

## PETROGRAPHY OF THE UPPER PART OF KOHISTAN AND SOUTHWESTERN GILGIT AGENCY ALONG THE INDUS AND KANDIA RIVERS

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### ABSTRACT

*This paper presents a petrographic account of the common rocks of the previously unmapped area of Indus Kohistan and southwestern Gilgit Agency. The study is based on field observations and thin sections of 55 rocks selected from over 200 samples quickly collected along the Indus Valley Road and Kandia River.*

*The major rocks of the area are amphibolites (gneissose metaigneous; some banded ? metasedimentary) and norites-diorites (the former also having a clinopyroxene), and minor (?) alpine peridotites, granitic rocks, pegmatites, and low grade regionally metamorphosed schists in the Kandia Valley. The norites-diorites are abundant in the north, the amphibolites in the south. Tentative ages have been assigned to the rocks; the various igneous rocks are considered to be related to the Himalayan orogeny and emplaced between Middle/Late Cretaceous and Early Tertiary.*

*Comparison of the rocks from various parts of the northern West Pakistan shows that the Hornblende Group of Martin et al. (1962) extends from Chilas in Gilgit Agency to at least western Dir — a distance over 160 miles. There is a probability that the group may be extending in the adjacent eastern Afghanistan which is covered by the Hindukush Range. North to south, the group may occupy a territory as wide as 60 miles.*

### INTRODUCTION

In the geological map of Pakistan, compiled by Bakr and Jackson (1964), an area over 7,000 square miles in Kohistan of Hazara, Swat and Dir, and the southern part of Chitral and Gilgit is shown unmapped. The Department of Geology, University of Peshawar, started a project in 1968 to investigate this area, mainly along the Indus and Swat Rivers which are easy of access because of roads. Results of the first phase, covering the southern part of Indus Kohistan, Swat, have already been

published (Jan and Tahirkheli, 1969). It was mainly a continuation of the work of Martin, Siddiqui and King (1962) in the Lower Swat. Later on, when the work was extended to the north, the area was found to be geologically very complex and needed a more careful and thorough investigation before producing an account of its geology. In the meanwhile, it was thought appropriate to give some information on the petrography of the rocks sampled.

This paper is based on field observations and thin section study of the common rocks quickly sampled along the Kandia River and the Indus Valley Road between Thor (Gilgit Agency) and Kayal (Indus Kohistan, Swat) talas. Over 200 samples were collected and 55 of these were selected for thin section study. Another 50 were crushed and studied in oil under the microscope for quicker composition determination. Since norites are abundant, fresh, and previously undescribed, many of the sections were cut from these in order to get more information on their mineral composition.

Most of the area under discussion is covered by amphibolites (metaigneous and minor ? metasedimentary) and norites-diorites which have been intruded by ultramafic, granitic and pegmatitic rocks. Similar rocks, occurring along the Swat River, have been called the Upper Swat Hornblende Group by Martin *et al.* (1962). Low grade schists, entirely different from these, also occur along the east-west trend of the Kandia River. The age relationship of these to the metasedimentary amphibolites is not clear.

### The Upper Swat Hornblende Group.

Martin *et al.* (1962) gave this name to the hornblende-rich rocks occupying a wide belt of country in the Upper Swat. The group was considered to be thrust over the younger (Siluro-Devonian) rocks of the Lower Swat-Buner Schistose Group which occur to the south. Bakr and Jackson (1964) have tentatively placed such rocks, exposed south of Kalam along the Swat River, in the Precambrian. Recent work shows that the group extends from Chilas in the Gilgit Agency to western Dir and it is just possible that it may be extending further west into Afghanistan\*— a

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\*If these rocks extend in eastern Afghanistan, which is covered by the Hindukush-Karakorum System, then they pose a serious structural problem on regional basis too. Throughout the Indus Valley, the Shah Dheri-Kabal area (Rehman and Zeb, *Ibid.*) and in Timurgara, Dir (Jan, Kempe and Tahirkheli, 1969), the Hornblende Group has a general east-west or northeast-southwest trend. This is in proximity to the general trend of the Hindukush Range in the adjacent regions. On the other hand, the Himalayas in the Kohistan have been shown to extend, at least, up to the Indus River (Wadia, 1961; Gansser, 1964). Hayden (1915) considered the belt of igneous and metamorphic rocks of the outer mountains of Dir and Swat to be a continuation of that found in Hazara. The Hazaran area is generally agreed upon to be Himalayan.

It may also be mentioned here that Pasco had pointed out the similarity between the hornblende gneisses near Timurgara and the Jagdalak ruby mines, 130 miles WSW in Afghanistan, in 1950. Interesting enough, by 1968, purplish ruby-corundum was found to occur also near Timurgara.

distance well over 160 miles. South to north, the group extends for about 60 miles in the Swat River Valley before the pink and green mottled volcanic rocks are encountered north of Kalam.

According to Martin *et al.*, the Hornblendic Group ranges in composition from hornblende-bearing schists and gneisses to diorites, and quartz diorites and granites. In addition, the group also contains more basic rocks such as norites and peridotites. Davies (1964) also reported the presence of syenites, and considered the rocks to be plutonic in character. Jan and Tahirkheli (1969) distinguished the garnet-rich amphibolites from the rest of the rocks of the group in Indus Kohistan, Swat. So far, however, none of these workers mapped separately the various rock units in the group.

The rocks of the Timurgara, Dir, area are a continuation of the Hornblendic Group and have been classified into four separately mapped units, namely: Banded Gneisses, Dioritic Rocks, Ultramafic Rocks, and Granitic Rocks (Jan, Kempe and Tahirkheli, 1969). A similar mapping pattern was followed by Rehman and Zeb (*Ibid.*) in the Shah Dheri-Kabal area of the Upper Swat and the group was classified into Amphibolites and Banded Amphibole Gneisses, Dioritic Rocks, Ultramafic Rocks, and Quartz Diorites. In the present work, it was found that such a sub-division can be extended through most of the area covered by the Hornblendic Group, provided the map used is at least 1" = 1 mile or even larger.

The banded (? metasedimentary) amphibolites, pink feldspar norites, peridotites and granitic rocks, easily distinguishable in the field, can be mapped. However, one faces a great difficulty in telling apart the "igneous looking" amphibolites from diorites and non-pinkish norites not only in hand specimens but also under the microscope some times. On an inch to four miles map (used by the author), separate mapping of most of the rocks, particularly the amphibolites and diorites-norites, is impossible.\* In some places, this may be the case even on a large scale map because the amphibolites and diorites-norites are intimately associated. It is possible that the "igneous-looking" amphibolites may in fact be diorite-norite intrusions now metamorphosed (see p. 40). If this is true, drawing a line between the amphibolites and diorites-norites will be difficult because of all types of gradational rocks. For this reason also, the author is unable to produce a geological map at this stage.

