2.0 Ga Granite of the Lower Package of the Higher Himalayan Crystallines, Maglad Khad, Sutlej Valley, Himachal Pradesh

SANDEEP SINGH[1*], STEFAN CLAESSON[2], A.K. JAIN[1], DAVID G. GEE[3], P.G. ANDREASSON[4] and RM. MANICKAVASAGAM[5]

[1]Department of Earth Sciences, Indian Institute of Technology Roorkee, Roorkee - 247 667
[2]Laboratory for Isotope Geology, Swedish Museum of Natural History, Box 50007, SE-104 05 Stockholm, Sweden
[3]Department of Earth Sciences, Uppsala University, Villavägen 16, SE-752 36, Uppsala, Sweden
[4]Department of Lithosphere and Biosphere Science, Solvegatan 12, SE-223 62 Lund, Sweden
[5]Institute Instrumentation Centre, Indian Institute of Technology Roorkee, Roorkee 247 667
[1]**Email:** sandpfes@iitr.ernet.in and himalfes@iitr.ernet.in

Abstract: Along the Sutlej valley, the lower package of the Higher Himalayan Crystallines (HHC) exposes a small concordant to discordant intrusive grey granite — The Maglad Khad Granite, within garnet mica schist/banded gneiss of the Jeori Formation. This body is fine grained and foliated along the margins, whereas the central part is relatively undeformed. This body along with aplites and pegmatites intrudes the country rock during early to syn-D_1 deformation. This is later affected by the most pervasive D_2–deformation producing gneissosity within the granite. U-Pb dating of zircons by conventional isotopic dilution technique yield an upper intercept age of 2068±5 Ma (2σ) from 6 zircon-fractions with MSWD=0.93, constraining the age of crystallization in the basal parts of the HHC during Early Proterozoic as well as the constraining pre-Himalayan fabric development.

Keywords: Higher Himalayan Crystallines, Maglad Khad granite, Geochronology, U-Pb Zircon dating, Sutlej valley, Himachal Pradesh.

The Cenozoic Himalayan orogenic belt provides a unique opportunity to investigate the collision-related crustal shortening and remobilization of the Proterozoic basement and cover sediments within a major intracontinental ductile shear zone (Bouchez and Pecher, 1981; Brunel, 1986; Le Fort, 1986; Jain and Anand, 1988; Jain et al. 2002). The ages from the Himalayan granitoids indicate a broad division into two main categories: (i) Pre-Himalayan and (ii) Syn-to Post-Himalayan (Singh, 2001; Singh and Jain, 2003). The processes responsible for these intrusions are important for modeling the pre-collisional history of the Himalayan segment.

The Higher Himalayan metamorphic Belt (HHMB), exposed in the Lesser and Higher Himalaya exhibit polyphase Barrovian metamorphism throughout the orogenic belt (Windley, 1983; Sandhu, 1985; Das, 1987; Pecher, 1989; Staubli, 1989). This belt constitutes large Higher Himalayan nappes, which are thrust southward over the Lesser Himalayan Proterozoic sedimentary foreland along the Main Central Thrust (MCT) and its splay like the Jutogh/ Vaikrita Thrust (Auden, 1948; Bertehlsen, 1951; Frank et al. 1977; Sharma, 1977; Bhargava, 1980; Bhargava et al. 1991). The hanging walls of these thrusts incorporate pelite, psammite, and quartzite sequences, which are metamorphosed to upper greenschist to almandine-amphibolite facies during main Himalayan phase (Pilgrim and West, 1928; Berthelsen, 1951; Roy and Mukherjee, 1976; Sharma, 1977, Chakrabarti, 1976; Bhargava, 1980, 1982).

In Himachal Pradesh, the Lesser and Higher Himalayan morphotectonic domains reveal extensive allochthonous folded metamorphic nappes, which are thrust over the Lesser Himalayan Proterozoic sedimentary foreland, now exposed as tectonic windows and linear belts in the frontal parts (Sharma, 1977; Bhargava, 1980; Bhargava et al. 1991). An intervening sub-nappe between the two main units is made up of a 800 m-thick, dismembered mylonite of the Kulu–Bajura Nappe and is bounded by the Kulu Thrust at its base and MCT/Jutogh Thrust at its top (Frank et al. 1977; Bhargava et al. 1991; Singh, 1993).

