Age and Tectonic Implications of Granitoids from the Indian Plate of Northern Pakistan

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Abstract: Reassessment of the radiometric data illustrates, that the Indian plate in northern Pakistan contains a good record of granitic rocks ranging from Late Archean to Quaternary. They are pre- syn-, and post-orogenic with respect to Himalayan and older orogenies. Occurrences are restricted to the hinterland region of Pakistan between the Panjal-Khairabad fault and the Indus suture zone. Areas with the best constrained radiometric dates are Nanga Parbat and the Indus syntaxis-Peshawar Basin region. The granitic rocks can be broadly classified into seven categories; 1) Late Archean/Early Proterozoic (>2175 Ma); 2) Early Proterozoic (ca. 1850 Ma); 3) Late Proterozoic (ca. 825 Ma); 4) Early Paleozoic (ca. 400-516 Ma); 5) Late Paleozoic (ca. 315-260 Ma); 6) Early Tertiary (ca. 35-50 Ma); and 7) Late Tertiary-Quaternary (ca. 1-10 Ma).

The Precambrian magmatic rocks can be correlated with Precambrian orogenic or anorogenic magmatic episodes of the Indian craton. Early Paleozoic plutons may belong to an anorogenic phase or to the last stages of Pan African magmatism. A Late Paleozoic rifting is well documented across the northwestern Himalayas and resulted in generally bimodal basic and acid (with some alkaline) magmatism in Kashmir, Hazara and the Peshawar Basin. While the Cretaceous-Tertiary period experienced large magmatism in response to the closure of the Neo-Tethys and ultimate collision of India with "Asia" to the north of Indus suture, few granitic rocks of this age occur in the Indian plate. The small granite bodies of 1-10 Ma occur only in the Nanga-Parbat area and have been considered as product of partial melting accompanying the rapid uplift of the massif and thermal relaxation.

INTRODUCTION

Northern Pakistan is a collage of three distinct tectonic domains: the Indian plate in the south, the Kohistan- Ladakh magmatic arc in the middle and the Karakoram plate in the north. The latter may itself comprise two or more microplates (Kazmi & Jan, 1997; Zanchi *et al*., 1997). Rocks of the Indian craton were remobilized and metamorphosed during the late Cretaceous-Cenozoic Himalayan orogeny resulting from subduction beneath Indus suture zone melange and collision of the Indian plate with the Kohistan arc and Eurasia (Figure 1). This orogeny overshadows a long and complex history of sedimentation, igneous intrusion, metamorphism and deformation on the Indian plate dating back to the Archean. Granitic rocks are by far the most abundant igneous rocks found in northern Pakistan. In addition to constituting extensive belts and plutons, there also occur numerous smaller bodies.

Several attempts were made on the grouping of granitic rocks in the past (e.g. Shams, 1983; Jan *et al*., 1981). Unfortunately, however, due to lack of reliable and extensive radiometric data these studies suffered discrepancies. During the past decade many radiometric dates have been published for granitic rocks of the Indian plate in northern Pakistan. A reassessment of the correlation of these granites, and their tectonic implications is needed in light of these new data. Here we attempt to summarize and synthesize the available radiometric age data. For the sake of avoiding metamorphic cooling and uplift ages, we have relied primarily on U-Pb zircon, Sm-Nd and Rb-Sr dates. The ages with their respective systems are listed in Table 1.

GENERAL GEOLOGY

The Indian plate margin in northern Pakistan extends from Nanga Parbat through Naran and the Indus syntaxis, and across the Peshawar Basin. In this paper we refer primarily to the: (1) The Nanga Parbat-Haramosh Massif (NPHM), (2) the Indus syntaxis including Swat and Hazara, and (3) the Peshawar basin west of the Indus syntaxis.

