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THE GEOLOGY OF THE WARSAK AREA, PESHAWAR, WEST PAKISTAN

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ABSTRACT

The Warsak Area, Peshawar, West Pakistan, has been geologically mapped and the petrography of the rocks described in detail. The area consists of a series of metasediments of the greenschist facies (slates, phyllites, mica schists, garnet schists, hornblende schists, calcareous schists and marbles), which have been divided into a Lower, Middle and Upper Series. On the eastern side the metasediments disappear under the alluvium of the Peshawar plain. They range from Siluro-Devonian to Upper Palaeozoic in age, and are intruded by sills of metagabbro and metadolerite (? Cretaceous), porphyritic microgranite (?Upper Cretaceous to Lower Tertiary) and the Warsak alkaline granite (?Lower Tertiary).

The chemistry and alkaline nature of the granites (which contain aegirine, riebeckite and astrophyllite) is briefly discussed.

The structure of the area is shown to be a northwards plunging syncline, faulted on the east on the northern side of the Kabul River. The joint patterns and other structural features are described, and the economic geology of the area discussed.

INTRODUCTION

This paper presents a geological map of the Warsak area, Peshawar district, NW Pakistan, together with detailed accounts of the petrography of the metasedimentary and igneous rocks of the area. The structure of the rocks is discussed and a brief account of their economic potential given.

The paper is a revised and edited compilation of two M.Sc. theses submitted to this University in August, 1969; the field work was undertaken between December, 1968, and February, 1969, and the laboratory investigation completed subsequently. Mapping was carried out using Survey of Pakistan toposheets (Nos. 38 N/4 and N/8) enlarged to the scale of 1:20,000 (1 inch=0.314 miles).

The area lies across the Kabul River, some 18 miles WNW of Peshawar, in Mohmand Agency (to the north) and Khyber Agency (to the south). It is bounded

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by 34°6′ and 34°14′ north, latitude, and 71°20′ and 71°26′ east, longitude. There is easy access from the main Jamrud-Warsak road, and also from the Mulagori road leading from the latter at Shahgai to Shaid Mena. There are also jeepable tracks, nullas and footpaths covering the whole area.

The topography of the area is primarily that of steep low-topped mountains ranging from 1000 to 4000 feet in height. The mountains increase in altitude and ruggedness towards the west and, especially, northwest, whilst to the east they drop to low hills before the flat, alluvial Peshawar plain is reached. At some places, the low, flat hills and valleys are covered with rounded gravel and clayey matter which may have been deposited in lake beds, or more probably, by river floods. Their roundness indicates a distant source area. In an early report on Mohmand Agency, Mark writes: "The aspect of Mohmand hills is exceedingly dreary and the eye is everywhere met by the dry ravines between long rows of rocky hills and crags, scantily clothed with coarse grass and scrub wood, and dwarf palm (Mazri)."

The ravines are steep-walled, with a slope of some 45°, and the nullas rarely exceed 20 feet in width. Drainage is both radial and dendritic, very few of the streams being permanent. The streams have dissected narrow (youthful) valleys and flow usually towards the north and south, joining the Kabul River. The middle ridge of the Warsak alkaline granite serves as the main drainage divide in the area south of the river, resulting in two main drainage systems, one flowing to the north of it, directly discharging its water into the Kabul River, whilst the southern one ultimately joins the Kabul River flowing through bedrock. The granites and other resistant rocks form the ridges both regionally and locally, where the streams usually follow the general strike for some distance. The Kabul River valley is narrow and has cut a steep-walled canyon over 2000 feet deep. The region has an arid, extreme, continental climate, with a hot, dry summer and a cold winter. The hottest months are June, July and August (average maximum temperature, 105°) and the coldest December and January (average minimum temperature, 40°). The vegetation is poor and of the desert type, shrubs and herbs being common. Trees are very scarce and are deciduous. The area is thinly populated, the inhabitants being Pushto-speaking members of the Mulagori and Mohmand tribes. Their houses are katcha but a few people live in interconnected caves; the main source of income is agriculture and cattle-raising.

Previous Work.

Little work has been carried out in the area, mainly because of the inaccessibility of tribal areas. What literature is available is mainly concerned with economic aspects of the region, especially marble and, latterly, the Warsak dam site.

C. L. Griesbach (1892) and Sir Henry Hayden (1898) first entered the Khyber Hills whilst working on the regional geology of the Safed Koh mountain ranges. Griesbach (1892) divided the rocks into the following formations:

Complex of shales and earthy beds	..	Triassic?
Limestone and alum shales series Metamorphic strata with graphitic layers	)) ..	Carboniferous
Phyllites and schists Gneissic series	)) ..	Older Palaeozoic

Fox visited the Khyber Pass in the 1920's and 1930's whilst working on the permanent way for the Peshawar-Torkham railway, and published an account of the main rocks and structure of the area.

Sir Lewis Fermor collected the first specimen of the Warsak alkaline granite from the Mulagori road in 1935, whilst inspecting the Shaid Mena marble quarries, and noted the presence of aegirine. Coulson (1936) investigated this rock and collected further samples, when visiting the Kambella Khwar marble. He compared them with the 'Shahbazghari porphyries' (the Shewa Formation of Martin *et al.*, 1962) and considered them to be consanguineous.

More recently, Ahmad (1951) carried out a detailed survey to locate a suitable site for the Warsak dam. By surface and sub-surface (exploration tunnel) mapping, he covered a few square miles on scales of 1 inch=200 yards, and 80 feet, plotting the smallest lithological units. He mentions the Warsak alkaline granite ('granite-schists') and describes the geology of the dam site thus:

"The rocks cropping out at the dam site were previously igneous and sedimentary rocks intruded by basic dykes metamorphosed later on by the intrusion of granite and quartz dykes. Igneous activity poured out lenticular layers of acidic lava separated by volcanic ashes. Subsequent subsidence of the land deposited bands of limestone. Later on upheavals and (?) folding brought in their wake intrusions of basic igneous rocks followed by the injection of granite and quartz, which probably metamorphosed the whole sequence. Thus, acidic igneous rocks changed into granite-schists and ash beds and basic rocks were metamorphosed into bands of mica-schists and hornblende-schists respectively." However, as is shown below, it is not considered here that the metamorphism of the sediments and early basic intrusions is a contact phenomenon, but is due to low-grade regional metamorphism.

In the Geological Map of Pakistan, Bakr and Jackson (1964) place the metasediments in the Precambrian, along with the Attock Slates. However, Tahirkheli

(1968) regards the Attock Slates as Mesozoic in the main, and it is probable that a similar broad age pattern applies to the Warsak area.

Concerning the granitic rocks, Kempe and Jan (in press) have suggested a broad correlation with similar granitic and alkaline rocks belonging to the Shewa Formation, the Koga Alkaline Complex, and, possibly, the Ambela Granite (see also Martin *et al.*, 1962; Siddiqui, 1965; and Siddiqui, 1967).

REGIONAL GEOLOGY

The metasediments of the area form a part of the Khyber Formation, which lies within a belt of low-grade regionally metamorphosed geosynclinal sediments extending from Attock in the east for several hundred miles westwards into Afghanistan. The belt in turn is linked with the Safed Koh mountain range, comprising rocks ranging from Palaeozoic to Tertiary. North of the Kabul River the predominant east-west strike of the Safed Koh gives way to a NE-SW trend. The whole belt of Khyber Slates was correlated with the Attock Slates on lithological and structural evidence in 1868 by Waagen and Wynne. They suggested a Lower Silurian age for the Khyber rocks on the basis of fossils which were collected by Falconer and Vicary in the Kabul River gravels. Vicary himself obtained "a small *Spirifer*, *Orthis* in abundance, and also collected a *Terebratula* and some *Polyparia*" from limestone boulders in the watercourses near Peshawar. The Attock Slates extend westwards until they are lost near Julazai beneath the gravels of the Peshawar plain; they probably reappear in the Khyber Pass and can thus possibly be regarded as one flank of a broad antiform from which the core has been eroded, separating it from the other flank, the core now being occupied by the Peshawar valley plain.

Recently, fossils of Siluro-Devonian age (*Favosites*, *Heliolites*, *Thamnopora* and Stromatoporoids) have been found (Badshah and Rehman, 1969), and also the Upper Devonian nautiloid, *Platyclimenia* (Ibrahim Shah, 1969), in the marble near Jamrud, some four miles south of the area. The same marble band extends into the area, associated with the Phyllites and Marble, enabling this group to be positively assigned an age.

Most of the slaty shales, phyllites, limestones and marbles, and quartzites which make up the Khyber Formation extend into the Warsak area, and have been intruded by basic and granitic rocks. To the north of the area, intrusions of peridotite and pegmatite are found, and the metamorphic grade of the sediments increases northwards.

The metasediments within the area have been divided into a Lower Series, comprising essentially pelitic rocks, a Middle (Hornblende Schist) Series, and an Upper Series, comprising pelitic and calcareous rocks. To the southwest, outside the area, the Lower Series overlies the Mulagori Marble. The full sequence is given in Table I, together with tentative ages and the igneous intrusions.

STRUCTURE

The Safed Koh range, in which the Warsak area is structurally included, forms part of the Cretaceous-Tertiary Himalayan orogenic system. The structural features in the northern part of the system are the products of compressive pressure from the north. Prior to the Himalayan episode, the tectonic history of the region is less well known.

The main structural feature of the area is the syncline, partially obscured to the northeast by alluvium, formed by the southern part of the metasediments. The rocks dip inwards at angles varying from 30° to 70° and the syncline plunges to the north. To the northeast, the metasediments form a continuous series dipping northeast, and it is considered that they are displaced from the southern part by a fault striking ENE, running just north of the river and largely obscured by alluvium. The aerial photographs fail to illuminate the structure further.

