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Geological Map of the Kishtwar-Chamba-Kulu Region (NW Himalayas, India)

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1 Plate (in pocket)

India
NW-Himalayas
Paleogeography
Tectonics
Kishtwar Window

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Erläuterungen zur Geologischen Karte der Kishtwar-Chamba-Kulu-Region (Nordwestlicher Himalaya, Indien)

Zusammenfassung

Zwischen dem Chamba-Becken und dem Kulu-Tal bestehen die Serien des Higher Himalaya Crystalline (HHC) hauptsächlich aus den präkambrischen Haimantas. Paläozoische und mesozoische Serien beschränken sich auf die eng gefalteten Chamba- und Tandi-Synklinalen. Die Gesteine sind generell schwach metamorph außer in der Region um Kishtwar und Manali im N Kulu Tal, wo die Serien die Amphibolitfazies erreichen. Lithologisch werden die Haimantas in drei Einheiten gegliedert:

– Die Lower Haimantas bestehen aus feinkörnigen Schiefern.
– Die Middle Haimantas sind ein matrixgestütztes Konglomerat mit lokalen Karbonateinschaltungen.
– Die Upper Haimantas haben teilweise turbiditischen Charakter.

Aus der Kartierung geht hervor, daß der Großteil der stark gefalteten Serien zwischen Chamba und dem Kulu-Tal aus Middle und Upper Haimantas aufgebaut ist. Nur im südlichsten Teil diese Gebietes treten die Lower Haimantas auf. Sie stehen in Verbindung mit der Pandoh-Synklinale N Mandi. Für die auffälligen Konglomerate der Middle Haimantas wurden bisher ein paläozoisches Alter vermutet. Unsere Kartierung zeigt aber deutlich, daß

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diese Serien stets im Kern von großen Antiklinalen unterhalb der Upper Haimantas auftreten. Überdies wird das Konglomerat NE des Sach-Passes immer höher metamorph und ist am Urgos-Paß von frühpaläozoischen Graniten intrudiert, womit der Haimanta-Sedimentation größtenteils ein spät-präkambrisches Alter zukommt.

In den höher metamorphen Serien im Kishtwar-Gebiet konnten unterschiedliche Phasen der Metamorphose und Deformation in den verschiedenen tektonischen Einheiten festgestellt werden:

Die Gesteine des HHC zeigen eine temperaturbetonte Metamorphose und lokale Migmatitbildung im Zusammenhang mit der kambro-ordovizischen Intrusion des Kaplas-Granites. Alle tektonischen Einheiten zeigen ein tertiäre polyphase Regionalmetamorphose. Eine druckbetonte Phase M1 – syn- bis postkinematisch zur Deformation D1 – könnte mit einer beginnenden Krustenverkürzung im Zusammenhang stehen. Eine in der mittleren und oberen tektonischen Position innerhalb des HHC dominierende M2-Paragenese zeigt eine Dekompression als Folge der Main Central Thrust (MCT) Überschiebung an. Der SE–NW-streichende Großfaltenbau südlich des Kishtwar Fensters bewirkt bei andauernder Dekompression eine M3-Paragenese. Die D4-Deformation bewirkt im HHC eine N–S-streichende Kink-Faltung.

Im Unterschied zu der Deformation im HHC werden die Gesteine des Lesser Himalaya syn- bis postkinematisch unter grünschiefer- und lokal auch amphibolitfaziellen Bedingungen überprägt, wobei sie insbesondere am Nordrand der tektonischen Fenster in die inverse Metamorphosezonierung einbezogen sind.

Abstract

In the area between Chamba and the Kulu Valley the Higher Himalaya Crystalline (HHC) consists mainly of the Precambrian Haimantas series. Paleozoic and Mesozoic series are limited to the tightly folded Chamba and Tandi Synclines. The HHC in the area between Chamba and the Kulu Valley has been mainly metamorphosed to greenschist facies whereas the Kishtwar and N Kulu areas have experienced an amphibolite facies overprint. Lithologically, the Haimanta Group comprises three units:

- The Lower Haimantas consist of fine grained slates.
- The Middle Haimantas consist of boulder slates locally followed by carbonates.
- The Upper Haimantas are flysch-type deposits characterized by thick sequences of graded sandstones. They contain a marker horizon of graphitic quartzite.

By solving the problem of the widely traceable lateral folding and by comparison with areas around Chamba investigated by other authors it could be shown, that the western part of the Chamba Syncline up to the Kulu Valley virtually consists only of Middle and Upper Haimantas. Only the most southern frontal zone of the HHC in which the Paleozoic Dalhousie granite is intruded is part of the Lower Haimantas. This region can obviously be connected with the syncline near Pandoh N of Mandi. The widespread conglomeratic deposits in the Chamba Himalayas were recognised by many authors who assigned these sediments various ages (Lower Paleozoic to Permian). Our mapping shows that these conglomeratic Middle Haimantas deposits always form the core of huge anticlines and clearly underlie the Upper Haimantas. These anticlines continue to the NW to the higher metamorphosed area in the Saichu Nal (NE of Sach Pass) where they are intruded by the early Paleozoic granitoids. NW of Manali the early Paleozoic Hanuman Tibba granite intrudes into the higher parts of the Upper Haimantas and cuts the graphitic quartzite horizon. These observations document the mainly Precambrian age of the Haimantas sedimentation.

In the Kishtwar area, several phases of deformation and metamorphism have been documented in the different tectonic units. The rocks of the HHC even record a pre-Tertiary metamorphic event: a static thermal metamorphism (T = 650–700°C, P = 4–5 kbar at the base of the Kaplas granitic stock) with Grt I – Kfsp – Bio – Sph in metapelitic rocks and the formation of migmatites in connection with the intrusion of the Cambrian–Ordovician Kaplas granite. All tectonic units record the Tertiary, polyphase, Barrowian-type regional metamorphism. M1, which corresponds to the metamorphic assemblage of Grt II – Kya I – Bio – Rut – Ilm ± Stau I in the metapelitic schists of the HHC, was a first pressure-dominated phase. The prograde crystallisation M1 is syn- to postkinematic with respect to deformation D1 that is probably associated with the onset of crustal shortening in the NW Himalayas. The later M2 assemblages (Bio-fibrolitic Sill – Stau II ± Grt II) become dominant towards the middle and upper levels of the HHC where they indicate beginning decompression as a result of thrusting. The M2/D2 phase is a result of the southwest verging nappe transport of the HHC over the Lower Crystalline Nappe, the Outer Foldbelt and the Kishtwar Window (Main Central Thrust (MCT) deformation). The M3 phase characterized by synkinematic growth of andalusite – biotite/chlorite – quartz ± staurolite documents ongoing decompression associated with a large scale, SE–NW striking folds in the HHC southwest of the Kishtwar Window.The deformation phase D4 in the HHC produced well recrystallized NS trending kink folds. The latest recognised deformation is related to movements along the lower Main Boundary Thrust (MBT). The lithologies along the MBT are characterised by cataclasis and brittle deformation.

