THE KOHISTAN BASIC COMPLEX
A SUMMARY BASED ON RECENT PETROLOGICAL RESEARCH

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ABSTRACT

The central part of the Kohistan basic complex in the Swat district has been studied in detail petrographically and geochemically. The main rocks of the area —amphibolites, noritic rocks, and quartz diorites—do not appear to be directly related mutually or to the rocks of the Jijal complex (garnet granulites and alpine-type ultramafic rocks). Temperature and pressure estimates suggest that the various metamorphic rocks of the area were formed under different geothermal gradients. It is recommended that the noritic rocks be henceforth called pyroxene granulites.

INTRODUCTION

The 'Kohistan basic complex' (Jan and Mian, 1971), composed mainly of amphibolites, noritic rocks, and quartz diorites, stretches E-W for more than 200 km between the Nanga Parbat area and western Dir, and N-S along the Swat River for about 70 km between Kalam and to the south of Kabal. It has been studied in some detail in Dir and Swat (Chaudhry and Chaudhry, 1974; Jan and Kempe, 1973; and other references given by these authors), and in Thak valley, Chilas (Shams, 1975). The Swat district rocks were recently studied in greater detail with the help of 235 new mineral and rock analyses and more than 600 thin sections (Jan, 1977). The following account gives a summary of this research which will be presented in detail at later dates.