The possibility was considered that the Upper Series are the same rocks as the Lower Series, forming the northeastern limb of the syncline, which would then be a basin. However, the strikes and dips of the two groups are totally inconsistent with this interpretation in the northeastern corner of the area unless either the northeastern metasediments are overfolded, or the synclinal axis swings abruptly from a northerly to an easterly direction, to disappear under the alluvium parallel to the river. Neither of these possibilities is considered likely. The metasediments form the western flank of a larger, antiform structure, the eastern flank lying to the east of the Peshawar plain, where it consists of the Attock Slates. Strong isoclinal and recumbent folding is common outside the area but, within it, is limited to local bending and implication, especially in incompetent rocks such as the Phyllitic Schist. Near Umardin Kili and elsewhere it may be due to irregularities within the Warsak alkaline granite sill.

There are no other proven major faults in the area, unless faulting is responsible for the breaking up of the Warsak alkaline granite into two sections northwest of the dam. Ahmad (1951) considered that the Kabul River does not represent a fault zone, as was previously thought to be the case, since there is no break in the continuity of the rocks on both banks. However, the present interpretation suggests that the river is a fault zone east of the dam.

The metasediments are intruded, apparently concordantly, by the igneous intrusions, which thus form sills; the relative ages of the intrusions are indicated by the degree of metamorphism to which they have been subjected and by structural evidence, Thus, south of Pakhan Kili, a metagabbro is truncated by microgranite, and north-west of Spera Ghar by the Warsak alkaline granite. The relative ages of the granites can only be inferred from the greater degree of metamorphism of the microgranites.

The Hornblende Schists near Karerai show a considerable change in strike across a nulla and this is attributed to a minor fault. It could not be traced further east because of alluvium cover. There are similar possible minor faults further north; near Gaza Banda a microgranite is displaced and near Shakar Ghu a recumbent fold in the Slates, defined by a quartzite band, shows a displacement of some 20 feet resulting from a fault.

Shear zones resulting from the forceful injection of the igneous intrusions are fairly common in the area. The intrusion of metadolerites has produced highly corrugated micaceous and graphitic layers, which never exceed two feet in width. This could be seen in several places on the Warsak dam road near Ali Baba Ziarat. Ahmad (1951) located two shear zones near the alkaline granite intrusion, one about 400 feet downstream and the other 40 feet upstream ot the dam site, resulting in a 20 foot crush zone of mica schist and a 2 foot thick sheared zone of hornblende schist, respectively. Minor slumping of local extent could also be seen near Umardin Kili, where the original sequence is disturbed by the intrusion of apophyses ot the alkaline granite.

The metasediments and granitic intrusions are well jointed, although in the former the joints tend to be obscured by intense weathering. A considerable number of dip and strike readings were taken and their poles plotted on a stereogram. The joints in the metasediments show a much greater scatter than those in the granites, as might be expected, and, in general, joints north of the river show a greater scatter than those to the south. No significant pattern could be obtained from the metasediment readings but in the granitic rocks, especially the Warsak alkaline granite, three sets are clearly visible, and two of these are shown in Fig 1. The first strikes approximately N 65°E, the second N 15°W, and the third approximately E-W, dipping 15°N. It is interesting that the second set possesses two maxima, with a difference in dip of some 40°. The two sets plotted form an angle approximating to 60° and are clearly a conjugate system, produced by pressure from the north.

Schistosity, cleavage and drag folds are well developed in the metasediments and there are some interesting examples of lineation. In the Warsak alkaline granite the riebeckite and aegirine are frequently aligned in parallel orientation. This may partly be due to magmatic primary flow but also represents a gneissose texture such as has been described by Floor (1966) from the astrophyllite-bearing aegirine-riebeckite gneiss from Vigo, Spain. The metaconglomerates and quartzites contain pebbles

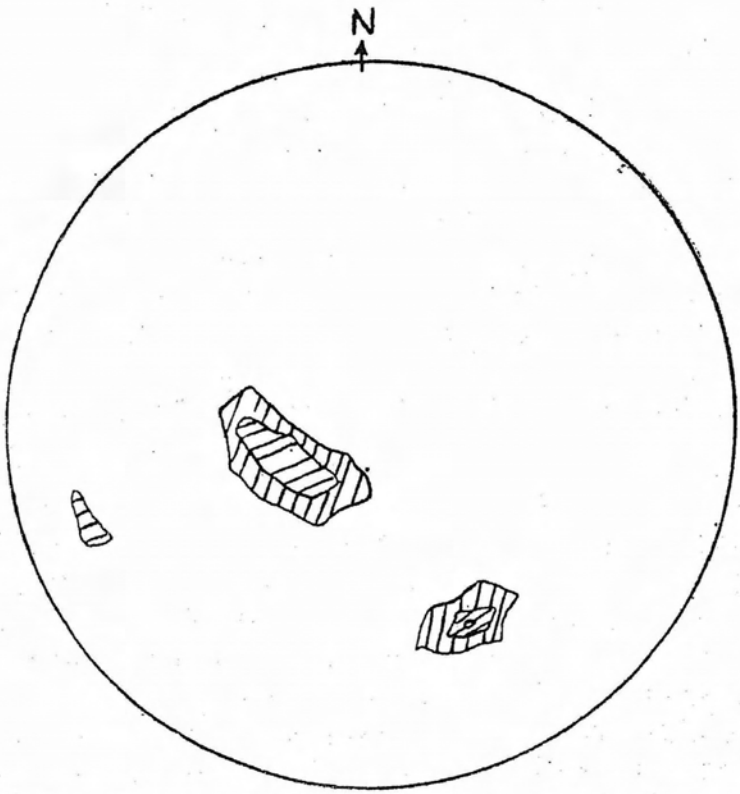

Fig. 1. Stereogram of the poles of two sets of cross joints in the granites, forming a conjugate system.

commonly striking N 43°W (dipping 74°NW), due north (dipping 35°N), or N 15°W (dipping 35°NW), whilst pebbles within the metagabbro near Umardin Kili strike N 80°E, dipping 76° NE.

TABLE I

Sequence of rocks in the Warsak area

Alluvium		Quaternary
Warsak alkaline granite		? Lower Tertiary
Porphyritic micrograniites		? Upper Cretaceous to Lower Tertiary
Metagabbros and metadolerites		? Cretaceous
UPPER SERIES	Calcareous schists with marble, shaly slates and quartzite, etc. Garnet-chlorite schists Phyllitic schist and marbles	? Upper Palaeozoic
MIDDLE (HORNBLENDE SCHIST) SERIES	(*iii*) Hornblende schist (*ii*) Acicular hornblende schist (*i*) Quartz-mica schist	? Carboniferous
LOWER SERIES	Pebbly quartz-biotite schist Phyllites and marble Slates	? Siluro-Devonian

THE METASEDIMENTS

Introduction.

Low grade regionally metamorphosed geosynclinal sediments (greenschist facies) are the oldest rocks in the area (Table I). These, represented by pelitic, psammitic and calcareous rocks, are divided as follows, the Lower and Middle Series being separated by the Warsak alkaline granite sill:

Calcareous schists with marble, shaly slates and quartzite, etc. Garnet-chlorite schists Phyllitic schist and marbles	Upper Series
(*iii*) Hornblende schist (*ii*) Acicular hornblende schist (*i*) Quartz-mica schist	Middle (Hornblende Schist) Series
Pebbly quartz-biotite schist Phyllites and marble Slates	Lower Series

In the south the metasediments are all conformable and form a north-plunging syncline, with inward dips ranging from 30° to nearly vertical, 50° being a typical angle. The Lower Series is exposed to the southwest, much of the eastern side of the syncline being covered by alluvium. The central portion of the area is occupied by the Middle (Hornblende Schist) Series and the igneous intrusions, and the northeast by the Upper Series, the fault along the northern bank of the Kabul River disrupting the synclinal structure. The metasediments show little lateral variation and the degree of metamorphism tends to increase northwards. All are well jointed, the competent rocks showing more prominent joints, and the less competent rocks schistosity and cleavage. All are deeply weathered, with varying intensity, both mechanical and chemical processes having operated together.

Many amphibolite bodies in the form of thin sills and lenses occur within the Lower Series, and, in the vicinity of the Warsak alkaline granite, abundant quartz veins. The Middle (Hornblende Schist) Series, above the alkaline granite sill, contains the metagabbro, metadolerite and microgranite sills, which appear to be locally discordant. There tends to be a rise in metamorphic grade of the sediments near to the sills, suggesting that contact metamorphism has been operative locally in addition to the overall regional metamorphism.

LOWER SERIES

Slates.

The Slates occur in the extreme southwest, overlying the Mulagori marble, which is absent from the area. They comprise slates with interlayered phyllites and slaty shales; the whole formation is about one mile thick. The rocks are well exposed south of Lwar Mena, where they form high hills along the Mulagori road, in the Jangzi Khwar, near Zamakka Baro, and in the Kundian Khwar.

The rocks are commonly thinly bedded, with layers varying from a centimetre to several centimetres in thickness, with occasional thick beds. They have no systematic lithological arrangement but are randomly interbedded with eachother. They have the same consistent strike, and dip steeply northwards. Some parts of the slaty shales and slates exhibit well developed slaty cleavage, slightly oblique to the bedding, whilst the phyllites show weak cleavage. Joints are very common in the slates, generally oblique to the bedding. The whole of the series is deeply weathered, being more or less friable depending on the rock types. Slates are less weathered than the other units, with brown staining common and concentrated especially in certain horizons due to the leaching of pyrite. The colours of the outcrops are dark grey (slates), shiny yellowish-green (phyllites) and dirty brown (slaty shales).

