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TECTONIC SUBDIVISION OF GRANITIC ROCKS OF NORTH PAKISTAN

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ABSTRACT

The granitic rocks of north Pakistan can be divided into five types on the basis of available radiometric, petrographic, geochemical, tectonic and geographic data. The granitic gneisses in the Nanga Parbat, Mansehra, and Swat areas are Late Precambrian(?) to Cambrian, S–type and possibly related to the Pan-African orogeny. The peralkaline to alkaline granits of Tarbela, Shewa-Shahbazgarhi, Ambela, Malakand proper, and Warsak were originated in extensional environments (rift/graben-related) during Eocene (50 to 40 m.y. ago). Dominantly calc-alkaline, Creto-Tertiary granitic rocks constitute three, several hundred kilometer long belts in the Himalaya-Karakoram-Hindukush region.

The Khunjerab-Tirich Mir belt is the oldest (~ 115 to 86 m.y.) of the three and produced in continental margin environment in response to the subduction of the Paleotethys during the Cretaceous. Radiometric ages in the Karakoram granitic belt (continental margin) range from 65 to 5 m.y. whilst those in the Ladakh-Kohistan granitic belt (continental margin or island arc) from 63 to 19 m.y. It is possible that both these belts are a product of simultaneous subduction along the MMT and (?)MKT. It is likely that the more basic plutons in these two belts were produced by the partial melting of a predominantly oceanic crust, whilst in the rest of the rocks of the two belts both oceanic and continental crust contributed to the magma formation.

INTRODUCTION

Granites (i.e., Si-saturated intrusive rocks ranging from quartz diorite, through tonalite, granodiorite, quartz monzonite, to granite proper) are by far the most abundant of the igneous rocks found in north Pakistan. In addition to constituting extensive belts and plutons of batholithic dimensions, they also occur in numerous smaller bodies (see maps by Bakr and Jackson, 1964; Calkins *et al.*, 1975, 1981; Tahirkheli and Jan, 1979). Radiometric ages for most of them are either lacking or insufficient and the available dates in many cases may be suggesting resetting of the clock at dates later than the actual ages of formation. Most of the available dates are scattered over Cretaceous and Tertiary periods, however, much older dates (Cambrian) have also been reported in two cases.

Desio *et al.* (1964) and Badshah (1979) suggested that granites in Pakistan have different ages. Tahirkheli (1979) subdivided them geographically into three main groups, occurring in the Asian Platform, Kohistan zone, and Indo-Pakistan plate. He also subdivided them into coarse-grained syntectonic gneisses, meduim– to fine-grained foliated (late orogenic) gneisses, and homogeneous post-tectonic granites. This classification does not appear to be realistic; for instance, the Chakdara gneisses and Warsak granites, which are calc-alkaline and alkaline respectively, and in our opinion belong to two entirely different ages and tectonic settings, were lumped together in the second category. Similarly, use of the term orogenic and tectonic with prefixes pre–, syn–, and post–, is a matter of opinion. Since the alpine orogeny in N. Pakistan has been going on since the Cretaceous, all the granites produced in this period are synorogenic/tectonic *sensu stricto,* irrespective of whether or not they are gneissose. Similarly, the pre-alpine Mansehra granites are homogeneous in the south but alpine deformation has produced a strongly gneissose fabric in the north; should the two portions of the same pluton be termed pre– and post–orogenic ?

In this paper we have attempted to classify the granitic rocks of N. Pakistan on the basis of available data on age, geochemistry, tectonics, petrography and geographic location. There are a number of granitic rocks occurring in the remote areas along the Pakistan-Afghanistan border and between Nanga Parbat, Kaghan and Muzaffarabad for wihch petrographic data are scanty and geochemical data altogether lacking. These are only tentatively dealt with in this paper. A brief account of the geology of N. Pakistan is essential in order to understand the problem on a regional scale.

The Indus suture zone (ISZ), considered to mark the subduction of the Indo-Pakistan plate under the Asiatic mass (Gansser, 1977), splits into two in N. Pakistan. The northern branch has been termed the Northern Megashear (Tahirkheli and Jan, 1979) or the Main Karakoram Thrust (MKT) (Bard *et al.,* 1979) whilst the southern one is termed the Main Mantle Thrust (MMT) (Tahirkheli *et al.,* 1979). Both have melange zones with ultramafic and mafic rocks, the MMT also having blueschists and a wedge of high–P mafic garnet granulites. Sedimentary rocks to the north of the MKT are only mildly metamorphosed, generally Palaeozoic in age, and considered to represent the Asiatic mass or a micro continent. However, in the immediate northern vicinity of the MKT along the Hunza River the metasediments show a rapid northwards increase in metamorphic grade. Granitic intrusions in this northernmost part of Pakistan are represented by a) Khunjerab-Tirich Mir belt, and b) Karakoram belt.

To the south of the MMT occur rocks of the Indo-Pakistan Plate; these include Precambrian to Palaeozoic metasediments with a cover of Mesozoic rocks (Calkins *et al.,* 1975). Granitic rocks in this area are represented by a) an older set of plutons (Nanga Parbat-Haramosh gneisses, Mansehra Granites, Swat granitic

