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Preliminary data on the High Himalayan Crystallines along the Padum-Darcha Traverse (South-Eastern Zanskar, India)

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ABSTRACT. — Preliminary study of the High Himalayan Crystallines (HHC) in SE Zanskar has shown the existence of an early high temperature event of hypothetical Late Proterozoic age associated with migmatization and to production of leucocratic granitoids; this event is followed by a lower pressure high/medium temperature metamorphism of Himalayan age. During Miocene times the HHC have been intruded by the Gumburanjon leucogranite which, like other Himalayan leucogranites, derives by partial melting of crustal rocks and post-dates the main Himalayan metamorphism. The HHC are overthrust by a sequence of low grade metasediments (Shingo La metagraywackes) and are in tectonic contact with the very low grade metasediments of the Tibetan Zone.

Key words: metamorphism, migmatite, leucogranite, thrust, Himalaya.

RIASSUNTO. — Lo studio preliminare del Cristallino dell'Alto Himalaya (HHC) nel settore sud-orientale dello Zanskar (India nord-occidentale) ha messo in evidenza un evento metamorfico di alta temperatura di ipotetica età tardo Proterozoica associato a processi di migmatizzazione con produzione di granitoidi leucocratici. Un successivo evento metamorfico di età himalayana ha prodotto una ricristallizzazione in condizioni di temperatura medio/alta e pressioni più basse associata ad intensi fenomeni deformativi e traspositivi. Durante il Miocene il HHC è stato intruso dal leucogranito del Gumburanjon, che è successivo ai principali eventi metamorfici himalayani e deriva da processi di fusione parziale di rocce crostali. Il HHC è stato tettonicamente sovrascorso da metasedimenti di basso grado (metagrovacche dello Shingo La) e dalle sequence metasedimentarie di grado molto basso della Zona Tibetana.

Parole chiave: metamorfismo, migmatiti, leucograniti, sovrascorrimenti, Himalaya.

Introduction

This work deals with a preliminary study carried out during summer 1985 in south-eastern Zanskar (Fig. 1) on the High Himalayan Crystallines (HHC; FRANK et al., 1977; SRIKANTIA et al., 1980; HONEGGER et al., 1982; SEARLE and FRYER, 1986) near the boundary with the Late Precambrian-Paleocene sedimentary nappes of the Tibetan Zone (BAUD et al., 1984; GAETANI et al., 1985) (Fig. 2). In particular the work describes the geological setting and the metamorphic evolution of the HHC along the traverse Padum (Zanskar) - Darcha (Lahul). The areas studied are, from north-west to south-east, the Haptal valley, the Temasa valley and the Shingo La - Gumburanjon area (Fig. 2).

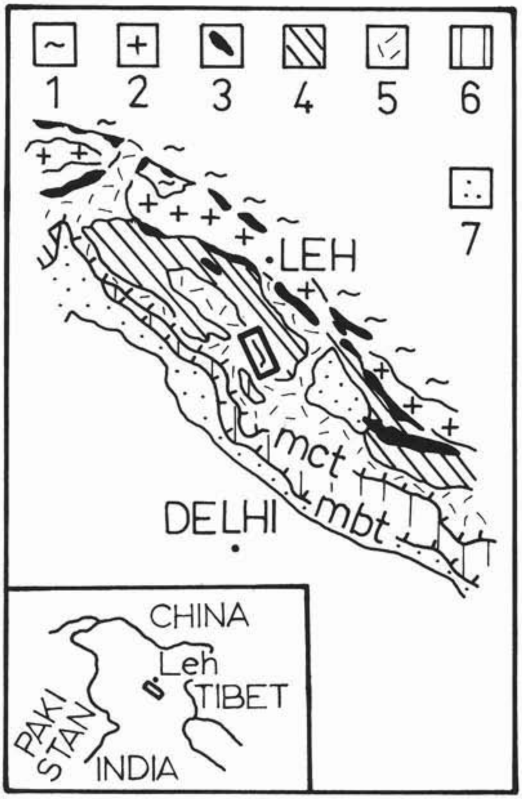

Fig. 1. — Tectonic sketch map of western Himalaya. Legend. 1: Tibetan block; 2: Trans-Himalayan batoliths; 3: Ophiolites and related sediments; 4: Sediments of the Tibetan Zone; 5: High Himalayan Crystallines; 6: Lesser Himalaya; 7: Molasse-type sediments (Siwaliks). mct: main central thrust; mbt: main boundary thrust. Inset indicates location of the studied area shown in detail in Fig. 2.