The Nanga Parbat-Haramosh Massif (NPHM)

The Indus suture, along which rocks of the Cretaceous Kohistan magmatic arc were thrust over the Indian plate, loops around the NPHM (Tahirkheli & Jan, 1979). The N-S extending NPHM was considered as a promontory (Wadia, 1933) or edge of a west-facing embayment (Madin *et al*., 1989) of the Indian plate. Butler *et al*. (1992) and Coward *et al*. (1988) showed that the massif is controlled by an anticlinal fold structure. Rapid Quaternary unroofing of the massif has been accommodated by faulting along the Raikot fault on the western side and Stak fault on the eastern edge as well as along the Shahbatot strike-slip zone. On its western margin, the Indus Suture was rotated along the still active Raikot Fault such that Indian plate rocks are carried back over Kohistan.

The NPHM is composed of high-grade Precambrian basement gneisses that have been overprinted by Himalayan metamorphism. Correlations of the deformation histories with the Hazara area have been discussed by Treloar *et al*. (1991). Misch (1949) presented the rocks as a type example of granitization of batholithic dimensions. Shams and Ahmad (1979) reported that the massif is made up

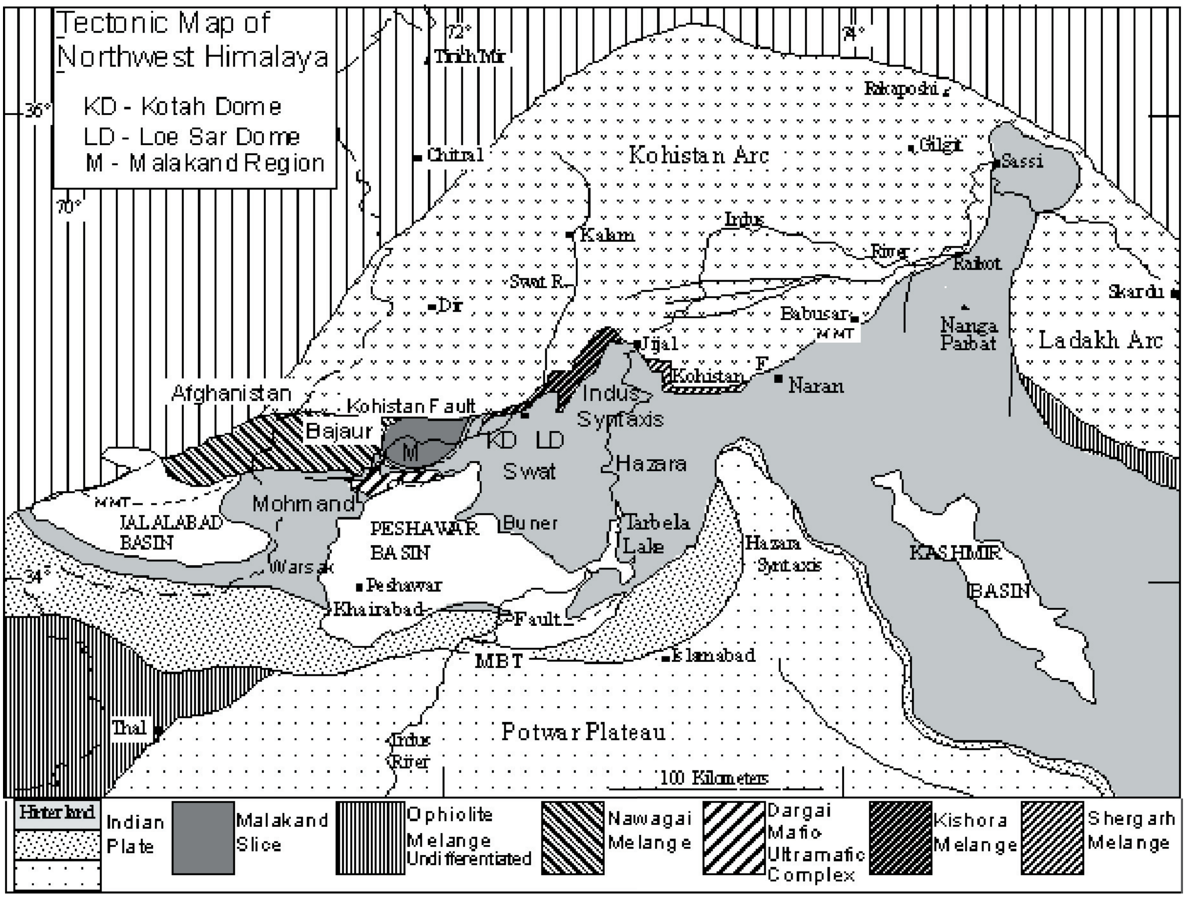

Figure 1. Tectonic map of Western Himalaya. The melange units collectively form the Indus suture zone which is also known as the Main Mantle thrust (MMT) in Pakistan. Regions in which granitic rock are present include Nanga Parbat, Naran, Hazara, Tarbela Lake, Swat, Buner, Malakand (M), and Warsak. Structures mentioned in the text include the Indus Syntaxis in the Swat-Hazara region, and the Malakand slice which is a fault slice of Indian plate rock nearly surrounded by Indus melange. MBT-Main Boundary thrust.

Age Group	Location	Rock type	Method	Age (Ma)	Reference