The Jakhri-Wangtu region along the Sutlej valley provides a good cross-section of the Higher Himalayan Crystallines (HHC) – forming a part of the HHMB. A thick

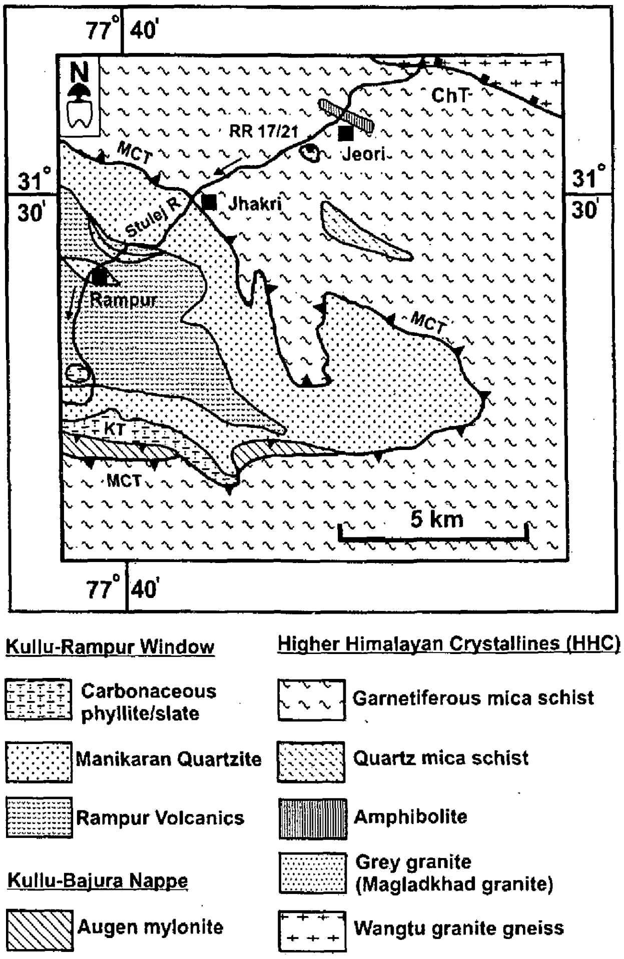

Fig.1. Geological map of the Rampur-Wangtu region along the Sutlej valley, Himachal Pradesh. MCT = Main Central Thrust. KT = Kulu Thrust. ChT = Chaura thrust. Sample locations for U-Pb zircon dating: Grey granite (RR 17/21 - 90056). Based on our own mapping.

stack of about 15 to 20 km of the HHC is exposed along the NE flank of the Kulu-Rampur window beyond Jakhri along the Sutlej valley section (Fig.1). The HHC belt includes the Jeori Formation near its base between the MCT and the newly recognized Chaura Thrust (Singh, 1993; Singh and Jain, 1993; Jain et al. 2000). Metapelitic sequence of this formation is made up of predominantly well foliated, medium grained garnetiferous mica schist with very thin alternating bands of quartzo-feldspathic mica-rich gneiss on cm-scale. Fine to medium grained, dark coloured and highly foliated amphibolite bodies are occasionally exposed within the Jeori Formation. These are mostly 1 to 10 m thick, except for a mappable band of about 300 m thickness near Jeori along the National Highway 22. Near Jeori along the Maglad khad, discordant fine grained grey granite gneiss, aplite and pegmatite intrude the metapelite as concordant to discordant igneous bodies along the metamorphic banding of Jeori Formation (Fig.2). Grey granite, aplite and pegmatite intrude the country rock during early to syn-D_1 deformation and later affected by the most pervasive D_2 deformation producing gneissosity within the granite (Singh, 1993; Singh and Jain, 1993). The body is fine grained and foliated along the margins, whereas the central part is relatively undeformed.

In the northeastern parts of the area, the overlying Wangtu granite gneiss, which is a monotonous medium to coarse, porphyroclastic granitic gneiss, is thrust over the Jeori Formation along the Chaura Thrust. The gneiss imperceptibly grades into the undeformed granitoid of about 1.8 Ga near Wangtu (Singh, 1993; Singh et al. 1994). These gneisses contain numerous xenoliths of strongly foliated metamorphics. The Wangtu granite gneiss is overrriden by garnetiferous mica schist, staurolite-kyanite schist/gneiss, sillimanite schist/gneiss, calc-silicate, augen gneiss and migmatites of Higher Himalayn Crystallines (HHC) (Vaikrita Group of Sharma, 1977; and Karcham Group of Kakkar, 1988) and leucogranite along the Vaikrita Thrust. These metamorphic packages along with leucogranite are seperated from the Tethyan Sedimentary zone by the Zanskar Shear Zone (Herren, 1987; Patel et al. 1993), the Martoli Fault, the Trans-Himadri Fault (Valdiya, 1989) or Sangla Detachment (Vannay and Grassemann, 1998).