In contrast, the rocks of the Lesser Himalayas show syn- to postkinematic prograde overprinting under greenschist and, locally, lower amphibolite facies conditions. This metamorphic overprint is inverted: The metamorphic grade increases upwards in the Outer Fold Belt and the Lower Crystalline Nappe towards the tectonically higher, strongly mylonitic MCT-zone of the nappe pile.

1. Introduction

The geological map 1 : 300.000 covers approximately 15.000 km^2 in the Kishtwar-Chamba-Kulu area. It is a compilation of the reconnaissance mapping of our working group in this largely unmapped area, based on field work of PhD students from the ETH-Zürich and Vienna University, and of data by Frank et al. (1973), Rattan (1973), Sharma et al. (1975), Thöni (1977), Sandhu (1985), Jangpangi et al. (1986), Kündig (1988), Stäubli (1988), Raina et al. (1990) and Fuchs & Linner (in press). This paper provides additional notes on the geology, paleogeography and stratigraphy. Up to now, geological information for considerable parts of the map did not exist. Compilations of the geology were also given for example by Thakur (1990), by Sharma (1977) and by Fuchs (1975).

The most striking feature within the HHC is the continuous structural relationship of high grade areas along the Chenab Valley at Kishtwar and the northern Kulu Valley with the vast low grade basin of Chamba.

The mapped area serves as a reference area where we discuss the structural evolution of the HHC, the provenance of clastic sediments (especially the Haimanta series), the timing of metamorphism and significance of the cooling history during the Himalayan orogeny in a series of papers in other journals.

2. Lithology

The purpose of this short overview is to describe the lithologies of the tectonic units of the map. For some series, which are discussed in detail, new ages and stratigraphic positions are suggested. Other lithologies, which were not of central interest to this work are only summarised and discussed elsewhere.

2.1. Higher Himalaya

2.1.1. Permomesozoic Series of Tandi Syncline

The Tandi Syncline has been subject to several investigations (e.g. FRANK et al., 1973; POWELL & CONAGHAN, 1973; RAINA & PRASHA, 1974; SRIKANTIA & BHARGAVA, 1982) but remained a structure of enigmatic lithology and age. RAINA & PRASHA (1974) suggested a Permian to Jurassic age for the series of the Tandi Syncline and VANNAY (1993) confirmed this age with the discovery of new fossils. VANNAY (1993) proposed a discordant transgression of conglomerates and dolomites on the Precambrian Haimantas followed by calcarous, sandy and dolomitic sedimentation. Concerning the lithology of the Tandi Syncline no detailed investigations were made during this study. The dolomitic and clastic series between the Haimantas and the grey carbonates at the western and eastern end of the Tandi Syncline were mapped as undifferentiated Upper Paleozoic.

2.1.2. Permomesozoic Series of Chamba Syncline

Detailed investigations of the stratigraphy and age of the series of the western end of the Chamba Syncline were done by THAKUR & PANDE (1971), KAPOOR (1972), SHARMA et al. (1975), DATTA & BATTACHARYYA (1975), RAINA et al. (1975) and FUCHS (1975). According to these authors these series include the Agglomeratic Slate (dark slates and tuffitic layers with carbonaceous lenses), Panjal Trap, the laminated carbonaceous Zewan (Kashmir) or Kuling Formation (Zanskar) and carbonates and dolomites of Triassic age.

In the ESE continuation of the Chamba Syncline in the cross section near Kalhel, RATTAN (1973) reports similar lithologies – the Salooni Formation and the Kalhel Limestone –, which transgress on the Manjir Conglomerate. The regional aspect of this unconformity is not yet fully understood and subject to further investigations. Possibly it represents a similar situation as described by VANNAY (1993) for the relation between the Tandi Syncline and the Haimantas.

2.1.3. Paleozoic–Mesozoic Series of the Eastern Kashmir Syncline

The geology of the southeastern end of the Kashmir syncline was mainly compiled from the work of RAINA et al. (1990a,b). As in the Chamba area, the sedimentary cover rocks of the HHC can be divided into a Precambrian and a late Paleozoic–Mesozoic sequence. The base of the latter is formed by Panjal Trap metabasalts. Up to now Agglomeratic slates are not known from this part of the Kashmir syncline. Above the Panjal Trap basalts carbonaceous sediments start with the Zewan limestone followed by Triassic limestones and dolomites.

2.1.4. Haimantas

In the area between Chamba and the Kulu Valley, the HHC consists mainly of an enormous but weakly metamorphosed flysch-type sequence with a thick boulder-slate horizon of Precambrian age. These series are sheared off above the basal detachment system of the MCT and overlain by the Paleozoic and Mesozoic of the tightly folded Chamba and Tandi Synclines. In the area of Pangi (Chenab Valley SE Kilar) and further W, the grade of metamorphism gradually increases. Several names were used for this sequence, which is known in different areas along the whole Himalayan range (e.g. Attock Slates [WYNNE, 1878], Haimanta System [GRIESBACH, 1891], Dogra Slates [WADIA, 1928], Phe Formation [NANDA & SINGH, 1976]). As the series in the Chamba-Kulu region is clearly a continuation of the Haimanta Formation in Spiti (HAYDEN, 1904) we suggest to use this name for all clastic Late Precambrian series in the NW Higher Himalayas with the following characteristics: The Haimantas represent a continuous Late Precambrian clastic sedimentation of great thickness, often of graded character. Locally this sedimentation continues without a major lithological break into the Lower Cambrian. Based on significant lithological and sedimentological differences in our mapping area the group is divided in Lower, Middle and Upper Haimantas. These, however, are not synonymous with the terms defined by HAYDEN (1904) for a certain locality in Spiti.