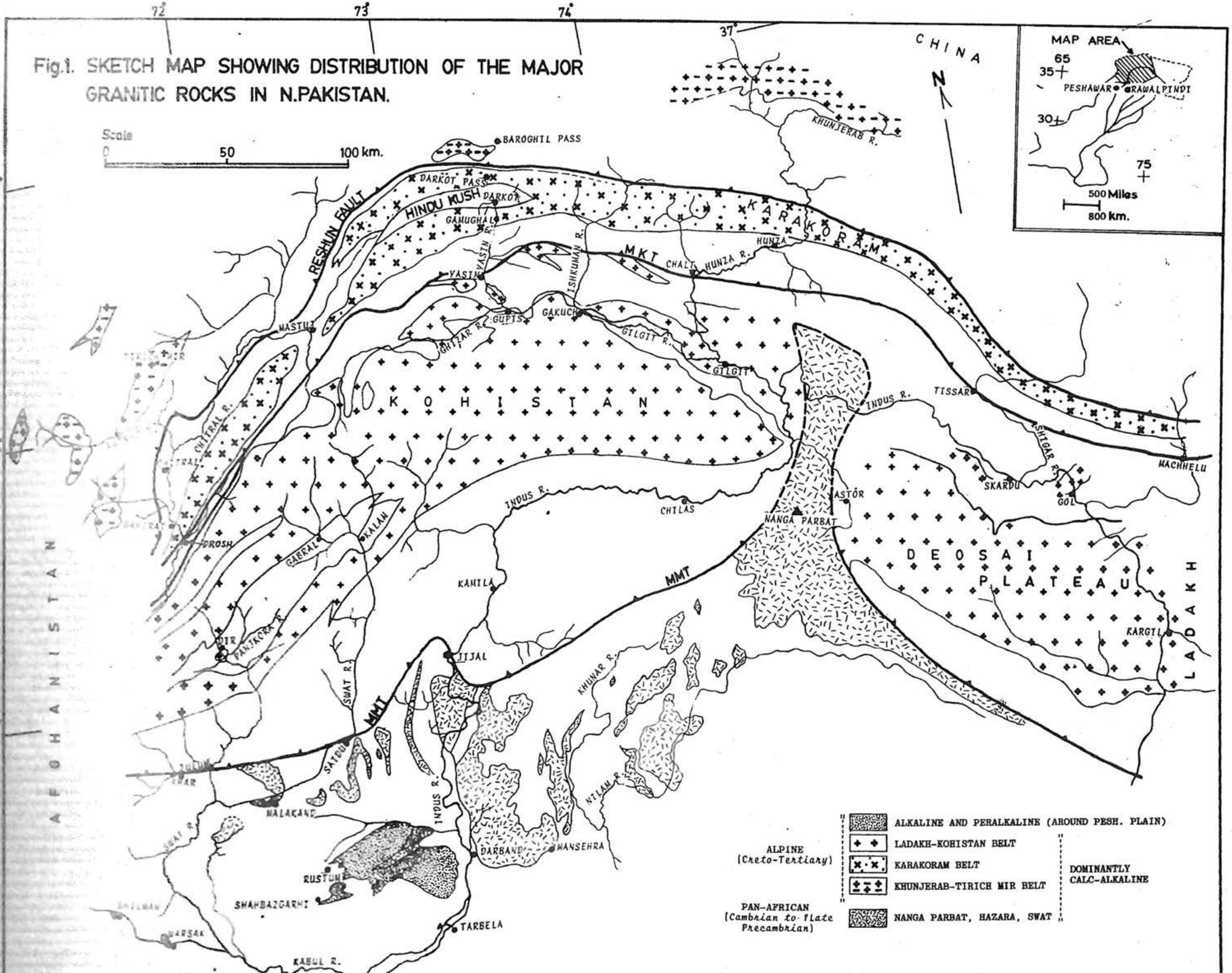

Fig.1. SKETCH MAP SHOWING DISTRIBUTION OF THE MAJOR GRANITIC ROCKS IN N.PAKISTAN.

pneisses), and b) a younger set of rocks of alkaline to peralkaline nature (Ambela, Shewa-Shahbazgarhi, Malakand proper, Warsak). The former granites are generally gneissose and pre-alpine (Late Precambrian(?) to Cambrian) whilst the latter are generally non-gneissose and alpine (Eocene).

Between the two sutures occur rocks of the Kohistan sequence (Tahirkheli *et al.*, 1979), principally Cretaceous to Eocene in age. These are dominantly igneous (mostly intrusive) and range from ultrabasic to acidic in chemistry, with a subordinate amount of (meta)sediments. Tahirkheli *et al.* (1979) and Bard *et al.* (1980) think that the Kohistan sequence is an island arc turned on end during the Himalayan orogeny. However, the structure of the region is very complex with more than one phases of folding and requires a more detailed study (Coward *et al.*, 1982). Jan and Kempe (1973) and Jan (1977) had previously suggested that the basic and intermediate rocks from Swat Kohistan are similar to those of the orogenic belts of continental margins, and of island arcs. The Kohistan sequence contains numerous occurrences of veins to stock-size granitic bodies, especially in the southern amphibolite belt*. However, the principal occurrence of granites is found in the Ladakh-Kohistan plutonic belt which stretches for several hundred kilometers between India and Afghanistan across N. Pakistan.

THE PROPOSED SUBDIVISION OF THE GRANITIC ROCKS

The N. Pakistan granites can principally be divided into two major age groups: 1) Late Precambrian(?) and Cambrian granites of the Indo-Pakistan Gondwanic Plate, represented by those of Swat, Mansehra, Kaghan, Nauseri, and Nanga Parbat areas, and 2) Creto-Tertiary (Alpine) granites related to the subduction of the Indo-Pakistan Plate under Asia and the accompanying high–grade metamorphic episode(s). To this group belong the remainder of the granitic rocks found in the Himalaya-Karakoram-Hindukush region and around the Peshawar Plain. We do not know of any reliable dates to suggest that granite magmatism took place in the intervening 450 m.y.

The Creto-Tertiary alpine granites can further be subdivided on the basis of age, chemistry, and location into: i) dominantly calc-alkaline rocks forming three extensive belts, from N to S–Khunjerab-Tirich Mir, Karakoram, and Ladakh-Kohistan and ii) peralkaline to alkaline granites, commonly in small intrusions, of the alkaline igneous province around Peshawar. Among the calc-alkaline granites, the Khunjerab-Tirich Mir belt is older (115 to 86 m.y.) than the other two (< 70 m.y.). There is a possibility that the Khunjerab-Tirich Mir and Karakoram belts are of continental margin (cordilleran) type whilst the Ladakh-Kohistan granitoids may

*Minor to stock-size bodies of granitic rocks are common in the amphibolite belt of Kohistan. These have not been studied in sufficient detail, but they appear to be of the following types: 1) (?) oceanic plagiogranites, 2) younger plutons related to Kohistan-Ladakh activity, and 3) partial melting products of amphibolites during high amphibolite facies metamorphism.

either be of continental margin or island arc type or both. The alkaline granites might be associated with rifting whilst the Late Precambrian(?)–Cambrian ones might be related to Pan-African orogeny. A summary of the proposed subdivision is given in Table 1, whilst Fig. 1 shows the distribution of the granitic rocks.

TABLE 1. TECTONIC SUBDIVISION OF GRANITIC ROCKS FROM N. PAKISTAN

2. Alpine Granites	ii) Alkaline to Peralkaline—Ambela, Shewa-Shahbazgarhi, Malakand proper, Warsak, Tarbela — 50–40 m.y., Rift–related
	i) Dominantly calc-alkaline
	c) Ladakh-Kohistan, < 70 m.y., Island arc and/or continental margin
	b) Karakoram, < 70 m.y., continental margin
	a) Khunjerab-Tirich Mir ~ 115–86 m.y., continental margin
1.	Late Precambrian(?) to Cambrian, dominantly calc-alkaline granites and gneisses of Nanga Parbat, Nauseri, Kaghan, Mansehra, Swat, (?)Pan-African

LATE PRECAMBRIAN(?) TO CAMBRIAN GRANITES OF THE INDO-PAKISTAN PLATE

On the basis of mineralogical similarity and other considerations, Le Fort *et al.* (1980) proposed an extensive, discontinuous belt of cordierite granites in the Himalaya foothills. The rocks stretch from Katmandu in Nepal to Mansehra, with a well-defined Rb/Sr whole rock isochron age of 516±16 m.y. Although the Nanga Parbat and Lower Swat granitic gneisses were not studied, their general similarity with those of Mansehra suggests a similar age. A biotite Ar^{40}/Ar^{39} age of 515 m.y. (Maluski, pers. comm. to M.Q.J.) supports this view although a probable Precambrian age is suggested for the Nanga Parbat gneisses by Zeitler *et al.* (in preparation). On purely stratigraphic grounds, Shakoor (1976) suggested a Late Cambrian age for the granitic gneisses near Nauseri, Azad Kashmir, whilst Ashraf *et al.* (1980) assigned a Precambrian age to the gneisses around Besham in northeastern Swat district. It is thus probable that a large discontinuous belt of granitic rocks of (?)Late Precambrian to Cambrian age, and belonging to the Indo-Pakistan Plate, exists to the south of the MMT.

