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SEZIONE II

(Fisica, chimica, geologia, paleontologia e mineralogia)

Geologia. — *The ultramafic and high-grade metamorphic rocks of Jijal, Indus Kohistan Swat, NW Pakistan.* Nota di AZIZ AHMED QURESHI (*) e M. QASIM JAN (**), presentata (***) dal Socio A. DESIO.

RIASSUNTO. — Diopsiditi di tipo alpino associate con scarse duniti e peridotiti si trovano lungo una faglia regionale e sono interposte fra scisti pelitici di basso grado metamorfico e gneiss di alto grado. Quest'ultimi contengono plagioclasio, granato, salite e/o orneblenda, quarzo e talvolta anche clinozoisite. Alcuni di essi sono granoblastici, privi di plagioclasio e sono composti prevalentemente di granato o orneblenda, o, più raramente da pirosseni.

Nel lavoro sono contenute descrizioni petrografiche accompagnate da 8 analisi semiquantitative. Non sembra che le rocce ultramafiche siano in relazione genetica con gli gneiss. Quest'ultimi sembrano essere rocce da mafiche a ultramafiche – principalmente gabbri olivinici – che hanno subito un metamorfismo di alto grado a facies di anfibolite con almandino, ma con alcune rocce a facies di anfibolite con epidoto e di granulite.

INTRODUCTION

Three types of ultramafic complexes are now universally recognized: the stratiform complexes, the alpine/ophiolite type, and the zoned (concentric) complexes. Ultramafic rocks are also found in a number of other circumstances (see Wyllie, 1967) including those produced by metasomatism and/or metamorphism, as in Greenland (Sorensen, 1967). The three major types can be distinguished on the basis of geological setting, varieties and proportions of rocks, mineralogy, texture, structure and form, thermal effects, and economic mineral deposits (Thayer, 1960; Jackson and Thayer, 1972). Of the three the alpine complexes present special problems; their rock associations, mode of emplacement, contact effects, and origin have been differently interpreted by various authors. Thermal effects around them are usually feeble but some of them have been regarded to have produced high-grade metamorphism, such as those of the Lizard area, Cornwall (Green, 1964, but see also Thayer, 1967, pp. 223–28).

The Jijal ultramafic rocks form a body over 10×5 km with a general NW trend and NE dip. This lies along a faulted contact between high-grade metamorphic rocks (garnet gneisses) in the north and schistose rocks in the south. They appear to be alpine type even though there are certain features which are not compatible with the usual characteristics of the typical alpine complexes. In this paper the petrography of the garnet gneisses and ultra

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mafic rocks is presented and the relationship between the two, and to other basic rocks of Swat, is discussed. The work is based on the study of 87 rocks in thin section and 50 in crushed grains. The composition of the clinopyroxene was determined from the β refractive index and 2 V plotted on Hess's (1949) chart. The 2 V was determined by plotting the three refractive indices on Martie's (1942) chart. Eight of the rocks were semiquantitatively analysed by 'wet chemistry' by one of us (A.A.Q.) who also did most of the field work. The petrogenesis of the rocks is not yet clearly understood and further work is in progress (M.Q.J.).

General Geology

The Swat district is mainly occupied by two groups of rocks: The Palaeozoic Lower Swat-Buner schistose group covering the southern part, and the Upper Swat hornblendic group the northern part. The latter comprises amphibolites, norites and quartz diorites although a number of other rocks have also been reported (Martin *et al.*, 1962; Davies, 1964; Jan and others, 1969, 1970, 1971, 1973; Rehman and Zeb, 1970; Desio, 1974). Desio named these rocks the Middle Indus norite group while Jan and Mian (1971) called them the Kohistan basic complex. (The latter name will be used in this paper). Martin *et al.* (1962) hinted at the possibility of the complex's having been thrust-faulted over the schistose group. Although no detailed work has been carried out in this regard, there are a number of reasons for thinking that this may be so. The differences in the regional trends, the composition and the grade of metamorphism of the rocks in the two; the termination near this contact of some elongated northerly-extending granitic bodies in the schistose group; the occurrence of glaucophane rocks (Shams, 1972; Desio, 1974) and large ultramafic bodies near/along the contact lend enough support to the idea that the contact is of major tectonic significance.

