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# Rendiconti

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## The Petrology of the Thak Valley Igneous Complex, Gilgit Agency, Northern Pakistan

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**Geologia.** — *The Petrology of the Thak Valley Igneous Complex, Gilgit Agency, Northern Pakistan.* Nota di F. A. SHAMS, presentata (*) dal Socio A. DESIO.

RIASSUNTO. — L'Autore illustra una porzione della così detta « Fascia ofiolititica dell'Indo » affiorante come massa plutonica nella valle di Thak. Il complesso è composto di un più antico Gruppo Noritico (rocce basiche e ultrabasiche) e di un più recente Gruppo Dioritico (rocce acide intermedie). Pegmatiti basiche sono limitate al Gruppo Noritico, mentre pegmatiti e apliti acide attraversano sporadicamente l'intera area.

Un'ampia fascia di metadioriti, con vene e banchi di granodioriti intrusive, contrassegnano la principale zona tettonica che corre parallelamente agli assi regionali. A sud di questa zona le rocce mostrano una diffusa epidotizzazione ed una foliazione regionale con intensità crescente verso sud, verso la cupola granitico-gneissica del Nanga Parbat.

La serie di rocce suddetta deriva da una magma basaltico tholeiitico.

## INTRODUCTION

One of the prominent features of Himalayan geology is the occurrence of regional belts of basic plutonic masses, with associated volcanics and bodies of alpine-type serpentinites, recently grouped together as the Indus Ophiolite Belt by Gansser (1964). From Afghanistan such a belt enters Pakistan in western Dir and, passing through upper Swat and Swat Kohistan, takes a northwards swing in southern Gilgit and ultimately runs northwesterly. A portion of this belt, as exposed in upper Swat, was originally described by Martin, Siddiqui and King (1962) who named it as the Upper Swat Hornblendic Group, recognizing the dominance of hornblende. Recently, Jan and Kempe (1973 and other refs. therein) published a detailed account of the basic and intermediate rocks of the Group and showed that these belonged to a differentiated (calcalkaline) tholeiitic series. Afterwards, firstly M. Q. Jan (1971, 1973), then A. Desio (1974)—the one independently of the other—announced the occurrence of the same group in the middle Indus valley (Desio's "Middle Indus Noritic Group") and modified the geochronological interpretation of Martin, Siddiqui and King referring the group to the Cretaceous-Eocene.

The present article is concerned with another portion of (apparently) the same belt as exposed in the Thak valley, Gilgit Agency.

The Thak valley area (long 74°15′ E to 74°3′ E and lat. 35°13′ N to 35°27′ N) is situated in the inner Himalayas, about 32 km west of the majestic Nanga Parbat. Previous information is available in Wadia's (1932)

(*) Nella seduta del 15 novembre 1975.

general account of the Nanga Parbat region and Chilas, which also included a regional geological map. In the part of his map pertaining to the Thak valley area he showed the eastern part occupied by epidiorites and basic intrusives, the central part occupied by biotite gneiss and inter-bedded meta-sediments, the west central part as biotite gneiss with acid intrusives and the southwestern part as hornblende granite with basic intrusives; the northwestern part was left blank. Later, during a general survey of the inner Himalayas,