A dominant characteristic of these granitic rocks is their strongly gneissose fabric, and generally porphyritic/porphyroblastic aspect with feldspar megacrysts up to 15 cm long. However, the Mansehra granites are non-foliated in the southern part, the deformation front being marked by a line passing just north of Mansehra (Shams, 1969; Coward *et al.,* 1982). The Swat granitic gneisses, according to

Martin *et al.* (1962), are non-foliated at the base. The Nanga Parbat gneisses display the phenomenon of migmatization on an extensive scale, especially in the marginal parts, however, the central part of the massif is homogeneous and massive (Shams and Ahmad, 1979).

Nanga Parbat-Haramosh Gneisses. Modal analyses of 11 samples from this complex (Saleemi, 1978; Shams and Ahmad, 1979) show much variation and the rocks range from granite to potassic granite, alkali granite, alkali syenite, and quartz syenite, with a trend of variation towards syenite. For a large pluton such as this, only 11 samples might not be sufficient to consider this data truly representative. In addition to quartz, oligoclase–andesine, and perthitic to non-perthitic alkali feldspar, the rocks contain two micas and Fe–ore with remnants of kyanite, staurolite, garnet of two generations, and rare sillimanite (Shams and Ahmad, 1979).

The Nanga Parbat granites were made classic by Peter Misch (1949) who suggested a metasomatic origin for them, being derived from the Precambrian Salkhala sediments. Such an origin was also suggested for them by Zanettin (1964), Saleemni (1978), and Shams and Ahmad (1979). However, Gansser (1949) considered that they were formed by the internal rearrangement of the Salkhalas, whereas Matsushita *et al.* (1965) suggested that they were of purely igneous origin and derived from a Himalayan tholeiitic magma. Significant is the finding from fission track ages (Zeitler *et al.*, in preparation) that the Nanga Parbat region was uplifted during the Pleistocene at a phenomenal rate of nearly 1 cm/year.

Nauseri Granitic Gneisses, Azad Kashmir. These show gradational contacts with the Precambrian Salkhalas and Titwal schists and their foliation is parallel to that of the two as well as to the "original bedding which can be seen clearly" in the gneisses (Shakoor, 1976). From the description given by this author, it appears that the rocks are potassic granites composed of abundant quartz, K–feldspar (orthoclase reaching 7½ cm in length, microcline, perthite), muscovite, biotite, sphene and calcite. Again a metasomatic origin has been suggested for them. The granitic rocks of the Kaghan valley and around Babu Sar have not been studied in detail and no published accounts are available. However, they are generally gneissose and deformed and we tentatively place them with those of Nauseri and Mansehra in the Cambrian.

Mansehra Granites. Covering more than 2000 km², these granites have been studied in detail for more than two decades by Shams and his students (1961a, 1966, 1969, 1980). According to Calkins *et al.* (1975) and Le Fort *et al.* (1980), they constitute a sheet tightly folded along with country rocks. The rocks range from granite to granodiorite, are calc-alkaline in chemistry, and composed of quartz, albite-oligoclase, K–feldspar (orthoclase to microcline, mostly perthitic), biotite and small quantities of a number of other minerals, including garnet. Modal analyses of 21 samples from Battle-Batgram area of the complex (Saleemi, 1978) range from potassic to normal granites with a variation towards quartz monzonite.

Shams (1969) classified the rocks into earlier Susalgali gneiss, Mansehra porphyritic granite, andalusite granite (commonly also containing sillimanite grown at the expense of micas), and associated minor bodies of pegmatites, aplites, albitites, and granite porphyries. (These minor bodies have been studied in detail by Ashraf, 1974). A massive to weakly porphyritic tourmaline granite with albite, microcline, garnet, etc., intruding schists on its western margin, is considered by Shams to be a younger derivative. The occurrence of cordierite (Le Fort *et al.*, 1980), sillimanite and andalusite in the granites on one hand, and of garnet on the other, coupled with staurolite and kyanite in the nearby rocks is interesting. The area has been affected by Barrovian type, alpine metamorphism which increases northwards towards the MMT, as does deformation (Le Fort *et al.*, 1980; Coward *et al.*, 1982). However, it is not clear whether the granites have passed through an earlier (?Pan-African) episode of low pressure metamorphism or the minerals cordierite, andalusite and sillimanite are the result of contamination/contact metamorphism.

Like the Nanga Parbat and Nauseri gneisses, a metasomatic "origin of pre-existing sediments through the agency of hot permeating fluids of ultimate magmatic origin" was also suggested for the Mansehra granites (Shams, 1969). We have not studied any of these granites in sufficient detail to evaluate the credibility of this hypothesis. However, in view of the current thoughts on granites, the gradually diminishing support for the hypothesis of large-scale granitization, and the information provided by Le Fort *et al.* (1980) for the Mansehra pluton, we would favour a partial melting origin of the Precambrian sediments for the magma of these complexes.

Swat Granitic Gneisses. Briefly described by Martin *et al.* (1962) and Jan and Tahirkheli (1969), these rocks are very similar to those of Mansehra and their dating by Maluski (515 m.y.) confirms that the two are of the same age and origin. Like those of Mansehra, they also appear to have been emplaced in a sheet and tightly folded. The geological map by Martin *et al.* (1962) suggests that the eastern bodies of these granites may pass into those of Mansehra across the Indus. They are composed of quartz, feldspar, micas, garnet, epidote and, according to Shams (in Saleemi, 1978); plot in the quartz-rich granitoid field with "two pronged extension towards granite and quartz monzonite field". A tourmaline-bearing granite/gneiss is a minor marginal variant of the Swat Granitic gneisses. Wollastonite-bearing calc-silicate rocks occur in contact marbles near Manglaur (Shams, 1961b) and Pir Baba.

The biotite gneisses at Chakdara, N of Malakand, were considered to be the extension of the Swat granitic gneisses (Martin *et al.*, 1962). Chaudhry *et al.* (1974) thought them to be syntectonic and older than the Malkand granite. However, in a later publication (Chaudhry *et al.*, 1976) they considered the gneisses (potash granite) to be magmatically related to the "soda granite" of Malakand proper. We think that the close association of the two granites is merely accidental and not an undisputed proof of a common parentage. The gneisses show a tectonic fabric and are probably an extension of those of Swat whilst the Malakand granite is undeformed and possibly belongs to the alkaline province of Early Tertiary age (see below). Modally also, the Chakdarra Gneisses resemble those of Swat.

