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Himalayan Granitoids

S. SINGH AND A. K. JAIN

Department of Earth Sciences, Indian Institute of
Technology Roorkee, Roorkee - 247 667, INDIA

Abstract: The Himalaya is considered as a typical example of continent-continent collision between the Indian and Eurasian Plates during Cenozoic time. The Himalayan collision zone contains various granitoids with ages ranging from Proterozoic to Recent. These granitoids can be classified into two (2) main type related to the orogeny or can be divided into five (5) main types on the basis of their varied geographical distribution in diverse stratigraphic and tectonic setup as linear belts parallel to orogen. Dating of Himalayan granites has generated some of the first order data required to understand crustal growth history of the Indian Plate since Paleo-Meso Proterozoic. The time of crystallisation has been constrained mostly by Rb-Sr whole rock isochron analysis and zircon and monazite U-Th-Pb dating techniques.

Background

The Himalayan mountain chain is classical example of Continental Collision Tectonics and links up the present-day geodynamic processes with those of Late Mesozoic and Cenozoic. The geodynamic evolution of the Himalaya has at least 5 (five) different chronological stages: (a) Late Mesozoic subduction and accretion, (b) Cenozoic Collision, (c) Late Collision extensional tectonics, (d) Post-Collision sedimentation in foredeeps and (e) Present-day geodynamics (Jain et al., 2002 and references therein). This geodynamic evolution has been modelled into a global framework of underthrusting Indian Plate beneath the Eurasian Plate along two major suture zones i.e., the Indus-Tsangpo Suture Zone (… Main Mantle Thrust) and the Shyok Suture Zone (… Northern Suture Zone).

The overthrust Eurasian Plate reveals its character in a Late Mesozoic Andean-type Kohistan-Ladakh Batholith Complex, which is separated from the Karakoram metamorphic and its batholithic complexes by the Shyok Suture Zone. The suture between the two plates is exposed into two suture zones of the Indus-Tsangpo and Shyok; both are characterised by island-arc setting, fore-arc and back-arc sediments and ophiolite emplacement.

Early Mesozoic reconstruction reveals the existence of the Tethys Ocean of some 2500 km width between the Indian Plate and the Tibet block. The latter represents a passive continental margin through the Mesozoic and Early Eocene, as represented by the Tethys Himalayan sequence from Zanskar, Spiti, Kumaun, Nepal and southern Tibet. The shelf and the slope facies are recognised in the Mesozoic of the Tethys Himalaya along the passive Indian margin in Zanskar and southern Tibet. The Karakoram Supergroup and the Lhasa block sequence of Late Carboniferous to late Cretaceous age, located north of the ITSZ, represent deposits on the southern margin of the Tibet block of the Eurasia Plate. A stable carbonate platform recognised in the Mesozoic of the Tibet block existed until initial closure of this ocean.

The Tethys oceanic lithosphere has disappeared along the ITSZ by northward subduction of the Indian oceanic plate beneath the Tibet block and ophiolite emplacement. The ophiolite complexes are located along the entire belt of Indus- Tsangpo Suture Zone (ITSZ) from Ladakh to southern Tibet and within the Shyok Suture Zone. These occur in two main tectonic settings. Thrust Sheets of ophiolite are obducted southward on to the Tethyan Sedimentary Zone of northern continental margin of Indian Plate. Secondly, discontinuous tectonic lenses occur within the ITSZ. The Spongtong ophiolite klippe in Zanskar is one example of this obduction, while the Nidar and Shergol melanges in Ladakh and the Shigaze ophiolites in southern Tibet are described from within the Indus-Tsangpo suture zone. These ophiolite complexes represent the dismembered Jurassic-Cretaceous oceanic lithosphere of the Tethys Ocean that was closed along the suture zones. Through 125 to 45 Ma during Jurassic-Cretaceous-Eocene, accretion and subduction-related crustal processes are documented in geological and isotopic signatures of the Indus flysch deposits, Dras Volcanics, Ladakh Batholith complex, dismembered oceanic crust of the Tethyan Ocean and blueschist metamorphism along the 500 km long Indus Suture Zone in Ladakh (Jain et al., 2002 and references therein).

The Trans-Himalayan plutons, referred to as the Ladakh, Kohistan and Karakoram batholiths and Gangdese magmatic belt are manifestations of the subducting Indian Plate (Coward et al., 1982; Honegger et al., 1982; Dietrich et al., 1983; Khan et al., 1989; Rolland et al., 2000). The Trans-Himalayan plutons are compatible with I-type Cordillearn batholiths of Peru. Initial Nd, Sr and Pb isotopic compositions of the Gangdese and Ladakh batholiths indicate that these bodies have predominantly mantle-derived components. U-Pb ages vary from 105 to 45 Ma ages for Trans-Himalayan plutons. These ages and geochemistry point to northward subduction of the Tethyan oceanic lithosphere beneath the Eurasian Plate, formation of magma and minor crustal contamination during rise of these batholiths. The calc-alkaline Kohistan and Dras island arcs are also product of subduction. They are developed in oceanic regime and later accreted to the Indian Plate.

Closure of the Tethys Ocean is mainly confined along the Indus-Tsangpo Suture Zone (ITSZ) and the Kohistan Arc. The northern margin of the Indian Plate in the Higher Himalaya encompasses a basement and its sedimentary cover of Proterozoic age in the Higher Himalayan Crystalline (HHC). This basement is overlain by a Paleo-Mesozoic platform sequence of the Tethyan Sedimentary Zone. Subsequent crustal shortening of the Indian Plate during Continental Collision has considerably deformed the Higher Himalayan basement metamorphics. This is thrust southward along the Main Central Thrust (MCT) and its numerous splays over a central part of the dismembered Indian Plate whose Proterozoic-Paleozoic sedimentary basins in the Lesser Himalaya was covered by two marine transgressions during the Permian and Eocene (Ganseer, 1964; Valdiya, 1980; Thakur, 1993; Jain et al., 2002; and references therein). The whole succession is thrust southward over the Cenozoic Foredeep Molasse deposits along the Main Boundary Thrust (MBT). However, the southern margin of the Himalaya is in contact with a Proterozoic basement of the Aravalli and its platform in the Vindhyan Basin, which is covered by the Holocene alluvium of the Indo-Gangetic Plains.

Introduction

The Himalayan orogenic belt contains various granitoids, which have been assigned ages ranging from Proterozoic to Late Cenozoic by earlier workers, mainly based on field relationships, nature of xenoliths, degree of metamorphism, petrographical similarities, structural trends, etc. (McMahon, 1884; Greisbach, 1893; Auden, 1935; Wadia, 1928, 1957; and others), prior to the application of isotopic methods of age determination. Many workers have also observed that most of the peaks having a height of more than 7,000 m are made up of gneiss, granite or crystalline rocks in the Higher Himalaya and beyond (Hayden, 1908; Wadia, 1931; Odell, 1983).

In Himalaya the first Rb-Sr whole-rock isochron is reported by Jager et al. (1971) for the Mandi Granite and was followed by additional Rb-Sr age determinations by Bhanot et al. (1974, 1975, 1976), Frank et al. (1977), Mehta (1977) and many more in the NW-Himalaya on granitoids exposed around Rohtang, Manali, Kulu, Mandi, Dalhousie and Bandal. The initial ages were calculated by using an old decay constant (1.47x10-11 y-1), whereas after 1977 the ages were calculated by new decay constant (1.42 x 10-11 y-1; Steiger and Jager, 1977). Therefore, for the comparison between pre-1977 and after-1977 Rb-Sr age data all the earlier Rb-Sr whole-rock isochron ages have to be multiplied by a factor of 1.0352.

The Himalayan granitoids can be broadly classified into two main types in relation to the Himalayan orogeny: (i) pre-collisional bodies now occurring as granite/gneiss and (ii) syn-to post-collisional bodies being leucocratic in nature. Geochronological data, reported on a variety of granitoids and minerals using radioactive decay techniques, have constrained the age of emplacement, cooling and exhumation history (Pande, 1999; Jain et al., 2000; Hodges, 2000; Singh, 2001 and references therein). Age data from the granitoids of the Himalaya reveal distinct episodes of magmatic activity around 2100-1800 Ma, 1200-1000 Ma, 600-400 Ma, 100-50 Ma and 25-15Ma (Singh, 2001).