Previous studies on the HHC in the Zanskar-Lahul region

In the last decade petrographical studies of the HHC in this sector of the Himalayan belt were mainly concentrated in north-westernmore (HONEGGER et al., 1982) and in south-easternmore areas (FRANK et al., 1977). These studies have demonstrated that the HHC mainly consist of high/medium grade metamorphics and of granitoids more or less transformed into orthogneisses. Reliable radiometric dating of these orthogneisses has been only obtained on some Lahul stocks (550 ± 50 Ma; FRANK et al., 1977; MEHTA, 1977), while has not been wholly successful in the leucocratic orthogneisses of the Zanskar region. The latter have been ascribed to the pre-Himalayan cycle (550 ± 50 Ma) by HONEGGER et al. (1982) and to the Himalayan cycle (Miocene) by SEARLE and FRYER (1986). As to the metamorphism it has been described by HONEGGER et al. (1982) which defined a series of isograds of Himalayan age (cooling ages for biotite: 11-13 Ma).

Our data demonstrate that the history is more complicated than suggested by the previous authors; notably *two generations of leucocratic granitoids of different ages* occur in Zanskar and, in addition to the Himalayan mineral zones described by HONEGGER et al. (1982), the metamorphic crystallization has a composite history with *relics of a hypothetical pre-Himalayan event overprinted by the Tertiary Himalayan recrystallization.*

Geologic and metamorphic settings

The geologic and tectonic settings of south-eastern Zanskar are shown in Figures 2 and 3, while the main mineral compositions are summarized in Table 1.

Haptal valley

The Haptal valley is located south of Sani, a small hamlet NW of Padum. In this valley, the tectonic boundary between the HHC and the overlying late Precambrian-Paleozoic Pughtal nappe of the Tibetan Zone (BAUD et al., 1984) crops out just SW of Sani. This boundary is defined by a mylonitic belt, a few tens of metres thick, which dips 30-40° north-eastward (Figs. 2, 3). In the Haptal valley the rocks of the Pughtal nappe consist of very low grade metagraywackes (Phe Formation; NANDA and SINGH, 1977) with a pervasive foliation defined by fine grained white mica and chlorite. Mica and chlorite form films that anastomose around pre-metamorphic clasts of quartz, plagioclase and K-feldspar. In the mylonitic belt similar white mica-chlorite-bearing assemblages also occur in the HHC rocks.

The HHC include a sequence of dark gneisses associated with dykes a few decimetres to metres thick and with kilometric intrusive bodies; both dykes and bodies consist of leucocratic orthogneisses rich in garnet and in tourmaline. These rock-types are pervasively deformed and are refolded with the mon assemblages include quartz, plagioclase, biotite, white mica, garnet ± K-feldspar porphyroclasts ± rare clinopyroxene. About 3 kilometres from the contact with the overlying Pughtal nappe, the dark gneisses also include sillimanite.