Concerning the age of the Hornblendic Group, it is thought here that the group is not entirely a Precambrian or Palaeozoic mass. There might be some justification to consider the banded amphibolites (? metasediments) so old, but the rest of the

\*The maps were enlarged to 2 Inches = 1 mile but on these one can not accurately locate himself because the present road is not shown on the original topographic maps.

rocks are younger in age and might be connected with the Himalayan orogeny. Misch (1949, p. 216) writes: "Another group of rocks in the Nanga Parbat area consists of very extensive masses of norite and hypersthene diorite with local dunite. These rocks border the gneiss massif both on the east and northwest. The eastern norite area is on the south in contact with the predominantly basic lavas of the Cretaceous-Eocene volcanic formation. The norite is contemporaneous with or slightly younger than the lavas. That both are genetically related has already been pointed out by D. N. Wadia (1932)."

"Most of the noritic rocks", according to Misch, "have been more or less metamorphosed. There are all passages to statically recrystallized metanorites and meta-diorites with crystalloblastic hornblende, epidote, etc. As the borders of the gneiss massif are approached, static recrystallization gradually gives way to kinematic metamorphism, and mesozonal amphibolites are formed . . . . Both rock units, e.g. the norite bodies and the gneiss massif, have here participated in the same process of tectonic deformation and of crystallization . . . . This process of synkinematic metamorphism took place during the Early Tertiary main Himalayan orogeny, not a very long time after the original norite bodies had formed." The western noritic outcrop of the Nanga Parbat region has been shown by Misch (p. 212) to extend towards Chilas. In a later section, the present author has considered that the norites occurring about 10 miles to the east of Chilas are petrographically similar to those of the Kohistan area. The alpine peridotites of the Himalayas, according to Krishnan (1956, p. 79), are Middle to Late Cretaceous. It is considered here that such peridotites are intrusive in the norite-diorite rocks of the area and are thus younger than the latter.

On these grounds, it is tentatively thought here that the noritic-dioritic rocks may have been emplaced during the earliest phases of the Himalayan orogeny (Middle to Late Cretaceous), followed by the alpine peridotites and the granitic rocks in the Late Cretaceous to Early Tertiary period. There, however, is no positive evidence to support this, and detailed field and geochronological work is needed to clarify the whole problem.

### THE KANDIA SCHISTS

For most of its east-west course between Tuti and Richa, the Kandia River flows in low grade regionally metamorphosed rocks of grey, brown, pinkish and green colours. The rocks are well-jointed and often make vertical cliffs along the northern bank of the river and at other places. The major outcrop appears to be wider (over 5 miles) in the east, gradually thinning out in the west and becoming less significant to the west of Richa. The rocks are distinctly schistose, some tend to

be gneissose, and strike parallel to the general east-west trend of the Hornblende Group which, apparently, surrounds the schists on all sides. At many places, the Hornblende Group crops out within the schists, indicating the intrusive nature of the former. Also, there are a few minor outcrops of the schists within the Hornblende Group north of Richa.

It may be mentioned that a sharp contact could not be observed between the two; the contact rocks appear to be of mixed character. They are composed of altered feldspar and micaceous minerals and mid-way between gneisses and schists in texture. Such a difficulty was also encountered on the contact of the Hornblende and the Lower Swat-Buner Schistose Groups by Martin *et al.* (1962) and Rehman and Zeb (*Ibid.*). Possible explanations for this may be that the schists have been feldspathised on the contact by the Hornblende Group; or that the latter has undergone weathering due to the availability of water from the schists, chlorite having been, at least, partially produced after hornblende. One of such rocks (map no. 3) is composed of abundant plagioclase and (?) actinolite with lesser biotite, chlorite, and minor epidote, quartz, ore and sphene. The plagioclase is all epidotized (some of it has lower relief than quartz and may be secondary albite) and its boundaries are ill-defined. Chlorite is fibrous and some, intimately intermixed with actinolite and biotite, may be secondary. Sphene is also secondary after ore. Actinolite in some cases appears to be pseudomorphing some pre-existing mineral (? hornblende or pyroxene). The actinolite, biotite, and chlorite float around larger plagioclase grains. The rock may originally have been a diorite or norite altered on contact with schists and modified (as indicated by the parallel arrangement of minerals) by later metamorphism.

Some of the Kandia Schists are banded — an inherent sedimentary structure that has survived metamorphism. In many, the bands vary from dark grey to light grey or even white. A few are stained brown by weathered iron oxide. The bands may be coarse or megascopically very fine and at many places show minor distortion and twisting. Some are microfolded into zig zag and other patterns. In Kanwai nala, very distinct chlorite-rich bands (one to two inches thick) alternate with felsic bands. Thin quartz veins, from a few inches to a few feet in length, are associated with some of the bands. More rarely, they are more abundant and alternate with the schists. The former, being more resistant to weathering, may stand out distinctly.

The rocks are made up of various combinations of quartz, muscovite, biotite, carbonate mineral(s), sodic plagioclase, minor ore and, in some, amphibole. Rock no. 1 is composed of epidote, (?) hornblende, plagioclase (? albite), sericitic muscovite (floating around porphyroblasts of the first three), chlorite, minor carbonate and

ore, and traces, if any, of quartz. Rock no. 2 is formed of quartz (40%), sericite-muscovite (15%), biotite (10%), calcite and epidote (10-15% each), ore (<5%) and minor (?) albite. In both, quartz and plagioclase have undulose extinction. In the latter section, some muscovite is in large grains incorporating other mineral grains, and calcite may be in streaks.

Rock no. 4 is very interesting texturally and looks different from the rest of the schists. It has clots of larger grains of amphibole (? actinolite), quartz, ore (partly altered to sphene) and chlorite in a finer grained material, composed of abundant feldspar and minor epidote, muscovite, biotite and (?) quartz. Quartz is undulose and, in rare cases, clearly surrounds corroded amphibole. The finer grained material may be a feldspar that has been intensely altered. However, the possibility can not be ruled out that it may have been a felsic groundmass of some volcanic rock metamorphosed.

So far as grade of metamorphism and the types of rocks are concerned, the Kandja River schists are fairly similar to those of the Lower Swat-Buner Schistose Group. Jan and Kempe (Ibid.) have shown that many of the regionally metamorphosed rocks of the northern Hazara and Lower Swat-Buner area have been considered Siluro-Devonian by various authors. Thus, there is a possibility that the Kandja Schists may also be of this age.