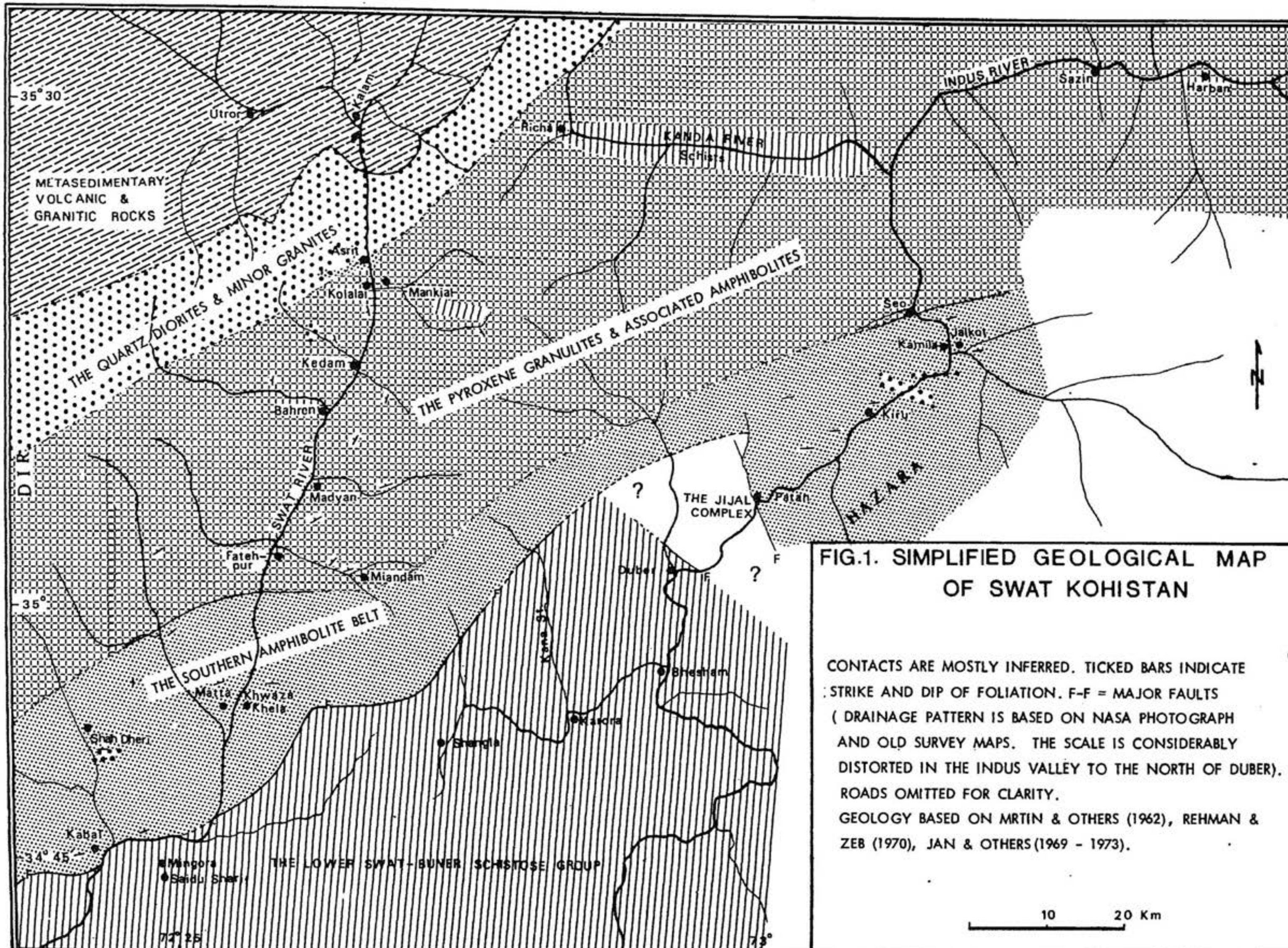

FIG.1. SIMPLIFIED GEOLOGICAL MAP OF SWAT KOHISTAN

CONTACTS ARE MOSTLY INFERRED. TICKED BARS INDICATE STRIKE AND DIP OF FOLIATION. F-F = MAJOR FAULTS (DRAINAGE PATTERN IS BASED ON NASA PHOTOGRAPH AND OLD SURVEY MAPS. THE SCALE IS CONSIDERABLY DISTORTED IN THE INDUS VALLEY TO THE NORTH OF DUBER). ROADS OMITTED FOR CLARITY.

GEOLOGY BASED ON MRTIN & OTHERS (1962), REHMAN & ZEB (1970), JAN & OTHERS (1969 - 1973).

GENERAL GEOLOGY AND PETROLOGY

The complex can be petrographically divided into the following types of rocks:

The minor ultramafic and mafic intrusions in 'norites' and amphibolites

The quartz diorites and granitic rocks

The pyroxene granulites ('interlayered' noritic, anorthositic and pyroxenitic rocks)

The amphibolites and associated rocks

The Jijal complex.

The main rocks of the complex extend in three NE-stretching belts represented by, from S to N along the Swat River, amphibolites, noritic rocks, and quartz diorites (Fig. 1). The amphibolites are in tectonic contact with the Palaeozoic Lower Swat - Buner schistose group of Martin *et al.* (1962). Occurrence along/near this contact of glaucophane-bearing and ultramafic rocks is suggestive of a major tectonic activity; the fault, probably, is a westwards extension of the "Indus suture". The latter, according to Gansser (1974), marks the subduction of the Indian plate and its thrust below the Tibetan mass.

Along the Indus River, however, the amphibolites are separated from the Palaeozoic schistose group by a more than 150 sq. km tectonic block of basic garnet granulites and the associated alpine-type ultramafic rocks (henceforth suggested to be called collectively the Jijal complex). The contact relationship of the noritic rocks (pyroxene granulites) with the Palaeozoic metasediments of the Kalam group and Early Tertiary Utror volcanics is exacerbated by the intrusions of the (?) Creto-Tertiary quartz diorites and granites.

Petrography and chemistry do not reveal genetic links between the three main rock-types (amphibolites, noritic rocks, and quartz diorites) of the area. Small bodies of ultramafic rocks and olivine-corona gabbros have been found in a number of places in the amphibolites and noritic rocks whilst granitic rocks are sprinkled throughout the area. Of particular interest is a small intrusive mass of an altered bytownite anorthosite in the noritic rocks in the Indus valley. These small intrusive bodies are inconsistent in texture, mineralogy and chemistry, and some of them present unequivocal evidence of metamorphism. A few of the ultramafic lenses are metamorphosed in the granulite facies environments (Jan and Howie, in preparation) and some of these (those occurring in the amphibolites) may be remobilised bodies.

The ultramafic rocks, and the anorthosite mentioned above, have significant chemical differences with the pyroxenites found in layers and bands in the noritic rocks. It seems as if the minor ultramafic, mafic and granitic bodies have originated at different times and depths and are not related directly to the three main rock-types, a consideration previously hinted at by Jan and Kempe (1973).