In the Swat valley the complex consists of a belt of epidote amphibolites, passing into belts of amphibolites, noritic gabbros, and diorites along a northwards traverse, and the metamorphic grade in the southern part of the complex increases northwards (Jan and Kempe, 1973). In the Indus valley, however, a 'belt' of garnet gneisses (probably the highest grade metamorphic rocks of the district) occurs to the south of the epidote amphibolites. This may be due to variations in the intensity of metamorphism, or strong later metamorphism may have occurred only along the garnet gneiss belt. Conversely, the latter may have been emplaced tectonically.

The ultramafic rocks occur between the schists in the south and garnet gneisses in the north, the latter also surrounding them locally in the south (fig. 1). Isolated lenses of ultramafic rocks also occur in the schists close to the contact with the main body. The contact between the garnet gneisses and the ultramafic body in the north is 'gradational' or 'interfingering' through garnet-bearing pyroxenites while the two have sheared contact in the south. In the northwest the ultramafic rocks extend towards Chopra Peak

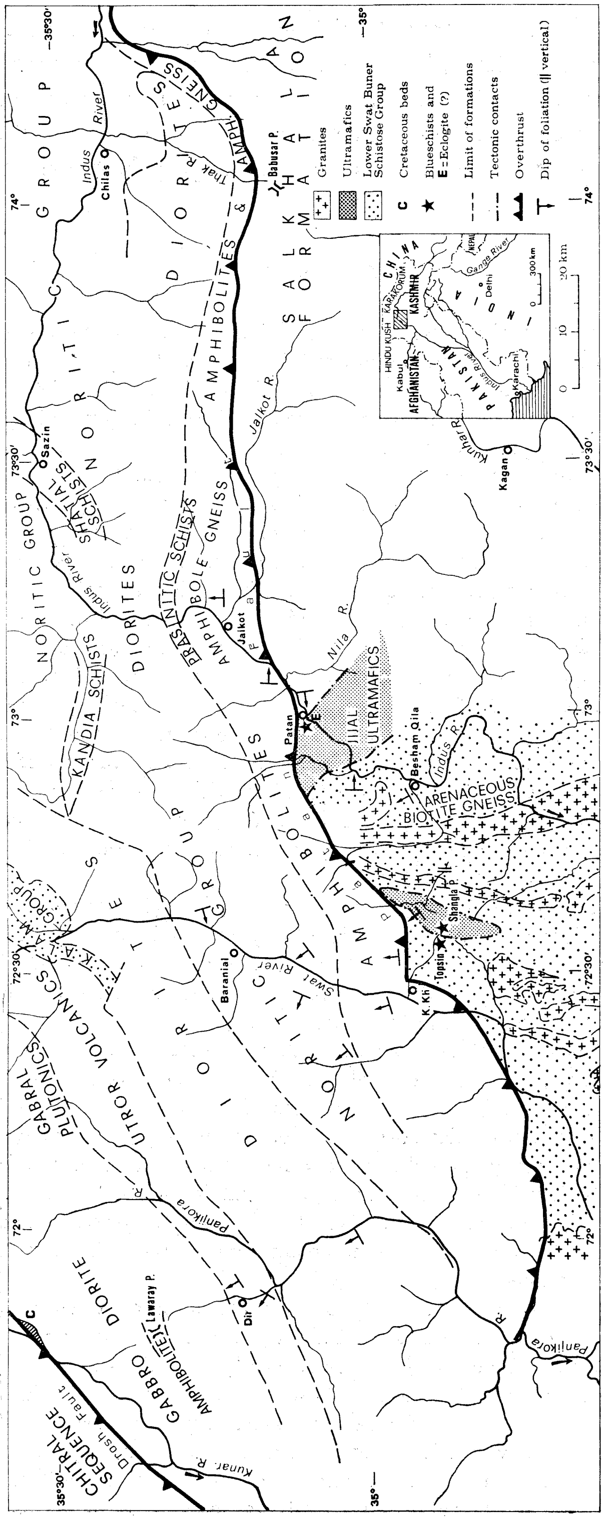
Granites
Ultramafics
Lower Swat Buner Schistose Group
Cretaceous beds
Blueschists and E=Eclogite (?)
Limit of formations
Tectonic contacts
Overthrust
Dip of foliation (|| vertical)
AFGHANISTAN
PAKISTAN
KASHMIR
CHINA
INDIA
Kabul
Karachi
Delhi
HINDU KUSH
KARAKORUM
NEPAL
Ganga River
Indus River
300 km
20 km
CHITRAL SEQUENCE
Drosh Fault
GABBRO
AMPHIBOLITE
DIORITE
Laway P.
Dir
Panjkora R.
GABRAL PLUTONICS
UTROR VOLCANICS
KALAM GROUP
Baranial
Swat River
K. Kh.
Topsin
Shangla P.
ARENACEOUS BIOTITE GNEISS
Besham Qila
Indus R.
JIJAL ULTRAMAFICS
Patan
Nila R.
Jalkot
KANDIA SCHISTS
PRASINITIC SCHISTS
AMPHIBOLE GNEISS
SHATIAL SCHISTS
Sazin
Jalkot R.
AMPHIBOLITES & AMPH. GNEISS
Thak R.
Babusar P.
Chilas
Indus River
Kagan
Kunhar R.
Kunar R.
SALKHALA FORMATION
NORITIC GROUP
DIORITES
NORITIC DIORITES
35°30'
35°
74°
73°30'
73°
72°30'
72°