2.1.4.1. Lower Haimantas (Chamba Formation)

The Lower Haimantas are the lowest member of the sequence and comprise the metasediments above the detachment system of the MCT up to the first occurrence of large boulders in the matrix. It includes the lithologically similar Blahai Formation, the Chamba Formation and the Pukhri Slates (RATTAN, 1973) of slightly different metamorphic grade. Because of the typical appearance around the village of Chamba the name Chamba Formation (SEHGAL, 1966) is also suggested.

In the Kishtwar, Chamba and Kulu areas the Lower Haimantas are exposed in the S above the MCT and NW of the closing of the Chamba Syncline at Bhadarwah in the Kishtwar Doda region. Here, these series reach amphibolite facies conditions. Along the frontal parts of the HHC, the Lower Haimantas are intruded by the 476±12 Ma old Kaplas, Dalhousie and Mandi granites (GUNTLI, 1993; FRANK et al., in press).

Lithologically, the Chamba Formation consists of alternating metapelitic schists, phyllites, metasiltstones, metagreywackes and subordinate quartzites, interbedded with carbonaceous layers. Whereas the metamorphism in these sediments reaches amphibolite facies in the Kishtwar-Doda area, only greenschist facies conditions with a gradual upward-decrease prevail in the basal, frontal parts of the Chamba region and in the Kulu Valley. Sedimentary structures are generally well preserved. The sequence comprises about 6000 m but due to intense deformation its primary thickness is unknown. The Lower Haimantas show a coarsening-upward trend towards the Middle Haimantas. Because of the monotonous alternation of graded coarse and fine grained clastic sediments we suggest a deposition in a flysch-type environment. Sedimentary structures like load casts, pointed flame structures, flute casts, ripples and convoluted bedding are frequently observed.

In the metapelitic schists and phyllites of the lower parts of the Chamba Formation fine grained quartz and subordinate fine grains of feldspar (mostly plagioclase) are the most dominant detritic minerals. The upper parts of the Chamba Formation are characterized by beds of greywacke several meters thick. Purple, strongly undulant quartz, rock fragments (fine grained quartzites, slates, cherts) and elongated subangular grains of feldspar. With the exception of some large grains of well rounded tourmaline and zircon the rocks are generally poor in accessory minerals.

2.1.4.2. Middle Haimantas (Manjir Conglomerate)

This formation is characterized and easily recognized within the monotonous Haimantas by its boulder slate appearance. In spite of its conspicuous lithology described by many workers (McMahon, 1881, 1883; Sehgal, 1966; Gupta, 1970; Fuchs & Gupta, 1971; Fuchs, 1975; Powell & Saxena, 1971; Thakur & Pande, 1971; Rattan, 1973, 1974, 1978 and 1985; Sharma et al., 1975; Rawat & Thakur, 1988; Grasemann, 1993) there is a little agreement about the stratigraphic correlation, age, nomenclature and origin of this series. Because of its position within the huge Haimanta sequence we suggest the name Middle Haimantas. It corresponds to the Manjir Conglomerate investigated in detail by Rattan (1973).

The Middle Haimantas have an average thickness up to 1000 m and conformly overly the Lower Haimantas. The transition between the Lower und Upper Haimantas is defined as the first occurrence of rounded pebbles of quartzite.

The Manjir Conglomerate forms the limbs of the Chamba Syncline along the Dhaula Dhar range from Bhadarwah in the W toward SE. In the area between Chamba and Kulu the Manjir Conglomerate forms the core of huge anticlines, which strike NW–SE. In the Sach Pass-Kilar-Pangi area the grade of metamorphism and deformation within this series gradually increases. Its continuation towards the N and NW is an integral part of the crystalline of the Great Himalayan Range. This gradual metamorphic increase can be observed in the Saichu Nal towards the Urgos Pass where the Boulder Slates are more and more deformed and metamorphosed along a broad SSW dipping ductile shear zone of normal sense. The continuation of the Manjir Conglomerate towards the SE is not so clear. Similar lithologies, strongly deformed, are exposed in the Pandoh syncline between Mandi and Larji. Some observations in thin sections document the presence of a highly deformed and metamorphosed conglomeratic slate near Kulu and N of the Larji-Kulu-Rampur Window suggesting a continuation of the Manjir Conglomerate towards SE. The conglomeratic sequence of the Middle Haimantas is not restricted to the Chamba-Kulu area. Similar lithologies are documented by Raina et al. (1990a) from the Kashmir syncline – the NW continuation of the Chamba Syncline –, where the diamictites are in a position clearly below the Agglomeratic Slates and Panjal Traps. Other occurrences of boulder slates are known S of Sutlej valley between Rohrur and Shagri Pass and below the Spiti Syncline (Azmi, pers. comm., 1994).

The Manjir Conglomerate consists of thick massive and seldom stratified beds of pebbly mudstones, argillites and meta-greywackes intercalated with thin slates/phyllites forming sharp boundaries. The matrix of the conglomerate is similar to the underlying greywackes of the Lower Haimantas and contains characteristic grains of blue quartz. The sorting is very poor and clasts of various size ($\leq$1m) and composition are dispersed in a chaotic manner. The pebble concentration ranges between 5–40 percent. The majority of components consists of pure white, well rounded to subrounded quartzites of different size (mostly between 1–20 cm) with a prolate shape. Clasts of slates and phyllites, which are angular to subrounded with an oblate or bladed shape, may be of intrabasinal origin of the underlying Lower Haimantas. Subordinate, angular to subrounded pebbles of granites and gneisses, several cm in diameter, sometimes show an old foliation that clearly predates the general Alpine cleavage. At some places (e.g. Ravi valley W of Bara Bangahal) cm-sized calcareous components are frequent. In less deformed sections they form angular, rodshaped bricks but mostly they are elongated along the main foliation.

In the matrix monocrystalline and polycrystalline quartz is always present. If purple, the grains (0.05–5 mm) are subrounded and show undulose extinction. The polycrystalline grains are deformed and elongated to various degrees along the main lineation and foliation direction. Angular feldspar grains are less frequent. Lithic fragments comprise quartzites, slates, phyllites and carbonates. The grains are corroded to various degrees, elongated along the foliation and sometimes difficult to identify.