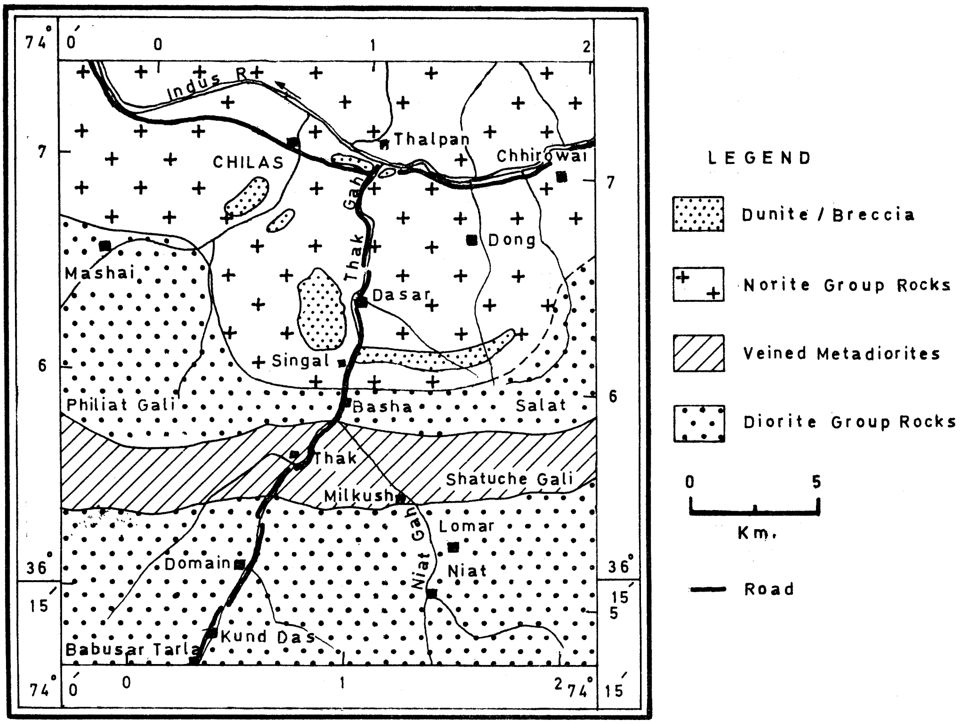


Fig. 1. – Tentative geological map of the Thak valley igneous complex, after Butt and Zaidi (1969).

Burrard and Heron (1934) referred to rocks of the area as " unclassified gneisses with acid and basic intrusives ", while Misch (1949) recognised norites and hypersthene diorites with local dunites, repeated as such by Gansser (1964). Shams (1956) recognised the presence of a differentiated basic complex in the area and reported on the dunite occurrences in detail. Butt and Zaidi (1969) mapped the area (fig. 1) on a 1 inch to 1 mile (1.61 km) scale and gave a general account of the igneous complex. Recently, during a reconnaissance petrographic survey of the Indus river section, Jan (1970) described norites and diorites about 12 km NW of Chilas, obviously an extension of the Thak valley complex. More recently, Desio (1974) gave a detailed field and petrographic description of rocks exposed between Chilas and Besham Qila and recognised norites and diorites, with ultrabasic and basic concentrations respectively, and associated amphibole orthogneisses. Considering their mutually gradational contacts, Desio grouped them together into his " Middle Indus Noritic Group " and stressed their correlation with " Epidiorites and Basic Intrusives " of Wadia (1932), " Norites and Hypersthene Diorites " of Misch (1949) and " Twar Diorites " of Desio (1963, 1964) and of Zanettin (1964).

## GENERAL GEOLOGY AND STRUCTURE

Approaching the area, via Kaghan valley road, a considerable stretch of the pre-Cambrian Salkhala metasediments are crossed. In the Gitti Das-Babusar region, south of Thak valley area, the Salkhalas consist of graphitic schists, amphibolites, calc-schists and granulites, pelitic schists and quartzites, with sporadic outcrops of quartzofeldspathic gneisses towards the east. At the Babusar Pass, the Salkhalas are represented by graphitic schist with calc-schist intercalations. With an apparently tectonic break, these rocks are succeeded by an approximately 3.3 km thick belt of horn blende-epidote gneisses and amphibolites with a rich garnetiferous zone in the north. A folded body of an alpine-type serpentinite, about 0.8 km thick and 2.5 km long, crosses the gneiss zone in a NW-SE direction. The garnetiferous amphibolites are succeeded by a relatively thin layer of biotite-chlorite gneiss to be followed by a belt of mixed chlorite-epidote schists and gneisses about 5 km wide; these extend up to the southern limit of the Thak valley area under discussion. Throughout this stretch, the rocks retain an essentially E-W regional strike and high to moderate dip towards the north, with an up to 25° northwards swing in strike in the southeastern part of the area with a subsequent change in the dip direction to NNW. About 2.0 km north of Utla Babusar, prisms of hornblende become visible and thereafter it remains the characteristic mineral of granodiorite to diorite rocks till about 1 km north of the junction of Thak Gah and Niat Gah, where the edge of the norite mass is met; thereafter, a similar status is acquired by pyroxene, ortho- dominating over the clino-variety. From about 3.3. km north of Domain to the vicinity of Jal, an E–W trending belt of dark metadiorite rocks outcrops with widespread intrusions of acid vein, layers and dykes; their folding, pinch and swell structure and off-setting along minor faults and slip surfaces proves the tectonic nature of this zone. In the north, dioritic rocks become extensively xenolithic and particularly after crossing Basha, angular xenoliths with dark kernels and zoned shells of decreasing colour index increase in frequency to produce local agmatite outcrops; this marks the hybrid zone between diorites and norites and allows a major subdivision of the complex. The norite mass extends northwards beyond the river Indus but its northern limit is not delineated yet, although acid plutonic rocks are known to constitute the Hurpoi massif about 40 km in the north, reminiscent of a situation fairly similar to the Nanga Parbat region east of Thak valley. Ultramafic dykes and conformable layers of peridotite, pyroxenite and hornblendite are met with at many a places within the norite mass while dunites make thick outcrops mappable on the scale adopted. The dunites, with a 6.5 km arc-like outcrop east of Singal and a 3.5 km long ovoid mass in the NW, a 2.0 km long outcrop east of Chilas and bodies of breccia about 2 km in the south, together mark a circular structure with inward dips; this structure is complemented by a southwards bulge of the norite mass. Although the dunite bodies show fracturing and crushing, as if of intrusive nature, yet their conformable contact with the enclosing norite through transitional zones of peridotites and/or olivine corona gabbro, such as in the Singal outcrops, justifies their genetic association and consideration within the Norite Group of rocks. Considering general criteria, the mass may be a concentric type complex of Jackson and Thayer (1972); as already described, an alpine type serpentinite mass is met outside the Thak valley area in the south.