Under the microscope, the texture of the rocks is schistose to semi-schistose, where flaky minerals, chiefly white mica, chlorite and biotite, are aligned parallel to eachother; graphite gives the rock a pitted appearance and is distributed randomly. Biotite and chlorite are coarser and sometimes form porphyroblasts whilst the rest of the rock is xenoblastic.

The mineral composition of the slates is muscovite (about 5 per cent), chlorite (2 per cent), biotite (23 per cent), graphite (26 per cent), feldspar (19 per cent), quartz (13 per cent), and pyrite, with some calcite, sphene and iron oxide (all forming about 12 per cent). The assemblages are typically those of the chlorite-muscovite-albite-quartz sub-facies of the greenschist facies, showing the metamorphism of pelitic sediments containing excess silica and potash.

Phyllites and Marble.

There is no definite demarcation line by which the Phyllites and Marble can be divided from the Slates. The division is mainly based on the predominance of phyllites in the formation, with other rock types, mainly slates, mica schist, graphitic schist, phyllitic schist and marble beds, interbedded. The average thickness of the series, based on the average dip, is about 3,500 feet, of which phyllite makes about three-quarters.

The rocks are exposed north of Murdar Dand and Zamakka Baro, and on the Mulagori road about half a mile east of Lwar Mena. This series forms low hills and the catchment area for the southern drainage system.

The colour of the rocks varies according to the intensity of weathering. Phyllites are greenish-grey when fresh and shiny light green on weathered surfaces. Other units, which are randomly interbedded throughout the phyllites, are of varying thickness and show various colours, with dark brownish-grey for the slates and schists. Parts of the mica schist and phyllitic schist contain garnet and pyrite, the latter being locally weathered to a brownish-red stain on the crust. Graphitic schist forms some thin bands, associated with marbles. The schistosity is poor and usually the laminae are convoluted; some parts are extremely weathered, forming a slaty grey mass of loose angular fragments. The average phyllite contains feldspar (about 22 per cent), quartz (20 per cent), biotite (17 per cent), muscovite (10 per cent), chlorite (23 per cent), garnet (2 per cent), and opaque and accessory minerals (6 per cent).

Marble beds forming the upper portion of the Phyllites and Marble formation overlie the carbonaceous and graphitic schist. They are exposed on the Mulagori road and in all the major streams, forming a ridge. This marble is the extension of the Kambella Khwar marble through Pahari Khwar, crossing the Mulagori road, and vanishing beneath alluvium in Loe Khwar to the east, near the Police Camp. The total thickness exceeds 400 feet, with thick interbedded bands of phyllite and schist. Each marble band varies in width, colour and economic quality. The upper part of the sequence is banded whilst the lower part consists of comparatively pure, saccharoidal, white marble. Individual marble beds are approximately 10 to 12 feet thick.

Pebbly Quartz-Biotite Schist.

This group is 2,000 feet thick and is mainly composed of mica schist, with various other interbedded rock units, chiefly phyllitic schist, phyllites, slaty shales, quartzites and metaconglomerates. These individual units are too thin to be shown on the map. The formation is exposed in all the major streams, chiefly the Jangzi Khwar, and along the Mulagori road. The rocks were named 'mica-schist' by Ahmad (1951).

Several amphibolite masses of various size, forming local detached bodies, could be seen throughout the series. The Pebbly Quartz-Biotite Schists have a fine to moderate schistosity, the layers ranging from a few millimetres to several centimetres in thickness; they are locally microfolded. Joints are common throughout the series, although obscured locally by weathering. The pebbles are usually flattened and elongated parallel to the schistosity, and range from a few millimetres up to about five centimetres in length. The schists are grey or greyish-brown in colour, weathered to a greyish-yellow; the other units are of various colours. All are deeply weathered, its intensity affecting the colour and texture of the rocks. Quartz lenses and veins are common, usually following the schistosity but in some cases cutting it obliquely. A thin layer of actinolite schist is found near the contact with the Warsak alkaline granite.

The quartz-biotite schists are porphyroblastic and fine-grained. Biotite, making about one third of the rock, is brown and pleochroic, and is orientated with its flat surfaces parallel to the schistosity. Idioblastic crystals of garnet make about three per cent in some sections, but only a few grains are present in others. At one point, there is a zone 1½ feet thick in which garnets are concentrated, with dark red crystals reaching 2 to 4 mm in size. Generally, however, garnet develops as larger grains in a fine matrix of quartz, biotite and iron ore. Most of the garnet grains have abundant inclusions of ore, quartz, etc., mainly concentrated in the centre. Elongated biotite crystals terminate at the garnet boundaries, and do not flow around them. Tourmaline is present in traces, not elongated parallel to the schistosity but at some 60° to it. Quartz, mainly in the groundmass but also forming inclusions in the garnets, feldspar and iron ore (ilmenite, sometimes altered to sphene) make up the remainder of the rock.

The quartzites and metaconglomerates which are found near the granite are unusual in some respects. They are about 100 feet thick and show considerable local variation. There are three main types.

Firstly, a metamorphosed orthoquartzite with fine-grained texture, containing no clastic pebbles. Secondly, a pebbly quartzite containing 20 to 30 per cent pebbles of various sizes, ranging from a few to about ten centimetres in diameter. Thirdly, the metaconglomerate, which has more than 80 per cent pebbles of varying sizes. All the pebbles have more or less smooth surfaces, generally orientated parallel to each-other.

The orthoquartzite is greyish-white in colour and is more than 40 feet thick, forming the lowest unit of the quartzite sequence. The pebbly quartzite is grey-green, due to its chloritic matrix,with white to grey-black pebbles of several kinds, commonly of quartz. The metaconglomerate is pale green with abundant chlorite forming the matrix of the pebbles, some of which are enclosed in a sheath of chlorite flakes.

The orthoquartzite exhibits an excellent joint system, with two sets of longitudinal joints cutting eachother at an acute angle, and a third set, of cross joints, at right angles to the first two and the bedding. In some parts of the orthoquartzite polygonal joints are well developed, resulting in smooth vertical columns cut at right angles by the cross joints. There are some actinolite schist lenses, having cores and outer shells of quartzite, with intermediate zones of actinolite-bearing schist. Other actinolite amphibolite lenses have a core and intermediate sheath of amphibolite, with alternate layers of pink and light quartzite enclosing it in the form of a shell.

Another common feature is ptygmatic folding of granitic veins, which have a pe-peculiar zigzag and convoluted structure, sometimes cutting the pebbles. Quartz lenses are also common and are usually curved, tapering bluntly at both ends.

The quartzites do not form a continuous sequence, but alternate with thick bands of mica schist, chiefly in the upper part of the formation. The upper quartzite, 60 feet thick, shows abrupt changes, without gradation, in the relative proportions and colours of its pebbles. The ellipsoidal fragments are orientated with a strong linear arrangement and more than 80 per cent have preferred orientation, with their flattened surfaces parallel to the schistosity. The average strike of the lineation of the pebbles is N 43°W, dipping 74° NW.

MIDDLE (HORNBLENDE SCHIST) SERIES

The Middle (Hornblende Schist) Series forms the most abundant metamorphic group in the area. The rocks are mostly fine-grained, but some varieties have a coarser texture and apparently differ in mineralogy, especially at the contact with metadolerites. The rocks of the Middle Series are separated from those of the Lower Series by the Warsak alkaline granite. The series is divided into three major groups, mainly on the basis of lithological characters and abundance of certain rock types within these groups, as follows:

(*iii*) Hornblende schist
(*ii*) Acicular hornblende schist
(*i*) Quartz - mica schist

The division, however, is arbitrary and difficult to apply north of the river. There are many gabbroic and granitic intrusions cutting this series, most of them concordant with the regional structure. Prior to these, the series was intruded by numerous dolerites that have since been metamorphosed into amphibolites. (In many cases it was difficult to mark the contact of the Hornblende Schists with the amphibolites, so the two are shown collectively on the map). Higher grade greenschist facies assemblages in the metasediments of the Middle Series may be due to contact effects of the intrusions, superimposed on regional metamorphism.

(*i*) *Quartz-mica schist:* This group forms a thick band of metasediments, more than 1200 feet in width, composed mainly of quartz-biotite schists, with other minor rock units, chiefly quartzose schists, phyllitic schists, slaty schists, marbles, and amphibolities. There are small intrusions of metagabbro and microgranite which have sharp contacts with the quartz-mica schist, and assimilation effects could not be detected. The series disappears beneath alluvium on the southeastern side.

The general colour of the rocks is a dirty brown to brownish-grey, with several local variations. They are thinly bedded, locally variable, and show strong schistosity, generally parallel to the bedding planes. They are deeply weathered, with development of sericite and clay minerals, forming a highly friable mass, with partially altered bands commonly alternating with completely fresh bands. The rock contains feldspar (about 35 per cent), quartz (42 per cent), biotite (13 per cent), chlorite (1 per cent), epidote (1 per cent), and opaque minerals (8 per cent).

The three marble beds associated and interlayered with quartz-mica schist and hornblende schist are comparatively little affected by weathering, forming ridges and local cliffs, but with pits and grooves common on their surfaces due to chemical action. One of the beds is black in colour, about ten feet thick, and contains quartz boudins and veins, which are folded to some extent. Another marble bed, about 15 to 20 feet thick, is white and appears to consist entirely of calcite.

A thick bed ot quartzose schist, in contact with the Warsak alkaline granite and mica schists, strongly resembles rhyolite. It shows excellent lineation and pinches out to the west. Within this series is a lensoid body of cream-coloured talc schist, about 100 feet by 500 feet in size. Several thin sections of the quartzose schist show no plagioclase in the groundmass, although plagioclase occurs as large porphyroblasts. The groundmass consists of biotite, muscovite, orthoclase, and quartz, with some epidote and opaque minerals. In view of the general lack of evidence for volcanic rocks, however, this group has been treated as metasedimentary.