These Himalayan granitoids can also be divided on the basis of their varied geographical distribution in diverse stratigraphic and tectonic set up as linear belts parallel to the Himalayan orogen (Fig. 1). Granitoid bodies of large dimensions occur in almost all the tectonic units, except

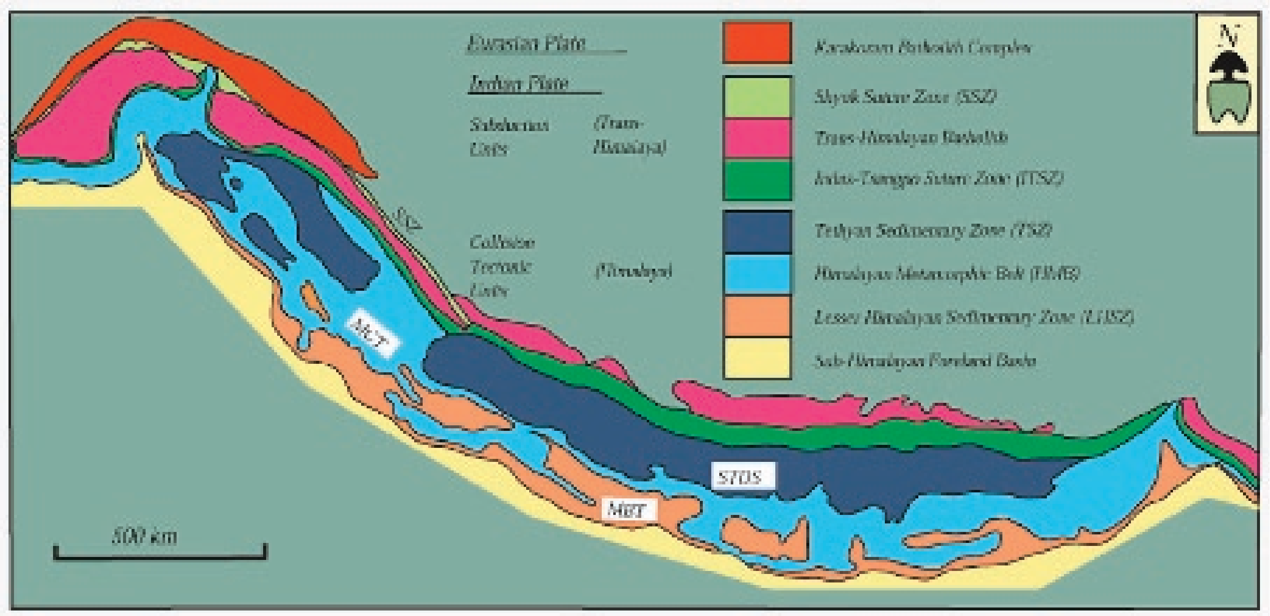

Figure 1. Simplified regional geological framework of the Himalaya in plate tectonic framework. Abbreviations: SSZ-Shyok Suture Zone. ITSZ-Indus Tsangpo Suture Zone. THSZ/STDZ-Trans Himadri Shear Zone/South Tibetan Detachment Zone. MCT-Main Central Thrust. MBT-Main Boundary Thrust. Complied from published data.

the Sub-Himalaya. On the basis of the geographical distribution, granitic plutons constitute five major belts in the Himalaya and adjoining Karakoram (Le Fort, 1988). From north to south, these belts include: (i) Karakoram Axial Batholith, (ii) Trans-Himalayan Batholith, (iii) Northern Himalayan Granite Belt, (iv) Granitoids of the Higher Himalayan Crystalline (HHC) Belt and (v) Lesser Himalayan Granite Belt. A brief account of these granitoid belts are given below.

Karakoram Axial Batholith

The Karakoram belt of granitoids is of batholithic dimension extending for about 700 km and intrudes the Palaeozoic to Triassic sedimentary sequences of southern edge of the Eurasian Plates. This belt comprises two major intrusive phases i.e., older phase pre-dating the collision and younger phase post-dating the suturing of the Indian and Eurasian Plates. Figure 2 shows the extent while Table 1 contains ages of Karakoram Axial Batholith. The belt occurs as an elongated arcuate composite body comprising different sub-alkaline and calc-alkaline units which occupy high peaks of the eastern Karakoram and the Pangong Mountains in Ladakh. Debon et al. (1987) have recognised three major magmatic episodes, out of which dominant phase is monzonitic in composition, while the other large plutons are mildly peraluminous e.g., Hunza granite (Rex et al., 1988), Baltoro granite (Searle et al., 1992), Batura granite (Debon, 1995). Petrographically these bodies are predominantly biotite granite with subordinate two-mica and hornblende-biotite granite. Age of the batholith ranges between 130 to 50 Ma (Srimal et al., 1987; Searle, 1991; Debon and Khan, 1996; Sinha et al., 1997; Weinberg and Searle, 1998) along with the younger phase of bodies ranging between 25 to 17 Ma (Parrish and Tirrul, 1989; Searle et al., 1998). The older phase in Karakoram Batholith is of calc-alkaline composition such as the Hushe gneiss, the K2 gneiss and the Muztagh Tower gneiss ranging in age between 120-85 Ma (Searle, 1991) along with Kuk pluton (63±2 Ma - Debon, 1995), Sarbzea pluton (43±6 Ma - Debon et al., 1987) and a distinct younger peraluminous leucogranite suite having bodies like Baltoro in Pakistan (U-Pb zircon age of 21.0±0.5 Ma -Parrish and Tirrul, 1989; U-Pb monazite age of biotite leucogranite as 25.5+0.3/-0.6 Ma and of two mica garnet leucogranite as 21.4+0.3/-0.8 Ma - Scharer et al., 1990), which is somewhat older than the Tangtse leucogranite of Ladakh (U-Pb zircon SHRIMP age of 18.0±0.6 Ma - Searle et al., 1998).

Trivedi et al. (1997) obtained a 3-point whole rock Rb-Sr isochron from the KBC as 83±9 Ma with an initial 87Sr/86Sr ratio of 0.7994±0.00023 from the syncollisional S-type granite. The chemistry of these granitoids are very similar to that of the Trans-Himalayan Ladakh Batholith indicating I-type affinity. A few workers are of the opinion that these bodies have been disconnected by a right-lateral strike-slip movement along the Karakoram Fault (Le Fort et al., 1983; Debon et al., 1987; Le Fort, 1988).

Table 1: Ages from Karakoram Axial Batholith

Body	Age	Initial (86Sr/87Sr)i	Reference
Darkot Plutonic unit, Karakoram	109±4 Ma		Debon et al., 1987
	111±6 Ma		Debon et al., 1987
Hunza Plutonic unit, Karakoram	97±17 Ma		Debon et al., 1987
	105.7±0.5 Ma (U -Pb Zr)		Fraser et al., 1999
K2 gneiss and Muztang Tower gneiss	120 - 85 Ma		Searle, 1991
Kuk	63_2 Ma		Debon, 1995
Sarbzea	43_6 Ma		Debon et al., 1987
Baltoro	21.0_0.5 Ma (U-Pb zir)		
	25.5+0.3/-0.6 Ma (U-Pb monazite)		Parrish and Tirrul, 1989
	21.4+0.3/-0.8 Ma		Scharer et al., 1990
Chiklas Igneous complex, Kohistan, N. Pakistan	111± 24 Ma (14 pt.)	0.70403±0.00006	Mikoshiba et al., 1999
Gabug, South Tibet	43±3 Ma (7 Pt.)		Wang et al., 1981
Lagol Kangri, South Tibet	15.1±0.5 Ma (U- Pb mon)		Scharer et al., 1986
Nyalam, South Tibet	16.8±0.6 Ma (U- Pb mon)		Scharer et al., 1986
Maitia (Maja), South Tibet	9.8±0.2 Ma (U- Pb mon)		Scharer et al., 1986
Tangtse Leucogranite, Ladakh, India	18.0_0.6 Ma (SHRIMP U-Pb zir)		Searle et al., 1998
Panamic Body	83_9 Ma (3 pt isochron)	0.7994_0.00023	Trivedi et al., 1997