Everywhere rocks are foliated to a different degree with primary foliation dominating in the Norite Group rocks and secondary foliation dominating in the Diorite Group bodies. In the former the foliation is marked by flow layering, alignment of xenoliths and surfaces of easy splitting, while in the case of Diorite Group rocks mineral rotation and streakiness supplement flow planes of essentially igneous origin. Rocks are everywhere strongly jointed with older joint openings filled with aplitic/pegmatitic material and younger joints with surfaces carrying mineral smears and traces of slippage. In rocks of the Norite Group, horizontal joints (500 observations) are the most prominent while diagonal joints (700 observations) are well developed in the Diorite Group rocks. In the south, with increase in the influence of tectonic elements, foliation-plane joints become important and give rise to rather slabby outcrops. Structural differences between regions of Norite and Diorite Groups, along with the existence of a xenolithic zone between the two, provided the basis for field division and petrographic description. The original mapping was carried out on a scale of 1 inch to 1 mile (1.61 km) but the lithological details have been simplified in the map presented here.

Wadia's (1932) map was found to be much out of location. For instance, he showed the western edge of the complex as ending about 2 km east of Thak Gah while the latter actually flows through it; in fact the complex extends considerably west, as has also been shown by the survey of Jan (1972) and Desio (1974). Wadia's map being the only one available, it has been incorporated *in toto* into the regional maps published by Desio (1974), Gansser (1964) and Bakr *et al.* (1964).

## Rocks of the Norite Group

Norites and related gabbroic rocks occupy more than half of the map area. The gabbroic rocks are mainly of two types: olivine corona gabbro and hornblende gabbro, the former is older and the latter is younger than norites. Cummulus rocks like dunites, peridotites and pyroxenites are present also either as xenolithic bodies or as independent outcrops intimately related to norites; hornblendites almost always occur as joint filling material.

*Norites* vary from completely massive to flow-foliated and banded varieties. The rocks vary in colour from flesh to dark grey but in all cases schillerized plagioclase is distinctive. Foliation is always primary and is marked by alignment of coloured minerals, mineral schlieren and rhythmic banding of relatively light and dark coloured bands. The rocks are medium grained, composed of orthopyroxene (up to 54%) as pleochroic crystals with composition ranging from bronzite to hypersthene ($Fs_{23}$ to $Fs_{32}$), occasionally carrying clinopyroxene lamellae (? inverted pigeonite) and frequently iron oxide blades. Coarser than, locally associated with and with a tendency to aggiegate with orthopyroxene, is the pale green, nonpleochroic to slightly pleochroic augite (up to 18%) with an average composition of $En_{45}Fs_{14}Wo_{41}$ ($2\,V_z = 50°$, $\beta = 1.691$). Complexely twinned plagioclasse (up to 66%) shows a tendency for dimensional orientation, with composition ranging from $An_{68}$ to $An_{60}$. Uralitic hornblende (up to 29%) is ubiquitous and mostly borders pyroxene, thereby showing its deuteric origin; generally formless or lobate quartz and ore grains are located inside, or in the vicinity of the transitional zone. Olivine is generally absent but may make up to 2% of the rock for instance in outcrops south of Indus. Traces of strongly pleochroic (pale brown to reddish brown) biotite are occasionally present, up to 1%. Ore minerals consists of ilmenite, hematite, pyrite and chalcopyrite; the first two are generally intergrown, with ilmenite dominating. Chalcopyrite shows alteration to tetrahedrite and the pyrite to goethite.

Marginal facies of the noritic mass, such as near Singal bridge, are commonly laminated with rhythmic layering due to repetition of femic and feldspathic bands which vary in thickness up to 10 cm. Augite and hypersthene ($Fs_{31}$) are concentrated in the dark bands relative to whitish grey bands which contain dominant plagioclase ($An_{61}$), quartz and minor epidote. In varieties where quartz becomes high, the clinopyroxene content drops sharply relative to orthopyroxene ($Fs_{35}$), the plagioclase composition falls into andesine range ($An_{46}$) and the rock may be called *hypersthene diorite*. Locally, the pyroxene content may also drop so low (5%) relative to plagioclasse (88%) that the rock becomes an *anorthosite*, such an occurrence is found near the junction of Thak Gah and Indus east of Chilas. A pegmatitic facies, composed of large hornblende and plagioclase ($An_{56}$) crystals, is found scattered in the noritic mass particularly near the contact with diorite in the south. Sometimes, a considerable area is made over to such a *hornblende gabbro* (*bojite*) as north of Singal, which is markedly different from the fine-grained variety that fills joint openings.