Late Archean/	NPHM	Granite Gneiss	U-Pb zircon	2300-2800	Whittington et al., 1999
Early Proterozoic	Besham	Pb-Zn deposit	Pb isotope	2120-2200	Shah et al., 1992
	Besham	Kishar metagreywacke*	U-Pb zircon	ca. 2930	DiPietro and Isachsen, 2001
Early Proterozoic	Besham	Granite gneiss	Ar-Ar	ca. 2031-1865	Baig, 1991; Baig et al., 1989
	Duber (Besham)	Amphibolite sheet	Ar-Ar	1920 ±24	Treloar et al., 1989
	Lesser Himilaya	Granite Gneiss	Isochron	1600-1900	Valdiya, 1983
	Besham	Shang Granodiorite	U-Pb	1864 ±4	DiPietro and Isachsen, 2001
	Besham	Kotla Orthogneiss	U-Pb	1836 ±1	DiPietro and Isachsen, 2001
	Pinjkora complex	Pinjkora paragneiss*	U-Pb Pb-Pb	ca. 2560	DiPietro and Isachsen, 2001
Late Proterozoic	Black Mountains	Orthogneiss	U-Pb	823 ±2	DiPietro and Isachsen, 2001
Early Paleozoic	Mansehra	Granite	Rb-Sr WR	516 ±16	Le Fort et al., 1980
	NPHM	Shengus Gneiss	U-Pb	400-500	Zeitler et al., 1989
	Swat (Choga)	Granodiorite gneiss	U-Pb zircon	468 ±5	Anczkiewicz et al., 1998
Late Paleozoic/	Swat (Ser)	Gneiss	U-Pb zircon	268 +7/-3	Anczkiewwicz et al., 1998
Early Mesozoic	Swat (Ilam)	Granite gneiss	U-Pb zircon	265 ±2	DiPietro and Isachsen, 2001
	Swat (Ilam)	Granite gneiss	Rb-Sr isochron	260 ±52	Ahmed et al., 1997
	Swat (Manglaur)	Granite gneiss	Rb-Sr isochron	285 ±8	Ahmed et al., 1997
	Chakdara	Granite gneiss	U-Pb zircon	278 ±4	DiPietro and Isachsen, 2001
	Ambela	Carbonatite	Rb-Sr	297-315	LeBas et al., 1987
Early Tertiary	Malakand	Malakand Granite	U-Pb zircon	47 ±3	Smith et al., 1994
	Swat (Saidu)	Leucogranite	U-Pb zircon	ca. 35	Zeitler & Chamberlain, 1991
	Kaghan (Naran)	Leucogranite	U-Pb zircon	ca. 50	Zeitler & Chamberlain, 1991
	Kaghan	Leucogranite	U-Pb zircon	ca. 45-49	Smith et al., 1994
Late Tertiary-	NPHM	Gneiss	Monazite	1-11	Smith et al., 1992
Quaternary					Schneider et al., 2001