*The **Amphibolites** :* The amphibolites are gneissose and most of them contain prograde epidote. The homogeneous and medium- to coarse-grained varieties are derived from igneous rocks which were intruded in banded tuffs (now banded amphibolites) before the two were metamorphosed. Some of the leucocratic bands are derived from quartzo-feldspathic material. The banded amphibolites may locally have been contaminated with sedimentary material as suggested by the rare occurrence of rocks of undoubted metasedimentary origin (quartzites, calc-silicate and some other rocks).

Most of the amphibolites are basic to intermediate rocks of tholeiitic affinities and the homogeneous varieties show an iron-enrichment trend on $MgO-(FeO+Fe_2O_3)-(Na_2O+K_2O)$ diagram. A significant feature of the mineralogy of the amphibolites is the enrichment of their amphibole in Al_2O_3 and Al^6 (averaging 14.6% and 0.82, respectively); probably suggesting a high-pressure metamorphism. The development of garnet, epidote or clinopyroxene is a function of bulk composition rather than metamorphic grade. From various considerations, estimates of temperature and pressure conditions for the amphibolites are 550°–700°C and 4–6 kb.

The Pyroxene Granulites: The amphibolites are 'intruded' by the noritic rocks whose metamorphic status has not been clearly understood before the present work. Field and detaild petrographic and mineralogical work has revealed strong evidence of metamorphism and it is recommended that these rocks be henceforth called pyroxene granulites. Detailed field and petrographic investigations carried out in Dir by M.N. Chaudhry (personal communication) do not disfavour a granulite facies metamorphism for these rocks.

The pyroxene granulites are basic to intermediate in composition, (no charnockites have so far been found). They were derived from a tholeiitic (andesitic basalt) magma, probably during the Archaean as part of a major crust-building activity in a continental margin/island arc type of location. Since then they have suffered polyphase metamorphism and de formation and were probably intruded in their present environments as remobilised crystalline material capable of plastic flow. At the time of their final emplacement they had sufficiently cooled down and they could not produce a higher than the amphibolite grade metamorphism through which the country rocks were passing. During their upward transport they had access to water so that local amphibolitisation took place, especially on their southern margin (Madyan-Fatehpur area).

Based on two-pyroxene-, two-feldspar-, amphibole-plagioclase-, and other methods of geothermometry, and high pressure-temperature experiments on rocks of similar composition, it is thought that the pyroxene granulites formed under relatively uniform TP conditions of about 800°C and 7-8 kb. Such a uniformity of metamorphic conditions over a vast area of some thousand square kilometres is a little strange. However, it is supported by the uniformity in the K_D Mg-Fe in 17 pyroxene pairs analysed, in their tie-line intersections on Wo-En join of the pyroxene triangle, and by the uniformity of their pyroxene and plagioclase compositions.

The Quartz Diorites: The quartz diorits and most granites seem to be much younger (?Creto-Eocene) intrusive rocks forming a NE-trending belt and separating the pyroxene granulites, and metasediments and volcanic rocks between Asrit and Kalam. The quartz diorites seem to have different alkali and some trace element 'patterns' than those of the pyroxene granul ites and are not comagmatic with the latter. In fact the present work cannot even endorse the idea that the diorites are mutally relate d directly. It is possible that they crystallised from magmas generated i ndependently and at different sites during the collision of the Indian-Tibetan landmasses, and the Himalayan orogeny. Alternatively, they and the rest of the Kohistan rocks may be representing a typical sequen ce developed in an island arc (Tahirkheli *et al.*, in preparation).

The Jijal Complex: The Jijal complex, occurring in the Indus valley in the Jijal-Patan area, is apparently a fault—bounded block consisting of garnet granulites and ultramafic rocks. Most of the granulites are composed of garnet+intermediate plagioclase+clinopyroxene and/ro hornblende+quartz+rutile$\pm$clinozoisite, but some lack plagioclase and quartz and are essentially composed of two or three mafic silicates. The presence or absence of the plagioclase is essentially a function of bulk chemistry; rocks poor in silica and soda (ultrabasic) are devoid of plagioclase. Based on types and proportions of minerals, 17 mineral assemblages have been recognised. The garnets of these rocks contain 17 to 29% grossular and 28 to 46% pyrope components; and the pyroxenes are aluminous (up to 10% Al_2O_3), but not omphacitic.