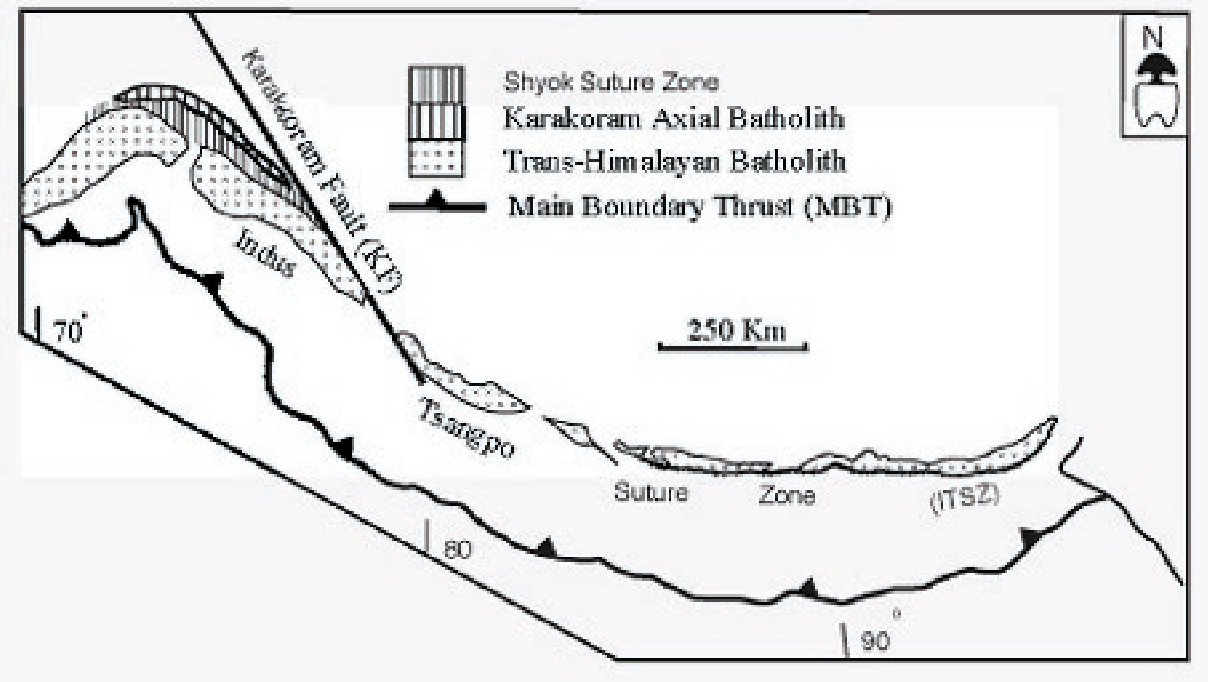

Figure 2. Trans Himalayan granitoid belts. A-Karakoram belt. B-Trans Himalayan batholiths. MBT-Main Boundary Thrust. ITSZ-Indus Tsango Suture Zone. SSZ-Shyok Suture Zone. KF-Karakoram Fault. Modified after Le Fort (1994).

Trans-Himalayan Batholith

The Trans-Himalayan Batholith belt, lying immediately to the north of Indus Tsangpo Suture Zone (ITSZ) and occurs as a long linear belt of granodiorite-diorite association for about 2500 km long and 20-80 km wide zone (Fig. 2). It represents the Andean-type magmatism due to melting of the north-dipping Tethyan oceanic crust (Scharer et al., 1984) below an island arc situated along the southern margin of Eurasia (Raz and Honegger, 1989). The batholith extends from Afghanistan in the west through Astor-Deosai-Skardu in Pakistan Kohistan Arc (Auden, 1935; Wadia, 1937; Deosai, 1977) to Leh-Hanle as Ladakh Batholith (Frank et al., 1977; Sharma, 1982; Thakur, 1993), Gangdese belt in southern Tibet (Academica Sinica, 1980; Xu et al., 1985; Debon et al., 1986; Scharer et al., 1984) to Lohit Complex in Arunachal Pradesh (Thakur and Jain, 1975; Sharma et al., 1991). In composition, the belt varies from quartz-diorite, granodiorite, quartz monzodiorite, quartz monzonite to granite. Occasionally, bodies of diorite, gabbro, pyroxinite and anorthosite are also seen associated with it, however, bulk composition of these plutons is largely quartz diorite to granodiorite. The belt has intrusive relationship with the volcanics of island arc setting like the Dras volcanics and Khardung volcanics (Sharma and Gupta, 1983; Chaudhry, 1983). Sharma (1983) and Sharma and Choubey (1983) recognized four phases of magmatic activity. However, Singh (1993) divided the Ladakh Granitoid Complex into five distinct units: diorite-tonalite, granodiorite-quartz monzodiorite, biotite-hornblende granite, leucogranite, and calc-alkaline pink porphyritic granite. Though several types of igneous bodies are reported from these plutons ranging from gabbro to granite, predominant rock type is biotite-and hornblende-bearing granodiorite throughout the body.

The Ladakh Batholith is largely undeformed and has escaped intense penetrative deformation to a very large extent. However, intense penetrative ductile shear fabric within this batholith has been observed by Weinberg and Dunlap (2000) within NNW-trending dextral Thanglaso Shear Zone and a diffused deformation zone to north of Leh. Our own observations on the deformation pattern reveals intense development of mylonitized gneiss with large-scale and deformed ellipsoidal enclaves of the country rocks trending almost N900 to N 1200 with steep dips towards north. A series of dolerite dykes cuts across the deformed batholith and trends almost orthogonal towards NE. A few observations also reveal the presence of NW-trending ductile shear zone having top-to-southwest overthrust sense of shear, while others are brittle-ductile to brittle in character.

The age of these body predate collision between the Indian and Eurasian plates representing subduction related magmatism (Table 2). U-Pb zircon age from Kargil yield an age of 102±2 Ma, whole rock Rb-Sr isochron age of 60±5 Ma around Leh and SHRIMP U-Pb zircon age on Leh Pluton (including the Shey body) yield an age of 49.8±0.8 Ma with older components present there, however, Gyamsa body yield SHRIMP U-Pb zircon age of 61.5±2.0 Ma and body at Digar yield 58.4±1.0 Ma age (Honegger et al., 1982; Scharer et al., 1984; Weinberg and Dunlap, 2000). Whereas, Rb-Sr whole rock isochron from Kohistan Arc indicate ages of 102±12 Ma and 54±4 Ma (Petterson and Windley, 1985) and 49±11 Ma and 26±1 Ma (George et al., 1993) indicating similarity in age between Ladakh Batholithic complex and Kohistan Arc. Similarly, the plutonic rocks of the Gangdese Batholith have crystallization age from about 120 Ma to 40 Ma (Harris et al., 1988; Scharer et al., 1984) with two distinct period of plutons having 120 Ma -90 Ma and 70 Ma - 40 Ma and the large portion of ages are between 55 Ma -40 Ma.

SiO2 content of these bodies varies from 53 to 75 wt% with normative quartz between 8% and 36%. These bodies are predominantly meta-aluminous with I-type character, whereas only a few samples do reveal signatures of S-type granite. Rb content is less; whereas, Sr appears to be high for the belt but Rb/Sr ratios do not vary significantly. Chondrite-normalised REE plots exhibit enriched LREE with feeble negative Eu anomaly and moderately fractionated HREE content, thus indicating the mantle affinity (Honegger et al., 1982; Sharma and Choubey, 1983; Petterson and Windley, 1985; Singh, 1993; Ahmed et al., 1998).

North-Himalayan Granite Belt

This belt comprises a series of domes to the south of Indus-Tsangpo Suture Zone (ITSZ) in a distributed manner as independent plutons e.g. the Kaghan pluton, Lhago-Kangri pluton, Kangmar pluton, Nyimaling pluton, Tso-Morari gneiss, Rupshu pluton, Jispa pluton, Kade gneiss, Koksar gneiss, Kaghan gneiss and belongs to the Cambro-Ordovician event (Gansser, 1977; Frank et al., 1977; Wang et al., 1981; Tapponnier et al., 1981; Sharma, 1983; Pognante et al., 1990; Stutz and Thoni, 1987; Spencer, 1993; Girard and Bussy, 1999). The age assigned to these bodies are also of Cambro-Ordovician related to Pan-African Magmatism in the Himalayan Collisional Zone (Table 3). These bodies are present as gneissic bodies with varying grain size from very fine-grained to coarse-grained. This belt is composed of two different granitoid rocks. (i) More or less gneissose porphyritic granite group of lower Ordovician age resembling with the Lesser Himalayan granites belt and (ii) two-mica leucocratic group with heterogeneous Sr isotope ratios giving very young age. These bodies are mainly peraluminous with S-type granite with typically high Sr/Sr ratio. The body mostly fall within monzo- to syno-granite field with few falling in the granodiorite field. The SiO2 content of the body is narrow and varies from 65 to 75 wt%.

Granitoids of the Higher Himalayan Crystalline (HHC) Belt

The Higher Himalayan Crystalline (HHC) Belt contain three main types of granitoids ranging in age from 2600 Ma to as young as 2 Ma viz. Proterozoic belt, Pan-African belt and collision related Higher Himalayan Leucogranite (HHL) belt (Fig. 3, Table 4).