We have no idea about the extension of the granitic gneisses to the west of Chakdarra; neither are we certain whether the biotite granite gneisses in southern Khyber Agency along the Pak-Afghan border (Jan, 1975) are of similar age. However, similar rocks have been noted in the Shamozai Utmankhel tribal territory to the west of Malakand (Badshah, 1979 and M. Rafiq, pers comm.). The Chingalai granodiorite gneiss (K–feldspar phenocrysts+oligoclase+quartz+"abundant" biotite± hornblende) was considered by Siddiqui *et al.* (1968) to be genetically related to the alkaline rocks of Koga Area in Buner. Recent investigation of this area by M. Rafiq (pers comm.) casts doubt on the relation since a major fault separates the two types of rocks. We tentatively include the granodiorite in the Swat granitic gneisses.

Besham Granitic Gneisses. These rocks were reported by Jan and Tahirkheli (1969) from the northeastern part of Swat district along the Indus river. Ashraf *et al.* (1980) divided them into Lahor granite, Shang granite, and Mansehra granite gneiss which occurs along the eastern bank of the Indus. The Lahor granite, according to these authors, is Precambrian and covers about 800 km^2 area, however ,at least a third of the outcrop comprises metasediments. This granite is composed of perthitic K–feldspar, albite-oligoclase, quartz, biotite and a number of other minerals including garnet. The Shang granite (granodiorite according to Jan and Tahirkheli, 1969) contains perthite, oligoclase-andesine, quartz, hornblende, biotite, garnet, etc. It is a younger phase of the igneous activity and contains xenoliths of Lahor granite.

Pegmatites are abundant in the area and not all of them show tectonic fabric. It is thus not clear whether they are principally a late product of granite magma crystallization or produced at a much later date due to partial melting accompanying the Late Cretaceous-Early Tertiary (alpine) high–grade metamorphism. A significant aspect of the Lahor granite is the development of Pb–Zn–Mo and other metallic minerals in the contact skarns.

Discussion

According to Le Fort et al. (1980), "it is difficult to relate the generation of these granites either to a definite orogeny — say a late Pan-African one for example, or to another phenomenon — like an extended thining of the crust". Some deformation, according to them, is still recognizable but to a limited extent and no indicatoin of a previous metamorphism has yet been observed. One aspect of the granites worth a careful study is the occurrence of andalusite, sillimanite., and cordierite in them. Are these low pressure minerals due to contamination and contact metamorphism, or have they been produced by a regional metamorphic episode during Pan-African orogeny? Shams' (1969) observation regarding the growth of sillimanite at the expense of micas hints at the second possibility. On the other hand there is ample evidence to suggest that the granites and the surrounding rocks have been affected by alpine metamorphism (Barrovian-type) and deformation.

The composition, isotopic ratios, and evolutionary trend for the Mansehra pluton suggest that they resemble closely the S–type series derived from an old crustal basement (Le Fort *et al.*, 1980). The petrography, stratigraphic details and, in a number of cases gradational contacts between the granites and country rocks, as presented by previous workers, suggest to us that the Cambrian granites were derived by the partial melting of Precambrian sediments. Thus it is not totally surprising that so many workers suggested a metasomatic origin for them. The Swat, Besham, Mansehra, Kaghan, and Nauseri gneisses were intruded as sheets and folded tightly along with country rocks. The whole association, according to Le Fort *et al.* (1980) was overthrusted along the Main Central Thrust.

EARLY TERTIARY GRANITES OF THE PESHAWAR PLAIN ALKALINE IGNEOUS PROVINCE

Kempe and Jan (1970, 1980) and Kempe (1973) suggested that an alkaline igneous province extends across NW Pakistan from Tarbela or even Mansehra in the east, through Peshawar, to the Afghan border, a distance of more than 200 km. The intrusive complexes, comprising alkaline granites and microgranites, syenites, albitites and carbonatites, occur along fault zones in the older sedimentary rocks around the alluvial plateau forming the Peshawar Plain. They have not been found in the Mesozoic and Tertiary sedimentary sequences to the south of the Plain, which are thrust-faulted against the older meta-sediments (see map in Tahirkheli and Jan, 1979). Only two reliable radiometric ages (50 m.y. for Koga syenites and 41 m.y. for the Warsak alkaline granites) suggest that the complexes were intruded during the Eocene. The homogeneous part of the Ambela granite contains xenoliths of pelitic schists with abundant chloritoid in a few cases. Although chloritoid is not always a stress mineral (Ribbe, 1980), its presence in a schistose rock may suggest that the xenoliths were metamorphosed during alpine (Creto-Paleocene) metamorphism before the intrusion of the granite. Thus, we assume that the alkaline and related rocks of the region may be of Eocene age. In the following, a brief account of only the granitic rocks in the alkaline complexes is given. It should be noted, however, that not all the alkaline complexes contain granites. Kempe (in prep.) gives a detailed review of these rocks.

The *Loe Shilman carbonatite complex* in the western part of Khyber Agency consists of at least three phases of carbonatite intrusion, with minor syenite and lamprophyric rocks (Kempe and Jan, 1980; Jan *et al.*, 1981). Truly granitic bodies of mappable size have not been found but the syenites may contain quartz. However, within the syenitic and lamprophyric rocks, veins and small patches (up to a few tens of centimeters) of coarse-grained pegmatitic facies develop which, in addition to aegirine, alkali amphibole and feldspar, contain up to 25% quartz. Apatite, zircon, and sphene are the accessory minerals in these patches.

A series of sill-like alkaline granites and porphyritic microgranites, containing aegirine, riebeckite and astrophyllite, was described by Coulson (1936) and Kempe (1973) from the *Warsak area,* 20 km W of Peshawar. The microgranites, considered to be slightly older than the alkaline granite, are deformed, metamorphosed and locally contain garnet. The alkaline granite is mostly non-porphyritic and locally foliated, especially in the marginal parts. The predominant feldspar in the micro-granite is microperthite (Or_{73}) whilst that in the alkaline granite is albite with minor microcline. Allanite and fluorite are amongst the other minerals found in the rocks. Chemical analyses of the rocks show that the quantity of Na_2O is generally slightly higher than that of K_2O.

Further microgranite bodies were reported from 10 km S of Warsak, N of Jamrud, by Khan *et al.* (1970), whilst small bodies of foliated microgranites, some porphyritic, occur to the W between Warsak and Loe Shilman. Detailed mapping of the Warsak area (Ahmad *et al.,* 1969) has revealed that the granites, closely associated with metagabbros and metadolerites, occur in a northwards plunging synclinal series, possibly faulted on the northeast. The microgranites were equated by Kempe and Jan (1970) and Kempe (1973) with those of Shewa-Shahbazgarhi and Tarbela, whereas the alkaline granite was considered the broad equivalent of the Koga syenite which, in turn, can be equated with those of Loe Shilman.