Near the sillimanite-bearing dark gneisses,

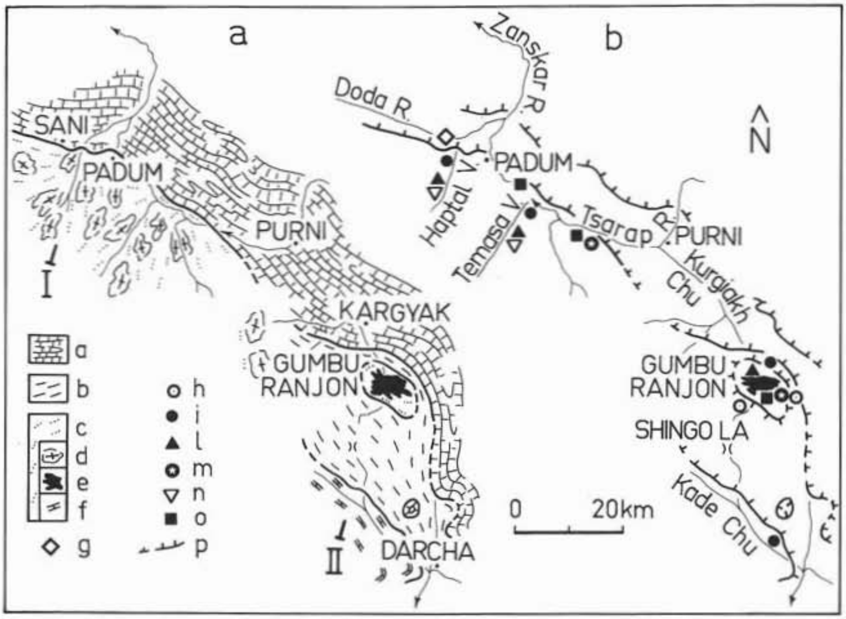

Fig. 2. — Geologic (a) and tectonic (b) maps of SE Zanskar along the Padum-Darcha geotraverse. Legend. a: metasediments of the Tibetan nappes; b: Shingo La dark metagraywackes. High Himalayan Cristallines; c: dark gneisses and micaschists; d: leucocratic orthogneisses; e: post-metamorphic Gumburanjon leucogranite; f: Kade Chu orthogneisses. — Metamorphic assemblages (for abbreviations see Table 1). g: wm-chl; h: am ± gt porphyroblasts in metasomatic veins; i: gt-bi in felsic rocks; l: gt-bi-pl-sill ± ky in felsic rocks; m: gt-bi-pl-st in felsic rocks; n: gt-cpx-qtz-hbl-pl-bi in mafic rocks; o: hbl-pl-bi in mafic rocks; p: main thrusts and tectonic contacts. I and II are locations of the cross-sections shown in Fig. 3.

development of a foliation marked by brown biotite and white mica. The dark gneisses and the leucocratic orthogneisses are crosscut by rare mafic dykes a few metres thick which have been also deformed during the metamorphic recrystallization. They still contain relics of magmatic minerals including pyroxene and plagioclase phenocrysts; the magmatic minerals are largely altered to a metamorphic assemblage consisting of hornblende, recrystallized plagioclase and pyroxene, garnet coronas around plagioclase, biotite and sphene. In the dark gneisses the most com- rare lenses of mafic rocks are closely associated with leucocratic gneisses and pegmatoids rich in K-feldspar, plagioclase, biotite and white mica. The mafic rocks show an early high temperature assemblage with clinopyroxene, garnet and quartz. The garnet has been later corroded with the formation of a composite corona consisting of zoned Ca-rich plagioclase ± hornblende ± biotite ± opaques; plagioclase in the coronas is usually crowded by small quartz inclusions. The garnet alteration is coeval with the transformation of clinopyroxene into hornblende. These

TABLE 1

Main minerals of the rock-types occurring along the Padum-Darcha traverse (SE Zanskar - NW Lahul, India)

	Rock-types	Minerals	Metamorphism
	PUGHTAL METAGRAYWACKES	(qtz)-(pl)-(Kf)-wm-chl-to	very low grade
HIGH HIMALAYAN CRYSTALLINES	SHINGO LA METAGRAYWACKES	(qtz)-(pl)-bi-wm±gt±cz±to±am	low grade
HIGH HIMALAYAN CRYSTALLINES	GUMBURANJON LEUCOGRANITE	qtz-pl-Kf-wm-bi-to±gt	no metam.
HIGH HIMALAYAN CRYSTALLINES	LEUCOCRATIC ORTHOGNEISSES	qtz-pl-Kf-bi-wm-to-gt	medium grade
HIGH HIMALAYAN CRYSTALLINES	KADE CHU ORTHOGNEISSES	qtz-Kf-pl-wm-bi	
HIGH HIMALAYAN CRYSTALLINES	METABASICS	cpx-gt-qtz-(pl?)	high grade
		pl-hbl-bi-sph-op-qtz	medium grade
HIGH HIMALAYAN CRYSTALLINES	DARK GNEISSES AND MICASCHISTS	qtz-bi-pl-gt-wm-ky-sill qtz-pl-bi-wm±cpx±am qtz-pl-Kf-bi-wm	high grade
		qtz-bi-wm-pl-st±gt qtz-bi-wm-pl-gt	medium grade