The rocks of the Himalayan Metamorphic Belt (HMB) is characterised by nappes containing metamorphic rocks and remobilised continental crust in the form of granite

Table 2: Ages from Trans-Himalyan Batholith

Body	Age	Initial (86Sr/87Sr)i	Reference
Giak granite, Ladakh Batholith	235±13	0.7125±0.0018	Trivedi et al., 1982
Dras volcanics	264 Ma (13 pt) psedo-isochron	0.70345	Honegger et al., 1982
Kargil Intrusive complex (granodiorite)	103±3 Ma		Honegger et al., 1982
	101±2 Ma (U- Pb zircon)		Scharer et al., 1984
Leh (granodiorite)	63±5 Ma (U-Pb zircon)		
	49.8±0.8 Ma _		
	58. 4±1.0 Ma_		
	61.5±2.0 Ma _		
	60±10 Ma (Rb-Sr)		
(U-Pb Zr SHRIMP)	no details		Scharer et al., 1984
			Weinberg and Dunlap 2000
			Weinberg and Dunlap 2000
Shey granites	60±10 Ma (3 pt)	0.7048±0.0005	Honegger et al., 1982
Kohistan Arc	102_12 Ma		
	54_4 Ma		
	49_11 Ma		Petterson and Windley, 1985
	26_1 Ma		George et al., 1993
Kailash intrusives and volcanics, Tibet	38.8±1.3 Ma	0.70609 ± 0.00015	Honegger et al., 1982
Gangdese	120 Ma -90 Ma and 70 Ma - 40 Ma		Harris et al., 1988;

Table 3: Ages of North Himalyan Granite Belt

Body	Age	Initial (86Sr/87Sr)i	Reference
South Lahaul	495±16 Ma (6 pt.)	0.720±0.002	Frank et al., 1977
Jispa Granite	495±16 Ma		Frank et al., 1977
Kangmar granite (South Tibet)	484±7 Ma (5 pt.)	0.7140±0.001	Debon et al., 1981
	485±6 Ma (6 pt.)	0.7186±0.0018	Wang et al., 1981
	435±37 Ma (8 pt.)	0.7207	Jin and Xu, 1984
562±4 (U - Pb Zircon)			Scharer et al., 1986
509±6 (U - Pb Zircon)			Lee et al., 2000
509±18 (U - Pb Zircon)			Lee et al., 2000
Anduo			
531+13/-14 (U-Pb zircon, sphenes)			Xu et al., 1985
Kangan, Kashmir	470±11 Ma (3 pt.)	0.7216±0.0023	Trivedi et al., 1985
	500±10 Ma		Rao et al., 1990
Kafristan	483±24 Ma (5 point)	0.7066	Debon et al., 1986
Shangus gneiss	472 +9/-6 Ma (U- Pb zircon and monazite single crystal)		Pognant et al., 1990
Orthogneisses Lahaul-Zanskar	549±70 Ma (5 point)	0.7175±0.0073	Pognant et al., 1990
Kade Gneiss Lahaul-Zanskar	470±56 Ma	0.7266±0.0012	Hohendorf et al., 1991
Koksar Gneiss	453±26 Ma (4 point)	0.741±0.003	Singh et al., 1991
Nyu Area	489±20 Ma (6 point)	0.717	Rao et al., 1990
Hant-Baramula	392±36 Ma (6 point)	0.7286±0.0053	Sarkar et al., 1996
Tso Morari Gneiss	479±2 Ma (U- Pb Zr)		Girard & Bussy, 1999
Polokongla granite	487±25 Ma (4 pt.)		Trivedi, 1990
	458±14 Ma		De Sigoyer et al., 1997
	479±2 Ma (U -Pb Zr)	0.7154±67	Girard & Bussy, 1999
Rupshu granite	487±14 Ma (4 pt.)		Trivedi, 1990
	482.5±1 Ma (U- Pb Zr)	0.7113±36	Girard & Bussy, 1999
Peltic Schist, Manali	498.6±20.2 Ma (U-Pb mon) (UI)		
	30.1±1.3 Ma LI		Walker et al., 1999
Pelitic Schist, Khoksar	489±84 Ma (U-Pb mon) (UI)		
	59±6.5 Ma (LI)		Walker et al., 1999

and granodiorite gneisses. These are of predominantly porphyritic in nature, showing post-magmatic deformation either as large-scale concordant sheets or as isolated circular- to elliptical-shaped bodies. These bodies are very similar in their structural, petrological and geochemical character. Observations on many such granitoids reveal localised high ductile shear strain along their margins, where numerous shear indicators consistently reveal initial top-to-SW verging displacement having overthrust geometry. It is likely that many such bodies might represent remnants of distinct granitoid sheets, which were intensely deformed during ductile shearing within the Lesser and Higher Himalaya (Singh and Jain, 1996). The rocks dated in the Himalayan Metamorphic Belt (HMB) are the oldest in the Himalaya as confirmed by the Rb-Sr ages along with few conventional and also SHRIMP U- Pb zircon dates and are mainly pre-Himalayan of Proterozoic and Early Palaeozoic age (Table 4A).

The Proterozoic bodies within the HHC are also known as the Central axial complex and are generally fine to coarse-grained gneiss with porphyroclastic development of feldspars associated with metasediments and amphibolites all along the Himalayan orogeny. The bodies occur between Main Central Thrust (MCT) in the south and Vaikrita Thrust in the north. It start from west having Besham gneiss, Iskere gneiss, Kotla Indress, Shasher gneiss (in Pakistan) to Rameshwar granite, Kulu-Bajura gneiss, Bandal Granite, Wangtu Granitic

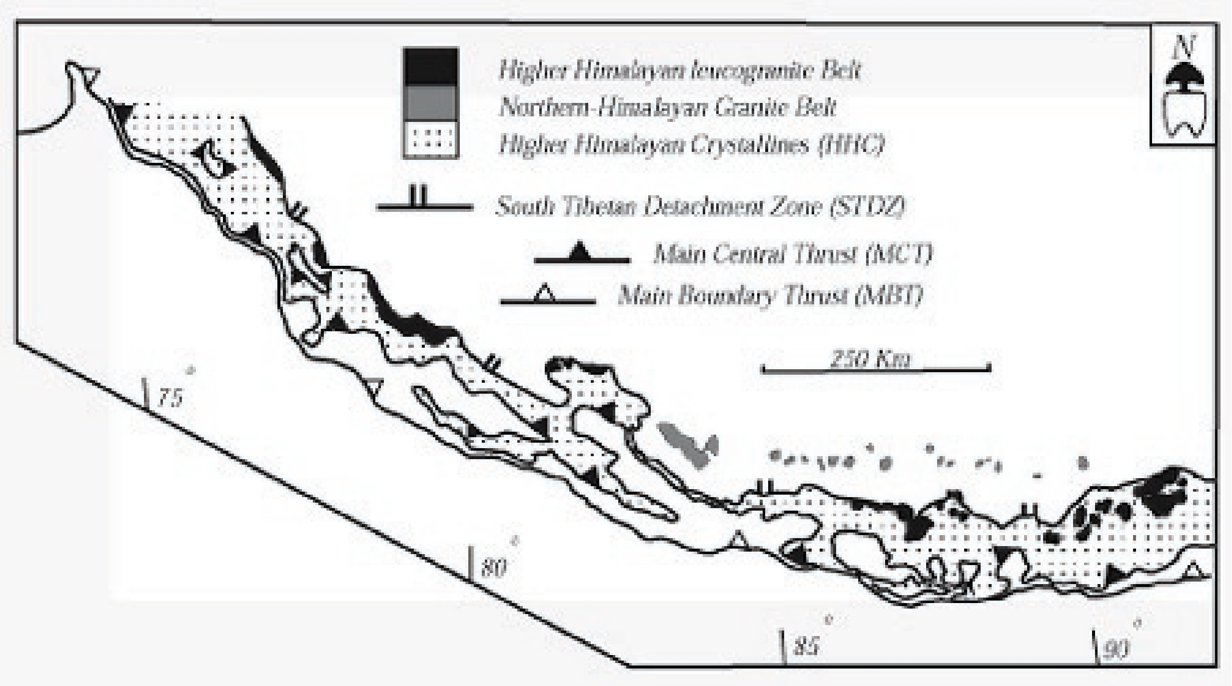

Figure 3. North Himalayan and Higher Himalayan granitoid belts. 1-Lesser Himalayan Proterozoic Belt. 2-Himalayan metamorphic Belt (HMB).

Complex, Naitwar, Hanuman Chatti, Bhatwari, Namik, Gwalda, Chailli, Ghuttu, Chirpatiya, Rihee-Ganga, Ramgarh, Tawaghat, Almora-Askot-Dhramgarh gneiss (in India) to Ulleri augen gneiss, Mellung augen gneiss (in Nepal) through Lingtse, Darjeeling-Sikkim, Bomdila and Kalaktang granite gneiss (in NE-India). They are meta-aluminous to para-aluminous in composition with S-type characteristics. The bodies have relatively SiO2 concentration between 60 to 76%. In Rb vs. Y+Nb discrimination diagram of Pearce et al (1984) they fall in the Within Plate Granite (WPG) indicating anorogenic character.