The individual beds are several meters thick and sometimes show a poor grading of the pebbles within the matrix. Within these beds lenses and channels of a clast supported conglomerate with subrounded pebbles of quartzite can be observed. The components have an oblate shape and are slightly imbricated. At the base of the thick beds flute casts and load casts are common.

Above the Manjir Conglomerate a conspicuous layer of grey carbonate with subordinate magnesite of varying thickness (~0–100 m) is often characteristic (e.g. Pangi Valley) but not always present (e.g. Kugti Pass). The occurrence of large pebbles continues up to the carbonate or clearly diminishes below this horizon.

We think the Manjir Conglomerate represents a glaciomarine deposit formed in the same basin but in a more northerly position than the Blaini Boulder Bed in the Krol Belt (Lesser Himalaya). This is indicated by the fact that coarse exotic pebbles (granites, quartzites, carbonates) occur in the northwestern parts of the Manjir Conglomerate only whereas the clasts in the southern domain are characterized entirely by fine grained slates derived from the underlying formation. A correlation of the Manjir conglomerate and the Blaini Boulder Bed has also been proposed by Shanker et al. (1989).

2.1.4.3. Upper Haimantas

According to Rattan (1978) the Manjir Conglomerate is unconformably overlain by the Salooni succession of dark carbonaceous pyritous slates, greenish and massive basic lava flows and grey calcarous slates in the Saho and Siul Nallas (Chamba area). Based on fossils Rattan divided this formation into three units:

- the lithologies of the Lower Salooni are correlated with the Agglomeratic Slate (Upper Carboniferous to Middle Perm),
- the Middle Salooni Formation is similar to the Panjal Trap and
- the Upper Salooni represents an analogue of the Zewan Formation in Kashmir or of the Kuling Series of Spiti.

However, the tightly folded Paleozoic–Mesozoic Chamba Syncline obviously has a similar position as the Tandi Syncline (Paleozoic Series unconformably transgrade over the Haimantas; Vannay, 1993; Steck et al., 1993). Because of the major time gap between the Manjir Conglomerate and the Paleozoic Salooni Formation, the Kalhel-Chamba section does not represent a continuous stratigraphic sequence. Therefore the Salooni Formation must not be correlated with the Upper Haimantas. Continuous stratigraphic sections within the Haimantas are exposed further east between Chamba and the Kulu Valley (e.g. Tindi, Chenab Valley), where the Manjir Conglomerate gradually passes into sometimes graded meta-greywackes and meta-sandstones intercalated with slates/phyllites similar to the matrix of the underlying Middle Haimantas. Further east this formation is intruded by several granites of Lower Paleozoic age (e.g. Hanuman Tibba) and joins the Precambrian Haimanta/Phe Formation of Spiti.

There are many similarities in the lithology of the Upper Haimantas and the Manjir Conglomerate: Although the large pebbles are restricted to the Middle Haimantas, there are also particles up to 2 mm large of the same composition (quartzite, shales, phyllites, carbonates and subordinate granites) in the Upper Haimantas. There is a remarkable content of detrital well rounded tourmaline, undulose purple quartz and orthite with clinozoisite rims. A calcareous influence becomes more and more important towards the top of the Upper Haimantas. This fact together with some observations of sedimentary structures like oscillation ripple marks (e.g. THÖNI, 1977; GARZANTI et al., 1986) suggest, that the Upper Haimanta Formation was deposited in a rather shallow-water environment. Other observations like the frequent internal grading, flute casts and load casts favor a continuation of the turbiditic environment.

Although there are several graphitic layers within the Upper Haimantas FRANK (1972) observed a graphitic quartzite marker horizon near Sissu N Rothang Pass, which turned out to be of great importance. This marker horizon is diagnostic for the Upper Haimanta sequence and can be traced below the Spiti basin in the E to the Sach Pass in the W. It consists of black cherts, black graphitic quartzites and white quartzites intercalated with layers of pyritous slates. It can be easily mapped because of the conspicuous yellow rusty weathering. The thickness of the marker horizon, which is sometimes connected with black graphitic carbonates and dolomites interlayered with black cherts, is typically between 10–50 m. This horizon was recognized by several authors (e.g. THAKUR et al., 1990), who interpreted this zone as a Tertiary shear plane (i.e. Tethyan Thrust). This opinion is rejected because there is no concentration of high deformation within or any metamorphic or structural break across this horizon. On the contrary, this horizon is sometimes highly folded (Section CD) and cut by the Hanuman Tibba granite dated at 495±16 Ma (FRANK et al., 1977).

2.1.5. Granitoids

The granitic rocks in the NW Higher Himalaya can be classified into two different age groups: An extensive lower Paleozoic magmatic event and the Late Tertiary leucogranites:

The early Paleozoic granitic rocks are clearly restricted to the HHC where they occur as layers of augengneisses or as intrusives emplaced around 476 Ma at relatively high structural levels within the Proterozoic Haimanta series. Intrusive contacts and contact metamorphism are preserved locally. Peraluminous affinities, elevated ^{87}Sr/^{86}Sr initial ratios (0.714–0.726) and negative end values suggest that the sources had long crustal histories. Mafic enclaves do occur, but only for the Mandi granite a local contribution of mantle melts is documented by mingling phenomena and isotopic data (FRANK et al., 1977; FRANK et al. in press). According to LE FORT et al., 1986 these “500 Ma” granitoids have been generated in a late Pan-African megazone of crustal extension and thinning. However, their S-type geochemistry is not consistent with such a tectonic setting. The generation of the subordinate basic and widespread granitic melts coincides with the end of the uniform clastic Haimanta sedimentation, connected with consolidation, uplift, erosion and a distinct rearrangement in the depositional environment. As we think that the Haimanta series represents a passive continental margin sequence derived from a continental source in the north (S-China block) the granitoids could indicate a short collisional event (FRANK et al., in press).

The Late Tertiary leucogranites are not very common in the NW Himalayas. They occur as concordant layers or lens-shaped bodies and dikes crosscutting the regional foliation in the northern part of the HHC close to its contact with the overlying sediments of the Tibetan zone, but outside our field area. These leucogranites are strongly peraluminous, extremely depleted in incompatible trace elements and characterized by isotopically inhomogeneous ^{87}Sr/^{86}Sr initial ratios around 0.750 (FERRARA et al., 1991; FRANK et al., in press).