Grey granite is fine-grained and contains mainly quartz and albite with less amount of K-feldspar (quartz > plagioclase > orthoclase > microcline). Coarse- to fine-grained muscovite and biotite are present in significant amounts along poorly-developed foliation. Feldspar shows minor alteration to sericite. Major elements indicate that the body is peraluminous and peralkaline in character, having Al_2O_3/Na_2O+K_2O+CaO ratio > 1 and Na_2O/K_2O < 1 with SiO_2 varying between 63-73%. The body contains high silica and alkalis, low FeO, CaO and TiO_2 contents. In the Nomenclature Diagram (*cf.*, Debon and Le Fort, 1982), the suite occupies granite and quartz-syenite fields. This body also shows distinct lower abundances of trace element along with very low LREE and HREE abundances. The REE normalized to C1 Chondrite patterns reveal that the grey granite has a very gentle slope, possibly due to unfractionated nature of the parent material (Singh, 1993).

To provide geochronological constraints, the U-Pb zircon age determination was carried out at the Laboratory for Isotope Geology, Swedish Museum of Natural History, Stockholm, Sweden. Fresh, unaltered, and undeformed samples with original textures were very carefully selected in the field (RR 17/21; Fig.1). The sample RR17/22 (90056 is the reference of sample kept at Swedish Museum of