Fig. 1.

after which they may take a southwesterly turn or there may be another body of similar rocks to the southwest of Chopra (Quresi and Khan, 1972).

Over 500 joint poles, plotted separately for the ultramafic rocks and garnet gneisses, show different patterns. It appears that in the gneisses the joints were produced in at least two phases while those in ultramafic rocks in one or two phases. The stresses have a roughly N–S orientation.

PETROGRAPHY

GARNET GNEISSES. Only the southern part of these rocks has been covered in the present investigation; the rocks extend for many kilometres to the north. They are generally medium- to coarse-grained and gneissose but the ' monomineralic ' varieties are granoblastic and some of the hornblende-rich ones are exceptionally coarse-grained with crystals over 6 cm long. Garnet porphyroblasts are common, up to 8 cm across and occasionally having a trailer arrangement or in clusters. Some of the porphyroblasts have an envelope or two of feldspar and hornblende and the foliation may fold around them. They may contain abundant inclusions, especially in the central parts. The rocks contain veins of epidote, calcite and quartz. Feldspar-garnet veins, with or without hornblende and at places studded with garnet porphyroblasts, are also present. The rocks are locally banded, probably due to metamorphic differentiation; the bands may be sharply or crudely developed and in rare cases pegmatitic.

The rocks in the northern part of the area investigated are made up of about equal proportions of feldspar, garnet, clinopyroxene and/or hornblende, with minor amounts of quartz, rutile and opaque minerals. The feldspar is much less in some, especially those near the contact with ultramafic rocks, and some rocks are totally lacking in it. Here garnet, hornblende and, less often, clinopyroxene may individually reach up to 85% in masses of rocks which are some metres across. Locally, the ' garnetites ' and hornblende-rich rocks also occur in the north within the plagioclase-bearing gneisses. Some of the rocks also contain clinozoisite (abundant in a few), apatite and, in rare cases, paragonite (?), hypersthene. The latter does not occur in rocks having clinozoisite and paragonite.

The feldspar is plagioclase (An 15–20), however, minor (?) orthoclase may also be present in a few. The former is clouded and is usually replaced by tiny prisms of an epidote mineral. Its low An content may be due to the breakdown of a more calaic plagioclase to epidote and oligoclase during retrograde stages. The less altered plagioclase grains show poor albite twinning while Carlsbad twinning is rare.

The garnet is pinkish in colour and subhedral to euhedral, usually having fractures along which secondary epidote, chlorite and, rarely, amphibole have developed. Its density is 3.76 and refractive index 1.743–1.745. In the gneisses the hornblende is bluish-green to green while in the ' hornblendites ' it is dark green. In some it has a purplish touch probably due to a higher Ti content. It may contain abundant rutile, ore blades and garnet inclusions, besides other minerals, and is locally sieved with quartz. In addition, a secondary amphibole is also found in some rocks. The clinopyroxene (Table I) is a faintly green pleochroic salite (En_{29} Fs_{21} Wo_{50}). Hypersthene is present in some epidote and mica-free rocks which usually also have hornblende and garnet.