### THE AMPHIBOLITES

Amphibolites occur throughout the area; they are particularly more common to the south of Seo village. They can be divided into two types: a) generally medium-grained, gneissose, igneous-looking and at places banded, b) distinctly banded, fine- to medium-grained (?) metasedimentary. In general, the latter are rather rare north of Seo, although, even to the south they are dominated by the other type. It is possible that, besides regional metamorphism in main, the amphibolites have also undergone some degree of contact metamorphism by diorite-norite intrusions. Some of the rocks are very deformed, folded (some ptygmatically), tongued and at places have the appearance of migmatites. Veins of feldspar, epidote ( $\pm$  garnet) are common. The rocks are generally gneissose, but some are schistose. Table I shows the mineral composition of some of these.

The banded amphibolites are composed of hornblende and plagioclase with minor quantities of epidote, ore (sulphides, ilmenite/magnetite) and, in some, quartz, garnet and rutile. A few, especially those near granites, also carry biotite and/or muscovite, the former being in distinct layers or patches at places. In some, chlorite occurs along (?) shear planes and microfractures and may be after hornblende. Garnet is concentrated more along certain bands and patches and it may be in

porphyroblasts up to an inch across. Epidote is fairly abundant along certain bands and joints, and in these, chlorite is a common associate of hornblende. The individual bands in some rocks are very sharp and may continue for a considerable distance without much change in thickness. They are defined by the abundance or scarcity of hornblende and plagioclase mainly. A clear picture of this is represented by section no. 6 (Fig. 2). Along some of the bands, more rarely, hornblende is nearly the only constituent. South of the last granite outcrop (to the south of Kamila), there is about a three road-mile sequence of such metasediments with a minor quantity of other rocks.

TABLE I

*Modal composition of amphibolites based on visual estimates*

Map No.	Name	*Hb	Pg	Ep	Gt	Qz	Ore	Rt	Others
5	Amphibolite	40	32	8	5	12	2	1	
**6A	"	65	24	3		1	7		Ap Tr
6B	"	10	70	2		15	3		Ap Tr
7	"	48	39	4		8	1		
8	Metahornblendite	96	Tr	2			2		Bi/Ch Tr
9	Amphibolite	50	30	5	10		3		Scapolite 2 ? Ap Tr
10	"	60	20	17		2			Sphene 1
11A	"	70	25	3		?Tr	Tr	2	
11B	"	28	50	20			Tr	2	

\*\*No. 6 Banded Amphibolite A: dark bands, B: light bands.

\*Mineral symbols used in tables I, II, III are: Hb (hornblende), Pg (plagioclase), Ep (epidote), Gt (garnet), Qz (quartz), Rt (rutile), Ap (apatite), Ch (chlorite), Bi (biotite) and Am (amphibole). Tr stands for traces.

One of the most unique amphibolites (no. 12), some miles to the south of Kamila, contains distinct but irregular streaks and rounded patches, generally < 1/2 inch across, of garnet and feldspar with minor epidote (Fig. 1). The streaks may not be parallel to the schistosity. The rock is composed of garnet (loaded with inclusions of feldspar, quartz, epidote, ore, etc.), hornblende, plagioclase, epidote, quartz, ore and partly chloritized biotite. Other minerals may twist around garnet porphyroblasts

and patches. Very similar rocks have been described from Timurgara, Dir, by Jan *et al.* (1969) who consider that the two may represent the same geological horizon.

The non-banded amphibolites look igneous in appearance and field relation but are well foliated. Streaks and patches of hornblende, very common in some, appear at places to be segregations and schlieren (straight, well-defined and less disturbed) but in others they look to be xenolithic. The rocks are essentially composed of amphibole, plagioclase and epidote with varying proportions of garnet, ore, quartz, and, in some, rutile, sphene, (?) apatite, biotite and scapolite. The amphibole appears to be hornblende, although other types might also be present. Jan *et al.* (1969) have shown that the corundum-bearing amphibolite of the Timurgara area has tremolite, and Siddiqui (1969, personal communication) thinks that the amphibole in the magnetite/ilmenite-bearing rocks north of Shah Dheri is edenitic in composition.

The amphibole is distinctly pleochroic and, in many cases, has a bluish green colour. It often carries inclusions of other minerals and, in rare cases, is seived. It may be microfractured and altered along these, cleavage planes and margins to chlorite. Plagioclase (andesine) may be fresh or altered; some is completely masked by clayey and/or saussuritic matter. In one case, only the cores are altered. Section no. 5 has two types of plagioclase. The larger grains are very cloudy and have secondary epidote; the smaller grains are fresh and twinned, and may be secondary (? metamorphic) themselves. In some of the rocks, the plagioclase is distinctly undulose. Less commonly, it may be in streaks or patches.

Colourless to neutral epidote (in a few yellowish) has inclusions of various minerals and in one case the included quartz grows in "graphic" manner. More rarely, it has cracks and along these slight alteration has taken place. In two cases, it grows up to 2 mm in length, enclosing finer grains of other minerals. In no. 5, it is in the form of rims around hornblende, both being set in larger plagioclase grains. Ore is mostly magnetite/ilmenitic but in some it is sulphide or both. Sulphide may alter along margins and fractures to opaque oxide, whereas the former may be oxidized or hydroxidized reddish. Garnet, in some pinkish, is generally poikiloblastic with abundant inclusions and generally less than half an inch across. It is rarely surrounded by white material. It may have a random distribution or be concentrated along certain "bands". More rarely, the larger grains may be arranged in trains. At one place, about a mile east of Karang, its porphyroblasts attain a maximum size of 3½ inches across. Quartz is always anhedral, and undulose in extinction.

Associated with the amphibolites are nearly pure hornblende rocks that merit special attention. Some of these rocks are medium- to fine-grained and may be metaigneous or metasedimentary in origin but some are characteristically coarse

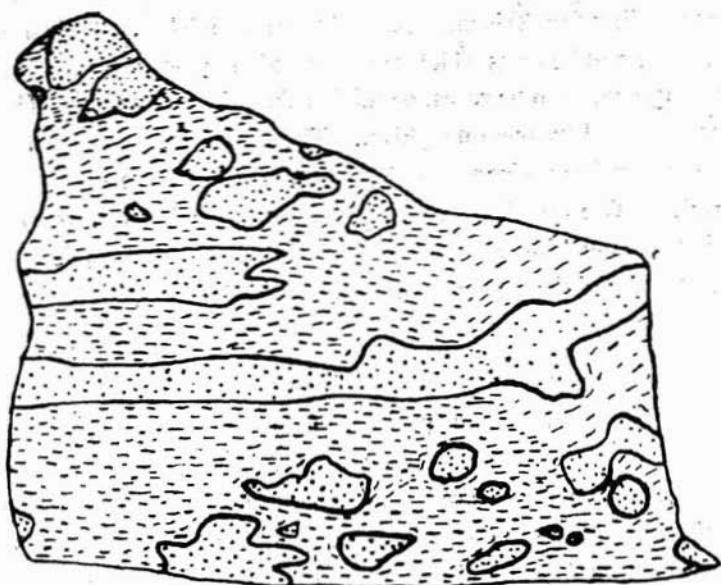


Fig. 1 Amphibolite with streaks and patches (stippled) of garnet and feldspar ( $\frac{3}{4}$  natural size).