*detrital zircon

Table 1. Published age data of some late Archean Quanternary rocks from the Indian plate, North Himalaya.

of migmatitic gneisses with interwoven micaceous folia. The gneisses consist of two feldspars, quartz, biotite, muscovite, chlorite, opaque grains and remnants of garnet, kyanite and staurolite of metamorphic origin. According to Rehman and Majid (1989), they are mostly granite and adamellite

Madin *et al.* (1989) divided the rocks of the northwestern part of the massif into three units. The Shengus Gneiss, forming the lowest structural unit, consists of fine-grained, finely laminated pelitic and psammitic gneisses with subordinate amphibolites and calc-silicate gneisses, and is at least 5 km thick. The Iskere Gneiss is a coarse-grained biotite gneiss with subordinate biotite schist, amphibolite, and calc-silicate gneiss, with a minimum thickness of 8 km. The gneisses are medium- to coarse-grained and contain quartz and feldspar megacrysts. The structurally high Haramosh schist unit (the layered unit of Butler *et al.*, 1992), which is more than 2.5 km thick, contains medium- to coarse-grained biotite schist and gneiss, with marble, calc-silicate gneiss, and subordinate amphibolite. The range in lithologies, which form up to meter thick layers, is the same as that of the Iskere Gneiss, except for a lack of coarse biotite orthogneiss. The amphibolites might be the components of Kohistan interlayered tectonically (Butler *et al.*, 1992), but they can also be Permian. Rare-earth geochemistry (Smith *et al.*, 1992) supports the widely held view that the Nanga Parbat granitic gneisses are derived from a pelitic protolith.

There are young, generally undeformed, granitic rocks in the NPHM. These are dominantly coarse-grained biotite-muscovite granite pegmatites. Tourmaline granite and aplite also occur as dykes, lensoid bodies and selvages on the pegmatites (Shams, 1983; Madin *et al.*, 1989). Very young granitic rocks of Pliocene-Pleistocene age have been reported from the massif.

Indus syntaxis

Some 160 km SW of the Nanga Parbat peak occurs the Indus syntaxis (Figure 1). It is a large anticlinal flexure that is cut deeply by the Indus River exposing a wide area of Precambrian rock. Late Paleozoic-Mesozoic rocks are exposed west of the Indus syntaxis surrounding the much smaller anticlinal flexures of the Loe Sar and Kotah domes. The Malakand slice, occurring 120 km farther west, represents an allochthonous slice of Precambrian- Paleozoic metasedimentary and metagranitic rock, underlain by the Malakand fault, and structurally above the Mesozoic rock of the Kotah dome. In all the rocks from the northern part of the Indus syntaxis, garnet is widespread in pelitic and calcareous schist and kyanite and sillimanite occur sporadically. Peak metamorphic conditions are ~600-700 °C and 9-11 kbar in the Loe Sar dome (DiPietro, 1991) and 500°-700°C and 6-11 kbar in the Hazara area east of the Indus syntaxis (Treloar *et al.*, 1989b).

DiPietro *et al.* (1999) outlined the stratigraphy that consists of a series of intruded metasedimentary rock sequences each separated by unconformities. The oldest Precambrian unit in the Indus syntaxis region is the Kishar formation, which unconformably underlies the Karora formation. The Amlo metaconglomerate member, at the base of the Karora formation, contains clasts of granitic and gneissic rocks implying deformation, intrusion, and regional metamorphism prior to deposition of the Karora. The Gandaf formation depositionally overlies the Karora and both are intruded by orthogneiss of the Besham and Kotla complexes. The Besham complex had until recently been considered to be unconformably below the Karora formation, but the two largest plutons, the Shang granodiorite gneiss of Jan and Tahirkheli (1969) and the Lahore leucogranite and leucogranitic gneiss of Ashraf *et al.* (1980), both intrude the Karora formation. On this basis, DiPietro *et al.* (1999) mapped the Besham as an intrusive complex and separated the Kishar formation as metasedimentary rock lying unconformably below the Karora. Field relationships suggest that intrusion of the Besham and Kotla complexes into the Karora/Gandaf sequence was associated with deformation and possibly with low-grade regional metamorphism. All of the rocks are unconformably overlain by the Tanawal formation, which shows no evidence of pre-Himalayan regional metamorphism but is intruded by Cambrian-Middle Ordovician and Early Permian Swat and Manshera augen gneisses. Manshera augen gneiss also intrudes the Black Mountain complex along the east side of the syntaxis.