The *Malakand granite* has been studied in considerable detail by Chaudhry *et al.* (1974, 1976). It is non-foliated, locally porphyritic, and composed of albite, microcline, quartz and muscovite, with biotite, apatite, epidote and local calcite, garnet, sphene and magnetite as the accessory minerals. Chemical analyses of the rocks are not very different from those of Ambela, Shewa-Shahbazgarhi and Warsak granites. Although the contents of Na_2O (up to 5.6%) and K_2O (up to 4.7%) are similar to those of the other silicic rocks within the alkaline province, the Al_2O_3 content is generally higher. Thus, neither acmite forms in the norms, nor is alkali pyrobole reported in the modes although Chaudhry *et al.* (1976) consider it "basically a soda granite". On SiO_2 *vs.* alkalinity index $(Al_2O_3+CaO+Na_2O+K_2O)/(Al_2O_3+CaO-Na_2O-K_2O)$ diagram (Wright, 1969), eight analyses plot in the field of alkali granites and one in calc-alkali granites. On SiO_2 *vs.* log (K_2O/MgO) diagram of Rogers and Greenberg (1981), only some analyses plot in the field of alkali granites. Samples from the Benton Hydroclectric Tunnel, passing through the granites and enclosing rocks, commonly contain allanite and sphene, with one small dyke containing riebeckite (Badshah, 1979, and pers. comm.). Thus, at least some phases of the granite are peralkaline.

Alkaline porphyritic microgranites ("porphyries"), striking E–W, constitute a fault-bounded triangular outcrop between *Shahbazgarhi,* Shewa and Machai in Mardan district. The principal outcrop covers about 35 km^2 area. Only limited petrographic account of these rocks has so far been presented (Martin *et al.,* 1962; Kempe, 1973) but it appears that most may be subvolcanic in origin. Some of the rocks look tuffaceous but these could, alternatively, be extensively sheared. Although they are almost identical to those of Warsak (Kempe, 1973), there are considerable variations in texture and mineralogy, with the local presence of aegirine, riebeckite, or of garnet. The garnet-bearing rocks, lacking peralkaline ferromagnesian minerals, consist of phenocrysts of albite, microperthite and quartz in a groundmass of alkali feldspar, quartz and biotite or chlorite. The alkaline micro-granites contain quartz and perthite phenocrysts, with aegirine and riebeckite needles and biotite, in a groundmass of quartz, alkali feldspar and accessory minerals (Kempe, 1973). Chemical analyses of the rocks from Warsak and this area (Coulson, 1936; Kempe, 1973) strongly support the suggested consanguinity of the two units.

The *Ambela granitic complex* in Buner is of batholithic dimension and consists of rather varied assemblages of granite, alkali granites, quartz-bearing aegirine-augite and arfvedsonite nordmarkite, quartz-free aegirine-augite syenite and aplites with aegirine-augite. Granites appear to be the most abundant but the west-central part of the complex is occupied by feldspathoidal syenites, carbonatites and related rocks (Siddiqui *et al.,* 1968). The complex shows some foliation in the north but is structurally different from the Swat granitic gneisses (Martin *et al.,* 1962) and, according to M. Rafiq (pers. comm.), is intruded along a major fault extending towards Shahbazgarhi.

The Ambela granitic rocks are granular to porphyritic with veins, patches and apophyses of microgranite, and a migmatised zone in the marginal parts (Ahmad and Ahmed, 1974). They consist of alkali feldspar (orthoclase, microperthite, microcline), albite-oligoclase, quartz, biotite, muscovite, ore, chlorite, sphene, tourmaline and zircon. Sodic pyrobole-bearing quartz syenites are closely associated with them but the mutual relationship has not been worked out so far. Based on five chemical analyses, Ahmad and Ahmed (1974) suggested that the granites are comagmatic with the microgranites of Warsak and the nearby Shewa-Shahbazgarhi area. On SiO_2 *vs.* log (K_2O/MgO) diagram (Rogers and Greenberg, 1981), only two of the five granite analyses plot in the alkali granite field. However, on Wright's (1969) diagram, four turn out to be alkalic and only one calc-alkalic. Granitic rocks of Gadoon area along the western bank of Indus appear to be similar to those of Ambela (Khan and Hammad, 1979), the two being separated by a 'slice' of Chingalai calc-alkaline granodiorite.

Small intrusions of medium-grained to porphyritic microgranites occur in the *Tarbela Dam* area. They contain albite (with rare oligoclase An_{16} cores), quartz, perthite/antiperthite, biotite and secondary white mica, chlorite, calcite, with ilmenite, apatite, sphene, rutile, zircon and allanite as the accessory minerals. Some rocks are granophyric, the intergrowth consisting of quartz and albite. The modes are indicative of an alkaline nature of the rocks, as also suggested by the presence of aegirine and reibeckite in a porphyritic microgranite (Kempe and Jan, 1970). The general petrography of these rocks, thus, is similar to those of Warsak and Shewa-Shahbazgarhi. The Tarbela rocks are found in association with (?)alkaline gabbros, albitites, albite-cargonate rocks and minor carbonatites. Unfortunately, many of the granitic outcrops have now been removed or covered due to construction connected with the dam, however, a detailed investigation of the neighbouring areas might reveal additional occurrences.

Discussion

The close association of alkaline to peralkaline granites with other alkaline rocks around the Peshawar Plain suggests a common origin for them. The Malakand proper and Ambela granites contain neither alkali pyroboles in their modes nor acmite in norms (except in one Ambela analysis as recalculated by us). However, the chemistry of the rocks, the close association of alkaline rocks with those of Ambela, and of a peralkaline dyke in the Malakand granites, as well as the presence of local sphene and allanite, suggest that the two granites have alkaline affinity.

Alkaline rocks are commonly associated with rifting: the heat so liberated has been suggested as capable of partially melting upper mantle periodotite. The magma so generated subsequently gives rise to an alkaline liquid due to combined processes of fractional crystallization, crustal contamination and wall rock alteration (Condei, 1976). Alternatively, extreme fractionation of suitable basalt magma, first at high and then at low pressure, can also yield alkaline liquids (Sorensen, 1974; Brown, 1981). It was suggested by Kempe (1973) that the alkaline rocks of the Peshawar Plain evolved from a quartz trachyte magma which, in turn, was derived from a Himalayan basaltic magma. Kempe and Jan (1980) proposed that the Peshawar Plain is an irregular rift valley or graben, extending for over 200 km, and greatly modified by Pleistocene glacial and fluvioglocial action. Nearly all the intrusions have been emplaced along faults which may have a close connection with the rifting. Such rifting might, perhaps, have been assisted by rebound relief tension or compression release following the initial collision of India and Asia or the island arcs about 55 m.y. ago. The chronology of the rocks (50 m.y. for Koga syenite and 41 m.y. for Warsak granite) and the marked slowing of the Indian palate's northwards motion from 15 to 6 cm/year at about 53 m.y. (Powell, 1979) are in agreement with this hypothesis.