Mica is restricted in occurrence; only a few small outcrops and the nearby occurring pegmatitic ' veins ' of similar mineralogy contain a white mica (? paragonite). It is probably secondary in origin, often found as large flakes, locally sieved, and constituting up to 10% of the rocks. The epidote mineral(s) is usually a retrograde product of plagioclase and, to a lesser extent, garnet. However, in the paragonite-bearing rocks and some others much of the clinozoisite looks primary and is in independent grains co-existing with fresh plagioclase. In a few rocks an epidote is the dominant mineral and in one of these it occurs in the form of radially grown crystals. Locally it surrounds garnet and pyroxene as irregular shells.

Quartz occurs in a small amount in the plagioclase-bearing rocks but in a few it is over 10%. The ore minerals include ilmenite, magnetite and pyrite. Minor amounts of secondary carbonate, sphene, and (?) talc are present in some rocks.

TABLE I

Optics and calculated composition of Clinopyroxenes.

	α	β	γ	δ	$2V_{\gamma}$	COMPOSITION
1.	1.699	1.675	1.700	0.031	59°	$En_{49}Fs_{2}Wo_{49}$
2.	1.675	1.679	1.702	0.027	56°	$En_{48}Fs_{6}Wo_{46}$
3.	1.673	1.678	1.700	0.027	56°	$E_{48.5}Fs_{5}Wo_{46.5}$
4.	1.670	1.676	1.698	0.028	59°	$En_{29.5}Fs_{20.5}Wo_{50}$
6.	1.693	1.701	1.719	0.026	62.5°	$En_{29}Fs_{21}Wo_{50}$

1. Diopside from alpine-type pyroxenite, 1.2 km N of Sandar.
2. Diopside from alpine-type pyroxenite, 400 m N of Sandar.
3. Diopside from alpine-type pyroxenite, 800 m N of Sandar.
4. Diopside from contact garnet-orthopyroxene-clinopyroxenite at Ziarat Bridge in Duber stream.
5. Salite from garnet gneiss, 2.5 km S of Patan (sample from the museum of Geol. Dpt., Univ. Peshawar).
6. Salite from garnet gneiss, 2 km N of Sandar (300 m N of mica-bearing gneiss).

ULTRAMAFIC ROCKS. These are mainly represented by diopsidites; peridotites and dunites are minor and the contacts between the various units may be sharp or gradational. Selective serpentinization, increasing southwards (Jan and Tahirkheli, 1969) and serpentinized shear zones are common. In Duber stream secondary veins of clinopyroxenite in peridotite, at places closely spaced, are also seen. The rocks are hypidiomorphic and medium-grained, however, some of the rocks, especially dunites, are highly granulated. Deformational features such as mortar and hour-glass textures, strain shadows, undulose extinction and fracturing of the grains are frequent. Locally the pyroxene may grow in large ophitic patches containing olivine.

Diopside is the main mineral in pyroxenites; enstatite and olivine occur in a lesser amount in some while a small amount of opaque minerals is usually present. The diopside is colourless to faintly green but in a few it has a purplish hue (? due to a higher Ti content). It occasionally contains irregularly exsolved lamellae of orthopyroxene and ore blades.

The peridotites consist of diopside and psuedomorphs of serpentine after olivine; fresh olivine is usually minor. Accessory minerals are magnetite, amphibole, talc, (?) sphene, carbonate, apparently being secondary in origin. The dunites may have smaller amounts of diopside, enstatite, chromian spinel, iddingsite, serpentine and talc. The composition of the olivine ($\alpha = 1.647$ to 1.648) is Fo_{93-94} though, in rare cases, it has a negative optic sign and may be chrysolite. It usually has fractures along which secondary magnetite is seen. Green spinel, picotite and pyrite are locally present in the Jijal rocks. Magnetite is usually minor except in the more serpentinized rocks. Some peridotites are harzburgitic.