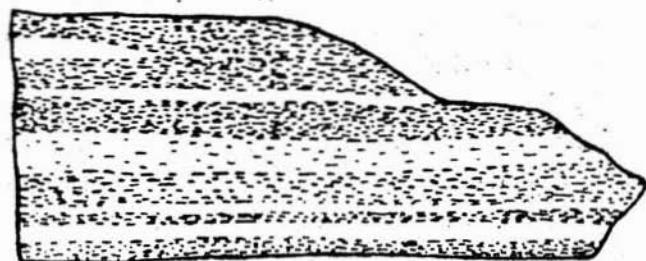


Fig. 2. Amphibolite with dark and light bands defined mainly by the abundance or scarcity of amphibole and feldspar (natural size)

(hornblende up to 1/2") and are, probably, hornblendites originally. It is not clear whether the latter had differentiated in place or intruded as hornblendites. One of such metahornblendites (no. 8) is medium-grained in which hornblende has abundant ore inclusions in the middle parts which are surrounded by optically continuous inclusion-free rims that may, in some cases, be thicker than the inner parts. The rims may be primary or produced by metamorphism. The grains are well-twinned and have fractures along which brown iron oxide and minor chlorite are seen. Some grains are very corroded. Ore (at places oxidized brown, some leucoxenized), interstitial epidote, plagioclase and biotite/chlorite (appearing after hornblende as retrograde products) are the rest of the constituents and account for only four per cent of the rock.

Those of the metaigneous amphibolites which are not very rich in hornblende are very difficult to be identified in hand specimens from diorite-norite rocks. Under the microscope, however, the author has noted a few characters which are of some help in distinguishing the two. The hornblende in the amphibolites is generally more bluish-green than in diorites and may be seived. The amphibolites may have a small quantity of garnet (in a few abundant) which is generally absent from the diorites. Plagioclase in many of the amphibolites is poorly twinned than in diorites; it appears that stresses were a hindrance in the development of twinning. It may, however, be mentioned that, in some cases, these characters are not strong enough to tell apart one from the other.

### NORITE-DIORITE ROCKS

Norite-diorite rocks occur throughout the area, however, they are particularly abundant along the east-west course of the Indus River. A quick comparison of the boulders and pebbles brought by the local streams (flowing westwards and northwards from the nearby mountains and discharging into the Indus) with the noritic rocks along the Indus Valley Road suggests that such rocks are more frequent than others. Similarly, some rock samples collected along the Swat River between Khwaza Khela and Kalam, and those around Chilas and some miles beyond are also similar to these in mineralogy (see Table II). Jan *et al.* (1969, p. 86) have already pointed out the similarity between the Kohistan norites and the dioritic rocks around Timurgara, Dir. This leaves little doubt to believe that the Hornblendic Group of Martin *et al.* (1962) extends from Chilas to western Dir and that the norites-diorites make a major proportion of the group.

The rocks can megascopically be divided into two types: a) those in which some or all of the feldspar has a pinkish appearance and, b) those in which feldspar is white. The first type, when studied in thin sections, is always noritic, whereas the second type may be noritic or dioritic. An interesting fact is that, apart from the

TABLE II  
 Modal composition of noritic rocks based on visual estimates

Map No.	Name	Pg	Pyroxene		Hb	Ore	Qz	Bi	Ap	Others
			Ortho	Clino						
13	? Norite	60	30 All serpen- tized		8	2				
14	Norite	65	15	7	5	3	4	1	Tr	
15	"	62	7	8	21	1				Garnet 1
16	"	60	18	17	1	4			Tr	
17	"	63	15	15	2	2			< 1	Scapolite 2
18A	"	60	17	12	Tr	10		Tr	1	
18B	"	64	16	14	1	5		Tr	Tr	
20	"	54	26	4	15	1				Epidote Tr
21	"	67	16	10	2	1	3	1		
22	"	65	15	13	3	4	Tr			
23	"	66	9	8	5	1	2	7	? Tr	Orthoclase 2 ?Spene Tr
24	"	65	15	15	Tr	4	Tr	1		
Average Norite		62.6	15.4	11.2	5.2	3.2	1	1	Tr	Tr
19	Metanorite	55	8 all steatized		28	1	5	3	Tr	Epidote Tr
25	"	55	14	6	15	2	5	2	Tr	Spene Tr
*	Norite	70	14	12	1	3	?Tr			
**	"	61	20	16	Tr	3				
***	"	62	19	16	Tr	2	1	Tr		
****	Dioritic Norite	56	10	7	17	2	5	3	Tr	
****	"	66	20		4	3	6			Epidote 1

\*Ten miles from Chilas towards Gilgit along road side

\*\*One mile form Madyan bridge towards Mingora

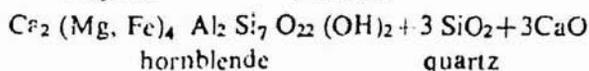
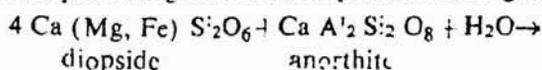
\*\*\*Two hundred yards north of Bahrain bridge along Swat River

\*\*\*\*Tangi Dara Khwar, Timurgara, Dir

dioritic rocks some of which might be pyroxene-free gabbros, all the mafic rocks contain two pyroxenes and mineralogically noritic, i.e. true gabbros have not been recorded. In general, there is no convincing evidence of magmatic differentiation. In some places (near Gabrachur nala), however, hornblende appears to be concentrated along certain bands, giving the rocks a layered appearance. It is thus probable that instead of a single or a few large intrusions, these rocks have intruded repeatedly in the form of small intrusions. This is evident in a few places where a rock of noritic composition has been intruded by a mineralogically similar rock of slightly different texture. It is also possible that the magma(s) may have been quite viscous at the time of intrusion and crystal fractionation by gravity and/or convection currents could not be very effective. A more careful study, however, is required to prove these ideas.