LATE CRETACEOUS-TERTIARY CALC-ALKALINE GRANITES

The calc-alkaline granitic-rocks of this age in N. Pakistan occur in three arcuate belts, each extending for hundreds of kilometers. The notable feature of these belts is their alignment amongst themselves as well as to the major "tectonic and orographic axes" of the region (Desio 1976, p. 115). Tectonically, the three belts are delineated by three major faults: MMT, MKT and Reshun fault. Of these the first two are considered as suture lines marking the interaction of the Indian Plate in the south and Asiatic mass or a Gondwanic microcontinent in the north, with an intervening zone of Kohistan-Ladakh "island arc". The latter zone is intruded by the southernmost of the three granitic belts, i.e., the Ladakh-Kohistan granitic belt. The other two (Khunjerab-Tirich Mir and Karakoram granitic belts) intrude the southern margin of a Gondwanic microcontinent and/or the Asiatic mass north of MKT, the two belts separated from each other by the Reshun fault. Radiometric ages suggest that the northernmost belt was emplaced approximately 100 m.y. ago, whilst the southern two were intruded during the Tertiary period. The characteristic parallelism between the alpine granitic belts and the suture lines/ major faults suggests a link between the magma production and subduction (Gansser, 1980). In the following a description of the three belts is given in a north to south order.

Khunjerab-Tirich Mir Granitic Belt

In the western Chitral and the area SW of Baroghil Pass, several granitic intrusions have been mapped by Calkins *et al.* (1981). These isolated but mutually aligned bodies intrude a Jurassic-Devonian tectono-stratigraphic zone that thrusts SSE along the Reshun fault over the Cretaceous Reshun Formation. This mega-thrust serves as a major tectonic break between the Tirich Mir-Khunjerab granitic rocks in the north and the Karakoram granitic belt in the south; the two belts being of different tectono-magmatic regimes. Eastwards granitic rocks, comparable in tectono-stratigraphic position to those of Baroghil Pass, occur in the watersheds of Hunza River in the Giraf and Khunjerab ranges. Insufficient work has been carried out in this remote northernmost part of Pakistan. The possibility of more extensive occurrences of granites should, therefore, not be excluded.

Desio *et al.* (1964) dated the granitic intrusions of Tirich Mir and Zebek, further NW, to be of 115 and 93 to 86 m.y. of ages, respectively. Recently, two ages in the range of 105 m.y. have been recorded from the Khunjerab granites (Rex-pers. comm. to M.Q.J.). These data coupled with the peculiar tectonic setting suggest that the above-mentioned granitic rocks belong to a separate belt, north of and parallel to the Karakoram and Ladakh-Kohistan granitic belts. Desio *et al.* (1964) dated a syenitic rock near Giraf to be of much younger age (53 m.y.). The absence of ages for the intervening 30 m.y. is surprising and may suggest that the Giraf syenite belongs to a much younger plutonic activity (? belonging to Karakoram batholithic regime), or there exists some discrepancy in the determined age.

The petrographic information at hand is not enough to provide a clue regarding the mutual relationship of various intrusives within this belt. Whilst the Khunjerab, Giraf and Kafiristan intrusions are characteristically undeformed, the Hot-spring and Tirich Mir ones are gneissose and well-foliated as shown by the deformation of K–feldspar and the partial generation of biotite in them (Desio, 1964). The major mass of the Giraf pluton is quartz-syenitic in composition, consisting of phenocrysts of perthite in a matrix of hornblende, quartz, pyroxene and biotite (Desio and Martina, 1972). The associated rocks include granodiorites, aplites, and porphyrites, which cut the main pluton as dykes. Similar lithologies have been recognized by us in the Khunjerab valley, except for the absence of syenites. The predominant rocks in this area are granodiorites and quartz monzonites/granites, which are in places cut by dykes that are finer grained, porphyritic granodiorites. The granodiorites contain oligoclase/andesine plagioclase, biotite, hornblende, and K–feldspar. The other rock types have little or no hornblende but more K–feldspar. The modal mineralogy of the Giraf syenite may suggest an alkalic affinity of some of the intrusive phases, but not necessarily anorogenic as suggested by Blasi *et al.* (1980).

The Karakoram Granitic Belt

South of the Khunjerab-Tirichmir granitic belt and the Main Karakorum thrust, there is another alignment of granitic rocks intruded in the Axial zone of the Karakoram range. The relatively better known part of the belt is about 10 km broad, between Sarat and Gulkin in the Hunza valley. These rocks extend ESE-wards, across the Batura, Hispar, Biafo, Panmah, Baltoro and Saltoro ranges (Desio, 1976) and reach up to Tegar peak to the north of Shyoke-Nubra confluence (Sharma and Kumar, 1978). Westwards, the rocks constitute the watersheds of the Ishkuman and Yasin valleys. In the upper Yasin valley, two granitic batholiths parallel to each other and extending WSW have been mapped (Ivanac *et al.*, 1956; Calkins *et al.*, 1981). The northern one of these terminates to the NE of Mastuj, whilst the southern one (Gamughal granite) continues up to Drosh in Chitral. Controversy has existed as to whether both or only the southern of these two batholiths is an extension of the Karakoram granitic belt (Matsushita and Huzita, 1965; Casnedi *et al.*, 1978; Desio, 1974, 1976; Ivanac *et al.*, 1956; Haydan, 1916). We tentatively include both the batholiths in the Karakoram belt on the basis of their tectonic setting, i.e., their location between two major faults — The MKT in the south and Reshun fault in the north. The geological maps of Ivanac *et al.* (1956) and Bakr (1965) suggest that the two batholiths may be merging eastwards into the main granitic belt. The Karakoram granitic rocks, as delineated by us, thus constitute an arcuate belt ~ 600 km long and approximately 10 km wide.

On the basis of structural and stratigraphic considerations, Ivanac *et al.* (1956) suggested that the granites are post-Cretaceous and intruded during the Himalayan orogeny. Radiometric ages from various parts of the belt range from 56 to 5 million years (Desio *et al.*, 1964; Casnedi *et al.*, 1978; Coward *et al.*, 1982), with a 65 m.y. age on a porphyritic granodiorite near Umalsit, Yasin valley (Rex, pers. comm. to M.Q.J.). Thus, there is a clear overlap of age between the Ladakh-Kohistan and Karakoram granitic belts for the early two thirds of their histories (i.e. ~ 65 to 20 m.y. ago). Similarly, some of the younger granitic phases and the layered garnetiferous aplite, pegmatite bodies in the two look very similar, and both have been intruded by young basic dykes and lamprophyric rocks.

The granitic rocks of the Karakoram belt display a wide range of compositional and textural variations. Gneissose biotite-hornblende granodiorite appears to be the principal and oldest rock-type, but adamellite, quartz diorite and hornblende diorite also occur, and some of these might be the oldest. These have been intruded by granitic, aplitic and pegmatitic dykes and rare dolerite and lamprophyre. Biotite microdiorites, tonalites, and microcline granites (Desio and Martina, 1972) are the other rocks reported from Hunza valley. Along the Karakoram Highway, the following sequence of intrusive activity has been recorded: gneissose biotite granodiorite with an early foliation is cut by coarse-grained adamellite/granite and pegmatite-aplite. The pegmatite may be banded, with some thin bands rich in either garnet or tourmaline and at places tightly folded. These are intruded by grey, medium-grained adamellite and by a younger phase of medium-grained leucogranite. These younger rocks normally occur in small dykes to thin veins. The final phase of intrusions are aplite-pegmatites with rare beryl.