Serpentinization in the Jijal rocks is not widespread and is selective. Within a thin section some of the grains may be highly serpentinized while others may be fresh due probably to differential shearing prior to serpentinization. Patches and networks of serpentine have been noticed. Stronger serpentinization seems to be post-tectonic, i.e. after the body had been emplaced in its present setup, however, in a few of the rocks the serpentine grains have parallel alignment suggesting that at least some of it may be syntectonic.

Many of the rocks have more than one serpentine mineral. Chrysotile and antigorite are common but minor amounts of bastite, serpophite and lizardite also occur in some rocks. In one peridotite section, two or more serpentine minerals form shells of their own around magnetite. It seems that alteration of olivine occurred in such a way that the iron content concentrated in the centre and Mg constituent migrated outwards to form serpentine shells. Talc is far rarer than serpentine and, in at least a few, it seems to replace the latter. It has already been noted by other workers (Jahn, 1967, p. 155) that steatisation follows serpentinization. Some of the rocks also contain chlorite.

A few of the pyroxenites near the contact zone contain clinopyroxene with usually lesser amounts of hypersthene/bronzite $\pm$ hornblende. In some of these rocks garnet is up to 15% and has a refractive index of 1.737 and density of 3.71; it seems to be more magnesian than the garnet of the gneisses. In one such rock hypersthene and garnet granules occur in ' lamellar trains ' in schillerized diopside, the hypersthene grains being in optical continuity among themselves. Elsewhere in this section, the three minerals may be independent or in places intricately intergrown. The hypersthene in this rock is strongly pleochroic and is concentrated along a loosely defined band due probably to metamorphic differentiation.

Chemistry and discussion

Partial analyses of eight rocks are presented in Table II. In the ultramafic rocks K_2O, TiO_2 increase and total iron (Fe_2O_3) and Na_2O fall with increase in SiO_2. The variation in Na_2O is unusual. P_2O_5 and MnO remain steady. In the gneisses, the various oxides are randomly distributed and they do not show systematic trends. The percentages of various oxides are different in the two groups of rocks; the gneisses are comparatively high in alkalis, TiO_2 and total iron. Analysis 4 (most common gneiss) is close to that of the average of olivine gabbros given by Nockolds (1954). The composition of the paragonite-bearing gneiss (No. 8) does not compare with the averages of normal igneous rocks of Nockolds' or Daly's (1933) tables. The $Na_2O : K_2O$ ratio is also unusual in Nos. 2 and 7.

The gneisses contain plagioclase, hornblende/salite and garnet, an amphibolite faceis assemblage. The local occurrence of paragonite is due to retrogression and so is much of the epidote except is some rocks, while hypersthene is found in a few rocks near the contact with the ultramafic rocks. Thus it appears that the rocks range from epidote amphibolites to hornblende granulites in grade of metamorphism, with a predominance of rocks in the upper grades of almandine amphibolite facies. The operative temperatures and pressures might have ranged from 600° to 900 °C and 5 to 12 *k* bars, respectively (Sobolev, 1972). Such a wide range in T and P is unusual in closely associated rocks which are not faulted against each other; it would seem that the epidote-bearing assemblages are also retrogressively produced after higher P–T assemblages (?) during upward movement of the rocks. Desio (1974) has called these rocks hornblende eclogites, and further work in this regard is being carried out by one of us. However, the mineral assemblages rich in plagioclase are atypical of eclogites while those with eclogitic mineralogy (No. 5) do not appear to have a basaltic composition. The gneisses appear to be metamorphosed olivine gabbros (as already pointed out by Jan and Takirkheli, 1969).

TABLE II

Semiquantitative Analyses of some rocks from Jijal.

	1	2	3	4	5	6	7	8
SiO_2	41.18	42.34	43.91	45.93	48.06	49.88	53.11	53.75
TiO_2	—	—	0.51	0.50	0.53	0.14	0.16	0.25
Fe_2O_3	8.22	11.26	8.82	10.54	6.84	6.21	3.25	4.31
MnO	0.20	0.69	0.06	0.04	0.23	0.15	0.11	0.19
Na_2O	1.22	0.17	1.49	2.01	0.82	0.39	0.02	1.60
K_2O	—	0.16	0.03	1.55	0.05	0.15	0.11	0.97
P_2O_5	0.01	0.17	0.10	0.14	0.04	0.17	0.04	0.19