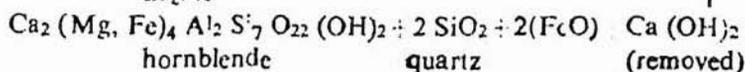
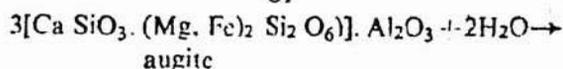
In at least two thin sections (nos. 19 and 25) some of the pyroxene appears to have changed to hornblende and minor quartz (in the form of intergrowth), indicating that advancement of metamorphism (? retrograde) might have completely changed the rocks to amphibolites. In no. 19, hornblende may surround a fine-grained fibrous material with high birefringence (? talc) but in a few cases relict granules of pyroxene are also seen in it. The plagioclase of the rock is partly twisted, fractured and undulose. In no. 25, some of the pyroxene grains are intimately intergrown with quartz (minor) and hornblende with a "seive texture". Similarly, hornblende stringers and granules extend through pyroxene (Fig. 3). In rare cases, a thin ore rim around pyroxene separates it from hornblende. It is interesting to mention that the pyroxene altering to hornblende is mostly diopsidic (? diallage type). Both of these rocks have a higher proportion of hornblende and quartz and low pyroxene as compared to other norites.

It is thought here that in no. 25, the metamorphism of clinopyroxene to hornblende and quartz might have taken place according to one of the following reactions:

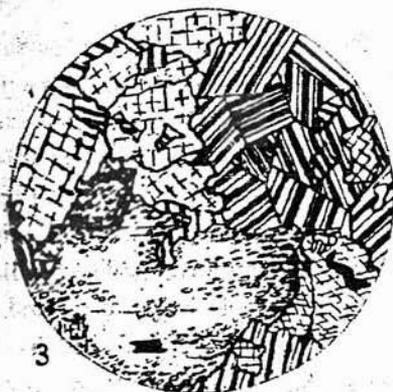


in which CaO has been removed as a soluble base or carbonate

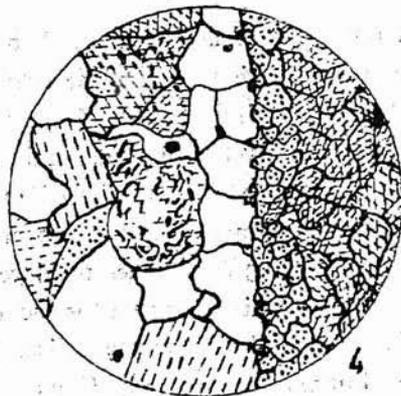
Or



FeO may be representing hematite or magnetite but they do not occur in association with hornblende and quartz. Therefore, the first reaction seems more probable.



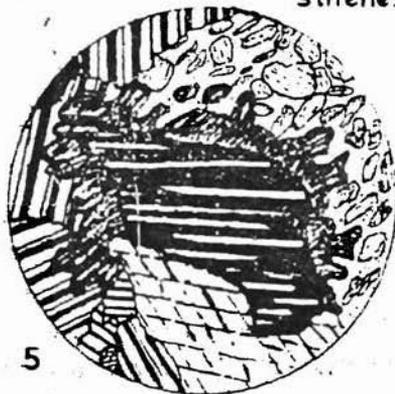
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4

Fig. 3. Metanorite. Plagioclase, hypersthene, hornblende, and diallage (bottom) changed on margins to an intergrowth of hornblende and quartz. Diam. 5 mm.

Fig. 4. Peridotite. Olivine (clear), diopside (bottom and left); minor hornblende (with graphic green spinel in the middle of some), hypersthene (stippled) and ore. To the right is a vein of hornblende bordered by hypersthene. Diam. 5 mm.



5



6

Fig. 5. Altered diorite. Plagioclase (twinned and stippled), amphibole, biotite, ilmenite (with biotite lamellae), and epidote radially grown around ilmenite. Dia.  $\frac{1}{2}$  mm.

Fig. 6. Norite. Symplectic intergrowth of radial biotite, quartz and (?) orthoclase (stippled), and plagioclase. Note myrmekitic and graphic intergrowths. Dia. 2 mm.

Thus, it would not be illogical to think, as pointed out by Siddiqui (personal communication), that many of the amphibolites of the Hornblendic Group are a product of metamorphism of norites (and diorites). This may mean that the intrusive activity was spread over a long span of time, geologically speaking; the earlier intrusions having been totally metamorphosed and the last ones (diorites-norites of this paper) only slightly. Conversely, it is also probable that the metamorphic intensity might have been varying from place to place and some rocks may have undergone little or no metamorphism, or that the metamorphism of norites, in some, produced no significant mineralogical changes. The author has in a previous section stated that the norites-diorites are probably Cretaceous, whereas, the main Himalayan orogeny (and the accompanying regional metamorphism) is generally considered to be Early Tertiary. Therefore, there is little chance that the norites could have escaped metamorphism. In light of this, the last probability seems to be more logical.

The separation of diorites and gabbros is a matter of opinion and different criteria have been used by various authors in telling apart the two. For most people, however, the gabbros have a colour index more than 40; the plagioclase is more calcic than andesine and the main mafic mineral is pyroxene. The diorites, on the other hand, have a lesser proportion of mafic minerals, dominated by hornblende, and the plagioclase is andesine or oligoclase. Williams (1954, p. 106) has pointed out that "no single criterion is really all-sufficient....." The present author has used the type of mafic mineral as the basis of distinction between the two. The colour index could not be applied because in most of the norites-diorites the mafic minerals are less than 40%. However, if the epidote content of the diorites is considered after plagioclase (and thus added in silic minerals), the norites then, generally, have a higher colour index than diorites on the average. The anorthite content of the plagioclase could not be used either because most of the diorites are very altered and only some plagioclases rendered themselves for composition determination. It may be pointed out that some of the so-called norites have calcic andesine and may actually be hypersthene diorites. Jan *et al.* (1969) were also faced with such a situation at Timurgara and they considered that there the plutonic rocks are a border-line case between true diorites, and norites and gabbros. It may also be mentioned that the noritic rocks generally are fresh, and the pyroxene-free diorites generally altered.

The rocks are generally medium-grained but some are finer and rarely sugary. With fewer exceptions, they are mostly gneissose, a few very strongly, suggesting the influence of metamorphism unless the magma was viscous and partly crystalline at the time of intrusion. Amphibolite xenoliths are sparsely present but between Tuti and Gayal they are more abundant. Two miles west of Thor nala, (?) silicic inclusions are also seen. Veins of feldspar, hornblende, and, rarely, epidote (a few also carry

garnet) are common in some places. Some of them have spongy appearance due to the weathering of less resistant feldspar; the cavities may be stained reddish. Some veins or parts are completely weathered. The hornblende in some veins may actually represent schlieren some of which are parallel to foliation. In a few, the dark minerals tend to be streaked or clustered. Chloritic alteration has rendered some of the rocks green.