Cambro-Ordovician Bodies associated with Pan-African magmatism within the Higher Himalayan Zone lie above Vaikrita thrust and the upper margin of these bodies are mostly defining a tectonic boundary with Tethyan Sedimentary Sequences marked by Martoli Fault/ Trans-Himadri Fault. The collision-related magmatism, known as Higher Himalayan Leucogranites (HHL), is being surrounded by this biotite-bearing porphyroclastic augen gneiss. The SiO2 composition of the bodies has higher content ranging between 70 to 80% and they fall within the monzogranitic field with peraluminous S-type character. The Pan-African ages are derived from Rb-Sr whole rock ages along with a few ages by conventional U-Pb ages. These ages indicate that the Lesser Himalayan granite belts have been emplaced/crystallised around the Cambro-Ordovician boundary (500±50 Ma) and their high initial 87Sr/86Sr isotopic ratios indicate involvement of the evolved continental crust (Table 4B). 187Re-187Os systematics have also been used in dating the organic rich sedimentary rocks of the Himalaya relating to the Pan-African orogenic event. The Re-Os isochron ages of Maldeota (554±16 Ma) and Durnala (552±22 Ma) black shales from the Lower Tal Formation (Singh et al., 1999) are consistent with stratigraphy age as estimated by the U-Pb zircon age of the other stratotype section of the world (540-520; Bowering et al., 1993; Brasier et al., 1994).

The High Himalayan Leucogranite (HHL) popularly known as the collision related rare magmatism forms a discontinuous belt for about 1500 km from Pakistan to Bhutan, having numerous intrusions of varying dimensions (Debon et al., 1986, Le Fort et al., 1983, 1986). These occur as sills and laccoliths and are intruded either within the HHC or near its interface with the overlying unmetamorphosed to low grade metamorphosed Tethyan Sedimentary Zone (TSZ), where a major structural break of Miocene age has been postulated (Debon et al. 1986; Le Fort, 1986; Searle and Rex, 1989; Hodges et al., 1992).

The Characteristic feature of the bodies is presence of tourmaline in almost every pluton and they are undeformed in nature with less quartz, more of feldspars and minor amount of muscovite. In the eastern Himalaya, covering parts of Nepal and Bhutan, HHL is generally homogeneous and larger in dimension, where the floor of the pluton is concordant with the foliation of the underlying formations, and the roof has the shape of a large cupola intruding the overlying Tethyan Sedimentary Zone. However, in the western parts the leucogranites are restricted to the HHC. A network of aplitic and pegmatitic veins, extending longitudinally for a considerable distance, is also observed around many of the leucogranites bodies. These bodies are devoid of any microgranular igneous inclusions, but contain numerous metasedimentary xenoliths along their margins, and sometimes, within the pluton as small biotite schlierens. These HHL are considered to have been formed in near-minimum melt composition under water-saturated condition. Since the magma composition was lying just above the solidus, it appears to be fairly immobile, and intruded near its source (Crawford and Windley, 1990).

Table 4: Ages of Granitoids of the High Himalayan Crystalline Belt

Table 4A. Proterozoic Bodies

Body	Age	Initial (86Sr/87Sr)i	Reference
Iskere gneiss	1852±14 Ma (U-Pb Zr)		Zeitler et al., 1989
	2500 Ma (Nd model age)		Whittington et al., 1999
Kotla Orthogneiss	1839±9 Ma (U-Pb Zr)		Dipietro and Isachsen, 1999
	1836±1 Ma (U-Pb Zr)		Dipietro and Isachsen, 2001
Shang Granodiorite	1864±4 Ma (U-Pb Zr)		Dipietro and Isachsen, 2001
Around Dalhousi	362±50 (375 Ma*) (3 Pt.)	0.709	Bhanot et al., 1974,1975
Bandal	1220±100 (3 Pt.)	0.748±0.100	Bhanot et al., 1976, 1979
	1840±0.0027 (4 Pt.)	0.7083	Frank et al., 1977
Around Mandi	311±6 (322 Ma*) (3 Pt.)	0.8110±0.0007	Mehta, 1977
Around Mandi	640±20 (662 Ma*) (3 Pt.)	0.7001±0.0005	Mehta, 1977
Munsiari	1830±200 (1894*) (2 Pt)	0.725	Bhanot et al., 1977
	1890±155(1956*) (3 Pt.)	0.725±0.010	Bhanot et al., 1977
Nirath-Baragaon	1430±150 (6 Pt.)	0.746	Bhanot et al., 1978
Manikaran (Uranite from quartzite)	1232±120 (6 Pt.)		Bhalla & Gupta, 1979
Almora-Askot	1620±90 (4 Pt.)	0.749±0.007	McPowell et al., 1979
Askot Dharamgarh	1795±30 (9 Pt.)	0.7090±0.0015	Pandey et al., 1981
Baijnath	1130±110 (4 Pt.)	0.736	Pandey et al., 1981
	1320±370 (4 Pt.)	0.755	Pandey et al., 1981
Gwaldam granite	1300±80 (5 Pt.)		
	1700±70 (6 Pt.)	0.793	Pandey et al., 1981
	0.7375±0.0127		Trivedi et al., 1984
Brijrani Gad, Bhilganga Valley	1276±12 (3 Pt.)	0.82	Bhattacharya et al., 1981
Ignedi nala, Bhilganga Valley	1139±46 (9 Pt.)	1.1	Bhattacharya et al., 1981
Lingtse granite, NE Himalaya	1075± 28 Ma.	0.7001	Paul et al., 1982
	1678 (Rb-Sr whole rock)		Paul et al., 1996
Chailli, Bhilganga Valley	2121±60 (4 Pt.)	0.710±0.20	Raju et al., 1982
Kiodal granite	731±120 (4 Pt.)		Singh, 1982
Rampur-Padampuri granite	1238±128 (5 Pt.)		Singh, 1982
Ramgarh granite	1765±60 (11 Pt.)	0.7235±0.0046	Trivedi et al., 1984
Rameshwar granite	1820±130 (6 Pt.)	0.7114±0.0118	Trivedi et al., 1984
Namik	1910±88 (5 Pt.)	0.724±0.013	Singh et al., 1985
Tawaghat	1906±220 (9 Pt.)	0.724±0.012	Singh et al., 1985
Ghuttu, Bhilganga Valley	1763±116 (5 Pt.)	0.727±0.029	Singh et al., 1985
Chirpatiya khal, Bhilganga Valley	1708±131 (4 Pt.)	0.732±0.147	Singh et al., 1985
Lansdown	334±24 (5 Pt.)	0.791±0.009	Singh et al., 1985
Amritpur granitoid	1110±131 (5 Pt.)	0.741	Singh et al., 1985
	1585±192 (4 Pt.)	0.947	Singh et al., 1985
Wangtu-Jeori	2075±86 (6 Pt.)	0.7074±0.01	Kwatra et al., 1986
Wangtu granite	1866±10 Ma (U- Pb Zr)	0.7044±0.0072	Singh, 1993; Singh et al., 1994
Magladgad granite stock	2068±5 Ma (U -Pb Zr)	0.7044±0.0072	Singh, 1993; Singh et al., 1994
Wangtu granite gneiss (CPG)	1895±64 Ma (6 pt)		Rao et al., 1995

Body	**Age**	**Initial (86Sr/87Sr)i**	**Reference**
Wangtu granite gneiss (FGG)	1895±64 Ma (6 pt)		Rao et al., 1995
Naitwar, Tons valley	1811±133 (4 Pt.)	0.707±0.017	Singh et al., 1986
Hanuman chatti, Yamuna valley	1972±102 (4 Pt.)	0.703±0.010	Singh et al., 1986
Bhatwari, Bhagirathi valley	2047±119 (4 Pt.)	0.706±0.007	Singh et al., 1986
Rihee-Gangi, Bhilganga Valley	1841±86 (4 Pt.)	0.710±0.010	Singh et al., 1986
Black Mountain orthogneiss, Pakistan	823±2 Ma (U-Pb Zr)	0.7065	Kwatra et al., 1989
Dipietro and Isachsen, 2001	1100±100 Ma (5 Pt)	0.7067	Kwatra et al., 1989
Chor Granite gneiss	940±100 Ma (5 Pt.)	0.732	Kwatra et al., 1989
Chor Granite (non foliated)	526±46 Ma (3 Pt.)		Singh, 1993; Singh et al., 1994
Chor Granite (undeformed)	910±23 Ma (U -Pb Zr)		Singh et al., 2002
Chor Granite (deformed)	823±5 Ma (SHRIMP U-Pb)		Singh, 1993
	859±11927Ma (U- Pb Zr)		
Tashi Yangtse augen gneiss, Bhutan	~825 Ma (U-Pb Zr)		Thimm et al., 1999
Darjeling-Sikkim granite gneis	1792 (Pb-Pb age)		Paul et al., 1996
Bomdila gneiss	1874±24 Ma (U- Pb Zr)		Rao, 1998 a
	1827±95 Ma (U- Pb Zr)		Rao, 1998 a
Kalaktang granite	1706±80 Ma (errorchron)	0.7055±0.0066	Rao, 1998 a