Total iron determined as Fe_2O_3 Analyst: A. A. Qureshi

1. Dunite, about 600 m north of Jijal police post in road cut.
2. Hornblende-bearing garnetite, close to northern ultramafic contact in road cut.
3. Garnet-bearing hornblende rock, close to northern contact in roadcut.
4. Salite-garnet-hornblende-plagioclase gneiss; the most common metamorphic rock; from the north central part of the area.
5. Garnet-hypersthene clinopyroxenite near Ziarat bridge in Duber stream.
6. Olivine pyroxenite, 3 km north of Duber Bazar in Duber stream.
7. Clinopyroxenite, midway between Jijal and Sandar along road side.
8. Plagioclase-hornblende-garnet-epidote-quartz-mica gneiss along road-side, about 3 km north of Sandar.

The garnetites and hornblende-rich rocks may be metamorphosed ultrabasic rocks containing plagioclase. However, the possibility of metasomatism cannot be ruled out. The very coarse-grained nature of some hornblende-rich rocks is suggestive of metasomatism but the source of metasomatic emanations is not clear. The two rocks are mainly developed in the southern part, and at places intermixed, although hornblende-rich rocks also occur to the north within the gneisses. It would thus appear that the garnet-bearing rocks of the Jijal area represent a series of basic igneous rocks, ultramafic in the south, that has undergone mainly high-grade metamorphism and, possibly, local metasomatism.

On the basis of field relations, texture and the presence of highly magnesian olivine and pyroxene, and chromian spinel (Jackson and Thayer, 1972) the Jijal ultramafic rocks seem to be of the alpine type. The deformational features, uniform composition of olivine and clinopyroxene and the absence of plagioclase, mica and primary hornblende further support this idea. The rocks apparently occur in the same belt that contains other alpine-type complexes of Pakistan. However, the complexes at Zhob (Bilgrami, 1964), Waziristan, and Harichand (Uppal, 1972) are mainly composed of dunites and peridotites in contrast with the diopsidites of Jijal. No data is available to us on the Parachinar complex shown on the geological map of Pakistan by Bakr and Jackson (1964).

Layering, noted in the Zhob valley complex (Bilgrami, 1968) and many other alpine complexes (D.L. Rossman, personal communication) is not apparent in the Jijal rocks. However, rare chromite streaks and short thin bands associating dunites do occur. They are often folded and at high angles to the NW trend of the main body. This, coupled with the ultramafic lenses in the schists, suggests that the mass might have been emplaced as a crystalline mush capable of plastic flow.

The predominance of diopsidites, their gradational-interfingering contacts with the garnet rocks, and the presence of garnet-bearing pyroxenites in the contact zone are puzzling features for which we can offer no satisfactory answers. Either the Jijal ultramafic rocks represent only a dismembered part of a larger ' normal ' alpine mass or, less likely, the diopsidites may be a product of metasomatism of olivine-rich rocks by the addition of CaO and SiO_2. At least the clinopyroxenite veins in the peridotites of Duber stream seem to have formed as such. The gradational contact zone may again need careful examination. The problem of identification is probably complicated by the occurrence of pyroxenites that belong to the garnet gneisses. Unpublished work by one of us (M.Q.J.) suggests that the garnet-hyperathene-clinopyroxene rocks of the contact zone are granulites related to the garnet gneisses rather than to the ultramafic rocks. In the south the two groups of rocks have sheared contacts suggesting that the ultramafic rocks have been emplaced in the gneisses, probably at a time when the latter had already been metamorphosed.

The Jijal ultramafic rocks and garnet gneisses do not seem to be related genetically to the noritic rocks of Swat whose parent magma was tholeiitic (Jan and Kempe, 1973). The ultramafic layers associating the Swat norites are pyroxenites made of hypersthene and salite with a little plagioclase. The Jijal rocks, on the other hand, have diopside (and minor enstatite) and no plagioclase. The pyroxenites of Swat are in thin layers up to a few meters thick in contrast with the huge size and cataclastic nature of the Jijal rocks. Also, olivine-bearing differentiates in Swat valley, if at all present, are very local and insignificant compared to the quantity of olivine in the Jijal rocks.

Nor do the ultramafic and metamorphic rocks of Jijal seem to be genetically related to each other.

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