*Olivine corons gabbro* occurs as vein material and as shells around bodies of feldspar-bearing peridotite enclosed in norite or as zones between dunite and the latter. The rock is easily recognised due to the coarse grain size and display of corona structure, such as east of Singal, across the Thak Gah. Sometimes the rock is veined by fine-grained hornblende gabbro that may also hold xenoliths of the corona gabbro. The rock is composed of coarse olivine ($Fo_{65}$, up to 11%), surrounded by pink, pleochroic hypersthene (up to 7%) and succeeded by diopside-spinel symplectite. Diopsidic augite ($c \wedge Z = 43°$) and plagioclase ($An_{68}$) are the other major constituents. Uralitic hornblende, talc, chlorite and tremolite together make up to 13%.

*Dunites* occur as greenish to greenish brown rocks under a thin crust of rusty brown colour. They are composed of xenomorphic aggregates of vitreous olivine (up to 98%) with an average composition of $Fo_{83}$. Along frequent fractures, incipient serpentinization is seen attended by ore grains and rare calcite. Picotite and chromite (together up to 3%) are commonly present as inclusions inside olivine and along fractures and intergranular spaces. Jointing is common and openings are filled by material of varied nature. Near Butto Gah, about 2.0 km south of Chilas, dunite breccia is met with, composed of angular pieces of rock in a greyish brown serpentinous matrix and calcite.

*Peridotites* occur as marginal zones around dunite bodies developed by progressive increase in pyroxene contest relative to olivine, such as near the Singal bridge. They also occur as xenoliths inside norite, as near the bridge on Thak Gah 1.5 km south of Indus. Peridotite bodies are occasionally cut by veins composed of hornblende and plagioclase ($An_{46}$)

while local shear zones are present accompanied by granulation. The weathered surfaces of dunites and peridotites resemble each other but the fresh surface of the latter is always darker. In thin section, a granular aggregate is seen composed of subhedral olivine ($Fo_{75}$, up to 74%), plagioclase ($An_{68}$, up to 15%), pleochroic hypersthene and diopsidic augite ($c \wedge Z = 52°$). Brownish green hornblende may make up to 22% while picotite and chromite are ubiquitous, with rare chalcopyrite, pyrite, cubanite, and pyrrhotite.

*Pyroxenites* occur as joint filling dykes inside dunite, as the outcrop east of Chilas, and as xenolithic bodies in norite. They are composed of pink to pale green hypersthene ($Fs_{30}$) and some hornblendes, developed after pyroxene; in other cases, pyroxene is entirely augite ($c \wedge Z = 44°$), while olivine may or may not be present. Minor ore is generally seen.

*Hornblendites* occur as dark green structureless rocks that occupy joint and fracture openings in ultrabasic bodies and norite. They are characterised by giant hornblende ($c \wedge Z = 27°$) prisms (up to 93%) projecting inwards from fracture walls. In addition, non-pleochroic cummingstonite (up to 5%) is present accompanied by ore, while natrolite (up to 2%) occurs as radiating crystals. A good example is present on the Thak Gah road, about 1.5 km south of Indus.

## Rocks of the Diorite Group

Outcrops of the Diorite Group start from about 1.5 km south of the Singal bridge and, with an intervening belt of veined metadiorites, passes into rocks of granodiorite composition near the junction of Thak Gah and Domain Gah. A prominant feature is the prevalence of xenoliths that sometime constitute almost 40% of the rock, particularly near veined metadiorites and norites. Xenoliths vary from pea-size to more than 30 cm long and with angular to rounded form, they are occasionally traversed by relatively coarse hornblende-plagioclase streaks and veins off-setting along minor faults and sometimes merging into the xenolithic body. Dark coloured (hornblende-rich) xenoliths sometime show zoned structure marked by an intervening less dark (feldspar-rich) border within the diorite host. Quartz-plagioclase aplite veins and rare muscovite-bearing pegmatites traverse the diorite while smears and thin veins of quartz are occasionally seen. Epidote is a common mineral on joint surfaces that have suffered tectonic slippage.