Joints in the quartz-mica schist are not pronounced due to intense weathering. Schistosity is common, with almost parallel alignment of the platy minerals, and lineation is well developed in quartzose schists in some places. Some epidote and calcite veins, cutting the rocks and following the joints, occur in the upper part.

(*ii*) *Acicular hornblende schist:* This formation, about 600 feet thick, overlies the quartz-mica schist (the two being separated by acid and basic intrusions) and is divided in two by a thick metagabbro body. The upper contact is with microgranites. It is chiefly composed of acicular hornblende schists, chloritic schists, actinolite schists, garnet schists, and metaconglomerates, with small microgranite sills and amphibolite bodies.

Yellowish-green, deeply weathered chloritic schist forms the main rock type, both in the upper and the lower part of the formation. Greenish garnet schists interbed with the chloritic schist in the lower and the middle, whereas acicular hornblende schists interbed only in the middle part of the formation. Garnet schists contain garnet porphyroblasts (ranging from two to eight millimetres in diameter) which gradually become smaller towards the top. These porphyroblasts are usually subrounded, probably due to rotation, whilst the smaller garnets are subhedral and occasionally exhibit perfect dodecahedral forms.

The main acicular hornblende schist rocks overlie the garnet schists. They contain fine acicular green hornblendes, ranging from 1½ to 3 centimetres in length. Although there are all gradations, the acicular hornblende schists can be divided into two groups: (1) light coloured, with distinct crystals of hornblende, 1½ centimetres long, sometimes with a radiating texture; and (2) hard, massive and dark coloured, due to the abundance of hornblende crystals, some of which may be three centimetres long. Their mineralogy also differs to some extent. The dark variety contains about 21 per cent calcite, associated with patches of iron oxide altered to a red coloured hydroxide, whilst the light coloured variety has more quartz and feldspar in the groundmass. Hornblende, pleochroic from green to blue-green, forms 50 per cent of the dark variety and 25 per cent of the light. Other minerals, besides quartz and feldspar (totalling about one third of the rock), in the groundmass are biotite, calcite, some hornblende, and iron ore. Inclusions of quartz, and sometimes of feldspar and ore, are common in the hornblende grains. The texture is fine - to medium - grained, and the rocks are notable for the sometimes radiating, subhedral, porphyroblastic hornblende and the patches of red iron hydroxide associated with calcite.

Towards the top ot the formation, north ot the river, are metaconglomerates associated with the acicular hornblende schists. They contain flattened ellipsoidal boulders and pebbles of varying colours and compositions in a finer matrix. The lineation ot the boulders strikes due north, plunging 35°N, more or less parallel to the schistosity. In composition, the pebbles range from predominant quartzites, less common amphibolites, to minor marble, imbedded in a green matrix of chlorite or (?) actinolite. The size of the pebbles is eight to ten centimetres in length (some may be much larger), and five centimetres in width. A thin section of an amphibolite pebble has 55 per cent hornblende. Quartz, along with feldspar, make about 20 per cent ot the groundmass. Biotite, calcite, and ilmenite (locally altered to sphene) are other constitutents. The rock is fine-grained and schistose, some parts being more schistose than others.

(iii) Hornblende schist: These rocks form the uppermost group of the Middle Series and are the most common metamorphic rocks of the northern part of the area. Besides forming a separate group, they are also found throughout most of the other metasedimentary groups.

The formation consists predominantly of hornblende schists, minor metadolerites and fine-grained metagabbros, and siliceous schists. The rocks are massive, compact, poorly bedded, well jointed, and are greenish, with yellowish-green weathered surfaces. The structure and texture varies from very dense, fine-grained, to local coarse patches where the grain size reaches half a centimetre. The rocks show slight variations in their mineralogy. There are several shear zones between the metadolerites and hornblende schists where corrugated micaceous layers have developed. The lower part of the formation is more or less uniform in texture, whereas the upper part is pebbly.

In the thin sections of the rocks from the lower part, hornblende (about 52 per cent) is the most abundant mineral, forming porphyroblasts as well as occuring in the groundmass. It is generally arranged with preferred orientation, its length being parallel to the schistosity. Brown pleochroic biotite, similarly aligned, is present in minor quantities. The rest of the rock is mainly composed of quartz and plagioclase (about 30 per cent), clinozoisite, iron oxide, sphene, and garnet. Plagioclase is largely altered to saussurite.

The hornblende schists in the upper part, as previously mentioned, are pebbly. The pebbles, up to 1½ centimetres, are sub-rounded, fine-grained, dark to white in colour, and flattened parallel to the schistosity and bedding. In thin section, the rocks of the upper part are fine-grained and porphyroblastic. There is a general tendency for parallel alignment, although schistosity is not well developed. The minerals in the rock include hornblende (75 per cent), generally in thin, very slender prisms (a few reaching $1\frac{1}{2}$ millimetres); biotite, pleochroic from brownish to colourless and in some cases chloritized; quartz, often in distinct bands and patches, containing abundant inclusions of hornblende and biotite; calcite, in clusters or as independent grains associated with quartz; chlorite, randomly distributed, fibrous, green and pleochroic, mostly after hornblende and biotite; and iron ore, altered to hematite and locally staining the section. Some rocks also contain garnet.

Most of the pebbles in these rocks appear to be of the same composition as the matrix. They are generally greenish in colour, extremely fine (slaty) textured, and have well defined boundaries with the enclosing rock matrix. In a few cases, however, the boundaries are more or less gradational due to later crystallization during metamorphism. They are predominantly composed of a matrix of greenish, very fine-grained (?)amphibolite in which are identifiable grains of hornblende, iron ore, quartz, biotite, (?)sphene, and chlorite. The latter might be an alteration product of hornblende, since it is sometimes in the form of stout prisms.

The siliceous schists, occurring in the Hornblende Schist formation north of the river, are in the form of small 'islands' (35 to 50 feet wide) in the large microgranite, and are partly digested by the latter. At some places, they are interbedded with a black coloured rock, probably limestone. They are usually fine- to medium-grained, light to dark grey, and weather to a yellowish-brown, sugary material at some places, whilst at others they are quite massive and variably coloured. Quartz veins, iron leaching, and jointing are common features. These schists are much more altered than the quartzose schists in the quartz-mica schist group.

The siliceous schists consist mainly of quartz, perthite (sericitized to some extent), biotite, iron ore (sometimes altered to sphene), and minor secondary calcite. The perthite crystals are subhedral and well-twinned. The perthite is mostly in porphyroblasts, whereas quartz may form porphyroblasts as well as occur in the groundmass. The minerals appear to be sorted and the rock is composed of two kinds of groundmass layers, fine- and medium - grained, separated from each other by layers rich in biotite.

UPPER SERIES

Phyllitic Schist and Marbles.

The phyllitic members of this group are conspicuous because of their micaceous sheen. They are variable in character and are associated at the top with slates; they contain ellipsoidal pebbles of quartzite, limestone, etc. Below these, garnet-bearing phyllites appear, grading into pebble- and boulder-bearing phyllites beneath. The pebbles here are of variable size and composition. The size of some boulders reaches 25 centimetres; jointing is well developed in these. Garnet appears again in the phyllites further below, although only locally. Associated with the phyllitic rocks are two marble beds, one at the top and the other towards the bottom of the formation; both are 35 or 40 feet thick. The phyllites below the lower marble horizon are somewhat different from the upper phyllites in character.

Most of the marble is white in colour, although some may be greyish with thin layers of shaly material along the bedding planes. Most of these layers are less than one inch in thickness. However, they prevent thick blocks of marble being available for extraction, the maximum thickness between layers of shale being one to two feet. The strike of the marble on the two sides of Mena Khwar is different, suggesting the possibility of a fault. A typical white marble is granoblastic in texture, consisting of calcium carbonate, with small quantities of other carbonates and opaque minerals; iron leaching is commonly present along fractures.

The lower phyllites are present at the top of the Hornblende Schist; they also are not very thick. The colour of their weathered surface is yellowish-brown, whilst the freshly broken surface is light grey. The rocks are well jointed and fractured, with predominant joint directions: N 65°W, dipping 32°N; N 75°E, dipping 84°S; and N 15°W, dipping 67°W. In thin section, they consist of quartz, biotite, a little sericite, and iron oxide altered to a red secondary hydroxide. Their texture is fine-grained and schistose.

Garnet-Chlorite Schists.

The garnet-chlorite schists form a 1500 feet thick band overlying the Phyllitic Schist and Marbles. In general it is soft, cleaved and differentially weathered, mechanical weathering having had more effect than chemical weathering. Veinlets and boudins of quartz, probably filling cracks and cavities opened by movement and folding of the rocks, are common. Microfolding, also, is characteristic. At some places, thin layers of greenish non-schistose quartzite are associated with these structures whilst at others thin layers (less than six centimetres) of intrusive (?)gabbro occur in them as sills.

In the softer schistose rocks, ellipsoidal or, in rare cases, angular fragments of medium-grained dioritic rock are present. Lineation readings on these fragments showed a strike of N 15°W and a dip of 30°NW. Jointing is very well developed in these schists, the prominent joint directions being the same as in the Phyllitic Schist and Marbles.

In hand specimen, these rocks are greenish and schistose, with porphyroblasts of garnet which may be locally absent. In a few outcrops needles of hornblende are very conspicuous.

In thin section quartz is the dominant mineral, constituting about 70 per cent of the rock. It occurs as an interlocking mosaic of small grains. Chlorite makes about 14 per cent of the rock and in some cases appears to have developed at the expense of biotite. It is also present in the cracks in other minerals, such as garnet. Biotite (about six per cent) is arranged in layers and at most places it is altered to chlorite. Garnet (forming four to six per cent) mostly occurs in large crystals which have abundant inclusions and are irregular in form. Some of the garnet crystals, however, are minute.