On the average, the norites are composed of 62.6% plagioclase, 26.6% pyroxene (orthopyroxene being more abundant), 5.2% hornblende, 3.2% ore, 1% each of quartz and biotite, traces of apatite, and minor quantities of other minerals such as garnet, scapolite, epidote, (?) sphene, and (?) orthoclase in some. The plagioclase is mostly labradorite but in some it is on the verge of andesine and labradorite. It has a minor degree of zoning and displays all three—albite, pericline and Carlsbad—twinnings one of which may be suppressed in some rocks. In no. 20, even the albite twinning is either poor or absent. Undulose extinction and microfractures, produced by stresses, are not uncommon. In some, the grains may be even bent. Less often, the fractures are filled by secondary clay or chlorite. Inclusions, mostly of ore and pyroxene, are few. In some of the rocks, it is partially altered to clayey, micaceous or, more rarely, saussuritic material. In no. 13, all of it is completely masked by a cloudy clayey material.

The orthopyroxene is strongly pleochroic (pink to green) hypersthene.\* In some it appears to have simultaneously crystallized with the clinopyroxene but in others it looks earlier. It has commonly included ore but some plagioclase and minor clinopyroxene may also occur as such. Besides, reddish iron ore and clinopyroxene are also present as exsolved lamellae. Many of the hypersthene grains have fractures along which minor alteration may result in iron oxide, serpentine/talc or, more rarely, chlorite, which may also occur along grain boundaries. In no. 24, there is a complex alteration rim of talc on the hypersthene side and serpentine (or chlorite) on the outer side. The clinopyroxene of the norites is green to light green and, in most cases, weakly pleochroic. It appears in diopside-augite range, with exsolved reddish ore and (?) orthopyroxene along with disoriented inclusions of these minerals and plagioclase. In a few cases, the pyroxene is schillerized and may be diallagic diopside. Along fractures and borders, the grains show alteration like the hypersthene. In section no. 13, all of the pyroxene is altered to talc with only a few relict granules. Fresh hornblende may surround the talc.

Hornblende appears to have crystallized later than the plagioclase and pyroxene and is therefore in anhedral to subhedral grains that may, in some cases, surround the

\* The orthopyroxene of the noritic rocks of Timurgara, Dir. is considered to be bronzite by Jan, Kempe and Tahirkheli (1969).

latter. In no. 16, some of it is in poikilitic grains. It may be associated with ore and/or biotite; with the latter and quartz, more rarely, it is in intergrowths. Ore is generally magnetite/ilmenite that may, in some, be altered to reddish oxide or hydroxide. In rare cases, the rocks may also have pyrite which is changed to opaque oxide along fractures and margins. The ores appear to have crystallized throughout the cooling; thus, some are in inclusions while others occupy the space between the early formed minerals. Quartz always occurs in the interstices or intergrowths and some of it has undulose extinction. In a few cases, it may be a by-product of the pyroxene transformed to hornblende. Biotite has strong pleochroism from pale to dark reddish-brown but in a few it is partially chloritized green. In some, it contains abundant ore dust. In a few rocks, it is in symplectic intergrowth with quartz, hornblende, etc. The best of such intergrowths is seen in section no. 23, in which it looks to radiate from a "nucleus" (Fig. 6). In this rock, quartz forms graphic and myrmekitic intergrowths with (?) potash feldspar and plagioclase, respectively. The latter intergrowth may form a part of the symplectic intergrowth or be independent.

Besides large fractures, the rocks also have minor fractures along which serpentine, chlorite (rarely talc), iron oxide and, in one, carbonate are seen. The nearby plagioclase may be kaolinized as in no. 16. Section 20 was cut along the contact of a vein and norite. The former is composed of abundant epidote and chlorite, plagioclase (? secondary) and minor iron oxide. Epidote is more common away from the rock, chlorite and ore towards the rock. These minerals, however, give way to the normal rock without a sharp contact. As one approaches the rock, it is seen that the pyroxene near the contact is altered to serpentine and talc, and the plagioclase to epidote, both ultimately grading into fresh rock. Hornblende, on the other hand, has skipped alteration even into the vein for some distance. The vein also has some garnet in the middle part. It appears that many, or all, of these minerals have been produced from norite by the action of pneumatolytic solutions.

The diorites are composed of plagioclase, hornblende, quartz and minor quantities of biotite, ore, epidote, etc. The plagioclase is nearly always altered to saussurite, sericite, or clay-like turbid material; in some, the alteration has virtually masked the twinning completely. In rare cases, when the plagioclase is surrounded by hornblende, the altering solutions, probably, could not penetrate deep enough and the plagioclase is fresh, with excellent twinning. The anorthite content could be determined in only a few cases and the plagioclase is either andesine or oligoclase. The amphibole of the rocks is occasionally-twinned hornblende but in many it is altered to a fibrous, pale green pleochroic (?) actinolite. Along margins and fractures it may also alter to, some times fibrous, chlorite. In no. 33, chlorite is 10% and may

represent completely altered amphibole. Hornblende may contain inclusions in some; more rarely, it grows in poikilitic patches.

Quartz is nearly always in small grains that are often strained and have undulose extinction. Rarely, the adjacent quartz grains have inter-penetrating borders. In some, it may be concentrated in clots and small patches. Deep brown to colourless biotite may be partially green due to chloritic alteration. Iron ore is mostly ilmenite that has completely altered, or only along margins and fractures; to sphene or leucocoxene. Some of the ore is reddish hematitic in reflected light and may be after magnetite. In no. 30, it has thin "lamellar" biotite in association and looks as if the latter is replacing it (Fig. 5). Detailed mineralogical composition of some of the diorites is shown in Table III. The percentages may be highly exaggerated in some because of the intense alteration.

Common, although minor associates of the rocks of the Hornblendic Group are pegmatitic rocks made up of hornblende, plagioclase  $\pm$  garnet. A few also carry quartz, mica, and sulphides of iron and (?) copper. In one place, about 20 miles north of Kamila, the pegmatite is very coarse-grained, containing euhedral crystals of hornblende that may grow over a foot long and  $3\frac{1}{2}$  inches across. In this and some others, the hornblende grows at  $90^\circ$  to the walls.

TABLE III

*Modal composition of dioritic rocks based on visual estimates*

Map No.	Name	Pg	Qz	Am	Bi	Ore	Ep	Others
27*	Quartz Diorite	62	10	22	Tr	1	5	
28	"	51	12	30			6	Rutile 1
29	Diorite	70	8	20		2		Zircon(?)Tr
30	"	62	2	28	4	3	1	
31	Quartz Diorite	51	13	25	6	3	2	
32	Diorite	55	5	38	<1	1	<1	
33	Quartz Diorite	63	15		2		7	Calcite 3 Chlorite 10

\*With the exception of No. 27, the rest are fairly altered to various degrees. The amphibole (hornblende) is commonly changed to actinolite, in some as much as three fourths or even more.

