic rocks in age and composition) in the Schistose Group indicates that the ultramafics are neither a part of the Hornblendic Group, nor are they intruded along this thrust. The thrust is older than the regional folding because the thrust plane itself is folded (Martin *et al.*, 1962, p. 10).

ECONOMIC GEOLOGY

Economic mineral deposits were a primary objective during the field mapping but the results were not very encouraging. The only metallic minerals are sulphides of iron, copper, and arsenic, generally disseminated sparsely and thus uneconomical. About two miles north of Patan, in a roadcut along the Indus Valley, is a fifteen-foot thick brecciated zone of quartz, feldspar and arsenopyrite. The latter makes about seven per cent of the surface area. The extent of the body could not be traced because of the overlying talus. Another zone of arsenopyrite and (?) pyrrhotite, 10 inches thick, was noticed in a roadcut one mile east of Shang. The host rock in this case is a hornblende-bearing metamorphosed intrusive.

There are abundant quartz-feldspar pegmatites and some of the feldspar-rich pegmatites may yield economic quantities of feldspar. A few of the pegmatites also carry minor quantities of vermiculite.

Some of the emerald-bearing rocks near Mingora (Swat), and Prang-Ghar (Mohmand Agency) are tuchsite-bearing carbonate rocks associated with ultramafic intrusions (Davies, 1962; Jan, 1968). Carbonate rocks carrying green minerals are closely associated with the serpentinites near Alpurai village. These rocks are

composed of carbonate and quartz, with subordinate biotite, talc, chlorite, and fuchsite. The latter increases towards the contact. No trace of emerald was seen, but some thin zones of quartz-carbonate rock carried small crystals of emerald green tourmaline. The refractive indices of the tourmaline ($\epsilon=1.627$, $\omega=1.660, \pm 0.003$) are the same as those of a chrome-tourmaline (dravite) for which an analysis is given by Deer *et al.* (1962, table 50, analysis 8). This tourmaline contains 10.86% Cr_2O_3 and it is thought that the Alpurai sample may well also be chromium-rich.

Many of the rocks can be used as building stones. Some of the marbles, serpentinites, and banded almandine-amphibolites may also be used for decorative building purposes. Two miles north of Nawe Kili is a 10 to 15 feet thick bed of metamorphosed nodular limestone in which fractured nodules of a beautiful green colour lie in a whitish friable matrix. These nodules might be utilized for flooring chips.

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