Calcareous Schists with Marble, Shaly Slates and Quartzite, etc.

This group forms the last, most northeasterly of the metasediments. It consists of intercalated beds of calcareous schist and marble, and slaty shales with occasional bands of quartzite. The first exposure of these schists appears to the west of Tarkhi Khwar and southeast of Rangina Ghawanda; from here onwards they extend in a northwest direction with a consistent strike of N 45°W.

The most prominent rock units of this group are dark grey marbles and calcareous schists, yellowish-brown on their weathered surfaces. Their interbedding with slaty shales is peculiar, and due to differential weathering they stand out prominently as ridges in the more deeply eroded shales. The calcareous schists contain quartz in some places and mica in others, indicating original impurities of quartz and clay in the limestone. The quartz-bearing portions also have iron oxide leaching along fractures. At one locality, they contain haphazardly arranged (?)cherty nodules. Towards the base, the calcareous schists are interbedded with garnet-chlorite schists, the contact of the two being gradational.

In thin section, the rocks are seen to be schistose, calcite being the dominant mineral and constituting about 80 per cent of the rock. Iron leaching along cleavages and grain boundaries has taken place. Quartz (about 10 per cent) is somewhat rounded and mostly occurs in the interstices of the calcite crystals. Ore (two to three per cent) is concentrated at a few places in a slide. Biotite and muscovite, making about three per cent, occur mostly in layers. Stout prisms of pale green, pleochroic tourmaline occur in traces.

Associated with the calcareous rocks are a few greenish-coloured quartzite beds. These are microfolded and relatively only slightly weathered. The colour of the weathered surfaces is deep brown. In thin section, they are fine-grained rocks containing quartz, feldspar, chlorite, apatite, tourmaline, garnet, muscovite, and traces of calcite and iron oxide. An interesting feature of this rock is that the quartz, feldspar and chlorite form radial intergrowths around large grains of quartz and feldspar. The feldspar is partially altered to sericite and clayey material. The large crystals of feldspar were probably not produced by metamorphism, since the general grade of metamorphism is not high enough to produce potash feldspar. They are probably relict grains (blastoporphyritic) from the original sandstones, which were poorly sorted and immature.

METAGABBROS AND OTHER BASIC ROCKS

There are two large and several smaller sills of metagabbro and amphibolite of presumed gabbroic origin running concordantly through the metasediments in the central and northwestern part of the area. The two larger sills are well exposed along the road leading to Warsak dam, west of Ali Baba Ziarat, and are some 400 and 600 yards wide, respectively. The smaller sills vary from a few feet to several hundred feet in width. In addition, there are some dykes and circular masses of metadolerite on the north side of the river, between Rahim Mena and Kashi Kili.

One of the two major metagabbro sills lies within the acicular hornblende rock, forming part of the Middle (Hornblende Schist) Series, and the other between two sills of microgranite. The latter has very sharp contacts and there is no sign of assimilation of the gabbro. The basic rocks are abruptly terminated by microgranite (south of Pakhan Kili) and alkaline granite (northwest of Spera Ghar), or cut by microgranitic veins (west of Ali Baba Ziarat, near the bridge), indicating the younger age of the acid rocks - which, further, are less highly metamorphosed - although it should be recorded that Ahmad (1951) considered the granites to be older. Locally, the granites contain xenoliths of metagabbro.

All the metagabbros are intensely weathered (sometimes spheroidally), fractured and jointed; there appears to be no systematic pattern in the jointing. Oblique joints are the most common.

Metagabbros.

The metagabbros are generally dark green in colour but are darker or greyish-yellow on weathered surfaces. Some (amphibolites) are more highly metamorphosed than others. Their texture varies from medium-grained (diabasic) to coarse (ophitic to subophitic, the secondary hornblende enveloping the plagioclase laths). The coarse variety is well exposed near the Warsak police camp north of Ali Baba Ziarat. Epidote-rich rocks, also containing quartz, biotite and iron ore, are sometimes found at zones in contact with the granites; and quartz veins, varying from a few inches to four feet in thickness, are also found. They are elongated or semi-circular, and some extend into the country rocks. A few contain iron oxides.

The rocks are chiefly composed of hornblende, plagioclase, epidote, quartz, biotite, sphene, ilmenite and, rarely, garnet. All the original pyroxene is altered to amphibole and much of the plagioclase to epidote. No olivine has been seen.

The plagioclase (about 31 per cent) is either subhedral or euhedral, depending on its textural relationship with the hornblende. It occurs as tabular phenocrysts averaging 4.5 but reaching 8 mm in length, and in the groundmass. It is commonly twinned on the albite and pericline laws, and sometimes on the Carlsbad law. It shows strong normal zoning, with saussuritized cores and comparatively fresh margins. It has the composition of sodic labradorite in the phenocrysts and calcic andesine in the groundmass. It forms more than a third of the rock. The feldspar usually contains abundant minute inclusions ot ore minerals, quartz and some ferromagnesian minerals.

Hornblende is subhedral to anhedral and usually forms phenocrysts, although occasionally it is interstitial to plagioclase. The prisms may reach 3.5 mm in length. It is pleochroic from pale green to dark bluish-green and torms about 42 per cent ot the rock. It is partially altered to biotite and quartz. On the average, it makes up about 45 per cent of the rock. Sometimes it occurs as elongated prisms, radially arranged, and rarely, in the torm of ghost structures.

Biotite is an accessory mineral in some gabbros, usually associated with hornblende and exhibiting yellowish-green to light brown pleochroism. It commonly occurs as small plates, generally surrounding the hornblende. In some portions of the upper gabbro it exceeds five per cent.

Quartz (about 6 per cent) occurs commonly in the groundmass, as anhedral grains associated with plagioclase. It is frequently found as inclusions in plagioclase and hornblende and is probably secondary as a consequence of metamorphism.

The chief ore mineral is ilmenite, in varying amounts. It is generally altered to sphene and less commonly to leucoxene. On the average it makes up four to five per cent of the total rock. Magnetite is less common and occurs in the form of octahedral grains.

Sphene is the most abundant secondary accessory mineral, generally surrounding the ilmenite from which it has formed. It occurs in the groundmass but sometimes forms large anhedral composite grains.

Epidote is a common metamorphic or secondary mineral, formed at the expense of plagioclase by saussuritization.

Hybrid gabbro.

This gabbro body, about 130 feet thick, lies north of the upper gabbro in contact with microgranite. It forms a part of the upper gabbro but is coarser-grained than the ordinary metagabbro of the area. Both amphibole (about 40 per cent) and plagioclase (about 40 per cent) form large porphyroblasts, ranging from two to three millimetres, and occur also in the groundmass with quartz (about 11 per cent), biotite (about 2 per cent) and garnet (about 3 per cent). The constituent minerals show different characteristics from those in the normal metagabbros. This is probably due to the action of the later granitic magma, when hybridization took place by ionic exchange from both sides. The gabbro is more siliceous than the normal metagabbros, containing abundant quartz in patches and interstitially. Hornblende, resulting from the metamorphic alteration of pyroxene, appears to have been partially changed later to (?)ferrohastingsite by soda metasomatism.

In texture, the rock is coarse-grained, holocrystalline and subophitic. Porphyroblasts of plagioclase are commonly twinned and some show normal zoning. There is also some microperthite. The plagioclase is partially altered to clinozoisite, with some inclusions of quartz, biotite and opaque minerals. The (?)ferrohastingsite forms porphyroblasts and is commonly associated with hornblende; it is pleochroic from deep blue-green to dark blue and has higher refractive indices than the associated hornblende. It is partially altered and contains inclusions of ilmenite and quartz. Hornblende has the same characteristics as in the normal metagabbros. Quartz is commonly interstitial, is generally corroded, and often shows undulose extinction. The other minerals are the same as in the normal metagabbros.

Metadolerites.

Associated with the gabbro bodies are some metamorphosed dolerites, in which the original structures and textures can still be easily recognized. They are consistently present within the Hornblende Schist, Pebbly Quartz-Biotite Schist, metagabbros and microgranites.

In hand specimen, the rocks are medium-grained and dark coloured, with distinct black and white spots. A rough schistosity, due to parallel alignment of the hornblende crystals, is present. The rocks are generally hard and compact, spheroidally weathered at places, and on weathered surfaces have a yellowish to greenish-brown colour.

In thin section, the metadolerites show well developed schistosity and nematoblastic texture. They are mainly composed of pleochroic green hornblende (55 per cent), occurring as porphyroblasts with a prismatic habit. The groundmass is mainly composed of plagioclase and quartz (32 per cent). The distinction between the latter two minerals is difficult to make, although the plagioclase is twinned and contains inclusions of iron ore. Ore (13 per cent) is mainly ilmenite, altered to sphene and leucoxene. Apatite is a constant accessory mineral. The mineral assemblages of the metadolerites thus more or less resemble those of the metagabbros.

THE GRANITES

Many intrusions of granitic rock are found in the area, mostly occurring as concordant sills but occasionally discordant (as, for example, just north of Umardin

Kili). Some of the intrusions are too small to be marked on the map. As previously shown, the granites are all younger than the metagabbros and other basic intrusions.

The granites fall into two groups: the porphyritic microgranites and the Warsak alkaline granite. The former are considered to be older since they frequently show a marked schistose texture, shearing, and locally contain garnet, indicating some degree of metamorphism. The Warsak alkaline granite, which is largely aphyric, shows very little sign of metamorphism. Locally, especially along the margins, a gneissose texture is developed but elsewhere the rock is unmetamorphosed, although Ahmad (1951) referred to it as 'granite-schist'.

Xenolithic inclusions of the metasediments (schists, quartzites and amphibolites) are found in the granites. They are orientated with their longer dimensions parallel to the flow direction and are in general little altered, although there is often a considerable development of muscovite at the contacts. The granites, which were intruded at low temperatures, have had little metamorphic effect on the country rocks. Possibly, they have locally raised the grade of metamorphism within the greenschist facies, close to the contact.