A very unique associate (no. 26) of the noritic-dioritic rocks is a greyish leucocratic rock that was identified in the field as 'minor, epidote-bearing syenite intrusion'. Under the microscope, the rock is seen to be composed almost wholly of plagioclase which is entirely altered to sericite and epidote with the exception of a few fresh parts. These parts have a maximum symmetrical extinction angle of  $14^\circ$ . The optic sign could not be determined; some grains seem positive, others negative. However, its refractive index on rare fresh margins in contact with the balsam is very close to that of the latter. The rock was crushed for refractive index determination on (001) and (010) cleavages but, again, the alteration prohibited any satisfactory determination. The extinction angle and low relief, however, suggest that it may be (?) albite in composition and the rock may be called albitite. It is possible that the albite is secondary after a more calcic plagioclase and the rock may originally have been anorthositic (? a local differentiate). The epidote (green in sample), only a few per cent along with traces of ore, is in clots and patches and has been probably introduced by later solutions.

### ULTRAMAFIC ROCKS

Small bodies of ultramafic rocks are sporadically present in the area. They are mostly fractured (one looks cataclastic), weathered and look fairly distinctive in hand specimens. In view of the general lack of a positive evidence of magmatic differentiation in diorites-norites, the peridotites are considered to be alpine type and Middle to Late Cretaceous equivalents of other alpine peridotites of the Himalayas (Krishnan, 1956, p. 79). That the clinopyroxene of these peridotites may not be genetically related to that of the norites is also supported by the difference in the colour of the two. In norites it is always greenish, in peridotites it is colourless. Such intrusions have also been recorded in Timurgara (Jan *et al.*, 1969, p. 86), Shah Dheri-Kabal area (Rehman and Zeb, *Ibid.*) and near Jijal along the Indus River to the south (Jan and Tahirkheli, 1969).

The rocks range in composition from dunites to peridotites and pyroxenites. Section no. 37, cut from a boulder in Chilasy nala (some miles to the south of the major bend in the Indus; not shown on the original toposheet) is a dunite composed of olivine and minor (<5%) primary ore. The olivine has a  $2V=90^\circ$  (? forsterite) and is altered to serpentine, iron ore, and traces of carbonate along abundant fractures. Section no. 35 (peridotite) is composed of clinopyroxene (? diopside) and minor olivine (10-15%) along with ophitic orthopyroxene (? bronzite) that contains a few exsolved lamellae of ore and another pyroxene. The orthopyroxene has a low birefringence and a high  $2V$  of  $90^\circ$ ; alteration has produced abundant ore, mostly in rods, which has rendered it dark. Fractures are common in diopside and, particularly, in olivine,

along which abundant secondary iron ore and serpentine occur. The rock also has about 2% pyrite.

Section no. 34, is principally composed of clinopyroxene (? diopside) that has been partially altered to serpentine, greenish chlorite, and less abundant talc and ore. Brown hornblende (15%, anhedral and tending to be ophitic), traces of biotite, primary ore, and rutile also occur in it. Besides these, anomalous birefringent granules of epidote set in a cloudy material, and a few granules of quartz are also seen. The presence of these minerals is rather strange in a pyroxenite and it is probable that they have been either modified by metamorphism or by extraneous (?) hydrothermal solutions.

Section 36, cut from a boulder found in Chilasy nala, is mainly composed of olivine and (?) diopside containing exsolved ore (in some grains abundant and along with hornblende "lamellae"). The rock also has minor proportions of hornblende, orthopyroxene (pale pleochroic bronzite or hypersthene), ores and traces of carbonate. Ores include a green type, opaque oxide, and minor sulphide. The green spinel is quite often included in the middle part of hornblende grains in the form of graphic intergrowth (Fig. 4). Some of the hornblende grains also have lamellae of opaque oxide. The rock is cut by abundant veins (black in specimens), generally straight, which are composed of hornblende, and minor talc and opaque ore. The outer margins of these veins are flanked by fine granules of pinkish orthopyroxene. The minerals along the veins are of secondary origin and, if so, at least some of the hornblende and orthopyroxene occurring away from these veins may also be secondary. It would be easy to explain this phenomenon if a liquid magma is considered to be the source of the peridotite but, as said previously, strong evidences of magmatic differentiation have not been found. It may be mentioned that Jan and Tahirkheli (1969) had also noted hypersthene and minor garnet in some of the peridotites near Jijal, which, apparently, are alpine in nature. They considered that the hypersthene-garnet-diopside assemblage may be a product of the metamorphism of the pyroxenites.

### THE KAMILA GRANITES

Abundant intrusions of granitic rocks, generally small and concordant to the regional trend of the Hornblendic Group, occur around Kamila. More rarely, they are also seen in other parts of the area. Some of them are in veins and small intrusions of a few yards thickness but some are fairly large. The largest of all, occurring about five miles to the south of Kamila, is over  $1\frac{1}{2}$  miles thick and extends towards Jalkot to the east, and Kayal stream in the west in which granite boulders are quite common. Along the Kandia River, one finds a lot of similar granite boulders at a distance of

about six miles to the south of Gabriel, where the traverse was abandoned. It is therefore expected that sizeable granite bodies occur in the upper reaches of the Kandia River. Some of the granite boulders, however, are slightly different from those of Kamila due, probably, to the greater proportion of chlorite, etc.

Some of the granites are leucocratic but some are comparatively darker, especially those near Kamila. The dark colour is mainly due to biotite but some also have other dark minerals. Sample no. 38, although containing about 10% muscovite and 2 to 3% garnet, looks pure white in hand specimen. The rocks are generally medium-grained and gneissose but some are nongneissose. They are irregularly fractured and contain abundant quartz veins and thin pegmatite veins and pockets. A few of the granites are porphyritic, the feldspar phenocrysts attaining a length of 0.4" in them. Amphibolite xenoliths are common. Some of the granites are in the form of repeated injections in amphibolites and mica schists. The main granite body (mentioned above) is strongly gneissose near the contact and contains hornblende and chlorite. At places, the body has the appearance of augen gneiss. Rarely, the dark minerals, mainly chlorite, may be more abundant along distinct bands. Thin layers of incorporated schistose amphibolites and mica schists are specially abundant near its contacts. Some of the amphibolite xenoliths also occur as big blocks. The body has muscovite and/or biotite, the latter being more common in the middle part. Some parts also contain garnet. Ore is both sulphide and oxide and appears in distinct cubic grains at places.