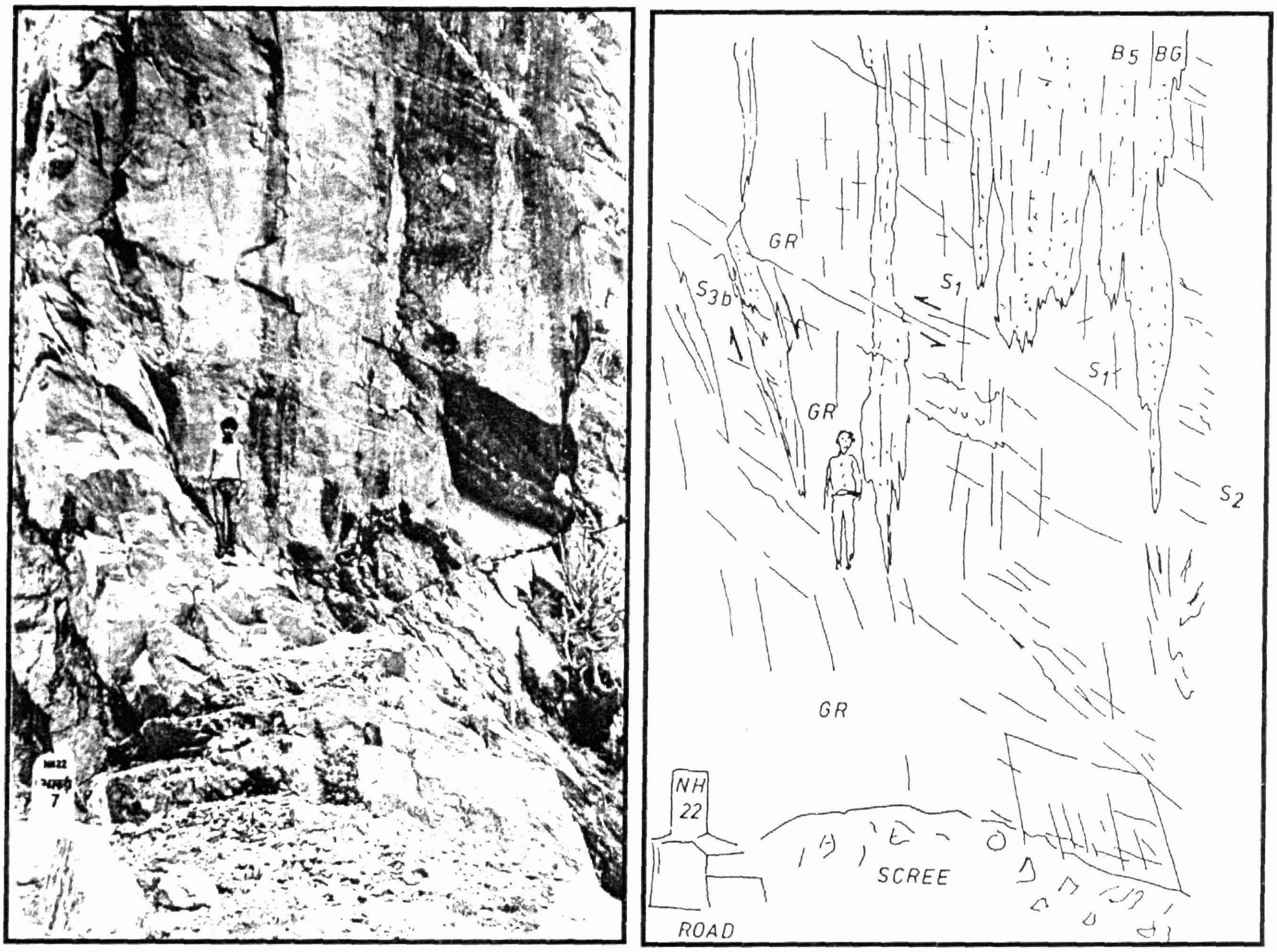

Fig.2. Photograph and sketch of the grey granite body showing intrusion within the dark coloured biotite paragneiss during early- to syn-D_1 deformational phase, subsequently affected by main deformational event D_2. Note slight penetrative displacement along gentle dipping S_2 – foliation towards to-to-left (southwestward). Also cutting across S_1 foliation are northeasterly dipping. Crenulation foliation, S_{3b} planes, which also indicate displacement. BG/BS – Biotite granite gneiss/Biotite Schist, GR – grey granite gneiss.

Natural History) weighing approximately 30 kg was treated for concentration and purification of zircon crystals by Wilfley table, heavy liquid and magnetic seperations. Heavy mineral concentrates were purified by handpicking under microscope to obtain clean homogeneous zircon fractions for the analysis. Air abrasion technique was used on certain fractions in order to increase the degree of concordancy of ages (*cf.* Krogh, 1973).

Zircons from the grey granite are euhedral prisms of variable length with average length:width ratio of 4:1. Most crystals are transparent with sharp crystal edges and pointed pyramidal terminations. Some of these contain opaque inclusions, and others are strongly zoned. A few crystals have dark euhedral centres, oriented parallel to the c-axis of crystals, and indicate a magmatic zonation pattern. Other zircon varieties include subrounded and rounded cloudy grains, and crystals having fluid inclusions. The zircons with internal structures, which could be interpreted as cores were avoided during the handpicking of the analysed fractions.

Chemical preparation following modification of the techniques, described by Krogh (1973) and Manhes et al. (1978) were used. A mixed $^{208}Pb/^{235}U$ spike was added to each sample, assuming a U content of 400 ppm and a Pb content of 100 ppm. U and Pb were seperated in anionic resin column, filled up with analytical grade cation exchange resin AG 1-X8 100-200 mesh in chloride form.

All isotopic measurements were made on a Finnigan MAT 261 mass-spectrometer. Pb was loaded with H_3PO_4 and silica gel on a single Re-filament. U was run as U_3O_3 on a single W-filament with Ta and H_3PO_4. The isotopic ratios were corrected for mass-fractions with precision of

Table 2. Conventional TIMS U-Pb zircon analytical data of the undeformed grey granite form MaghladKhad, Sutlej valley, Himachal Pradesh

Sample (Fractions)	Concentration in ppm			Atomic ratios[a] and model ages				
	U	Pb_{rad}	^{204}Pb	$^{206}P/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
<74 mm	1340	307	1 345	218	0.0303	0 23936±55 1383	3 953±45 1625	0 11984±120 1954
<74 mm ab	1386	325	1 330	230	0 0400	0 24225±44 1398	4 0048±100 1635	0 11990±19 1955
74-106 mm	1101	275	0 128	1865	0 0302	0 25279±40 1453	4 2105±147 1676	0.12080±34 1968
106 –150 mm	1059	276	1 89	1275	0 0287	0 26524±40 1517	4 4544±165 1723	0 12180±37 1983
>150 mm	1016	289	0 216	11650	0 0362	0 28729±43 1628	4 8868±83 1800	0 12337±10 2005
106-150mm ab	931	262	0 010	2290	0 0322	0 28476±46 1613	4 8284±126 1790	0 12298±22 2000