* Equivalent age using new decay constant of Steiger and Jager (1977)

Table 4B. Cambro-Ordovician Bodies

Body	**Age**	**Initial (86Sr/87Sr)i**	**Reference**
Rohtang Gneiss	612±100 Ma (Appr. age) (634 Ma*)		Bhanot et al., 1975
Kulu gneiss	500±8 Ma (518 Ma*) (4 pt.)	0.7190±0.0007	Mehta, 1976
Manali-Rohtang Gneiss	581±9 Ma (5 pt.) (601 Ma*)	0.7113±0.0007	Mehta, 1977
Granite NE of Manikaran	467±45 Ma (4 pt.)		Bhanot et al., 1979
Kinnar	675±70 Ma	(Source not mentioned)	Sharma, 1983
Kailash	495±50 Ma	(Source not mentioned)	Sharma, 1983
Karcham-Sangla granite gneiss	453 ± 9 Ma (5 pt.)	0.7370 ± 0.00202 (fine-grained)	Kwatra et al., 1999
Migmatite, Dudh Kosi valley, Nepal	550±16 Ma (4 pt.)	0.7283±0.0006	Ferrara et al., 1983
Upper paragneiss, Lhotse glacier	449±56 Ma	0.7236±0.0030	Ferrara et al., 1983
Kafristan	483±24 Ma (5 point)	0.7066	Debon et al., 1986
Doda-Bhadarwa	496±21 Ma (4 point)	0.7359±0.0081	Kwatra, 1986
Thatri-Kistawar	499±57 Ma (3 point)	0.702±0.0114	Kwatra, 1986
Kistwar-Chatru	724±99 Ma (6 point)	0.705±0.007	Kwatra, 1986
Harsil Area	529±43 Ma (4 point)	0.710±0.011	Singh, 1986
Ramban Gneiss Kashmir	720±40 Ma (6 point)	0.7069±0.0035	Kwatra and Bhanot 1988
Shangus gneiss	467±6 Ma (Th-Pb monazite)		Zeitler et al., 1989
Orthogneisses Lahaul-Zanskar	472 +9/-6 Ma (U- Pb zircon and monazite single crystal)		Pognant et al., 1990
Kade Gneiss Lahaul-Zanskar	549±70 Ma (5 point)	0.7175±0.0073	Pognant et al., 1990
Koksar Gneiss	567±22 Ma (7 point)	0.704±0.0098	Kwatra, 1986
Nyu Area	453±26 Ma (4 point)	0.741±0.003	Singh et al., 1991
Hant-Baramula	489±20 Ma (6 point)	0.717	Rao et al., 1990
Akpa	477±29 Ma (6 point)	0.7206 ± 0.00235	Kwatra et al., 1999

* Equivalent age using new decay constant of Steiger and Jager (1977)

Table 4C. High Himalyan Leucogranite (HHL)

Body	Age	Reference
Nanga-Parbat Harmosh Massif	2.3 Ma (U- Pb SHRIMP)	Zeitler and Chamberlain, 1991
	5 Ma (U- Pb SHRIMP)	Zeitler and Chamberlain, 1991
	7 Ma (U- Pb SHRIMP)	Zeitler and Chamberlain, 1991
Mango Gusar Granite	37.0±0.8 Ma (U -Pb Zr)	Parrish in Rex et al., 1988
Dassu Gneisses	6.8±0.2 (U- Pb monazite)	Smith et. al., 1992
	6.8±0.2 (U- Pb monazite)	Smith et. al., 1992
Jutial, Karakoram-Nanga Parbat	10 Ma (U- Pb Zr)	Schneider et al., 1997
	10-5.3 Ma (Th- Pb monazite)	Schneider et al., 1997
Sumayar leucogranite	9.2±0.5 Ma (U- Pb uranite)	Fraser et al., 1999
	8.6 Ma (U- Pb xenotime)	Fraser et al., 1999
Chichi granite	22-16 Ma (Th-Pb ionmicroprobe on monazite)	Schneider et al., 1999
MMT Dyke, Skardu Road near Sassi	13-6 Ma (U-Pb ionmicroprobe on Zircon)	Schneider et al., 2001
Rupal Leucogranite sheet (Tap Meadow)	1.95±0.14 Ma (U-Pb ionmicroprobe on Zircon)	
	1.98±0.19 Ma (Th-Pb ionmicroprobe on monazite)	Schneider et al., 2001
Rupal Leucogranite sheet (Lotbo Meadow)	4.3-1.8 Ma (U-Pb ionmicroprobe on Zircon)	Schneider et al., 2001
Safat leucogranite	26 Ma (U- Pb monazite)	Nobel and Searle, 1995
Zanskar leucogranite	20.8±0.3 Ma (U- Pb monazite)	Nobel and Searle, 1995
Ghumber Ranjung Leucogranite, Zanskar	21.4 ±0.1 Ma (U-Pb uranite)	Walker et al., 1999
	21.3±0.1 Ma (U-Pb 2 uranite, 1 xenotime, 1 monazite)	Walker et al., 1999
Gangotri Leucogranite	21.1±0.9 Ma (WR+mineral -2 felds, mus, tour)	Stern et al., 1989
	22.4±0.5 Ma (Th-Pb monazite)	Harrison et al., 1997
Shivling Leucogranite (Gangotri leucogranite)	21.9±0.5 Ma (Th-Pb monazite)	Harrison et al., 1997
	23.0±0.2 Ma (U-Pb monazite age)	Searle et al., 1999
Manaslu leucogranite	29±1 Ma (7 Pt.)	Hamet and Allegre, 1978
	15.3 - 20.5 (WR- mus-6Pt.)	Vidal et al., 1982
	24 Ma (U- Pb Zr)	Scharer et al., 1986
	21.9 Ma (U- Pb monazite)	Scharer et al., 1986
	18.1±0.5 Ma (11 Pt.)	Deniel et al., 1987
	21.3±0.4 Ma (Apa-WR-Kfel- mus.)	Copeland et al., 1990
	26.6 (U- Pb monazite)	Deniel et al., 1987
	22.3±0.5 Ma (ionprobe monazite)	Harrison and McKeegan, 1994
Makalu Leucogranite	24.0±0.2 Ma (U- Pb Zr)	Scharer, 1984
	21.9±0.2Ma (U- Pb mon)	Scharer, 1984
Rongbuk Leucogranite	19±0.2 Ma (U- Pb Zr)	Copeland et al., 1988
	20.6±0.2 Ma (U- Pb monazite)	Copeland et al., 1988
	19.5-21.6 Ma (U- Pb xenotime, monazite, Zr)	Hodges et al., 1992
	20.6±0.2 Ma (U- Pb xenotime)	Hodges et al., 1992
Everest Leucogranite	20.6 Ma (U- Pb y-phosphate, xenotime)	Parrish, 1990
Annpurna Leucogranite	22±1 Ma (U- Pb Zr)	Parrish and Hodges, 1992
Shisma-Pangme Leucogranite, South Tibet	17.3±0.2 Ma (U- Pb Zr, monazite and xenotime)	Searle et al., 1997

The faulted junction between the HHC and overlying Tethyan sediments (Herren, 1987; Patel et al., 1993) and also the thermal contrast between the two rock sequences (Jaupart and Provost, 1985) provided an ideal ponding site for the magmatic injection.

These syn-to post-Himalayan leucogranites have been paid special attention during the last few decade because of their importance of being rare magmatic product of Himalayan collided range (Le Fort et al., 1987 and references therein). Most of the Himalayan leucogranite occur fully within the Higher Himalayan Metamorphic Belt (HHMB) except Manaslu and Rongbuk plutons, which crosscut the South Tibet Detachment System (STDS). U-Pb geochronology has been used extensively for determining crystallisation age for them and their ages have been listed in Table 4C.