The granites are highly weathered, both mechanical and chemical weathering having been operative. Solution cavities and spheroidal weathering are common features, and some of the low hills show the typical rounded forms of weathered granite.

Jointing is very well developed in the granitic rocks and has been described in an earlier section. In some parts the best developed joint direction is parallel to the bedding, whilst elsewhere it is not.

Quartz veins, usually white but rarely pinkish, and veins of epidote, are common throughout the granites, generally, but not always, following the jointing. They vary from a fraction of an inch to several feet in thickness and may be planar, linear or circular in outcrop. Locally, they contain small amounts of muscovite and tourmaline. They are more abundant in the alkaline granite than in the microgranites. An almost complete absence of pegmatites and aplites is a characteristic feature of the granites.

THE PORPHYRITIC MICROGRANITES

The main body of this rock type, on the northern side of the Kabul River, starts near Chingai Banda. It is a partially discordant body of irregular shape, tending to be concentric. Almost immediately south of the river, it follows the arcuate change in strike from NW to NE and vanishes beneath the alluvium at Ali Baba Ziarat. It is about 600 feet thick at Rahim Mena and gradually widens northwards; at its centre it attains a width of over one mile. It becomes more discordant in the north, bending to the east instead of following the general NW strike. In the north it thins and finally pinches out at Chingai Banda. The total length of the microgranite is about two miles. The eastern side of the mass is more weathered than the western and there are small inlier outcrops in the alluvium one mile or more east of the main outcrop, suggesting that its total extent is considerable.

Besides the major microgranite intrusion, there are several other prominent masses towards the west which are more or less concordant with the country rocks; they follow the arcuate general strike and also disappear beneath the alluvium. They are well exposed on the road leading to the Warsak dam and form alternate bands with metagabbro and metasediments; they rarely exceed one hundred feet in width. In the extreme north there are more narrow sills, less schistose than those in the centre, and a few minor intrusions are found in the middle of the area.

In colour the microgranites are generally grey with minor variations, and on weathered surfaces are greyish-yellow or sometimes brownish, due to iron leaching. The rocks are compact and massive, and the groundmass is generally weathered to a greyish-white rusty material, leaving the phenocrysts of feldspar and quartz standing out on the weathered surface, giving a nodular appearance to the rocks. They are well jointed and fractured locally, especially in the major intrusion.

Petrography.

The rocks show a considerable variation in texture and appearance. All are fine to medium-grained, strongly porphyritic, and hypidiomorphic to allotriomorphic in thin section. Some are schistose and may have concentrations of light and dark minerals along different bands, whilst others are granular in texture. Flow texture is present in some of the microgranites, the phenocrysts usually being orientated parallel to the flow direction, but sometimes lying across it. Some examples are strongly sheared.

The phenocrysts are of microperthite, albite and quartz, whilst the groundmass consists of quartz, alkali feldspars and biotite, and accessory minerals (sphene, apatite, ilmenite, magnetite, pyrite, zircon, muscovite, calcite, fluorite and epidote). A few of the smaller sills, one of which is exposed beside the dam road, contain aegirine (in euhedral crystals up to 1 mm across, pleochroic from pale yellowish-green to dark green) and minute needles of riebeckite (pleochroic from brownish olive-green to deep cobalt blue). These minerals indicate the sodic nature of at least some of the microgranites but are rare when compared wth the Warsak alkaline granite. A pinkish-red garnet (? almandine), presumably of regional metamorphic origin, is present in a few of the microgranites.

Alkali feldspar (microperthite, orthoclase and albite) makes up about half the rock, of which microperthite phenocrysts constitute over two thirds. The phenocrysts may reach one centimetre in diameter and show selective alteration of the perthite strings. A visual estimate of their composition, made possible by the more altered state of the potash phase, is Or_{30} Ab_{70}. They sometimes show cross-hatched microcline twinning. Orthoclase occurs either in simple crystals or in Carlsbad twins in the groundmass, with a little microcline. Plagioclase, as phenocrysts and in the groundmass, constituting some five per cent, ranges from albite to oligoclase, albite being more common. The groundmass plagioclase tends to be more sodic. Some sections have fractured or bent plagioclase, due to straining. The plagioclase is considerably altered in a number of sections and epidote has developed at its expense. The alteration has mostly taken place along the margins or along fractures, but some crystals may be fresh on the margins and altered in the centre. In the fine groundmass, it was extremely difficult to distinguish feldspar from quartz and their relative percentages may only be approximate. Inclusions of biotite, quartz and iron ores are common in the feldspar phenocrysts.

Quartz forms about 20 per cent of the rocks, as phenocrysts and in the groundmass. The former are corroded and often granulated, with undulose extinction. They contain abundant inclusions of iron oxide in dust form. In the groundmass it is sometimes graphically intergrown with alkali feldspar.

Biotite is the dominant ferromagnesian mineral found in all the microgranites and accounts for up to 10 per cent of the rocks. It forms plates of varying size in the groundmass, generally in clusters surrounding the phenocrysts, and is pleochroic from yellowish-green to brownish-yellow. It is frequently altered to a greenish chlorite and always contains inclusions of iron oxide, zircon and sphene. Yellow or brown-stained calcite is often associated with it.

The sphene occurs as euhedral grains and also as alteration rims round crystals of ilmenite.

As mentioned earlier, aegirine, riebeckite and garnet occur in some of the microgranites.

THE WARSAK ALKALINE GRANITE

The Warsak alkaline granite is a large concordant mass, probably a sill, intruded between the Lower and Middle (Hornblende Schist) Series of metasediments. South of the river it follows the strike of the beds and disappears under the alluvium. On the eastern side a further outcrop rises from the alluvium at Zagai Sar. The main granite forms the highest peaks and ridges in the area and divides the drainage into two systems. In addition, two small sills to the north and south of Spera Ghar outcrop above and below the main mass. There are also many small satellites, veinlets, quartz and calcite veins, and, very rarely, pegmatites, both within the granite and cutting the country rocks. The largest satellite is some three quarters of a mile long and two hundred yards wide.

Immediately south of the river the main sill reaches its maximum width of about one mile. The Warsak dam is constructed on the granite and north of the river it continues for some one and a half miles before pinching out near Hasar Nao within the Pebbly Quartz-Biotite Schist. Where it crosses the Garang Nao, it is divided into two masses, separated possibly by a fault or, alternatively, by separate bifurcating intrusion. As mentioned earlier, Coulson (1936) first described the granite from specimens collected by himself and Sir Lewis Fermor from outcrops beside the Mulagori road.

Xenoliths of amphibolite and metagabbro up to 40 feet thick, resulting from piecemeal stoping, are found locally in the granite but contamination effects, beyond local development of biotite and amphibole layers, are small.

As already stated, all the granites can be seen to be younger than the metabasic rocks but there is no clear structural evidence to indicate that the alkaline granite is younger than the porphyritic microgranites. The opinion that it is so is based on the relative degree of metamorphism of the two types of granite.

The alkaline granite is leucocratic and thus generally white in colour, although it is locally greyish. It is considerably weathered by insolation and other mechanical means, as well as chemical action, the weathered surface being variously coloured yellow, brown and grey. It is well jointed, especially in the south; cross, tension and longitudinal joints are present. The cross joints were plotted and shown to form a conjugate system, as discussed in an earlier section (see Fig. 1). Cross joints are more common along the margins, especially on the eastern side, and are ascribed to differential cooling of the magma, the margins consolidating first. The tension joints, due to shearing stress, are also best developed along the margins, especially along the south-eastern limb of the sill.

Linear flow structures are found in much of the granite, resulting in the parallel orientation of the dark sodic minerals, riebeckite and aegirine. Locally, the tabular feldspars, phenocrysts and xenoliths also appear to show a linear orientation. The flow structures also are best developed along the margins but locally extend into the centre. Near Adam Khan Kili and elsewhere, the flow structures can be seen always to trend parallel to the wall rocks. They plunge northwards, following the structure of the country rocks, and it is clear that a secondary gneissose structure, resulting from metamorphism, has been superimposed on the primary flow structures.

Petrography.

The Warsak alkaline granite is much coarser-grained than the porphyritic microgranites. The central portion is medium-grained and equigranular, whilst the margins are finer-grained and distinctly gneissose. Minor local variations are common, some parts being strongly porphyritic, with phenocrysts of feldspar and quartz ranging from three to four millimetres in diameter, in a much finer matrix. The average grain size of the central mass is two to three millimetres, whereas the typical marginal granite has a fine-grained saccharoidal texture, of grain size less than one millimetre. Occasionally dark minerals are concentrated in the granite forming a comparatively greater proportion of the rock than normally. Quartz veins are very common throughout the granite, ranging from a few inches to several feet in thickness and running along joints. The main minerals are quartz, microcline, microperthite and albite, and the dark sodic minerals aegirine and riebeckite. Accessory minerals include astrophyllite (mainly in the marginal, gneissose portion), biotite, sphene, zircon, magnetite, hematite and epidote.

Microperthite (totalling about one third) is present throughout the granite, chiefly in the porphyritic parts, where it forms large phenocrysts; it also occurs in the groundmass. The phenocrysts are usually anhedral but are occasionally subhedral, the grains varying in size from three to four millimetres in diameter. The perthite is of the string variety with an estimated composition of Or_{25} Ab_{75}. It is partially altered to sericite and clay minerals. One perfect cleavage could be seen at a steep angle to the perthite lamellae, and the crystals show Carlsbad twinning. Inclusions of aegirine, in the form of small elongated laths, and of biotite, are very common in the perthite, generally concentrated along the perthite lamellae although some lie oblique or normal to them. Some opaque mineral inclusions are also seen.