*Diorites* are essentially massive rocks with mottled surface and weathering to a greyish colour. Hornblende and plagioclase are easily recognised, the former reaching lengths upto 7 cm in the pegmatitic facies. In the normal rock, the colour index is generally constant, but may increase locally up to 70% to give rise to *meladiorite*, such as near Loshe, or may drop considerably with or without quartz; sometimes quartz may increase up to 15% to make the rock a *quartz diorite*, such as 2.0 km SE of Domain. Most of the plagioclase is in the andesine range ($An_{48}$ to $An_{40}$) and is saussuritized with a tendency to keep clear margins. Twinning is common, with frequent curved lamellae while vague and irregular zoning is common. Sieve textured hornblende ($c \wedge Z = 19°$ to $30°$) is distinctly pleochroic while its colour varies from brownish green in diorites to bluish green in quartz diorites. In the former rock type it may hold relics of pyroxene with rims of progressive change in colour to bluish green ore is generally associated. Alteration of hornblende to dark brown to pale yellow biotite and/or chlorite and limonite is common. Small grains and anhedral aggregates of epidote, chlorite, ore, sphene and apatite are commonly present in traces. Quartz is streaky, strained and has embayed margins with modal proportion increasing towards the south. Ilmenite and goethite-limonite pseudomorphs after pyrite are frequently present.

TABLE I.

*Chemical analyses and* CIPW *norms of some igneous rocks from Thak valley, Gilgit Agency, Pakistan*
(Analyst: Shafeeq Ahmed).

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . . | 43.50 | 43.67 | 48.58 | 48.82 | 49.45 | 50.88 | 51.44 | 53.18 | 57.82 | 58.07 | 60.56 | 67.95 | 71.88 |
| $TiO_2$ . . | 0.51 | 0.38 | 0.60 | 0.73 | 0.53 | 1.45 | 1.11 | 0.73 | 0.45 | 0.45 | 0.37 | — | — |
| $Al_2O_3$ . . | 16.38 | 21.01 | 18.33 | 21.92 | 20.98 | 20.60 | 18.87 | 19.62 | 19.58 | 19.69 | 19.31 | 19.25 | 17.82 |
| $Fe_2O_3$ . . | 5.54 | 3.39 | 7.58 | 3.50 | 3.19 | 1.65 | 2.29 | 3.36 | 2.38 | 5.46 | 1.70 | 0.30 | — |
| FeO . . | 7.58 | 8.26 | 6.86 | 2.38 | 6.31 | 5.67 | 6.06 | 5.24 | 4.41 | 2.76 | 3.48 | 1.79 | 1.25 |
| MnO . . | 0.41 | 0.42 | 0.55 | 0.18 | 0.20 | 0.29 | 0.25 | 0.23 | 0.26 | 0.55 | 0.15 | tr | — |
| MgO . . | 11.76 | 6.70 | 5.53 | 6.70 | 3.24 | 4.82 | 5.11 | 2.69 | 2.69 | 1.86 | 1.73 | 0.73 | 0.69 |
| CaO . . | 11.29 | 12.60 | 6.20 | 12.60 | 12.00 | 9.89 | 10.50 | 8.95 | 6.36 | 7.90 | 5.82 | 2.89 | 2.35 |
| $Na_2O$ . . | 1.96 | 2.21 | 4.51 | 2.21 | 2.58 | 3.88 | 3.55 | 4.68 | 3.96 | 1.64 | 5.34 | 6.23 | 4.52 |
| $K_2O$ . . | 0.60 | 0.38 | 0.50 | 0.38 | 0.68 | 0.22 | 0.32 | 0.63 | 1.30 | 0.80 | 0.48 | 0.22 | 0.88 |
| $P_2O_5$ . . | — | 0.05 | — | 0.05 | tr | 0.14 | 0.06 | 0.11 | 0.05 | — | 0.11 | 0.08 | 0.06 |
| $H_2O^+$ . . | 0.35 | 0.42 | 0.48 | 0.42 | 0.65 | 0.28 | 0.27 | 0.32 | 0.46 | 0.25 | 0.28 | 0.20 | 0.33 |
| $H_2O^-$ . . | 0.09 | 0.9 | 0.03 | 0.09 | 0.09 | 0.18 | 0.09 | 0.16 | 0.23 | 0.49 | 0.20 | 0.26 | 0.16 |
| Totale . . | 99.97 | 99.98 | 99.98 | 99.98 | 99.90 | 99.95 | 99.92 | 99.90 | 99.95 | 99.91 | 99.63 | 99.90 | 99.94 |