The High Himalayan leucogranites are syntectonic intrusions. Among the High Himalayan plutons, the Manaslu is most thoroughly studied at present. The leucogranite bodies of Bhutan, Nepal, Garhwal and Zanskar regions have been dated between 24 Ma - 17 Ma (Searle, 1996; Harrison et al., 1997; Searle et al., 1999), but the majority of the leucogranite were emplaced during two pulses at 23 and 19 Ma (Harrison et al., 1997). However, timing of peak metamorphism has been constrained by U-Pb dating of metamorphic monazites and Sm-Nd dating of garnets.

During early phase of work on constraining the age of metamorphism, the work was mainly on the basis of cooling history by hornblende Ar-Ar and Rb-Sr muscovite ages representing post-metamorphic cooling of the rocks through 500-550° C. In Pakistan, hornblende Ar-Ar and Rb-Sr muscovite age constrained the metamorphism between 35 and 50 Ma (Maluski and Mate, 1984; Treloar et al., 1989; Treloar and Rex, 1990; Chamberlain et al., 1991; Hubbard, 1996). Mineral cooling ages of more than 30 Ma have also been reported from Zanskar (Searle et al., 1992; Sorkhabi et al., 1994), Garhwal (Metcalf, 1993; Sorkhabi et al., 1999) and Langtang in Nepal (Inger and Harris, 1992). During later phase, the work has been focused on dating metamorphic monazite by U-Th-Pb technique and Sm-Nd technique on garnet core and rim. Hodges et al. (1996) reported monazite U-Pb ages of 36.3±0.4 Ma from a gneiss sample of the HHC in the Annpurna area of Nepal. Edward and Harrison (1997) carried out Th-Pb ion microprobe dating of a monazite grain from Higher Himalayan leucogranite in Bhutan with a core of 34-36 Ma. However, U-Pb metamorphic monazite age of 37-29 Ma from Zanskar (Walker et al. 1999) and 32-23 Ma from Everest (Simpson et al., 2000) are also been reported. Further, garnet core and rim whole-rock Sm-Nd ages from Zanskar constrain age of metamorphism between 33-28 Ma (Vance and Harris, 1999) and from Garhwal between 40-29 Ma (Prince et al., 2000). Foster et al. (2000) also carried out U-Th-Pb SHRIMP II ion microprobe dating on monazite inclusion within garnets of three samples from Zanskar and Garhwal Himalaya and obtained ages between 44-36 Ma, while the matrix grain in one sample was dated between 30-26 Ma.

From west to east the HHL bodies can fall in the following geographical entity.

Nanga Parbat-Harmosh Massif (NPHM): In the northwestern Pakistan Himalaya, the Nanga Parbat-Harmosh Massif (NPHM) represents the northernmost exposure of the Indian Plate and is a complex mixture of ortho-and paragneiss (George et al., 1993) forming the part of the western syntaxis of the Himalaya. Zircon separates from small discordant bodies, intruded into the metamorphosed basement, have been dated by U-Pb SHRIMP method (Zeitler and Chamberlain, 1991). Three leucogranite dykes from this massif yielded intrusion ages of about 2.3 Ma, 5 Ma and 7 Ma, with an inherited core of 1850 Ma. However, two leucogranite dykes from southern localities yielded ages of about 35 Ma (Swat) and about 50 Ma (Naran) with older cores of ~1000 Ma, 1750 Ma and >2600 Ma. The bodies exposed at the deepest portion of the NPHM are the youngest in age ranging between 3-1 Ma (Zeitler et al., 1993, Schneider et al., 1999, 2001), however the ages increases towards north i.e. 7-5 Ma (Zeitler and Chamberlain, 1991) or 10 Ma (Schneider et al., 1999).

Zanskar (Ladakh): U-Pb data from leucograntie bodies of the High Himalayan Crystalline in the Umasi La and Shafat area of Zanskar in NW Himalaya reveal that crystallization occurred at 21-19.5 Ma and have been interpreted as the timing of anatexis in the Himalaya from Kashmir-Zanskar to eastern Nepal ~24-19.5 Ma (Nobel and Searle, 1995). In this section, migmatite from the deepest structural levels gives U-Pb monazite ages of 20.6-19.5 Ma, and at higher levels, migmatitic melt pods contain magmatic monazites of 20.8±0.3 Ma. Zircon from the leucogranite contains a ~ 460 Ma inherited component and reveals that the protolith were at least Ordovician in age (Noble and Searle, 1995). However, the Gumburanjon leucogranite, intruding the immediate footwall of the Zanskar Shear Zone in southeast Zanskar, gives crystallization age of 21.4±0.3 Ma from three uranite clusters with an upper intercept of 462±38 Ma, which has been interpreted as the age of source material. Monazite, xenotime and uranite from another sample also yielded an age of 21.3±0.1 Ma (Walker et al., 1999).

Garhwal: Further southeast in the Garhwal Himalaya, Stern et al. (1989) conducted Rb-Sr measurements on the whole rock and mineral separates (two feldspar, muscovite and tourmaline) from the Gangotri Granite, and observed significant scattering on the isochron diagram. The Gangotri Granite, also known as the Badrinath body, is composed of several bodies. Deep incision by the Bhagirathi River provides different exposures of these bodies at Shivling, Bhagirathi, Meru and Thalay Sagar peaks. The whole rock analyses of leucogranite have yielded a 5-point Rb-Sr isochron of 21.1±0.9 Ma (Stern et al., 1989). However, Th-Pb monazite gave an age of 22.4±0.5 Ma for the Gangotri and 21.9±0.5 Ma age for the Shivling leucogranites (Harrison et al., 1997). Searle et al. (1999) obtained a U-Pb monazite age of 23.0±0.2 Ma for the Shivling body. All these ages have been interpreted as the recrystallization age for the Gangotri-Badrinath group of leucogranites in the Garhwal Himalaya. Cooling ages for the Gangotri Granite are 17.9±0.1 Ma by 40Ar/39Ar method for muscovite and between 2.41±0.52 Ma and 1.48±0.60 Ma by fission track dating of zircon and apatite, respectively for a temperature range between 350±500C and 130±100C (Sorkhabi et al., 1996, 1999).

Nepal Himalaya: Amongst the syn- to post-Himalayan Cenozoic plutons, the Manaslu is presently the most thoroughly studied body, which apparently cross-cuts the South Tibetan Detachment Zone (STDS). In the earlier attempts to determine the crystallization age of the Manaslu granite, Rb-Sr isochron method was used by Deniel et al. (1987), who analysed 11 whole rock samples from a continuous outcrop of less than 75 m across on the southern margin of the pluton. These samples defined an isochron at 18.1±0.5 Ma with an initial 87Sr/86Sr ratio 0.7470±0.0005 (MSWD=7.3). However, 6 other samples from the same outcrop fall below the isochron and defined an approximate age. Deniel et al. (1987) also demonstrated that homogenization had occurred at least locally within the magma body. An apatite-whole rock-k-feldspar-muscovite isochron from a sample at the northern margin of the pluton has given an age of 21.3±0.4 Ma (Copeland et al., 1990), indicating that equilibrium has reached on the mineral scale. In the Manaslu area, the whole-rock isochron appears to have yielded an erroneous young age, and was confirmed by 40Ar/39Ar ages on hornblende from the metamorphic aureole (Guillot et al., 1994). Ion-microprobe analysis on monazite from the same body has yielded an age of 22.3±0.5 Ma with about 600 Ma inherited cores (Harrison and McKeegan, 1994).

Dating of zircon and monazite from the Manaslu granite by conventional U- Pb method has yielded ages of 24 Ma and 21.9 Ma, respectively (Scharer et al., 1986), while one U-Pb monazite age plots slightly above the concordia with a 207 Pb/235U age of ~ 25.5 Ma (Deniel et al., 1987). Deniel et al. (1987) have interpreted the Miocene age of 18.1 Ma by the Rb- Sr isochron and 25.5 Ma U-Pb on monazite to represent the time of crystallization of separate batches of magma and suggested that the Manaslu granite was produced by multiple magma injections within a span ~7 Ma. Based on the range of geothermal gradients, the depth of intrusion has been worked out to be about 8-15 km (Copeland et al., 1990).

Cooling history of the Manaslu granite has been analysed by 40Ar-39Ar dating of muscovite and biotite (Copeland et al., 1990). 13 muscovite samples from the main body yielded cooling ages from 18.4±0.1 Ma to 14.7±0.2 Ma, whereas 2 muscovites from the dyke at the structurally lower arm of Chhokang yielded 13.3±0.1 Ma age. 3 biotites from the main body gave ages from 17.0±0.1 Ma to 14.7±0.1 Ma.