The major Precambrian unit in the Loe Sar dome is the Manglaur formation which, although widely regarded as correlative with the Tanawal formation, may in part correlate with the older Karora/Gandaf sequence. The Manglaur is intruded by Early Permian Swat augen and flaser gneisses (Anczkiewicz *et al.*, 1998a, 1998b), and both are unconformably overlain by Late Permian metaclastics and metavolcanics of the Marghazar formation. Faulting accompanied Marghazar deposition. A Paleogene tourmaline-bearing granitic gneiss intrudes principally along the Swat gneiss-Marghazar unconformity. The Marghazar is, in turn, disconformably overlain by Triassic (and younger?) shelf and slope-rise deposits of the Kashala, Nikanai Ghar, and Saidu formations. Stratigraphy in the smaller Kotah dome is similar to the Loe Sar dome except that Precambrian rock is not exposed.

The oldest unit in the Malakand slice is the Pinjkora complex, which in addition to metasedimentary rock contains abundant granitic rock, orthogneiss, and metabasaltic rock. The abundance of intrusive rock suggests a correlation with the Karora/Gandaf sequence. This unit is unconformably(?) overlain by the Mekhband formation, and both are intruded by Chakdarra orthogneiss and by the Paleogene Malakand granite.

Peshawar basin

The area surrounding the southern Peshawar basin is marked by a sequence of alkaline rocks in Warsak, Buner, and Tarbela Lake (Figure 1; Siddiqui *et al.*, 1968). Kempe and Jan (1970) suggested that an alkaline igneous province stretched across the Peshawar basin for at least 150 km between the Indus River and the Pakistan- Afghanistan border. Field data summarized in Kempe and Jan (1980) indicate that the alkaline complexes are (1) generally emplaced along fault zones, and (2) restricted in occurrence to Paleozoic and Precambrian rocks. In recent years, the Panjal volcanics, and Permo-Triassic dykes, along with the large Ambela granitic complex, have been included in the alkaline province.

GRANITOIDS OF NORTHERN PAKISTAN

Spasmodic magmatism is documented in northern Pakistan from possibly as early as Archean to as late as the Quaternary (Table 1). All types of igneous rocks are present with granitoids being the most dominant. The latter can be divided into seven age groups:

1. Early Proterozoic (ca. >2175 Ma, Kishar, NPHM)
2. Early Proterozoic (ca. 1850 Ma, NPHM, Shang, Kotla)
3. Late Proterozoic (ca. 825 Ma, Black Mtn.)
4. Early Paleozoic (Mansehra, Choga, NPHM)
5. Late Paleozoic/Early Mesozoic (Swat, Buner, Peshawar alkaline complex)
6. Early Tertiary (Malakand, Swat, Kaghan)
7. Late Tertiary-Quaternary (NPHM)

These are summarized in the following section together with their radiometric ages.

1. Late Archean/Early Proterozoic

The Kishar formation in the Indus syntaxis is a metasedimentary rock unit which contains ca. 2930 Ma detrital zircons and hosts stratiform Pb-Zn deposits with Pb isotope ages ca. 2120 to 2200 Ma (Shah *et al.*, 1992). Mineralization may be associated with intrusion and metamorphism. The Amlo conglomerate unconformably overlies the Kishar formation and contains granitoid clasts. This rock is the basal member of the Karora formation which is intruded by ca. 1850 Ma granitoids. The overall relationships suggest granitoid intrusion at ca. 2200 Ma or earlier in the Indus syntaxis.