C.I.P.W. NORMS

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Q* . . . . | — | — | — | 0.18 | 0.42 | — | — | 0.67 | 10.12 | 25.61 | 10.79 | 22.75 | 35.51 |
| *or* . . . | 5.78 | 1.69 | 2.78 | 2.23 | 3.91 | 1.13 | 1.68 | 3.92 | 7.82 | 6.04 | 2.86 | 0.89 | 5.03 |
| *ab* . . . | 9.93 | 10.60 | 34.61 | 18.97 | 22.13 | 32.72 | 30.04 | 39.59 | 33.69 | 13.52 | 45.16 | 52.84 | 38.50 |
| *an* . . . | 34.07 | 43.01 | 28.07 | 48.95 | 43.60 | 38.64 | 34.94 | 30.80 | 31.55 | 38.92 | 27.29 | 14.58 | 11.76 |
| *ne* . . . | 2.29 | 8.62 | — | — | — | — | — | — | — | — | — | — | — |
| *C* . . . | — | — | — | — | — | — | — | — | — | 1.83 | — | 3.68 | 5.23 |
| *di* . . . | 17.50 | 14.25 | 4.17 | 10.90 | 13.43 | 8.96 | 14.11 | 11.52 | — | — | 1.34 | — | — |
| *hy* . . . | — | — | 11.73 | 12.26 | 11.03 | 8.97 | 13.83 | 7.22 | 12.56 | 5.35 | 8.55 | 4.88 | 3.97 |
| *ol* . . . . | 21.64 | 16.14 | 4.69 | — | — | — | — | — | — | — | — | — | — |
| *mt* . . . | 7.88 | 4.92 | 10.91 | 5.13 | 4.42 | 2.34 | 3.26 | 4.91 | 3.50 | 7.83 | 2.40 | 0.46 | — |
| *il* . . . | 0.91 | 0.77 | 1.06 | 1.38 | 1.06 | 2.76 | 2.14 | 1.37 | 0.76 | 0.90 | 0.61 | — | — |

*Granodiorites* are light greenish grey speckled rocks, generally showing tectonic foliation, with locally massive, banded and streaky portions. The southern marginal facies is strongly gneissose marked by augens of quartz aggregates and plagioclase/clinozoisite. Quartz-plagioclase and epidote-hornblende layers marks banding while facies with quartz streaks are common in the south. In the massive portions, xenolithic bodies are present composed of epidote, quartz and biotite or epidote only; these are mostly aligned to the foliation. Plagioclase ($An_{35}$ to $An_{18}$, up to 51%) occurs as short stumpy crytals, mostly saussuritized. Epidote (up to 13%), displaying bright interference colours and twinning in euhedral grains, occurs in a matrix of quartz (up to 45%), pale brown biotite (up tp 14%) and light green chlorite (up to 8%) with minor sphene and calcite. Quartz is generally granulated and embayed while alteration of biotite to chlorite is generally displayed.

*Pegmatites*. Pegmatites are found as tabular layers or as coarsened portions of rocks. On the basis of their mineralogy and mode of occurrence, pegmatites can be divided into two types:

*Basis pegmatites*, restricted to the noritic mass, are composed essentially of plagioclase ($An_{46}$) and hornblende. Local thin pegmatite veins of pyroxene and plagioclase are also seen, particularly traversing dunite east of Chilas; these are abundant in outcrops along the Indus road.

*Acid pegmatites* are generally found in the Diorite Group rocks but are not restricted to them; oligoclase, quartz and minor muscovite are their major constituents. A variety widely distributed is produced due to local coarsening of the diorite host with essentially similar mineralogy but with hornblende prisms up to 15 cm long. Rarely, acid pegmatites are present in the dunite outcrops as well, composed of oligoclase ($An_{27}$), brownish green to dark green hornblende ($c \wedge Z = 27°$), alkali feldspar and milky quartz. The tabular pegmatites, filling joint openings in dunite, show hornblende prisms projecting inwards from the walls and are zoned with successively talc, asbestos and vermiculite zones before the main body of the pegmatite is met; a good example is east of the junction of Thak Gah with Indus.

*Veined Metadiorites*. Occupying a position in the dioritic rocks, a 2.5 km to more than 3.0 km wide belt of veined metadiorites is present with a spectacular appearance due to white felsic material interlayered with a dark host of almost amphibolitic structure. Mostly intruded along foliation of the dark component, the felsic layers show pinch and swell structure, boudinage and ptygmatic folding and even cross-cutting relations. Occasionally, intrusive veins break through the metadiorite and reduce the latter to xenolithic status, sometimes merging into the inclusions through zoned gradation. The dark component is a foliated metadiorite, composed of complexly twinned plagioclase ($An_{45}$ to $An_{35}$, up to 36%), brown to pale yellow hornblende ($c \wedge Z = 26^0$, up to 61%) with relics of pyroxene, opaque ore (3%) and traces of quartz; the plagioclase is highly saussuritized. The felsic component is of granodioritic composition, composed of cloudy plagioclase ($An_{33-22}$, An up to 56%), granulated and strained quartz (38%), crystalline siderite and traces of hematite. Near contact with the dark host, the felsic layer generally contains some pink garnet which is missing in the main body. In addition, aplitic veins are present, composed of oligoclase, alkali feldspar and quartz, with traces of muscovite, biotite and chlorite.