2.2. Lower Crystalline Nappe

Below the MCT FUCHS (1967) recognized a few 10 to several 100 m thick distinct lithological unit composed of dark graphitic slates, fine grained micaschists associated with darkgrey impure limestones and some paragneisses. Fine-grained often mylonitic deformed microcline augengneisses are also typical. For this association the term Lower Kathmandu Nappe was used by FUCHS (1967). Later the term Lower Crystalline Nappe (LCN) was used (FUCHS & FRANK, 1970; FRANK & FUCHS, 1970). This typical lithological unit was observed in several sections just below the MCT: in the Kishtwar Window, along the foothills of the Dhaula Dhar range and at the contact between the different lithologies of the Larji-Kulu-Rampur Window and the overriding Haimantas of the HHC (Bajaura Nappe [FRANK et al., 1973; THÖNI, 1977]). Also parts of the Jutogh Klippe in the Simla area show similarities to the metasedimentary constituents of the LCN. In western Nepal this LCN was mapped by FUCHS & FRANK (1970) over a long distance. BORDET et al. (1981) mapped a graphitic micaschist-limestone assemblage below the MCT in the southern Anapurna region. These observations document that this series occurs in a position below the HHC and MCT for a distance of more than 1000 km – although not continuous and with some variations in lithology.

Because many local names were used for this unit its regional aspect was seldom adressed. Information about the depositional age of the sediments or the magmatic age of the augengneisses as well as the paleographic position of these series prior to the Tertiary tectonics were scarce and mostly speculative.

In the area shown in the map the following features are important: the augengneisses usually have the highest position in the sequence. These augengneisses continue to the Sutlej section, where they attain an unusual thickness at Bharagaon between the Shali and the LKR Window. At this locality they have been dated as 1960±29 Ma (Rb/Sr whole rock isochron). Similar ages around 1860 Ma have been obtained by us on single samples from the highly deformed varieties at Bajaura (Kulu Valley).

One of the best preserved sections in the dark arenaceous-argillaceous metasediments is exposed along the Chenab W of Doda. Here, limestone and especially gypsum yielded Sr isotopic ratios close to the Precambrian/ Cambrian boundary seawater value. As we think that this is a ±well preserved primary isotopic signature, an uppermost Precambrian age for the sequence is indicated.

We therefore conclude that the above mentioned augengneisses represent the top of the basement, on top of which the huge pile of the Haimanta sediments was deposited. The augengneiss horizon also serves as the main deformation zone of the MCT thrusting. The underlying dark shists and paragneisses could represent an equivalent of the Simla Slate series. This correlation is supported by the fact that in the Simla area above the Shali window the Simla Slate nappe is thinning out below the Baragaon augengneiss and grading into dark slates characterized by an intense polyphase deformation. This interpretation has several consequenes:

- The Simla Slates and the Haimantas developed in a continuous sedimentary depositional basin.
- The Simla Slates have been deposited on the Berinag/Chail (Shali) realm.
- The Simla Slate nappe together with the Krol-belt travelled quite a long distance immediately below the MCT.

In the outer parts of the Kishtwar section along the Chenab, the LCN and the HHC have a common metamorphic and deformational history. This section represents one of the best preserved examples of inverted isograds: starting with biotite, also garnet and staurolite grades are well developed in the lithologic unit of the LCN.

2.3. Lesser Himalaya

2.3.1. Shali Group

In the area presented on the map the Shali Group and equivalents are only exposed within the Larji-Kulu-Rampur Window (FRANK et al., 1973; THÖNI, 1977 and SHARMA, 1977) and along the frontal parts below the MCT south of the Dhaular Dhar range (Mandi Unit [FRANK et al., 1973]). The main components of the carbonate-slate-quartzite complex of the Shali Group are thickly bedded, fine grained, blue-grey dolomites containing silicified stromatolites, which suggest shallow-water conditions. According to SINHA (1972) the growth forms of the stromatolites suggest a lower to middle Riphean age. There is no independent geochronologic age information available up to now. An attempt to obtain an information from the primary Sr-isotopic ratios during deposition failed almost completely because large rock volumes must have experienced a considerable loss in their Sr-content during early diagenesis. In addition, they have exchanged with a fluid rich in radiogenic Sr during a very low-low grade overprint. However, locally preserved carbonates from the Shali Formation around Larji (^{87}Sr/^{86}Sr around 0.706) strongly corroborate the distinctly older age of the Shali carbonate platform compared to the Vendian Krol carbonates.

2.3.2. Khaira Group and Garsha Slates

The term Khaira Group is used for the shallow water deposits below the massive Shali dolomites. It consists of pink/purple, green and white orthoquartzites with small detrital grains of jasper, intercalations of pink/purple and green shales/slates associated with thin limestone layers and horizons of dark ferrugineous stromatolite bearing dolomites. The term Khaira Group is used here in a broader sense than for the type locality Khaira in the Sutlej valley (SRIKANTIA & SHARMA, 1976) and also comprises equivalents of the Ropri Member.

The Garsha Slates (THÖNI, 1977) consist of uniform brown fine-grained phyllites a few 100 m thick. Lithologically they have some similarities with the Simla Slates (THÖNI, 1977). They form a typical intercalation at the NW end of the Larji-Kulu-Rampur Window between the basal Rampur Formation (Chail/Berinag) and the Khaira/Shali Group at the top. We interpret this sequence as a continuous stratigraphic succession.

2.3.3. Rampur Formation (Chail/Berinag Group)

FUCHS (1967) realized that there exists a characteristic lithological sequence of pure white quartzites of deltaic origin associated with uniform slates, clastics, intrusives and volcanic metabasics which forms several windows below the HHC. He used the term Chail (Chail series, Chail nappe) for this usually low-grade series. The term Chail was originally coined by PILGRIM & WEST (1928) for a series of silvery/green-grey phyllites with thin quartzite intercalation around the Hillstation Chail SE Simla. There exists a major confusion how the Chail series can be distinguished from the Haimanta and Jutogh series. Therefore a variety of quite different maps has been published for the Simla/Sutlej-Kulu area. One reason for this confusion is the fact that the Chail series of the type locality is an isolated occurrence within the MCT zone, with an unspecific lithology and an unknown depositional age (Rb/Sr whole rock data from the phyllites of this locality yielded scattered rejuvenated age values).