The Shengus paragneiss covers much of the Nanga Parbat massif. It consists of two units of distinctly different ages. The older unit has yielded Nd model ages between 2300 and 2800 Ma whereas the younger is 400- 500 Ma (Whittington *et al.*, 1999; Treloar *et al.*, 2000a). Rocks with the older Nd model ages may belong to this obscure intrusive event.

2. Early Proterozoic

Granitoids of this age have been reported along the entire Pakistani Himalaya. U-Pb zircon ages show that the Iskere Gneiss covering the northeast part of the NPHM is about 1850 Ma (Zeitler *et al.*, 1989). In the Indus syntaxis there are U-Pb ages of 1864 ±4 from the Shang granodiorite gneiss of the Besham complex and 1836 ±1 Ma from an orthogneiss of the Kotla complex both of which intrude the Gandaf formation (DiPietro and Isachsen, 2001). These rocks intrude amphibolites with Ar-Ar dates of ca. 1900 Ma (Treloar *et al.*, 1989). Also reported are U-Pb and Pb-Pb detrital ages ranging from 1935 to 2567 Ma from the Pinjkora complex which forms the basal unit of the Malakand slice and crops out within the Pinjkora anticline, 120 km south west of the Indus syntaxis (Figure 1; DiPietro and Isachsen, 2001).

3. Late Proterozoic

The Black Mountain complex occurs along the crest of the Black Mountains, which border the eastern side of the Indus syntaxis. DiPietro and Isachsen (2001) reported U-Pb ages of 823 ±2 Ma from a biotite-quartz-feldspar orthogneiss of the Black Mountain complex.

4. Early Paleozoic

Early Paleozoic Lesser Himalayan granitic plutons of Cambrian-Ordovician age occur in a belt stretching for 1600 km from Kathmandu to the Indus River (Le Fort *et al.*, 1980, 1983). Similar granitic rocks occur in Nanga Parbat, the Indus syntaxis, the southern margin of the Tibetan slab, and the central mountains of Afghanistan (Le Fort *et al.*, 1980; Zeitler *et al.*, 1989, DiPietro *et al.*, 1999). The rocks are typically megacrystic granite and granodiorite in the Pakistan Himalaya, which become augen granitic gneisses in areas of Himalayan deformation and metamorphism. The Mansehra complex in the Indus syntaxis with a well-defined whole rock Rb-Sr isochron age of 516 ±16 is an extension of this belt in Pakistan. Also the Choga and Loe Sar plutons of the Swat complex. Anczkiewicz *et al.*, 1998b obtained a U-Pb zircon age of 468 ±5 Ma from the Choga granodiorite gneiss. The structurally lower Shengus Gneiss in the NPHM is partly 400-500 Ma in age. It is likely that farther studies would reveal additional occurrences of granites of this age in northern Pakistan. Suggestions have been made for some in Kaghan and Kashmir (Kazmi & Jan, 1997).

5. Late Paleozoic/Early Mesozoic

A Carboniferous-Permian intrusive event with ages that range from 350 to 268 Ma is largely restricted to the western flank of the Indus syntaxis and westward across the Peshawar basin. The rocks range from gabbro-basalt and granite-rhyolite to alkaline rocks and carbonatites. Bimodal granitic and mafic rocks of this alkaline province extend in the form of small intrusions up to Afghanistan and possibly beyond. U-Pb zircon ages of 268 +7/-3 Ma and 265 ±2 Ma were obtained from the Ilam pluton of the Swat complex west of the Indus syntaxis (Anczkiewicz *et al.*, 1998; DiPietro and Isachsen, 2001). Ahmed and others (1997) obtained a Rb/Sr isochron ages 260 ±52 and 285 ±8 Ma for the Ilam pluton. A U-Pb zircon age of 278 ±4 Ma was obtained for the Chakdarra granite gneiss in the Malakand slice (DiPietro and Isachsen 2001). East of Rustam, Rb/Sr determinations on the Koga carbonatite in the Ambela complex yielded ages of 297 to 315 Ma (Le Bas and others, 1987). According to Khan and others (1990) and Pogue and others (1992), the Shewa porphyritic alkaline acidic rocks are intercalated with Carboniferous sediments. Mafic volcanics and dolerite of this age also occur. According to Le Fort *et al*. (1980, 1983), it is difficult to relate the generation of these granites either to a definite orogeny (Late Pan-African, for example) or to other phenomenon such as extension and thinning of the crust or strike slip faulting giving rise to a sort of thermal corridor.