Abbreviations. qtz: quartz; to: tourmaline; chl: chlorite; wm: white mica; pl: plagioclase; bi: biotite; cz: clinozoisite; gt: garnet; am: amphibole; Kf: K-feldspar; cpx: clinopyroxene; hbl: hornblende; sph: sphene; op: opaques; sill: sillimanite; ky: kyanite; st: staurolite. Minerals in brackets are pre-metamorphic clasts of sedimentary origin.

petrographic and microstructural evidences point to the existence of a retrograde recrystallization at decreasing pressures which post-dates an early high temperature metamorphism. A petrologic study is currently in progress on these HHC rocks (POGNANTE and LOMBARDO, in prep.).

The leucocratic orthogneisses locally preserve the original intrusive relationships whilst the largest bodies preserve relics of magmatic structures. They consist of quartz, sodian plagioclase, K-feldspar, white mica, biotite, garnet, tourmaline.

Temasa valley

The Temasa valley is located south-east of Padum (Fig. 2). In this valley the HHC consist of the same sequence observed in the Haptal valley: dark gneisses rich in white mica, biotite, garnet ± sillimanite ± kyanite ± K-feldspar associated with garnet-bearing leucocratic orthogneisses. In some fine grained dark gneisses an early assemblage including kyanite, garnet, biotite, plagioclase ± rutile ± K-feldspar is replaced by an assemblage with muscovite, biotite, plagioclase, prismatic/acicular sillimanite, sphene. Among the dark gneisses have been observed abundant rock-types rich in large K-feldspar porphyroclasts. Locally the latter rocks are strongly refolded and grade to migmatites which in turn grade to homogeneous leucocratic granitoids. These rocks have later undergone synmetamorphic deformation and the leucocratic granitoids are recrystallized to leucocratic orthogneisses.

Near the migmatites a few mafic rocks (restites?) associated with leucocratic neosomes rich in K-feldspar occur. As observed in the Haptal valley, the mafic rocks show a high temperature assemblage with clinopyroxene, garnet and quartz, overprinted by a later assemblage with hornblende, Ca-plagioclase, biotite, sphene, ilmenite. The youngest assemblage also occurs in other metabasics in which garnet occurs as a rare, strongly corroded relic. In the Temasa valley some HHC rocks are characterized by the growth of fine grained biotite which overgrows the previous assemblages; this crystallization is well developed in the structurally higher levels of the HHC approaching the Gumburanjon area.

Shingo La - Gumburanjon area

This area is located in south-eastern Zanskar (Fig. 2) and is characterized by the existence of a lens-shaped leucogranitic body a few kilometres large which is not affected by metamorphism and intrudes the HHC metamorphics. The HHC rocks form an antiformal structure and are overlain by a sequence of dark metagraywackes and metapelites which are very thick in the Shingo La area and thin north of Gumburanjon (Fig. 3). The contact between the HHC rocks and the Shingo La metagraywackes is defined by a mylonitic belt. Finally, the Shingo La metagraywackes are in tectonic contact with dolomites and pelites of the Pughtal nappe (Tibetan Zone). According to E. HERREN (1987) the HHC rocks and the Shingo La

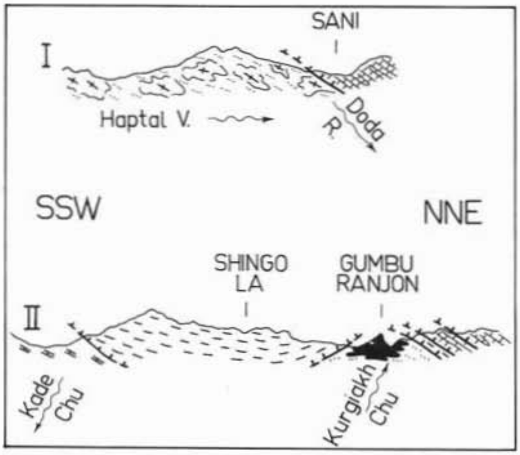

Fig. 3. — Geologic cross-sections through the High Himalayan Crystallines and the overlying metasedimentary nappes. For legend and cross-section orientations see Fig. 2.

metagraywackes are separated from the rocks of the Pughtal nappe by a normal fault.