Therefore we propose the term Rampur Formation (from Rampur in the Sutley Valley as a new general type locality) for the white quarzite/phyllite series. In the immediate vicinity of Rampur granitic gneisses, basic metavolvanics and intrusive diabases are associated with the metasediments. The granitic rocks from LKR-window yielded a well defined 1860 Ma Rb/Sr whole rock isochron (localities Sainj and Bandal). The metabasics from Rampur have been dated by BHAT & LE FORT (1992) as 2510 Ma in age. Field relations, however, suggest that the metabasics are nearly contemporaneous with the granitic rocks. Therefore we are not convinced that the Sm/Nd whole rock age of 2510 Ma is geologically meaningful. Unfortunately, it is not possible to check this result by a mineral isochron as the primary assemblage is usually quite altered.

In the Kishtwar Window the typical Rampur Formation is well exposed and was intruded by peraluminous granites 1860 Ma ago. Initial ^{87}Sr/^{86}Sr ratios for these 1860 Ma granitoids are in the range of 0.708 to 0.713. These and other geochemical data indicate a substantial contribution of old crustal material in the generation of the Proterozoic granitoids.

2.4. Outer Fold Belt

The Outer Fold Belt along the external zone of the Himalayan Range is the strongly imbricated and lowermost unit of the Himalayan nappes. In India it corresponds to the Autochthonous fold belt (WADIA, 1928, 1931), the Parautochthonous Unit (FUCHS, 1975) and the Parautochthonous Zone (THAKUR & GUPTA, 1983). In Pakistan it corresponds to the Panjal Unit (BOSSHART et al., 1988). In Azad Kashmir (Pakistan) and in the Pir Panjal (India) it is composed of Agglomeratic slates, Panjal Trap volcanics, some lenses of Mesozoic limestones and Eocene (WADIA, 1928; BOSSHART et al., 1988) without Proterozoic and early Paleozoic sediments. Proterozoic sediments including Simla slates, however, occur in Gulabgarh, SE Kashmir (FUCHS, 1975). In Himachal Pradesh the Outer Fold Belt corresponds to the Simla-Krol Belt.

In the study area (Tavi: cross-section MN, Chenab: cross-sections OP, QR) the Outer Fold Belt forms a several km wide imbricated thrust zone with upper Paleozoic sediments and Panjal Trap volcanics overthrust by Proterozoic phyllites and schists (Simla slates), a sandy dolomitic and evaporitic series and tectonic lenses of Eocene nummulitic limestones (JANGPANGI et al., 1986).

The Panjal Trap volcanics are up to 50–60 m thick and include basalts, diabases and volcanoclastic rocks which have been affected by the Tertiary metamorphism. They have suffered a greenschist facies overprint resulting in an assemblage consisting of actinolite, chlorite, pumpellyite, albite, epidote, calcite and quartz. Layering, clinopyroxene and plagioclase are magmatic relics. The metabasalts are associated with white coarse-grained quartzites/metaconglomerates, black silty and partly carbonaceous phyllites, graphitic phyllites and green, black or brown sericitic phyllites. In some parts, e.g. at Batote (cross-section QR), similar lithologies are included in a tectonic melange.

The dominant rocks of the Outer Fold Belt in the study area are dark sericitic phyllites and quartzites derived from former sandy, silty and pelitic sediments. Conglomeratic layers also occur. The monotonous phyllite series is topped by a conspicuous carbonate horizon consisting of grey/brown metasandstones with thin sericitic layers, dark dolomite marbles alternating with metasandstones, rauhwacke, laminated grey/white dolomites, green ore-bearing phyllites and calcite marbles intercalated with sericitic and chlorite phyllites (partly carbonaceous and/or pyrite bearing). This carbonate horizon can be traced all along the SW flank of the Kaplas ridge. It appears again in the Chenab valley near Ramgarh.

2.5. Subhimalaya

The Subhimalaya, the Tertiary foreland of molasse sediments, was mapped without going into details of stratigraphy and sedimentology. In the Tavi valley a clastic sequence of red/brown conglomerates alternating with silt- and mudstones and of pure sandstones occurs. The beds are up to a meter in thickness and graded. The conglomerates consist of a sandy matrix and well-rounded matrix-supported clasts up to 25 cm in diameter.

These coarse clastics are succeeded by a much finer grained sequence with different sedimentary structures: grey/light-brown sandstones form beds between 1–5 m characterized by cross-bedding and current lamination. These well sorted and cemented sandstones are commonly topped with a sharp contact by siltstones up to 10 m thick. In the Chenab valley near Batote the coarse conglomerates are not developed, red/brown sand- and siltstones and brown marls predominate.

The age and depositional environment of these clastic sediments are still somewhat controversial. According to WADIA (1931) and FUCHS (1975) they are a part of the Murree Formation. In the Jammu area conglomerates and planar cross-laminated sandbars are widespread suggesting deposition in a meandering river system. As these sediments are generally unfossiliferous the age of the Murrees is not well defined. They are certainly post-Eocene because they transgress the upper Paleocene to Eocene nummulitic Subathu (MEDLICOTT, 1864) limestones near Riasi (FUCHS, 1975). According to FUCHS (1975) they are Miocene. KHAN et al. (1971) determined Miocene fossils in Subhimalaya sediments near Udhampur.

3. Description of the Profiles and the Map

3.1. The Eastern Chamba-Kulu Region (Profiles AB, CD, EF and GH)

The structural character of the mountain ranges between the Dhaula Dhar in the S and the Pir Panjal in the N is dominated by huge anticlines and synclines with amplitudes of several thousand meters. The general strike in the Sach Pass area is W–E, in the Pangi Valley NW–SE, in the Bramaur-Mani Mahesh-Bara Bangahal area W–E and in the southern Kulu Valley NW–SE, which results in a sigmoidal-shaped trend of the hinge lines.