6. Early Tertiary

Despite their small volume, considerable attention has been paid over the past 15 years to leucogranite occurrence in orogenic belts. Detailed field and petrographic studies in the recent years, supported by radiometric dates, have shown that Tertiary granites are volumetrically minor in the region to the south of the Indus suture in Pakistan. There are occurrences of Tertiary tourmaline granite gneiss and biotite granite-granodiorite in the Indus syntaxis and Naran region. In Swat, west of the Indus syntaxis, tourmaline granite gneiss intrudes the metasedimentary sequence principally along the unconformity below the Alpurai group (Late Permian-Mesozoic). Based on synmetamorphic intrusive relations these granites are suggested to be Paleogene in age (Ahmad, 1986; DiPietro, 1990). A dyke of leucogranite which cross-cuts amphibolite facies rocks in Swat has a U-Pb zircon age of ca. 35 Ma (Zeitler & Chamberlain, 1991). Southeast of the Swat river, dates determined on biotite from the Loe Shilman and Silai Patti carbonatites yield 31 + 2 Ma (Le Bas and others, 1987). Zeitler and Chamberlain (1991) reported an approximate 50 Ma U-Pb zircon age for a leucogranite dyke near Naran. U-Pb zircon ages of 45 to 49 Ma have also reported by Smith *et al*. (1994) on the granites and pegmatite from the same area.

7. Late Tertiary-Quaternary

The Nanga Parbat-Haramosh Massif (NPHM) in the western Himalaya contains very young (Plio-Pliestocene) leucogranites. The only other occurrence of such young granites (1.9 to 0.8 Ma) has been recorded in the Japan Alps (Harayama, 1992). Monazite ages, ranging from 4 to 11 Ma are reported from the gneisses in the Indus and Astor valleys (Smith *et al*., 1992). The young Nanga Parbat granites and pegmatites are undeformed and occur in small bodies.

Chaudhry and Ghazanfar (1987) gave detailed accounts of the granitic gneisses of the Kaghan valley; the ages of most are unknown. These are syn-, late- and post tectonic to the surrounding deformation and metamorphism, and could potentially belong to any of the seven age groups. Included are many small bodies of leucogranites, aplites and pegmatites including garnet-tourmaline-muscovite leucogranites similar to those from other parts of the Himalaya.

TECTONIC IMPLICATIONS

Pre- syn- and post-orogenic granites and granitic gneisses, ranging in age from Early Proterozoic to Quaternary occur all along the Pakistani Himalaya. The oldest granitiods can be correlated with the Jutogh-Munsiari thrust sheet of the Indian Lesser Himalaya. These granites (2300-2800 Ma) may be the vestiges of the Precambrian granitic gneisses from northern margin of the Peninsular shield (Satpura orogeny) that was actively involved and remobilized during different orogenic phases of the Himalayan orogeny. The Satpura is broadly contemporaneous with the Limpopo orogeny (~ 2100 Ma) of Africa and the Marealbian - Balmorian (2100-1900 Ma) of Europe (Valdiya, 1983).