The young intrusive phases characterized by quartz, microcline, rare plagioclase, and two micas from the central part of the granitic belt are comparable to the two mica granites of Tegar range further east (Sharma and Kumar, 1978). Desio and Zanettin (1970) have reported numerous minette and vogesite veins in the upper basin of the Baltoro glacier. These have been considered by them to represent the last phases of magmatic activity in the Karakoram belt.

The Darkot Pass and Gamughal batholiths in the upper Yasin valley, like those of Hunza, are dominated by granodioritic compositions. Variations to granites and leucogranites are common in the Gamughal pluton, particularly in the southern margin where porphyritic texture is predominant. These rocks are composed of varying proportions of plagioclase, quartz and K–feldspar (microcline, perthite), with biotite and rarely hornblende as mafic components. The Darkot Pass granodiorite is strongly deformed with bent plagioclase and cataclastically developed bands of fine-grained quartz and feldspar (Blasi *et al.,* 1980). The Gamughal batholith also contains some gneissose phases.

Chemical analyses of the granodiorites and adamellites from the Yasin valley (Blasi *et al.,* 1980) show that the rocks have low ratio of $(Na_2O+K_2O)/Al_2O_3$ and $(Na_2O+K_2O)/CaO$, typical of calc-alkaline compositions found in orogenic zones. Most of the granodiorites and granites studied petrographically and chemically by Gamerith and Kolmer (1973), largely from the axial batholithic belt in the western Karakoram zone, are also calc-alkaline in affinity. Our petrographic data and the abundance of granodiorite support these authors. However, we consider that the young, leucocratic phases might be alkaline in chemistry.

Ladakh–Kohistan Granitic Belt

West of the Nanga Parbat-Haramosh massif, granitic rocks occur abundantly along the Indus, Gilgit, Ghizar and Swat rivers, extending into Dir (Ivanac *et al.,* 1956; Tahirkheli and Jan, 1979; Calkins *et al.,* 1981). East of the massif a corresponding alignment of the appropriate rocks traverses through Deosai plateau and Ladakh range (Desio, 1978; Sharma and Kamar, 1978). The granitic rocks on either side of the massif have a similar tectonic setting, i.e., emplacement in the so-called Kohistan-Ladakh island arc sequences (Tahirkheli *et al.,* 1979; Klootwijk *et al.,* 1979), and situation between the two suture zones, MMT in the south and MKT–ISZ in the north. The other consistent feature of the two areas is the composite nature of intrusions with general variations in rock-types from basic to acidic. Since the rise of the Nanga Parbat-Haramosh massif is a relatively young feature (principally Late Tertiary and Quaternary; Zeitler *et al.,* in press), we assume that the Ladakh-Kohistan granitic rocks may once have constituted a continuous belt.

In the Deosai plateau, the granitic lithologies include quartz-dioritic and granitic gneisses, amphibole ± mica diorites, two-mica and white mica granites, pegmatites and aplites (Desio, 1978). Of these the gneissose quartz diorites and granites are comparable to those of Swat (Khalil and Afridi, 1979) and Gilgit valleys, which are the earliest phases in their respective areas. Zanettin (1964) assigned a Late Cretaceous age to these granites, however, radiometric ages of undeformed, younger phases range from 48 to 43 m.y. (Desio *et al.*, 1964; Blasi *et al.*, 1980). The Ladakh batholith, a SE continuation of the belt, is also composite (Sharma and Kamar, 1978). The border zone of the batholith consists of hornblende-poor pink granite, whereas the core zone contains hornblende-biotite granite, and two-mica granite in aplitic, granitic and pegmatitic textures. Tonalites and granodiorites are reported to occur as apophyses in the aureole zone. The earliest ages from this suite group around 60 m.y. ago (Gansser, 1979), however, a K/Ar age as young as 27.8 m.y. is reported from the core zone of the batholith (Sharma *et al.*, 1978). The association of gabbroic and ultramafic rocks in the form of dykes, veins and xenoliths (Desio, 1978; Frank *et al.*, 1977; Kleeman and Sonnenfeld, in prep.) in the Ladakh-Deosai granitic belt is a puzzling feature yet to be explained

West of the Nanga Parbat-Haramosh massif, the Indus and lower Hunza valleys are occupied by large plutons of tonalites and quartz diorites, cut by swarms of aplite and pegmatite sheets. Generally the plutons are made up of more than one intrusive phases; earlier ones foliated and gneissose and later ones discordant and homogeneous containing xenoliths of igneous and sedimentary material. Up to five phases of intrusions can be recognized in some outcrops. One of the younger phases (but not the youngest) recorded SE of Gilgit is an undeformed biotite-clinopyroxene-hornblende-plagioclase lamprophyre having inclusions of biotite schist and norite. Westwards, the Gilgit valley is occupied by several intrusions ranging from quartz diorites to granodiorites to granites. Local gneissose phases occur frequently. Near Gakuch, in addition to these rocks, an outcrop of gabbros cut by leucogranites has also been observed. The Gindai pluton in lower Yasin valley is characterized by a central part of granodioritic composition with marginal facies being leucoratic granites and aplites. Basic dykes cut the core zone of the pluton. The leucogranites of the area principally consist of microcline, perthite, quartz and zoned plagioclase with minor biotite. The more basic facies contain hornblende in addition. Radiometric ages of the granitic rocks of Gilgit valley range from 63 to 19 m.y. (Gasnedi *et al.*, 1978; D. Rex-pers. comm. to M.Q.J.), most of them in the range of 32 to 55 m.y.

In Swat Valley much of the granitic suite is made up of quartz diorites and tonalites. The earliest phases of these rocks are gneissose and predominate in the granitic lithologies north of Kalam. Most of them carry biotite and hornblende and occur as coarse-grained intrusions. Some of the rocks occurring south of Kalam contain one or two pyroxenes. Of these the older ones are retrogressed intermediate rocks of pyroxene granulite belt (Jan, 1977, 1979) and thus do not constitute a part of the Ladakh-Kohistan granites. The younger ones occur as porphyritic intrusions. Excellent development of rounded and elliptical orbs (some 30 cm long) near

Deshai is a notable feature of some of the quartz diorites of the area (Jan and Mian, 1971). Amongst other intrusions granites occur as two large stocks near Diwargar and Matiltan. In addition minor stocks and dykes intrude the earlier phases of tonalites/quartz diorites as well as the Kalam sediments and volcanics. These rocks are predominantly porphyritic and carry perthite, quartz and plagioclase, with minor amounts of hornblende and biotite, but a few also contain pyroxenes. Also found are leucogranites that differ from granites in non-porphyritic texture, non-perthitic K–feldspar, and development of myrmekite. All the rocks of the suite are cut by aplitic and pegmatitic dykes. Maluski (personel communication to M.Q.J.) dated the hornblende from a quartz diorite south of Kalam by Ar^{39} / Ar^{40} method to be of 58 m.a. of age. Since the granitic rocks of this suite intrude the Cretaceous Kalam sediments and Eocene volcanics, and because of the fact that the latter carry pebbles of granitic rocks, it can be inferred that the granitic plutonism in Kalam area spanned the time from Paleocene/Late Cretaceous to the post-Eocene.