## Chemistry

In Table I are given chemical analyses and corresponding C.I.P.W. norms of 13 representative rock types from the Thak valley complex, excluding the commulus types such as dunites, peridotites and pyroxenites. The anomalous presence of appreciable normative C in analyses 10, 12 and 13, even with high Q content, is due to alteration of the rocks as is evidenced

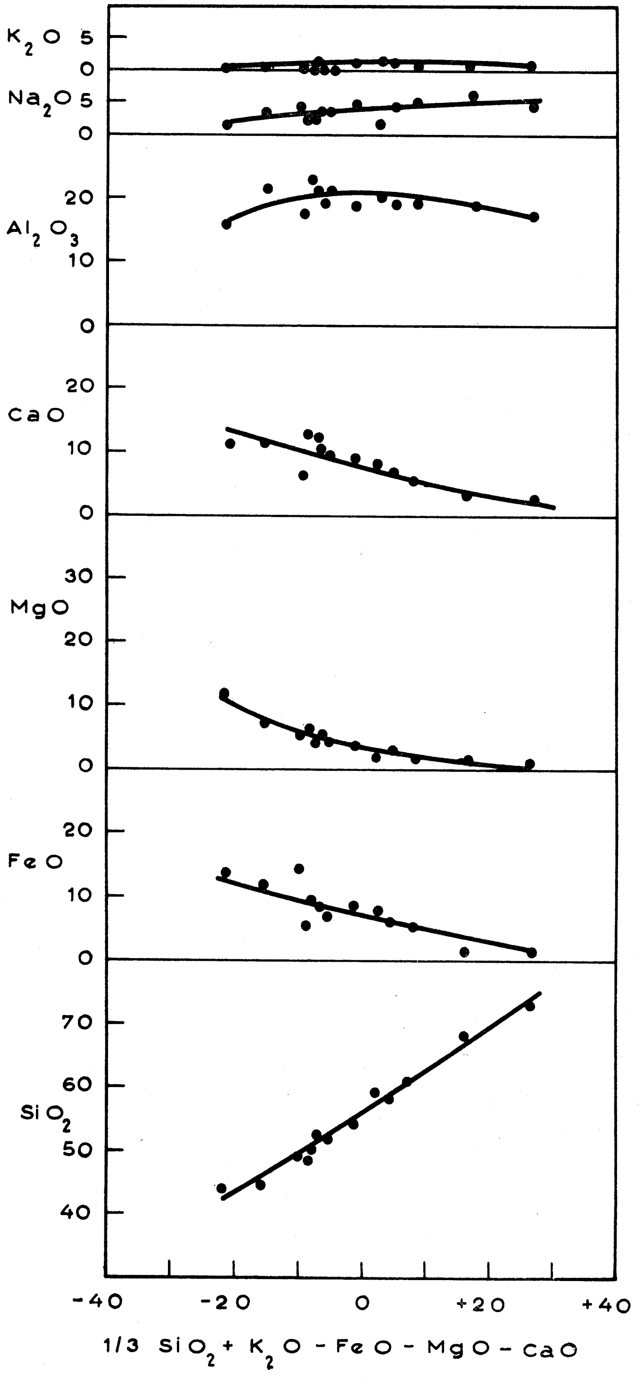


Fig. 2. – The Larsen diagram of rocks from the Thak valley, igneous complex.

by the presence in these of considerable modal epidote. The oxide variation diagram, based on the system of Larsen (1938), is given in fig. 2. Prominently, with increase in $SiO_3$, there is simultaneous decrease in CaO, MgO and FeO; $Al_3O_3$ shows an early increase followed by regular decrease. Among the alkalies, $NaO_2$ shows recognisable increase while $K_2O$ registers irregular variation without prominent increase. Fig. 3 shows the combined $FeC^t$—MgO—Alk and CaO—$NaO_2$—$K_2O$ diagram of the Thak valley rocks, based on recast