(a) $^{206}Pb/^{204}Pb$ corrected for blank and mass discrimination, all other atomic ratios also corrected for initial lead
Errors are given as least significant digits at the 95% confidence level

Discrimination	U 0 05% / AMU		Pb 0 12% / AMU	
Blank	U 0 5 ng		Pb 0 2 ng	
Common lead	$^{206}Pb/^{204}Pb$	15.1	$^{207}Pb/^{204}Pb$	15 2
	$^{208}Pb/^{204}Pb$	34.8		

(Stacey and Kramer (1995) growth curve), ab – abraded as described by Krogh (1973)

±0.05% AMU (atomic mass unit) for U and ±0.12% AMU for Pb. The U blank is 0.5 ng and the Pb blank varies from 0.1 ng to 0.3 ng. The initial Pb-corrections corresponding to ages were made, according to model of Stacey and Kramer (1975) growth curve. All ages were calculated using the conventional decay constants, as recommended by the IUGS (Steiger and Jager, 1977). Linear regression and concordia intercept ages were determined, according to Ludwig (1980). All errors are given as least significant digits at the 95% confidence level (Table 1).

The regression line for the grey granite, based on 6-zircon fractions, yields an upper intercept age of 2068±5 Ma (2σ) and a lower intercept age of 379±18 Ma (2σ) having MSWD of value 0.93 (Fig.3). The finer fractions < 74 µm are more discordant, whereas abraded fraction between 106-150 µm moves close to the upper intercept. There is no indication of any inherited Pb component or any disturbance in this granitoid body.

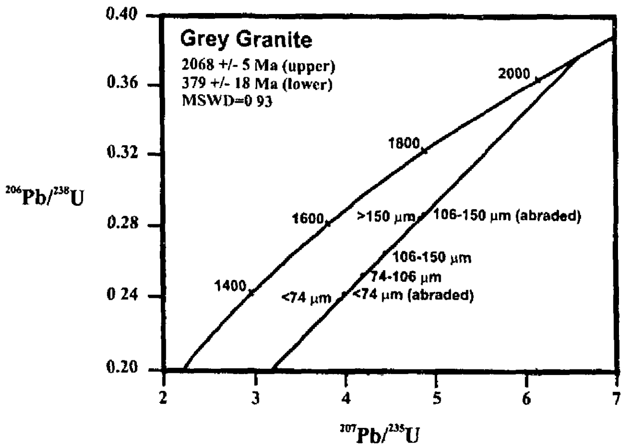

Fig.3. U-Pb concordia diagram for Grey granite RR 17/21 with upper and lower intercepts at 2068±5 Ma and 379±18 Ma (2σ) (MSWD = 0.93).

The U-Pb zircon data yield good-fit discordia line. The discordancy generally increases with decreasing grain size, and one abraded fraction is slightly less discordant than the other fractions. The upper intercept age is 2068±5 Ma have been interpreted to be the best estimate for the primary crystallisation age of this body. The Paleo-Proterozoic age of this body suggests that the rocks occurring in the basal part of the Higher Himalayan Crystalline are not a part of the Lesser Himalayan Metamorphic sequences and a part of the Kulu-Rampur Window rock as suggested by other workers (Vannay and Grassemann, 1998; Miller et al. 2000) They suggested that Jeori-Wangtu Granitoid gneiss Complex (JWGC) probably represents the basement for the Rampur Formation. The remarkably similar age of Bandal Granitoid and JWGC complex led them to think of them as an integral part of the Larji-Kullu-Rampur window. The obtained age of 2.0 Ga should prompt workers to have a re-look into the tectonic evolution of the area along Sutlej valley.

Acknowledgements: This work forms a part of the research project funded by the Department of Science and Technology (DST), New Delhi and has resulted from collobarative research between the then University of Roorkee, India, the Lund University, Lund, and the Swedish Museum of Natural History, Stockholm, Sweden. A visit by SS to Sweden for geochronological work was made possible by generous funding from DGG and PGA. Paula Alarta and Ann-Marie Kahr provided extensive backup during the seperation and chemical preparation of zircon samples in the isotope laboratory.

References

AUDEN, J.B. (1948) Some new limestone and dolomite occurrences in Northern India. Indian Minerals, v.2, pp.77-91

BERTHELSEN, A. (1951) A geological section through the Himalayan section. Meddelsar fra Dansk Geologish Forening Bd. 12 Kobenbavn, pp. 102-104.