The HHC metamorphics include a sequence of biotite - garnet ± staurolite ± sillimanite ± kyanite ± clinopyroxene-bearing dark gneisses, transposed dykes of leucocratic orthogneisses and minor metabasics (amphibolites).

The unmetamorphosed leucogranitic body shows a mineralogical composition similar to the leucocratic orthogneisses, but is more heterogeneous and crosscuts the leucocratic orthogneisses. The Gumburanjon leucogranite contains white mica, garnet ± biotite and is locally very rich in tourmaline; it shows sudden and marked grain size variations from pegmatoid to medium-grained varieties. Xenoliths ranging in size from a few decimetres to several metres and consisting of dark gneisses with transposed dykes of leucocratic orthogneisses rich in garnet, are abundant in the Gumburanjon leucogranite. Rb-Sr mineral ages (Ferrara, Lombardo and Tonarini, in prep.) suggest that, like most Himalayan leucogranites, the Gumburanjon body was emplaced in the HHC during Miocene times. The age difference between muscovite and biotite, about 2 Ma, suggests a cooling rate around 100° C/Ma. Comparable cooling rates have been computed from radiometric ages in the Gophu La and Nuptse granites of the eastern Himalaya (Villa and Lombardo, 1986).

The Shingo La metagraywackes are rich in clasts of quartz and feldspar and show a marked foliation defined by fine grained white mica ± biotite. The most common metamorphic assemblage includes white mica, brown/pale brown biotite partly altered to chlorite, garnet ± clinozoisite. Between Gumburanjon and Shingo La they are characterized by centimetric porphyroclasts of biotite ± garnet. The porphyroclasts are characterized by an internal foliation defined by quartz and opaques; in many samples they are rotated and strained during a deformation event which also produced a more or less pervasive crenulation cleavage marked by white mica and fine grained biotite. Moreover the Shingo La rocks are locally crosscut by centimetric metasomatic veins with amphibole ± garnet; these veins probably record a metasomatic event which may be related to the intrusion of the Gumburanjon leucogranite. Although the Shingo La metagraywackes seem to include deformed and transposed leucocratic orthogneisses, the contact with the other HHC rocks probably represents a tectonic thrust; that is suggested by the existence of mylonites and by the apparent metamorphic jump from the underlying medium/high grade metamorphics (staurolite-garnet-kyanite-sillimanite bearing assemblages) to the overlying low grade metagraywackes (biotite-muscovite ± clinozoisite ± garnet-bearing assemblages).

South of Shingo La, in the Kade Chu valley (Figs. 2, 3), the Shingo La metasediments display a sharp contact with the other HHC rocks, here represented by a huge body of orthogneisses which are less leucocratic than those described above.

The Kade Chu orthogneisses consist of quartz, K-feldspar, plagioclase ± biotite and show a foliation defined by fine grained white mica ± biotite. Rb/Sr whole-rock investigations (Ferrara et al., in progress) on these orthogneisses point to ages around 600 Ma, in agreement with previous data on similar HHC orthogneisses of the Rohtang-La area, some 50 km to the SSE, which yielded a Rb-Sr isochron age of 601 ± 9 Ma (Mehta, 1977). The Kade Chu orthogneisses thus appear to belong to the plutonic cycle spanning the Late Proterozoic-Cambrian boundary (550 ± 50 Ma) which is increasingly documented throughout the Himalayas (for a summary see BORTOLAMI et al., 1983). The 550 ± 50 Ma cycle is the youngest of the three granite cycles recognized so far in the Himalayas from radiometric evidences, the older cycles occurring at 1200-1300 Ma and 1800-1900 Ma respectively (BHANOT et al., 1979).

Discussion and conclusions

The preliminary results of our study on the High Himalayan Crystallines in south-eastern Zanskar can be summarised as follows:

1) *Two main events* have been recognized in the HHC. An early *event 1* produced migmatization in dark gneisses and formation of leucocratic granitoids (transformed to leucocratic orthogneisses during event 2a). The latter intrude as dykes or concentrate forming km-sized bodies. In some mafic rocks associated with orthogneisses and with migmatites event 1 produced clinopyroxene-garnet-quartz-bearing assemblages.