The Rongbuk Valley, north of Qomolangma (Mt. Everest) in southern Tibet, exposes at least two generations of leucogranite. The younger leucogranite, exposed on the east wall of Rongbuk valley, is referred to as the Rongbuk pluton. This body is also cross-cutting the STDS like the Manaslu granite. The intrusion age of the Rongbuk leucogranite has been constrained by conventional U-Pb systematics on zircon and monazite between 21 to 22 Ma with component of inherited radiogenic Pb (Copeland et al., 1988). Single crystal of igneous zircon gave a concordant age of 19.5±0.5 Ma, titanite as 19.5±1.3 Ma, and xenotime 20.6±0.1 Ma to 21.0±0.1 Ma (Hodges et al., 1992). The Everest leucogranite contained inherited core in both zircon and monazite (Copeland et al., 1988), and the true emplacement age of 20.6 Ma was obtained from xenotime (Parrish, 1990). Further, Hodges et al. (1998) have constrained the brittle movement along the STDS between 16.37 and 16.67 Ma by U-Pb and 40Ar-39Ar methods and observed that extensional deformation along the STDS was not restricted but spanned over at least 10 Ma of the Himalayan Orogeny.

The Shisa Pangma (Xixabangma) massif is exposed along the Langthag Valley in Central Nepal and south Tibet just beneath the STDS, where zircon, uranite and monazite give a U-Pb age of 17.3±0.2 Ma (Searle et al., 1997).

Lesser Himalayan Granite Belt (LHG)

The Lesser Himalayan Granitic (LHG) belt extends along the southern margin of the Himalayan range from Pakistan to eastern Nepal as independent isolated plutons to the north of the Main Boundary Thrust (MBT). These include Saidu Sharif, Utla and Manshera (Pakistan); Dalhousie, Dhauladhar, Mandi-Karseog, Chor, Kaichnawa, Landsdown, Dudatoli, Amritpur, Almora, Gwaladham and Champawat (India); and Dandaldhera/Kapre/Bhalukhok/Agra, Simchar/Doman, Palung/Daman/Sim Bhanjyang, Ipa-Arkaula, Timaldanda, Narayan Than, Sindhuli Garhi, Sun Koshi Changer, Dobare-Thumka (Nepal). These plutons occur as tabular concordant sheets within the Himalayan Metamorphic Belt, which is thrust over the Lesser Himalayan Sedimentary Sequence (Fig. 4; Table 5) with discontinous gneissose and non-gneissic bodies. Nearly all these plutons are porphyritic in character (Le Fort et al., 1983) and accompanied by post-magmatic deformation leading to development of mylonitic fabric along their margins (Singh and Jain, 1996). These S-type peraluminous bodies have almost similar tectonic, petrographic and geochemical characters, namely location in distinct tectonic zone as elongated medium to large size intrusive bodies within low to medium grade metamorphic rocks, absolute ages around 500 Ma, high Sr ratios around 0.72, marginally well foliated, coarse grained gneissose bodies having undeformed massive to porphyritic core, development of thermal contact areoles, presence of abundant metasedimentary xenoliths, and emplacement during Pan-African event that is superposed by Himalayan deformation and metamorphism.

The Lesser Himalayan granite belt represents a part of the Pan-African thermomagmatic episode in the fragmented Gondwana of Afghanistan, Australia and Antarctica and is associated with a megazone of crustal extension, thinning and melting of the lower crust (Le Fort et al. 1986; Le Fort, 1995).

Conclusion

The granitoids of Himalayan Collision Zone clearly indicate the presence of Paleo-Meso Proterozoic basement rocks, and emplacement of Early Palaeozoic granitoids. The initial geochronological studies were mostly from rocks of mixed nature and the analysis were made valley-wise and not much emphasis are being made to constrain the pre-Himalayan granitoids. However, the syn- to post-collisional Himalayan granitoids are being looked into different perspective mainly to constrain the collision related processes.

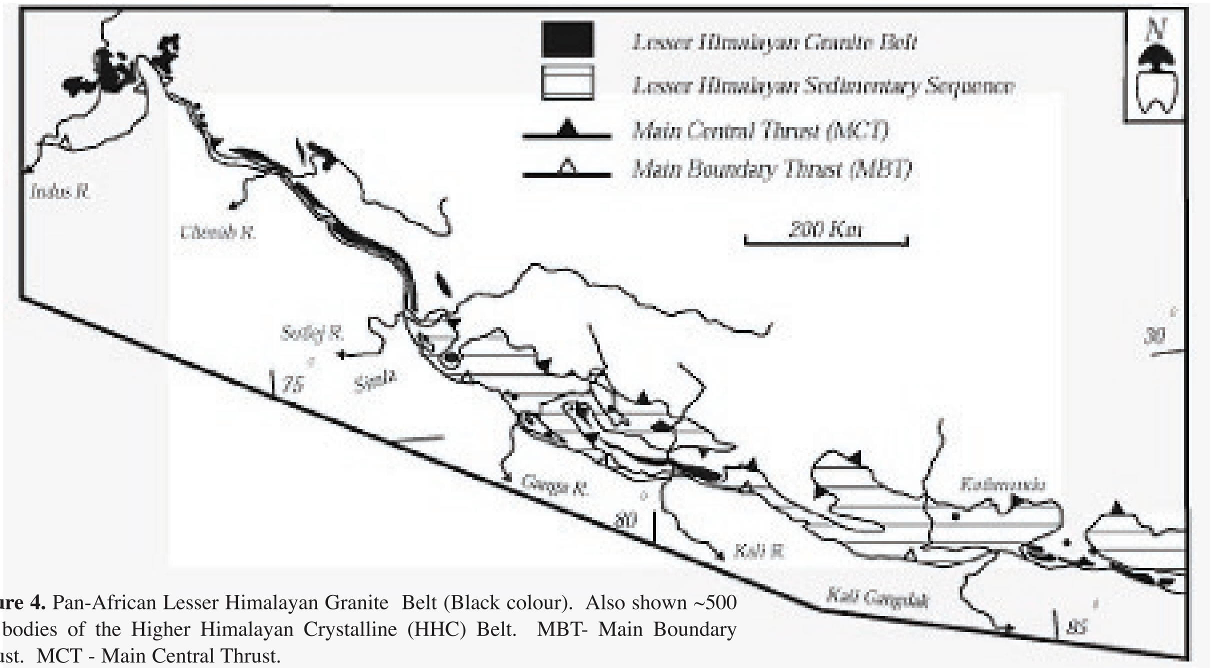

Figure 4. Pan-African Lesser Himalayan Granite Belt (Black colour). Also shown ~500 Ma bodies of the Higher Himalayan Crystalline (HHC) Belt. MBT- Main Boundary Thrust. MCT - Main Central Thrust.

Table 5: Ages of Lesser Himalayan Granite Belt

Body	Age	Initial (86Sr/87Sr)i	Reference
Mandi	500±100 Ma (518 Ma*) (4 pt.)	0.7189	Jager et al., 1971
	543±12 Ma (564 Ma*) (3 pt.)		Mehta, 1977
Dalhousie	456±50 Ma (Appr. age)		
	(472 Ma*)	0.709	Bhanot et al., 1974
Mansehra granite	516±16 Ma (7 pt.)		
	468±12 Ma (U -Pb Mon)	0.7189	Le Fort et al., 1980
			Zeitler et al., 1989
Choga granite Lr. Swat	468±5 Ma (U -Pb Zircon)		Anczkiewicz et al., 1998
Rilo granite, Arunanchal	413±19 Ma	0.7127±0.0016	Rao, 1998b
Sepa gneiss Arunanchal	554±14 Ma (4 pt)	0.7044±0.00041	Rao, 1999
Simchar granite	511±55 Ma (6 pt.)	0.7085±0.0048	Le Fort et al., 1983b
Palung granite	486±10 Ma	0.72	Beckinsale in Mitchell, 1981
	470±4 Ma (U-Pb zircon, monazite)		Scharer and Allegre, 1983
	517±62 Ma (8 pt. pseudo-isochron)	0.7097±0.0120	Le Fort et al., 1983
Champawat granitoid	560±20 Ma (12 pt.)	0.7109±0.0013	Trivedi et al., 1984
Kangan, Kashmir	470±11 Ma (3 pt.)	0.7216±0.0023	Trivedi et al., 1985
	500±10 Ma		Rao et al., 1990
Dudatoli Area	501±38 Ma (6 point)	0.732±0.005	Singh, 1986
Almora gneisses	370±60 Ma (8 point)	0.7575±0.010	Singh et al., 1986
Dadeldhura granite	470±56 Ma	0.7266±0.0012	Hohendorf et al., 1991
Kaplas Granite	392±36 Ma (6 point)	0.7286±0.0053	Sarkar et al., 1996
Khadrala granite	460±18 Ma (5 point)	0.7244±0.0041	Kishor et al., 1996

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