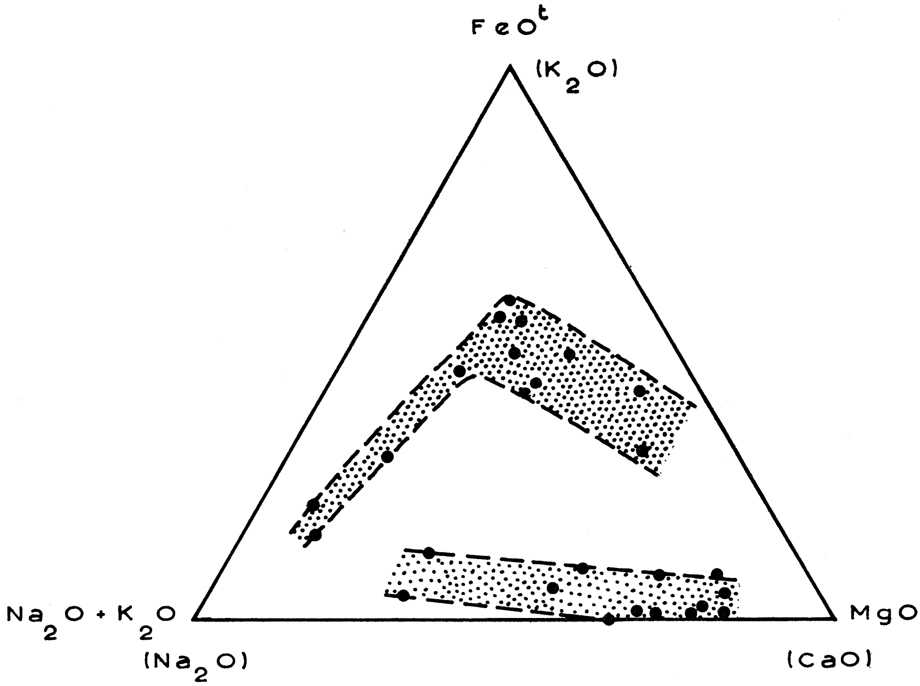


Fig. 3. – Combined FMA and lime-alkalies diagram of analysed rocks from the Thak valley, igneous complex.

oxide percentages. Two aspects of this diagram are prominent: first, there is a significant iron enrichment and second, there is a scatter of plotted points. The former fact proves the tholeiitic nature of the parental magma with its typical differentiation behaviour. The scatter of the plotted positions is considered to be due to inhomogeneity of the rocks as a result of small scale layering, hydrothermal/metamorphic alteration and xenolithic hybridization of the rocks. As a result, it has not been possible to draw a line of liquid descent, rather the area limiting plotted positions of analyses has been shaded to serve more or less a similar purpose.

## Conclusion

The field relations, systematic chemical and mineralogical variations, as described, show that the rocks of the Thak valley complex represent a differentiated tholeiitic series. The belt of metadiorites with intrusive acid layers combined with sporadic zones of xenolithic diorites, shows that emplacement of the Thak valley complex took place in at least two stages. In the first stage, noritic magma was intruded which gave rise to various basic to ultrabasic rocks and the set of basic pegmatites. During the second stage, diorite magma was intruded and gave rise to rocks ranging from meladiorite to granodiorite, acid pegmatites and veins. The joint filling acid layers in the Norite Group bodies and the intrusive veins of metadiorite were related to the second stage. The length of interval between the two stages is not known but it was long enough to solidify the noritic mass. Nevertheless, all available evidence proves that the two magmas were derived ultimately from a common parentage. Its trend of differentiation compares satisfactorily with those of known tholeiitic intrusions. The orthopyroxene jacketing of olivine and the presence of inverted pigeonite meet the mineralogical criteria of Tilley (1950) and Kuno (1950). A tholeiitic origin was also considered by Jan and Kempe (1973) for the basic and intermediate rocks of upper Swat, although no specific basis for the conclusion was given. The lower iron and higher potassium content of the upper Swat rocks appears to be due to contamination by pelitic rocks. In the Thak valley, however, hybridization due to later intrusion of diorite magma is the characteristic feature which may also be responsible for minor scatter of points in fig. 3. The epidotization of plagioclase and the chloritic break-down of hornblende in the granodioritic rocks, the occurrence of epidote-hornblende gneisses and garnetiferous amphibolites further south, show that the grade of metamorphism increased away from interior of the complex, a direction towards the Nanga Parbat (Misch, 1959). In the case of upper Swat, however, increase in metamorphic grade towards noritic interior has been claimed although no mineralogical basis could be found by Jan and Kempe (1973, p. 229). Final conclusions regarding this problem must await detailed investigation of the amphibolite belts and the related rocks.

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## LOCATIONS OF ANALYSED ROCKS FROM THAK VALLEY IGNEOUS COMPLEX

1. Meladiorite west of Domain Gah, about 0.8 km south of Domain.
2. Corona gabbro, east of Thak Gah, about 1.5 km north of Domain Gah-Niat Gah junction.
3. Amphibolite, 0.8 km SW of Domain, dyke rock in foliated diorite.
4. Norite, from edge of outcrop, south of Chilas.
5. Norite east of Thak Gah, about 1.6 km north of Singal.

6. Norite, about 1.5 km south of Indus-Thak Gah junction.
7. Norite east of junction of Thak Gah and Indus.
8. Pegmatite in norite, about 1.0 km SW of Singal.
9. Diorite, about 1.0 km SW of Domain.
10. Quartz diorite, opposite Domain, east of telephone wires accross Thak Gah.
11. Quartz diorite, 1.0 km NE of Domain, from «nala» cutting.
12. Pegmatitic diorite, south of southern border of veined metadiorites east of Thak Gah.
13. Granodiorite, Kund Das, west of Domain Gah.

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