The north vergent structures of the Tandi Syncline were recognised by several authors (e.g. FRANK et al. [1973], SRIKANTIA & BHARGAVA [1982] or STECK et al. [1993]). This special situation continues to the south, where a huge north vergent anticline overturns the Hanuman Tibba granite in an upside down position. In constrast to the general Tertiary tectonic movements, the general N–NNE vergence of the folds continues from the Tandi Syncline across the Myar Valley to the Saichu Nal. These huge structures are folded over quite large distances (several km) but neither displacement nor thrust planes could be observed. For that reason the interpretation of SRIKANTIA & BHARGAVA (1982), who relate this structure to a N-vergent thrust, is rejected.

Based mainly on the observation of amphibolite facies metamorphic conditions in the Chenab Valley around Koksar and the north vergent structure of the Tandi Syncline STECK et al. (1993) postulated a Shikar Beh Nappe. However, the north-vergent continuation of theTandi Syncline and the Hanuman Tibba anticline towards NW shows that the south dipping axial surfaces of the asymmetric folds gradually pass into an upright-symmetric position. Further towards WSW they even turn over into asymmetric folds with axial surfaces dipping to the N. Therefore we see no structural arguments for an indiviual Shikar Beh Nappe. The high-grade area around Koksar may indicate an incipient doming and thinning of the deeper structural levels similar to the doming structures in the Zanskar Crystalline NE of Kishtwar (STÄUBLI, 1989; KÜNDIG, 1989).

An excellent example of these fold structures is seen in the south of the Tandi Syncline along the Pir Panjal range: A huge anticline with local axial culminations and depressions can be followed from the Hanuman Tibba to the area NW of Udaipur. Due to a large north vergent anticline the Hanuman Tibba granite, which cuts through the graphitic quartzite marker horizon of the Upper Haimantas, comes to lie in an inverted position. The same tight anticline appears all along the Pir Panjal Range as an upright symmetric fold. Further to the NW this structure continues to overturn to the S and SW and is followed by a succession of south-vergent folds. Between the Ravi Valley and the Dhaular Dhar range the structures are dominated by isoclinal S–SW vergent folds, which are partly sheared off along graphitic horizons within the Upper Haimantas resulting in multiple imbricates.

The rotation of vergence can be best observed in the Sach Pass section, where the discovery of a north vergent anticline in the high-grade rocks south of Kilar completely changed the earlier interpretation of an upright sequence of Proterozoic–Paleozoic rocks. The southern slopes of the Sach Pass represent the continuation of a huge anticline north of the Chamba Syncline. This gently folded anticline passes north of the Sach Pass into a tightly folded syncline and further to the north into a north-vergent anticline. The Haimantas (including the Middle Haimantas continue to the Saichu Nal, where they are intruded by granites near the Urgos Pass. These granitoids are the direct continuation of the orthogneisses of the Myar Valley, which are part of the early Paleozoic granitoids of the Higher Himalayas (POGNANTE et al., 1990). Between the Sach Pass and Kilar the large folds with nearly horizontal fold axes striking WNW–ESE continue further to the WNW where these structures disappear in the high grade metamorphic Kishtwar area.

The style of deformation also changes in these north vergent structures in the Myar Valley, Saichu Nala and Kilar region. Whereas the style of folding south of the Pir Panjal range is dominated by flexural slip folds, the rocks N of the Sach Pass and further E show a penetrative deformation with a cleavage plane dipping to the S–SSW. Many microkinematic indicators as well as deformed pebbles of the Manjir Conglomerate between Kilar and the Saichu Nal document a displacement of the hanging wall towards the S, which suggests a faster exhumation of the higher metamorphic areas to the N along an ill defined broad brittle-ductile shear zone of normal sense. This observation is important and in strong disagreement with the model of SEARLE & REX (1989), where the isograds are telescoped along the MCT and the Zanskar Shear Zone. The observed normal shear sense is also different to the Myar Thrust of POGNANTE et al. (1990), which has a reversed shear sense in order to explain the higher metamorphic rocks to the north.

In the western flank of the Kulu Valley a completely different and younger style of deformation than the relatively earlier north-vergent folding style can be observed ([FRANK et al., 1973] Phojal-Kallath-giant-fold [THÖNI, 1977]). A large south-vergent, recumbent, isoclinal fold structure with complex internal folding deforms the metasedimentary rocks with granitic gneiss layers in the upper Beas Valley. The folded isograds of the medium grade metamorphic rocks suggest a syn- to mainly late metamorphic development. Numerical modelling by GRASEMANN (1993) shows that a local temperature maximum in the overriding plate above the MCT coincides with synmetamorphic shearing within the HHC inducing deformation of metamorphic zones. Up to now the transition from this recumbent fold – with all the complicated secondary folds resulting from the interference with the pre-existing north vergent folding style – to the open syncline near Pandoh is not well understood. Although not yet recognised in the field, a tightly folded syncline must exist north of the Pandoh syncline in order link the upright position in the northern limb with the inverted limb of the Phojal-Kallath fold.

3.2. The Eastern Kashmir, Kishtwar and Western Chamba Region (Profiles IJ, KL, MN and OP)

The tectonic elements of SE Kashmir, NW Chamba and the Kishtwar Window clearly document the large scale thrusting of the Higher Himalaya. WADIA (1934) introduced the term Kashmir nappe but it was FUCHS (1975) who first discovered the existence of the Kishtwar Window. The HHC and its sedimentary cover rocks exposed in the Kashmir and Chamba synclines were thrust over the low-grade Lesser Himalaya Rampur Formation exposed in the Kishtwar Window and over the Outer Fold Belt along the external zone. The minimum distance of this SW verging nappe transport is 80 km (measured in direction of the stretching lineation between the MCT and the northern edge of the Kishtwar Window). The deformation (D_2) associated with this nappe transport is recorded by the penetrative schistosity (S_2) and stretching lineation (L_2). A third phase of deformation (D_3) resulted in large-scale NW–SE striking folds in all tectonic units (cross-section MN). The steep axial planes of these open km-sized megafolds as well as of the associated crenulation folds trend parallel to the folds within the Kashmir and Chamba synclines. The interruption of the once connected Kashmir-Chamba sedimentary basin was caused by a N–S directed crustal doming structure (D4) which is probably a continuation of the Suru-Warwan cross fault (HONEGGER, 1983).

Thrusting of the HHC along the MCT resulted in a penetrative deformation of the MCT zone. This zone comprises the base of the HHC, the LCN, the Rampur Formation at the southern edge of the Kishtwar Window and the Outer Fold Belt. Troughout the MCT zone distinct mylonite zones occur and the rocks have been metamorphosed to different degrees during thrusting.