The rocks were probably derived from an Al-rich and alkali-poor tholeiitic magma of oceanic affinity (? Ti-depleted oceanic tholeiite) in the Tethyan crust/upper mantle, or an ancient continental margin. They may have subsequently been subducted to great depth (>40 km) during the collision of the Indian-Tibetan landmasses, metamorphosed in the high-pressure granulite facies environments (temperature 650°-800°C, pressure 11-15 kb) and finally uplifted tectonically during the Himalayan orogeny. The distinctly higher denity of these rocks (3.2 to 3.5) compared to those of the surrounding rocks (about 3.0) might bo a cause of the earth quakes reported from the Jijal-Patan area. This conclusion, however, should await detailed geophysical work.

The southern part of the Jijal eomplex is occupied by 3 - 4 km-thick body of alpine-type ultramafic rocks, mainly diopsidites. The abundance of the diopsidites is unusual and is not yet clearly understood. Like most other alpine-type ultramafic rocks, these rocks also have passed through a complex history; their present mineralogy appears, again , to be a product of regional metamorphism (800°-850°C, 8-12 kb). They do not seem to be related magmatically to the garnet granulites and were probably intruded in the latter as crystalline mushes after both had undergone the high-grade metamorphism, but before the two were tectonically transported to their present site. Chemistry of the rocks does not support the idea that the Jijal granulites or ultramafic rocks were derived from the same magma that produced the pyroxene granulites.

DISCUSSION

Perhaps the most important outcome of the T-P estimates is the likelihood that the various metamorphic rocks of Swat have formed under different geothermal gradients. This realisation, however, is based on the writer's optimistic view that the estimates are reasonably accurate, and that the gradient of pressure with depth has been constant. Assuming that the garnet granulites equilibrated finally at 750°C, 12 kb; the ultramafic rocks at 850°C, 10 kb; the pyroxene granulites at 800°C, 7.5 kb; and the amphibolites at 630°C, 5 kb, the geothermal gradients for the four types of rocks are calculated as 19°, 26°, 32°, and 37°C per kilometre, respectively.

Since it is commonly considered that the geothermal gradients have probably varied through geological times (O'Hara, 1976) and that geographical variations do exist in these gradients, it is possible that the various rocks of Swat have recrystallised either at different times or/and in separate areas with different geothermal gradients. That the Jijal granulites were intruded by the ultramafic rocks (after the two had already been metamorphosed independently under the granulite facies conditions), and subsequently the whole complex was tectonically brought into its present surroundings, has already been pointed out. The writer cannot enter into further details of the problem but would like to refer the reader to O'Hara's (1976) discussion concerning the complex history of the Scourian gneisses and other high-grade metamorphic rocks.

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REFERENCES

CHAUDHRY, M.N. & CHAUDHRY, A.G. 1974. Geology of Khagram area, Dir district. Geol. Bull. Punjab Univ., 11, 21-44.

GANSSER, A. 1974. The ophiolite melanage, a world-wide problem on Tethyan examples. Eclog. Geol. Helv., 97, 479-507.

JAN, M.Q 1977. The mineralogy, geochemistry, and petrology of Swat Kohisten, NW Pakistan. Unpub. Ph.D. thesis, Univ. London.

JAN, M.Q. & HOWIE, R.A. In preparation. Some minor olivine gabbros and ultramafic rocks from Upper Swat, NW Pakistan.

————————& KEMPE, D.R.C. 1973. The petrology of the basic and intermediate rocks of Upper Swat, Pakistan. Geol. Mag., 110, 285-300

————————& Mian, I. 1971. Prelimnary geology and petrography of Swa Kohistan. Geol. Bull. Univ. Peshawar, 6, 1-32.

MARTIN, N.R., SIDDIQUI, S.F.A. & KING, B.H. 1962. A geological reconnaissance of the egion between the lower Swat and Indus Rivers of Pakistan. Geol. Bull. Punjab Univ., 2, 1-13.

O 'HARA, M.J. 1976. Thermal history of excavetion of Archaean gneisses from the base of the continental crust. Crust Mantle boundary Mtg., 24th Nov. 1976, Mineral. Soc. & Geol. Soc. London.

SHAMS, F.A. 1975. The petrology of the Thok valley igneous complex, Gilgit agency, northern Pakisran. Accad. Nat. Lincie, Ser. 8, 59, 453-64.

TAHIRKHELI, R.A.K., MATTAUER, M., PROUST, F. & TAPPONNIER, P. In preparation. The India-Eurasia suture zone in northern Pakistan: Some data new for an interpretertion at plate scale.