BHARGAVA, O.N. (1980) Outline of the stratigraphy of Eastern Himachal Pradesh, with special reference to the Jutogh Group. *In:* K.S. Valdiya (Ed.), Stratigraphy and correlation of Lesser Himalayan formations. Hindustan Publ. Corp. (India), Delhi, pp.117-125.

BHARGAVA, O.N. (1982) The tectonic windows of the Lesser Himalaya. Himalayan Geol., v.10, pp.35-155.

BHARGAVA, O.N., BASSI, U.K. and SHARMA, R.K. (1991) The crystalline thrust sheets, age of metamorphism – evolution and mineralization of the Himachal Himalaya. Indian Minerals, v.45 (1&2), pp.1-18.

BOUCHEZ, J.L. and PECHER, A. (1981) The Himalayan Main Central Thrust pile and its quartz rich tectonites in Central Nepal. Tectonophysics, v.78, pp.23-50.

BRUNEL, M. (1986) Ductile thrusting in the Himalaya: Shear sense criteria and stretching lineation. Tectonics, v.5, pp.247-265.

CHAKRABARTI, B.K. (1976) Some observation on the rocks of Rampur Bushahr area, Himachal Pradesh. Abstract, Symp. Geol. Survey India, Lucknow.

DAS, B.K. (1987) Petrology of Barrovian type regional metamorphism in pelitic schists of Kishtwar, Kashmir Himalaya, India. Proc. Nat. sem. Tert. Orogeny, pp.153-187.

DEBON, F. and LE FORT, P. (1982) A chemical-mineralogical classification of common plutonic rocks and associations. Trans. R. Soc. Edinburgh (Earth Sci.), v.73, pp.135-149.

FRANK, W., THONI, M. and PURTSCHELLER, F. (1977) Geology and petrography of Kulu-South Lahul area. Colloq. Int. Cent. Nat. Res. Sci., v.33, pp.147-172.

HERREN, E. (1987) Zanskar Shear Zone: northeast-southwest extension within the Higher Himalaya (Ladakh, India). Geology, v.15, pp.409-413.

JAIN, A.K. and ANAND, A. (1988) Deformational and strain patterns of an intracontinental collision ductile shear zone – an example from the Higher Garhwal Himalaya. Jour. Struct. Geol., v.10(7), pp.717-734.

JAIN, A. K., KUMAR, D., SINGH, S., KUMAR, A. and LAL, N. (2000) Timing, quantification and tectonic modeling of Pliocene Quaternary movements in the NW Himalaya: evidences from fission track dating. Earth Planet. Sci. Lett., v.179, pp.437-451.

JAIN, A.K., SINGH, S. and MANICKAVASAGAM, RM (2002) Himalayan Collision Tectonics. Mem. Gondwana Res. Group, v.7, 114p.

KAKKAR, R.K. (1988) Gology and tectonic setting of Central Crystalline rocks of southern part of Higher Himachal Himalaya. Jour. Geol. Soc. India, v.31, pp.243-250.

KROGH, T. E. (1973) A low contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determination. Geochim. Cosmochim. Acta, v.37, pp.485-494.

LE FORT, P. (1986) Metamorphism and magmatism during the Himalayan Collision. *In:* M. P. Coward and A. Ries (Eds.), Collision Tectonics. Geol. Soc. London Spec. Publ., v.19, pp.159-172.

LUDWIG, K. R. (1980) Calculation of uncertainties of U-Pb isotope data. Earth Planet. Sci Lett., v.46(2), pp.212-220.

MANHES, G., MINSTER, J.F. and ALLEGRE, C. J. (1978) Comparative Uranium-Thorium-Lead and Rubidium- Strontium study of the Saint Severin Amphoterite: consequence for early solar system chronology. Earth Planet. Sci. Lett., v.39, pp.14-24.

MILLER, C., KLOTZLI, U., FRANK, W., THONI, M. and GRASSEMANN, B. (2000) Proterozoic crustal evolution in the NW Himalaya (India) as recorded by circa 1.80 Ga mafic and 1.84 Ga granitic magmatism. Precambrian Res., v.103, pp.191-206.

PATEL, R.C., SINGH, S., ASOKAN, A., MANICKAVASAGAM, RM. and JAIN, A.K. (1993) Extensional tectonics in the collisional Zanskar Himalayan belt. *In:* P.J. Treloar. and M.P. Searle (Eds.), Himalayan Tectonics. Geol. Soc. London Spec. Publ. No.74, pp.445-459.