Within the Kishtwar Window the Rampur Formation phyllonites at the base of the MCT zone are characterized by a fine-grained mylonitic fabric and the assemblage sericite-chlorite-biotite-quartz. At the western and southern edge of the Kishtwar Window there is marked discordance between these steeply inclined basal phyllonites of the MCT zone and the sericitic phyllites and quartzites within the window which gently dip towards N to NE (cross-sections OP, MN). According to FUCHS (1975), HONEGGER (1983) and STÄUBLI (1988) this discordance is due to a N–S directed late fault. However, no brittle fault contact could be observed in the Chenab valley near Kishtwar. Along the southern edge the ductile discordance even bends conformably with the lithologic boundaries around the domal structure of the Kishtwar Window.

The Outer Fold Belt is the lowest unit in the external zone of the Himalayan Range. Its tectonic contact (MBT) with the underlying folded molasse sediments of the Subhimalaya is characterized by cataclasis and brittle deformation. The brittle structures overprint older ductile and often mylonitic structures. Mineral growth during the ductile deformation (D_2) records lower greenschist facies conditions. In the fine-grained phyllites at the base of the Outer Fold Belt the assemblage chlorite-sericite-quartz developed. Near the top biotite is also present and quartz (calcite in metacarbonates) has recrystallized to medium- or coarse-grained aggregates with a granoblastic polygonal texture. These observations suggest an inversed metamorphic sequence within the Outer Fold Belt.

As the cross-sections QR, MN, OP show the LCN is thrust over the Outer Fold Belt along the external zone and over the Rampur Formation exposed in the Kishtwar window. In the Chenab valley (QR) the LCN is several km thick due to folding. Towards SE (Tavi valley, cross-section MN) this thickness decreases to less than 200 m. Its continuation towards NW is documented by sporadic gypsum intercalations that are mined in the Chenab valley (JANGPANGI et al., 1986).

Mineral growth in the rocks of the LCN occurred syn- to postkinematic as a result of the SW verging nappe transport of the HHC. In the Tavi section (MN, SW of the Kaplas range) assemblages are: chlorite-biotite-sericite-quartz-albite (ore) in metapelites and actinolite-biotite/chlorite-epidote-albite-quartz (calcite, sphene) in greenschists. In the section Batote-Doda (cross-section QR) the grade of the metamorphic overprint increases from the structurally deeper levels in the W towards the higher levels in the E. This is recorded by the metapelitic mineral assemblages comprising garnet-biotite-albite-quartz-ilmenite in the W and garnet-staurolite-biotite-plagioclase-quartz (ilmenite) in the E. This increase in metamorphic grade between the Panjal Thrust (base of the LCN) and the MCT (top of the LCN) clearly documents an inverse metamorphism within the LCN. This has also been recognized by STÄUBLI (1988) along the western and southern edge of the Kishtwar Window. The pelitic schists immediately below the MCT have been overprinted by a late-tectonic retrograde phase producing the assemblage andalusite-chlorite-quartz (also in veins).

In the study area the LCN always conforms to the base of the HHC without major structural and lithological breaks. Within the MCT zone both units are dominated by two-mica schists and gneisses. In the Chenab valley these schists and gneisses have been deformed by a large-scale anticlinal structure (D_4) associated with a strong crenulation. This updoming is strongly discordant to the generally SE–NW striking structural units and together with erosion resulted in the exposure of the deepest levels of the HHC.

The base of the HHC above the MCT has been newly defined because its metamorphic evolution differs from that in the LCN: within the HHC relics of a pre-Tertiary static metamorphism occur in connection with the intrusion of the Kaplas granite (476±2 Ma). This intrusion caused a partial migmatisation and the crystallization of andalusite-K-feldspar-sillimanite-garnet-biotite in the pelitic-psammitic country rocks. SW of Kaplas, at the base of the granite (cross-section MN) pressures of 4–5 kbar and temperatures of about 650–700°C are recorded for this migmatisation event. In contrast, near the top of the intrusion (Haimantas at the southern limb of the Chamba syncline) only sericitic phyllites have been observed. Along the Chenab the pre-Tertiary metamorphic rocks have been strongly overprinted. They now form coarse-grained muscovite- and leucocratic augengneisses isoclinally interfolded with orthogneisses.

In the HHC metapelitic mineral assemblages three phases can be distinguished for the Barrowian-type Tertiary metamorphism. During the pressure dominant pre-MCT phase, M_1, the assemblage kyanite-garnet-staurolite-biotite-quartz-rutile-ilmenite was formed probably in connection with early crustal thickening and initial nappe formation after collision. Kyanite (I) and garnet (I) may contain inclusion trails defining the schistosity S_1. The M_1 overprint decreases continually towards the stratigraphic higher levels of the Chamba syncline and towards its SW limb (Tavi valley, cross-section MN).

The amphibolite facies grade M_2 mineral assemblages are syn- to postkinematic and record a reduction in pressure as a result of thrusting during the MCT phase. M_2 is characterized by kyanite-staurolite in the lowest levels of the HHC around the Kishtwar Window (cross-sections OP, MN) and along the section Doda-Batote (cross-section QR). In middle levels (e.g. NE of Doda) kyanite breakdown and the growth of fibrolitic sillimanite, garnet, staurolite, biotite and muscovite indicate decompression.

In the area around Doda post-MCT growth of M_3 andalusite and chlorite and recrystallization of staurolite, biotite, muscovite, plagioclase and quartz has overprinted the M_1 and M_2 assemblages. This late retrograde mineral growth was probably caused by distinct structural D_4 readjustments (doming of the HHC, synformal depressions).

The minimum displacement of the M_1 and M_2 mineral assemblages across the Kishtwar Window towards SW is about 55 km (distance from the NE margin of the Kishtwar Window to the area S of Doda). In this cross-section the mineral zones are roughly parallel to the MCT.

In the Tavi cross-section (MN) the M_1 and M_2 metamorphic crystallization of garnet, biotite and chlorite did not exceed upper greenschist facies conditions. In the Tavi valley the MCT probably cuts into a higher tectonic level above a ramp and thus also cuts the mineral zones between the Chenab and Tavi valleys.

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