Microcline is fairly common in the groundmass of both porphyritic and non-porphyritic portions of the central mass, making less than 10 per cent of the rocks. It is generally fine-grained (usually less than two millimetres in diameter) and anhedral, but occasionally it may form phenocrysts. Inclusions of tiny laths of aegirine are common. The characteristic cross-hatched twinning is the best distinguishing feature and can be clearly seen.

Albite is generally present and makes about 15 per cent. It is commoner in the fine-grained parts than in the coarse and porphyritic section. The extinction angles of albite-twinned crystals suggest a composition of An_{12} (sodic oligoclase). It is interstitial and is generally associated with microcline. It might be a cooling product of the alkali feldspar, forming as the latter exsolved into microperthite, or it may be primary.

On the average, the total feldspars make up some 55 to 60 per cent of the rocks.

Quartz forms about one third of the total composition. It frequently forms the bulk of the groundmass, usually occurring in the form of anhedral crystals varying from one to two millimetres in size. It commonly has granulated margins and generally shows undulose extinction, thus suggesting the effects of strain.

Aegirine is the dominant dark mineral in the granite, but some of the alkali pyroxene is aegirine-augite. It forms some six to ten per cent of the rocks and occurs mainly in the groundmass in subhedral form, although it occasionally forms phenocrysts. The grain sizes vary from a half to three millimetres. In thin section, the aegirine shows the following pleochroic scheme and optical properties:

X	:	pale green
Y	:	light brownish-green
Z	:	green
$X^{\wedge}c$	:	1° to 3°
$2V_x$	:	65° to 70°

The aegirine is commonly associated with riebeckite and frequently contains magnetite inclusions, giving a speckled appearance to the grains.

Riebeckite occurs in the alkaline granite as small subhedral crystals in the groundmass, making up some three to five per cent of the rock. It has the following optical properties:

X	:	blue
Y	:	indicolite blue
Z	:	yellowish - to brownish-green

$X \geqslant Y > Z$

$X \wedge c$: 8°

Maximum absorption is thus parallel to the length of the crystal (X). Coulson (1936) referred to the alkali amphibole as arfvedsonite; it is not easy to distinguish this mineral from riebeckite but the latter, which is more common in granitic rocks, is regarded as the more accurate identification.

The common accessory minerals are astrophyllite, biotite, sphene, zircon, epidote and opaque minerals, forming a total of eight to ten per cent of the rocks. Biotite is restricted, forming small laths in the groundmass as well as inclusions in the microperthite. Sphene is the next most abundant accessory and is extremely variable; it occurs scattered throughout the rocks in subhedral form. Magnetite is the most common opaque mineral and, with some ilmenite, makes four to six per cent of the rocks on average. It is generally associated with aegirine. Astrophyllite is also found in small amounts, usually forming minute elongated laths. Zircon could also be seen in some sections, forming two per cent of the rock.

A hybrid granite is found just north of Chalghazi Ziarat. It contairs laths of albite (totalling about 40 per cent) in a groundmass of quartz (8 per cent), albite and microcline (17 per cent). The dark minerals form irregular lineated bands: a strongly pleochroic blue-green hornblende (? ferrohastingsite), with a $2V_x$ of ca. 10°, forming some 23 per cent, and biotite (6 per cent), are the most common. In addition there is abundant sphene, dark blue tourmaline (orientated at right angles to the banding) and allanite, altering round the edges into epidote; epidote is also present as innumerable small grains sieving the larger feldspar and amphibole crystals, and in the groundmass.

CHEMISTRY OF THE GRANITES AND DISCUSSION

Coulson (1936) gives an analysis of the Warsak alkaline granite ('biotite-aegirite-arfvedsonite gneiss (soda-granite)') from near Lwar Mena, by the Mulagori road. The analysis is given in Table II, together with the norm. The analysis resembles that of the average peralkaline granite of Nockolds (1954) closely, except that the Warsak rock has a higher silica content and less total iron; the alkalis are almost identical. The average rock is also given in Table II for comparison. Coulson compared the Niggli values of the type soda-granite and the type nordmarkite-pulaskite of Grubenmann and Niggli's alkali-granite-pulaskite magma group. He concluded that in the Mulagori sodic granite, the Niggli value for alkalies exceeds that for aluminium, showing the rock to be a very alkaline (sodic) type. Thus one would expect the excess alkalies, and high silica, to go into aegirine. The rock falls just within cross-section 1 of Niggli's rock system, the c/fm ratio (0.105) being between 0.000 and 0.110. It can also be seen that the rock is a member of Niggli's alkali-granite-pulaskite magma group.

The alkaline granite is plotted in the normative system Q-Ab-Or (Fig.2) and can be seen to fall close to the maximum obtained by Tuttle and Bowen (1958) from plotting all the suitable analyses from Washington's Tables.

The presence of perthite in the granites indicates that they are of the hypersolvus, one-feldspar, type, the perthites resulting from later exsolution during cooling. Some of the albite, however, may be primary, which would indicate that the granites were in this respect of the subsolvus type. It is concluded, therefore, that the granites are probably intermediate between true subsolvus and hypersolvus types.

Coulson also collected samples of the Shahbazgarhi 'porphyries' (the 'albite-porphyries' of the Shewa Formation of Martin *et al.*, 1962) and gave two analyses. These are also given in Table II, with their norms, and the similarities with the Warsak alkaline granite are obvious. These similarities, and those of the Niggli values, led Coulson to regard the two groups as consanguineous. Recently, Siddiqui (1965)

TABLE II

Chemical analysis and norm of the Warsak alkaline granite, with comparisons

	1	2	3	4
SiO_2	74.16	71.65	70.90	71.08
TiO_2	0.42	0.71	0.59	0.40
Al_2O_3	11.86	12.75	14.29	11.26
Fe_2O_3	2.72	2.68	2.48	4.28
FeO	1.15	0.94	0.29	2.19
MnO	0.19	0.13	0.06	0.11
MgO	0.14	0.34	0.35	0.25
CaO	0.38	0.42	0.56	0.84
Na_2O	4.74	4.26	4.65	4.92
K_2O	4.32	5.28	4.97	4.21
H_2O^+	0.08	0.51	0.26	0.39
H_2O^-	0.08	nil	0.20	—
P_2O_5	0.02	0.06	0.04	0.07
Others	0.03	0.10	0.07	—
Total	100.29	99.83	99.71	100.00
		CIPW norms		
q	30.0	25.8	23.2	26.2
or	25.6	31.3	29.4	25.0
ab	36.8	36.0	39.3	34.6
an	—	—	2.4	—
c	—	—	0.3	—
wo	0.7	1.0	—	1.4
en	0.4	0.6	0.9	0.6
fs	0.4	—	—	1.7
ac	2.9	—	—	6.0
mt	2.5	1.4	—	3.2
il	0.8	1.4	0.8	0.8
hm	—	1.7	2.5	—
ap	tr	0.1	0.1	0.2

1. Warsak alkaline granite ('soda-granite'). Mulagori road, Warsak area (no. 49/453), (Coulson, 1936).

2 and 3. Porphyritic microgranite ('porphry'). Shahbazgarhi (nos. 49/454 and 455), (Coulson, 1936).

4. Average peralkaline granite, (Nockolds, 1954).

ompared the Shewa 'porphyries' with the nepheline syenites of the Koga Alkaline Complex (see also Siddiqui, 1967; Deans and Powell, 1968) and suggested that these two groups might be related. Coulson and Siddiqui were not aware of the Warsak porphyritic microgranites, however, and Kempe and Jan (in press) have suggested a direct correlation between these microgranites and the Shewa 'porphyries', as well as a tentative correlation between the later Warsak alkaline granite and the Koga Alkaline Complex and, possibly, the Ambela Granite (Martin *et al.*, 1962). They further

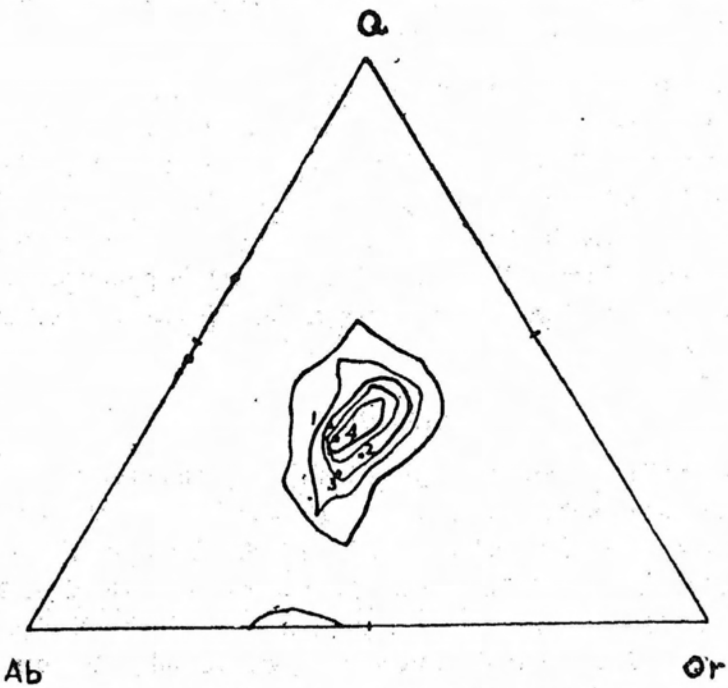

Fig. 2. Normative compositions of the granitic rocks plotted in the system Q-Ab-Or. 1: Warsak alkaline granite (Coulson, 1936); 2 and 3: Porphyritic microgranites, Shahbazgarhi (Coulson, 1936); 4: Average peralkaline granite (Nockolds, 1954). Superimposed are the contours illustrating the distribution of the normative compositions of all the analysed plutonic rocks (571) in Washington's tables that carry 80 per cent or more normative Q+Ab+Or (after Tuttle and Bowen, 1958).

suggest that the whole may form a fairly extensive alkaline igneous province, extending for some 100 miles, with the 60 mile wide Peshawar alluvial plain separating the two groups. If the first correlation (of the Warsak and Shewa microgranites) is correct, then the analyses of the Shahbazgarhi (Shewa) rocks can be regarded as giving a close approximation of the compositions of the Warsak microgranites. The two groups are remarkably similar in both mineralogy and textural variation, aegirine and riebeckite, and garnet, also being present in only a few of the Shewa rocks.