In Dir, a NE trending diorite belt stretches across Bajour, Jandul and the area north of Timurgara (Badshah, 1979; Kakar *et al.,* 1971; Butt *et al.*, 1980). The so-called diorites of this belt are rich in hornblende and may also carry garnet and well-developed epidote. In our opinion these rocks are metagabbros belonging to the amphibolite belt. The proper equivalents of Ladakh-Kohistan granites are tonalites, which outcrop to the N of Dir Town, in upper Jandul valley, and south of Baraul Banda. These rocks are medium-grained, homogeneous, and locally foliated. They contain biotite, hornblende and, at places, pyroxenes and petrographically resemble some of the tonalites of Swat Valley. The tonalites south of Baraul Banda are accompanied by granodiorites and pegmatites (Khan, 1979). Amongst other granitic rocks, one consisting of gronodiorite and quartz monzonite occurs SE of Dir Town, near Bibior (Chaudhry *et al.,* 1974). Numerous other dykes/stocks of granites, aplites, and pegmatites intrude the country rocks in this area. No radiometric age is available for granitic rocks in Dir, however intrusions of tonalite in the Eocene volcanics north of Dir Town and near Baraul Banda (Khan, 1979) suggest a post-Eocene age. Near Shahi, in the upper reaches of Jandul valley, quartz diorites intrude the Cretaceous Baraul Banda Slates but are themselves cut by porphyritic (?)feeder dykes of the Eocene volcanics. Thus a Paleocene intrusive age, like those of Kalam, is most likely for these rocks also.

Geochemical analyses are available only from Swat and Gilgit valley granitic suites (Jan, 1977; Majid, 1979; Blasi *et al.,* 1980). Whilst the Swat quartz diorites and tonalites are clearly calc-alkaline and marked by non iron-errichment trend (Majid, 1979), in the Gilgit valley both calc-alkaline and alkaline granodiorites, adamellites and granites have been reported. Blasi *et al.* (1980) consider that the latter are rift-related and anorogenic. On the basis of petrography, age data and geochemical informations at hand, we think that the Ladakh-Kohistan granitic belt is a composite product of primarily calc-alkaline orogenic magmatism, generated and emplaced in repeated pulses from (?)Late Cretaceous to Miocene. The alkali granites of the Gilgit Valley, probably, represent a differentiation product of early surges of tonalitic magma, a mechanism recently recognized from Ben Ghnema batholith of Central N. Africa (Rogers and Greenberg, 1981), or they may have been independently generated but not necessarily in anorogenic environments.

Discussion

The characteristic features of the three granitic belts described above include Creto-Tertiary radiometric ages, predominantly calc-alkaline chemistry and modes, situation in the continental margin and/or island arc type environment, and parallel alignment with the major faults and/or suture lines of the region. These features point out a link between the magma production and processes of subduction which were functioning during the alpine orogeny in north Pakistan.

The existing plate tectonic models, involving the subduction and accretion between the three tectonic elements, viz. Indian Plate, Kohistan-Ladakh arc sequences, and Asian mass, at two sites (first at MMT during Creto-Early Tertiary and then at MKT during Early Tertiary to Oligo-Miocene) may explain the genesis of the Ladakh-Kohistan and Karakoram granitic belts. Radiometric ages for the two batholiths (~ 63–19 m.y. for Ladakh-Kohistan and ~ 65–5 m.y. for Karakoram) show a notable overlap of magmatic activity. This may suggest that (1) simultaneous subduction took place during pre-Paleocene underneath the Kohistan-Ladakh arc and the southern margin of the Asian plate/Gondwanic microcontinent (Hindukush-Karakoram), and (2) whilst the subduction under the Kohistan-Ladakh arc might have ceased or very markedly slowed down, about 20 m.y. ago, that under the Asiatic mass/Gondwanic microcontinent has continued. It is yet not known whether magmatism in these belts was continuous or episodic.

One of the major differences between the Kohistan-Ladakh and Karakoram granitic belts is the relatively more basic nature of the former, as shown by a greater abundance of basic rocks and quartz diorites, particularly in the southern (lower) half. It is possible that the more basic plutons in the two belts were produced by the partial melting of a predominantly oceanic crust whilst in the rest of the rocks of the two belts both oceanic and continental crust contributed to the magma formation. Local evidences suggest that at least some of the Kohistan plutons are S–type and derived by partial melting of sediments.

CONCLUSIONS

The granitic rocks of N. Pakistan belong to two age groups: Late Precambrian(?) to Cambrian and Cretaceous–Tertiary. The former, represented by the granitic gneisses of Swat, Mansehra, and Nanga Parbat areas, were derived by anatexis of Precambrian sediments possibly during the Pan-African orogeny. The Creto–Tertiary granites are divisible into dominantly calc-alkaline, and peralkaline-alkaline types. The (per)alkaline granites (Tarbela, Shewa-Shahbazgarhi, Ambela, Malakand proper, Warsak) constitute a discontinuous, more than 150 km long belt around the northern half of Peshawar Plain. These are considered to have originated in extensional environments (i.e., rift/graben-related) during Eocene (~ 50 to 40 m.y. ago).

The Creto-Tertiary dominantly calc-alkaline granites constitute three E–W arcuate, and parallel belts, each composite in nature and several hundred kilometers long, in the Himalaya-Karakoram-Hindukush region. The northern one of these (Khunjerab-Tirich Mir belt) is the oldest (~ 115 to 86 m.y.) and occurs along the northern border of Pakistan N of Reshun fault. It may be a continental margin type, resulting from south facing subduction of the Paleotethys during the Cretaceous. The Karakoram granites constitute the middle belt between the Reshun fault and MKT whilst the southern (Ladakh-Kohistan) belt occurs between the MKT and MMT. The latter belt has possibly been split into two by the relatively recent uplift of the Nanga Parbat-Haramosh massif.

Granite magmatism seems to have started about 65 m.y. ago and continued for about 45 m.y. in the Ladakh-Kohistan belt and possibly 60 m.y. in the Karakoram region. There is a possibility that such magmatism in the latter region is active even at the present time. In general, both these belts appear to have become less mafic temporally and the Kohistan belt also appears to be more basic (dominated by quartz diorites and tonalites) towards the southern (? bottom) part. It is suggested that the two belts may owe their origin to simultaneous subduction along the MMT and MKT; the Ladakh-Kohistan belt being of continental margin and/or island arc type and the Karakoram belt having constituted the margin of the Asiatic continental or a Gondwanic microcontinental block. The post-Early Miocene ages (20 to 5 m.y.) reported only in the Karakoram granites might suggest that subduction along the MKT has continued more actively than along the MMT over the past 20 m.y.

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