Under the microscope, the rocks are composed mainly of feldspar, quartz and mica with minor proportions of epidote, garnet, chlorite, ore, apatite and, in some, hornblende and rutile. The feldspar is both plagioclase and potash variety one of which may be suppressed in some. The former is in the range of albite or oligoclase/andesine. Section nos. 40 and 42, have abundant plagioclase with anorthite content more than 20% and the rocks are granodioritic in composition. The K-feldspar is either orthoclase or microcline. Perthite has not been found and the rocks, probably, are subsolvus type. Slight alteration to sericite, kaolinite, and saussurite in some plagioclase is common, particularly along fractures and grain margins. In some cases, the plagioclase looks zoned. Quartz, making well over 20% in all the rocks, is mostly intersitial, nearly always undulose in extinction and, in some, fractured.

Hornblende is generally in traces except in some. In no. 42, it makes about 8%. Mica is represented by one or both of biotite and muscovite. The former is pleochroic from deep brown to pale but some has altered to chlorite and has greenish, more rarely khaki, colour. Muscovite is bent and twisted in a few. In some cases, there is abundant sericite along fractures. Epidote is colourless or neutral but

in no. 40, it is pale brownish pleochroic. In no. 39, a little of it is yellow pleochroic and is characteristically of higher birefringence than the major (colourless) type. Some of it is set in the plagioclase and some partially surrounds the colourless variety and may be a slightly altered variant of the latter. Garnet, in some pinkish, has common inclusions and may be altered to chlorite along fractures. It is generally in small quantity but in a few it is up to 8%. Ore, never more than a per cent, is sulphide and magnetite/ilmenite that may be altered to leucoxene in some. Rock no. 38 has thin pinkish veins which, in the microscope, are composed of feldspar, quartz and epidote.

The small pegmatites associated with these rocks are quartz and feldspar-bearing with biotite, muscovite (at places in patches) and traces of garnet in some. Some miles to the east of the major bend in the Indus are thin veins of pegmatites in which quartz and feldspar are spread all over but 'beautiful' white mica (up to one inch) is concentrated in the centre of the vein. The veins also have a few garnet grains.

Associated with the granites on the contact are minor bodies of hard, pinkish to greenish mixed rocks that appear to be contact metamorphic rocks or granites altered on margins. Section 43A of these rocks is composed of plagioclase, epidote, quartz, garnet, chlorite, muscovite and sulphide in decreasing order. Section no. 43B (20 feet to the north of 43A) is also made of the same minerals, with comparatively lesser quartz and more chlorite. It also has bluish green hornblende and traces of rutile. The plagioclase is completely epidotized and sericitized, and garnet is partly altered to chlorite and contains quartz and sulphide inclusions. Chlorite and muscovite may be twisted around larger grains and epidote is sieved with quartz and feldspar.

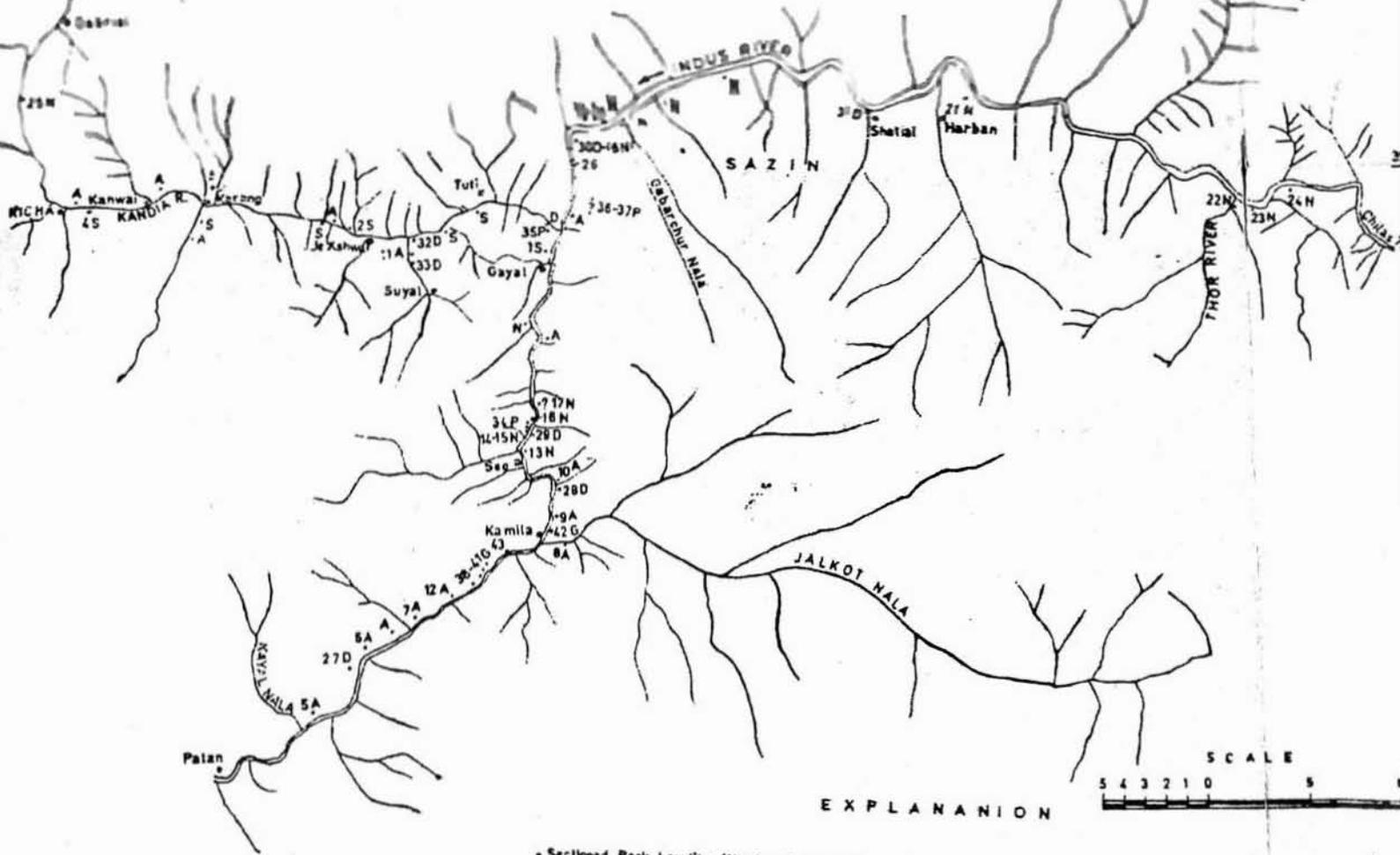
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• Sectioned Rock Locality (Numbered where the section is described in text)  
 Symbols A, D, N, G, P and S stand for amphibolite, diorite, norite, granite, peridotite and schist respectively.

DRAINAGE MAP OF THE INDUS AND KANDIA RIVERS IN KOHISTAN AND SOUTHWESTERN GILGIT AGENCY.