Both types of granite from the Warsak area are undoubtedly igneous in origin, and there seems little question that they derive from the same alkaline magmatic source. Both contain hydrous phases (biotite, riebeckite, astrophyllite), and perthitic feldspars. In general, the porphyritic microgranites have more ferromagnesian minerals (especially biotite) and less quartz than the Warsak alkaline granite. This suggests that in course of time the magma differentiated so that silica and alkalies were concentrated in the later alkaline granite.

Concerning the age of the granite intrusions and correlation wth other alkaline rocks, little more can be said. Coulson (1936) discussed the possible age of the Patigate Sar (Warsak) alkaline granite but reached no conclusion beyond suggesting that it and the Shewa Formation microgranites might be Mesozoic in age. Deans and Powell (1968) considered the carbonatite intruding the Koga Alkaline Complex to be Hercynian or later. Finally, Kempe and Jan (in press), in postulating an alkaline igneous province in northwest Pakistan, suggest late Himalayan (Tertiary) as the most likely age.

ALLUVIUM

Quaternary alluvium covers a large part of the land and the flat tops of the low hills to the east and southeast of the area. The alluvium generally consists of unconsolidated gravels, pebbles, cobbles, sands, and silts of fluvial origin on which a moderate soil has developed. The degree of roundness shows that these have been transported considerable distances. Most of the rocks in the alluvium are from various igneous and metamorphic sources. Some gravels and pebbles contain small cavities and pits in which secondary minerals like calcite, epidote, etc., have been deposited. Many of the stream beds are covered by angular to rounded rocks of all sizes. The alluvium generally surrounds the low hills in the south in such a manner that only small parts of the country rocks, forming the tops of the hills, are exposed as inliers after denudation. This indicates the considerable extent and height of the flood plains which covered the area in Quaternary times.

ECONOMIC GEOLOGY

The only economic minerals and rocks in the area are marble, talc, and granite and other hard, compact rocks suitable for building and road construction purposes. Emerald has recently been found in Mohmand Agency, however, and there is a fair likelihood that close examination of the rocks in the vicinity of the Warsak area might reveal similar small deposits of minerals of economic value, such as tourmaline.

Crystalline limestone and marble of good quality and in large quantities are found in Shaid Mena and Kambella Khwar (Coulson, 1937). These deposts have been worked on a very limited scale for several decades, for use as building stone and in lime making. Exploitation on a regular basis has been started recently and marble blocks are being marketed in Peshawar on a small scale, whilst marble chips are also being supplied to other major cities in West Pakistan. Selected blocks of marble have been used in monuments and public buildings and make one of the best materials for decorative purposes, both internally and externally.

The marble deposit at Kundian Khwar is the continuation of the Kambella Khwar marble. The deposits of the Mulagori area have been thoroughly investigated by Coulson (1937) and later by geologists of the Geological Survey of Pakistan. The marble forms a thick sequence of a total thickness, with interbedded rocks of other types, exceeding 600 feet. Several sets of widespaced joints are developed in the marble, with a fair regularity, so that blocks more than two feet wide can be extracted from certain of the beds. Their thickness, as already stated, is limited to a maximum of about two feet by the presence of interbedded shales and other rocks.

The Warsak marble, which is of almost pure calcite, varies widely in colour and quality. There are two types, white and banded; the banded marble forms the upper part of the sequence, whilst the white varieties occupy the lower part. The bands vary in colour from pink to grey or greenish-grey, and are due to the presence of iron oxides. The texture of the white marble varies from fine- to medium-grained; some parts are saccharoidal and therefore of good quality. Individual beds are frequently six to eight feet thick and occasionally reach as much as 30 or 40 feet in thickness. The banded marble is inferior in quality and would be difficult to work and polish.

No estimate of the reserves of marble is available, but it is probable that a 15 foot thick band of workable white marble would reach millions of tons. It has not been quarried up to the present but by proper excavation methods, blocks five feet long, three feet wide and two feet thick could be extracted. The nearby Mulagori road would link the quarries with the main road system, leading to the Peshawar marble factories which are only a few miles distant. Analyses of the white marble from Kundian Khwar and, for comparison, of the white marble from Kambella Khwar (Coulson, 1937), are given in Table III.

A talc body is located on the northward slope of the Warsak alkaline granite, half a mile from the Warsak road, near Adam Khan Kili. It forms a large lensoid mass, about 500 feet long and 100 feet wide, within the quartz-mica schist (Middle Series), running parallel to the metasediments and adjacent granite boundary, and pinching

TABLE III

Chemical analyses of economic minerals (marble and talc)

	1	2	3
SiO_2	0.08	0.06	58.14
Al_2O_3	0.21	0.18	0.96
Fe_2O_3	—		0.83
MgO	1.70	0.88	25.85
CaO	54.25	54.40	2.98
Loss on ignition	42.98	43.69	10.28
Total	99.22	99.21	99.04

1. White marble. Kundian Khwar, Warsak area. Anal. M. Riaz.
2. White marble. Kambella Khwar, near Lwar Mena (no. 49/485), (Coulson, 1937).
3. Talc. Jamrud, Peshawar. Anal. P.C.S.I.R. North Regional Laboratories, Peshawar.

out on both sides. It is associated with dolomitic marble and probably formed by hydration and silicification from a large quartz vein running parallel to its whole length on the northeastern side. In colour, it is whitish-green, with occasional white and greenish-grey patches; the colour derives from the presence of chlorite and iron oxides. It also contains quartz and is harder than the average talc, being a flaky and fibrous variety with a massive schistose texture. It has been mined locally in the past but has since been abandoned, probably because it is less pure than the talc found in several deposits near Jamrud, to the south of the area, where it has been mined extensively since 1954. The Jamrud talc has been thoroughly investigated and has an average brightness of 88.50. Its average composition is also given in Table III.

The Warsak alkaline granite, on which is built the Warsak dam, could be well employed as a building and ornamental stone and would fulfill the necessary architectural requirements. It has an excellent light colour and an attractive arrangement of dark minerals. It has regular widespaced sets of joints and is hardly fractured, so that it could be extracted in large regular blocks very easily. The eastern border of the granite is very near to the Warsak road and to the railway, thus minimising transport charges. Some of the phyllites, though thinly bedded, could be used for building, such as the construction locally of walls, roof tops and, especially, tiles. Some of the acicular hornblende rock might be used for decorative purposes.

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REFERENCES

AHMAD, M. I., 1951 — Report on the Warsak Hydro-Electric Project.

BADSHAH, M. S. and RAHMAN, F., 1969—Geology of the Jamrud area, Khyber Agency. Dept. Geol., Univ. Peshawar, unpublished thesis.

BAKR, M. A. and JACKSON, R.O., 1964—Geological Map of Pakistan. Geol. Survey Pakistan.

COULSON, A. L., 1936—A soda-granite suite in the North-West Frontier Province. Proc. Nat. Inst. Sc. Ind., vol. 2, no. 3, pp. 103-11.

——————1937—Marble of the North-West Frontier Province. Rec. Geol. Surv. Ind., vol. 71, pt. 3, pp. 328-44.

DEANS, T. and POWELL, J. L., 1968—Trace elements and strontium isotopes in carbonatites, fluorites and limestones from India and Pakistan. Nature, Lond., vol. 218, pp. 750-2.

FLOOR, P., 1966—Petrology of an aegirine-riebeckite gneiss-bearing part of the Hesperian Massif: the Galineiro and surrounding areas, Vigo, Spain. Leid. Geol. Meded., vol. 36, pp. 1-204.

GRIESBACH, C. L., 1892—Rec. Geol. Surv. Ind., vol. 25, pt. 2.

HAYDEN, H., 1898—Mem. Geol. Surv. Ind., vol. 28, pt. 1.

KEMPE, D. R. C. and JAN, M. QASIM—in press. An alkaline igneous province in the North-West Frontier Province, West Pakistan. Geol. Mag.

MARTIN, N. R., SIDDIQUI, S. F. A. and KING, B. H., 1962—A geological reconnaissance of the region between the Lower Swat and Indus Rivers of Pakistan. Geol. Bull. Panjab Univ., vol. 2, pp. 1-13.

NOCKOLDS, S. R., 1954—Average chemical compositions of some igneous rocks. Bull. Geol. Soc. Am., vol. 65, pp. 1007-32.

SHAH, IBRAHIM, 1969—Discovery of Palaeozoic rock in the Khyber Agency. Geonews, vol. 1, no. 3, pp. 31-4.

SIDDIQUI, S. F. A., 1965—Alkaline rocks of Swat, Chamla. Geol. Bull. Panjab Univ., vol. 5, p. 52.

——————— 1967—Note on the discovery of carbonatite rocks in the Chamla area, Swat State, West Pakistan. Ibid., vol. 6, pp. 85-8.

TAHIRKHELI, R. A. K., 1968—Stratigraphy of the outcrops exposed along the eastern bank of the Indus at Attock, W. Pakistan. Geol. Bull. Univ. Peshawar, vol. 3, pp. 19-25.

TUTTLE, O.F. and BOWEN, N.L., 1958—Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$ - $KAlSi_3O_8$ - SiO_2 - H_2O. Geol. Soc. Am. Memoir 74, 153 pp.

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