The granites of ca. 1850 Ma can possibly be correlated with the Aravalli orogenic cycle dated ca. 2000 Ma (Davies & Crawford, 1971) and with the Dharwar orogenic phase II dated ca. 2000 Ma (Venkatsubramaniam *et al*., 1971) of the Indian Peninsular shield. This orogenic cycle also corresponds to the Eburanian orogenesis dated at (1850 ±250 Ma) in southern and western Africa (Clifford, 1968). A magmatic correlation between the Indo-Pakistan craton and the Himalayas supports the idea that these rocks represent the northern extension of the Precambrian Indian craton (Thakur, 1983).

The 823 ±2 Ma date for the Black Mountain orthogneiss is unusual as intrusive rocks of this age have rarely been reported from the northwest Himalaya. It implies a minor late Proterozoic intrusive event that is possibly correlative with Malani rocks, which has been dated between 750 and 850 Ma on the Aravalli craton of northern India and with a ca. 870 Ma igneous suite of the Kirana hills in the Pakistani foreland (Kazmi & Jan, 1997). The Malani and Kirana rocks belong to an extensive igneous province in western India that has been related to hot spot (anorogenic) magmatism.

The late Cambrian-Middle Ordovician ages for the Mansehra and Choga (Swat) plutons group them with the Lesser Himalayan granitoid belt of Le Fort *et al*. (1983). These may belong to a regional, largely anorogenic, intrusive event. Uplift and erosion of Cambrian strata in the northern Peshawar Basin has been correlated with this phase of intrusion, but there is no evidence for strong deformation or regional metamorphism (Pogue *et al*., 1992b).

The Carboniferous- Early Permian magmatism reflects a major period of intrusion, and volcanism that includes several granitic/bimodal magmatic complexes such as Ambela, Shewa-Shahbazgarhi, Warsak and part of the Swat gneiss as well as Panjal volcanics and dolerite dykes in northern Pakistan. Kempe (1983) suggested that intrusive rock related to this event underlies much of the northern Peshawar Basin. Jan and Karim (1990) and Pogue *et al*. (1992a) have suggested that this magmatism was related to rifting in the northern part of the Indian plate. Magmatic rocks of this age also occur in southern Tibet.

The Cretaceous-Tertiary period is marked by a dramatic increase in magmatic intrusions in north and western Pakistan, however, much of it is confined to the region north of the Indus suture zone. This magmatism owes its origin mostly to the closure of the Neo-Tethys and ultimate collision of India with Asia. This resulted in subduction-related magmatism in island arcs, continental margins and, possibly, marginal basins. Despite the closure of the Neo-Tethys during Early Tertiary, magmatism continued in the Pakistan Himalaya south of the Indus suture zone until Plio-Pliestocene (Zeitler *et al*., 1985, Zeitler and Chamberlain 1991; Zeitler *et al*., 1993). The early Tertiary magmatism may be related to partial melting accompanying burial and high-grade metamorphism. The young NPHM granitic rocks have been correlated to partial melting accompanying rapid uplift and thermal relaxation.

DISCUSSION

Considering the magnitude and complexity of the Himalayan orogenic belt, available radiometric data on granitoid rocks in the last decade has helped in broadly delineating the various plutons of the Himalayas and has constrained the stratigraphic position of the Indian shelf sediments. The NPHM and Indus syntaxis terranes have their origin in an event at least as old as 2200 Ma with Archean detrital zircons as old as ca. 2930 Ma. The older population of zircons in the Kishar formation suggests Archean or Early Proterozoic deposition followed by Early Proterozoic (>2200 Ma) intrusion and lead-zinc mineralization. Similarly, an Early Permian age for part of the Swat gneisses constrains the base of the unconformably overlying Alpurai group as well as associated mafic dykes that intrude the Swat gneisses to be Late Permian or younger. Additional radiometric data is needed to further unravel and resolve the history and the origin of the different granitoids of the Himalaya.

Synthesis of the data shows that granite magmatism in present-day northwest India spans over 2200 Ma. It is episodic and apparently varied in origin. Some of it is related to orogeny, some to rifting, and that in NPHM to thermal relaxation. Indeed the granitic assembly of northern Pakistan is a laboratory for understanding tectonics, metamorphism and magmatism.

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