PECHER, A. (1989) The metamorphism in the central Himalaya. Jour. Metam. Geol., v.7, pp.31-41.

PILGRIM, G. E. and WEST, W. D. (1928) The structure and correlation of the Simla rocks. Mem. Geol. Surv. India, v.53, pp.1-140.

ROY, M.K. and MUKHERJEE, A. (1976) Time-relationship between the metamorphics and the movement episode in the Jutogh Series, west of the Chor ggr near Rajgarh, Himachal Himalaya. Himalyan Geol., v.6, pp.240-246.

SANDHU, C.S. (1985) Deon and Barrovian metamorphism of Kistwar area – an example from Malayan terrain, India. *In:* V.J. Gupta (Ed.), Geology of western Himalaya. Contrib. Him. Geol., v.3, pp.121-149.

SHARMA, V. P. (1977) The Stratigraphy and structure of parts of the Simla Himalaya. Mem. Geol. Surv. India, v.106, pp.235-407.

SINGH, S. (1993) Collision Tectonics : Metamorphic and Geochronological constraints from parts of Himachal Pradesh, NW-Himalaya. Unpublished Ph.D. Thesis, University of Roorkee, Roorkee, India, 289p.

SINGH, S. (2001) Status of geochronological studies in Himalaya: a review. Jour Indian Geophys. Union, v.5(1), pp.57-72.

SINGH, S. and JAIN, A.K. (1993) Deformational and strain patterns of the Jutogh Nappe along the Sutlej Valley in Jeori-Wangtu region, Himachal Pradesh, India. Jour. Him. Geol., v.4(1), pp.41-55.

SINGH, S. and JAIN, A.K. (2003) Himalayan Granitoids. *In:* S. Singh, (Ed.) Granitoids of the Himalayan Collisional Belt, Jour. Virtual Explorer, v.11, pp.1-20.

SINGH, S., CLAESSON, S., JAIN, A.K., SJOBERG, S., GEE, D.G., MANICKAVASAGAM, RM. and ANDREASSON, P.G. (1994) : Geochemistry of the Proterozoic Peraluminous granitoids from the Higher Himalayan Crystalline (HHC) and Jutogh Nappe, NW-Himalaya, Himachal Pradesh, India. Special Issue Jour. Nepal Geol. Soc., v.10, 125p.

STACEY, J.S. and KRAMER, J. D. (1975) Approximation of terrestrial lead isotope evolution by a two-stage model. Earth Planet. Sci. Lett., v.34, pp.207-226.

STAUBLI, A. (1989) Polyphase metamorphism and the development of the Main Central Thrust. Jour. Metamorph. Geol., v.7, pp.73-93.

STEIGER, R.H. and JAGER, E. (1977) Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. Earth Planet. Sci. Lett., v.36(3), pp.359-362.

VALDIYA, K.S. (1989) Trans-Himadri intracrustal fault and basement upwarps south of Indus-Tsangpo Suture Zone. *In:* L L. Malinconico, and R.J. Lillie, (Eds.), Tectonics of the western Himalaya. Geological Soc. Am. Spl., v.232, pp.53-168.

VANNAY, J.-C and GRASSEMANN, B. (1998) Himalayan inverted metamorphism in the High Himalaya of Kinnaur (NW India): petrography versus thermobarometry. Schweiz. Miner. Petrogr. Mitt., v.78, pp.107-132.

WINDLEY, B.F. (1983) Metamorphism and tectonics of the Himalaya. Jour. Geol. Soc. London, v.140, pp.849-865.

(Received: 17 December 2004; Revised form accepted: 23 September 2005)

Announcement

LAKSHMESWAR RAMA RAO BIRTH CENTENARY RESEARCH GRANTS: 2006-2007

A sum of Rs.10,000 shall be made available during the financial year 2006-2007 to Young Research Scholars for carrying out laboratory and fieldwork in the field of Palaeontology and Stratigraphy.

Those interested in seeking assistance are requested to apply to the Society furnishing full particulars of academic qualifications, synopsis of the research project they are engaged in and the extent of assistance required. The application should be supported by their Research Guide and the Head of the Institution and reach the Secretary, Geological Society of India, P.B. No.1922, Gavipuram P.O., Bangalore - 560 019 on or before 31st March 2006.