A hypothetical pre-Himalayan (possibly Late Proterozoic) age is suggested for event 1 by: a) the pervasive syn-tectonic medium temperature recrystallization of some migmatites and of the associated leucocratic granitoids to leucocratic orthogneisses during event 2a; b) the possible correlation of these leucocratic granitoids with granitoids dated around 600 my in the Kade Chu valley; Rb-Sr dating of the leucocratic granitoids in NE Zanskar (HONEGGER et al., 1982) has not been successful possibly in consequence of the lack of isotopic homogeneization; c) the existence of xenoliths rich in leucocratic orthogneisses within the Gumburanjon leucogranite which post-dates the main Himalayan metamorphism; d) the rare porphyritic mafic dykes which intrude the leucocratic granitoids, but are later affected by event 2a; though the significance of these dykes is still unclear, they support a major time-gap between events 1 and 2.

A later *event 2a* is associated with pervasive deformations and large scale transpositions in all the HHC rocks, except the Gumburanjon leucogranite. In the metabasics it produced a medium/high temperature crystallization with transformation of the older cpx-gt-qtz assemblage to a hornblende-plagioclase-biotite-ilmenite assemblage. Less obvious is the microstructural evolution of the dark gneisses; however, they locally show an early assemblage including kyanite, garnet, biotite ± K-feldspar ± rutile probably related to event 1, transformed to a later assemblage rich in muscovite, sillimanite, sphene related to event 2a. With respect to event 1, a decrease in pressure and in temperature is suggested for event 2a by the previous features and by the crystallization of staurolite ± garnet in some gneisses.

A Tertiary Himalayan age is implied for event 2a by the available radiometric ages from the studied area (FERRARA et al., in prep.) and from adjacent sectors (HONEGGER et al., 1982; SEARLE and FRYER, 1986).

Event 2a is followed by the growth of biotite ± amphibole (*event 2b*) as a thermal effect of the Gumburanjon leucogranite. The very low temperature syn-tectonic crystallization (*event 2c*) occurring at the contact with the overlying nappes of the Tibetan Zone probably post-dates the intrusion of the Gumburanjon stock; indeed, though no obvious evidence of deformation has been observed in the Gumburanjon leucogranite, some minerals crystallized during event 2b sustained a post-crystalline deformation. In that view the tectonic contact with the Tibetan nappes is younger than intrusion of the Gumburanjon stock.

2) North of Shingo La the HHC metamorphics (dark gneisses and leucocratic orthogneisses) are intruded by the Gumburanjon leucogranite body which clearly post-dates event 2a. The leucogranite body shows marked heterogeneity defined by grain size variations; in some host rocks it produced the growth of biotite and of amphibole ± garnet in veins (event 2b). These evidences and the geochronological works in progress suggest that the Gumburanjon leucogranite is comparable to the Miocene leucogranites of the

High Himalayas (e.g. LE FORT, 1973, 1981; DIETRICH and GANSSER, 1981; FERRARA et al., 1983; SEARLE and FRYER, 1986) which are interpreted as anatectic melts produced from high temperature metamorphics. Rb/Sr age differences on muscovites and biotites of the Gumburanjon leucogranite (FERRARA et al., in progress) point to cooling rates around 100° C/Ma.

Consequently *two generations of leucocratic granitoids* of different ages occur in the HHC of SE Zanskar.

3) As already inferred by BAUD et al. (1984) and by GAETANI et al. (1985), our data suggest that a major tectonic boundary exists between the HHC rocks and the sedimentary nappes of the Tibetan Zone. The petrographic evidences also indicate a metamorphic jump from the high/medium grade assemblages of the HHC metamorphites to the very low grade assemblages of the Tibetan metasediments. A recent work on this boundary (HERREN, 1987) suggests it is an important normal fault. The interpretation of the Shingo La metagraywackes and of their relationships with the HHC metamorphics is less obvious. They may either represent a sequence of metasediments which shared, in part, a common Himalayan history with the HHC, or they may derive from sediments of the Tibetan Zone (i.e. similar to the rocks of the Phe formation, Pughtal nappe) which, however, sustained a metamorphic crystallization at higher temperature with respect to the other Tibetan metasediments. In the former hypothesis, the existence of mylonitic belts and of a metamorphic jump between the Shingo La metasediments and the other HHC metamorphics may record an early thrust during the Himalayan history.

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