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Geology along the Arniko Highway between Barabise and Kodari (China-Nepal Boardar) area, central Nepal Himalaya

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ABSTRACT

The area between Barabise and Kodari in central Nepal along the Arniko Highway is geologically located into Higher Himalayan Crystallines (HHC) and Lesser Himalayan Sequence (LHS) that is separated by the Main Central Thrsut (MCT). The HHC consists of amphibolite facies rocks (pelitic schist, psamitic schist, pelitic gneiss and quartzite), while LHS is comprised by greenschist to amphibolite facies rocks (phyllite, calcaresous phyllite, garnet-mica schist, black schist, quartzite and augen gneiss) in uppermost section and carbonate (dolomite and limestone) with phyllite, and metasandstone in lower section. The MCT in the area is oriented in E-W direction with about 30^0 dip due north and S-C structure preserved in augen gneiss of LHS characterizes the top-to-south sense of shearing, which could be related to the movement along the MCT. Mineral lineation marked by stretched mica indicates N to NNE direction in both HHC and LHS.

Metamorphism of inverse grade from biotite at stratigraphically lowermost section of Kuncha Formation to garnet at the uppermost section having schist and augen gneiss is obvious close to the MCT in the section. However, the Kuncha Formation contains tiny crystals of garnet in the rocks of greenschist facies. Kyanite and sillimanite isograds are developed in pelitic and psamitic schists, and pelitic schists appeared at the basal part of HHC above the MCT. The transformation of garnet to chlorite at the margin and fractures and formation of chlorite within bulk rocks of the MCT zone and HHC are the indicators of traces of retrograde metamorphism because of dropping in pressure-temperature probably related to post deformation event.

Keywords: Lesser Himalayan Sequence, MCT zone, Higher Himalayan Crysrallines, central Nepal

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INTRODUCTION

In central Nepal, the Nawakot Nappe consisting of low-grade metamorphic rocks overlain by medium to high-grade metamorphic rocks of the Kathmandu Nappe was firstly recognized by Hagen (1969). The Nawakot Nappe corresponds to Lesser Himalayan Sequence (Nawakot Complex of Stöcklin and Bhattarai 1977) and Kathmandu Nappe is correlated to the Higher Himalayan Crystalline (Kathmandu Complex and undifferentiated gneiss of Stöcklin and Bhattarai 1977; Kathmandu and Gosainkund Crystalline nappes (Rai 1998; Rai et al. 1998; Upreti and Le Fort 1999; Rai 2001)). The Mahabharat Thrsut (MT), a major thrust fault separates the Nawakot Complex and the Kathmandu Complex and is considered as a southward continuation of the Main Central Thrust (MCT) (Stöcklin 1980; Pandey et al. 1995; Johnson et al. 2001). The MCT is the tectonic boundary between the Higher Himalayan Crystallines (HHC) and the Lesser Himalayan Sequence (LHS).

The present study focused along the Arniko Highway between Barabise and Kodari villages of central Nepal is geologically situated in the Lesser Himalayan Sequence and the Higher Himalayan Crystallines (Fig. 1), which has also been worked out by Stöcklin and Bhattarai (1977), Stöcklin (1980), Upreti and Rai (2000), Duvadi et al. (2005, Fig. 2) and Pradhanaga and Duvadi (2006). To the western and eastern continuation of the area were investigated in detail, respectively, by Arita et al. (1973), Stöcklin and Bhattarai (1977), Rai (1998, 2001), Dhital et al. (2001), and Maruo et al. (1973).

GEOLOGICAL SETTING

The study area is divided into two units: Higher Himalayan Crystallines (HHC) and Lesser Himalayan Sequences (LHS) separated by the MCT (Fig. 3). The LHS is named as Nawakot Complex (Stöcklin and Bhattarai 1977).

Higher Himalayan Crystallines and the MCT Zone

The rock sequences of HHC and LHS strike in NWW-SEE direction with a dip varying from 15^0 to 40^0. The MCT is a major syn-to post collisional thrust fault extending throughout the Himalaya (Gansser 1964; Le Fort 1975; Pêcher 1989). In central Nepal, two thrusts (MCT and MCT-I; Arita 1983) bound a ductile shear zone (i. e., upper Lesser Himalaya). Along Dudh Koshi Valley, Everest region, the

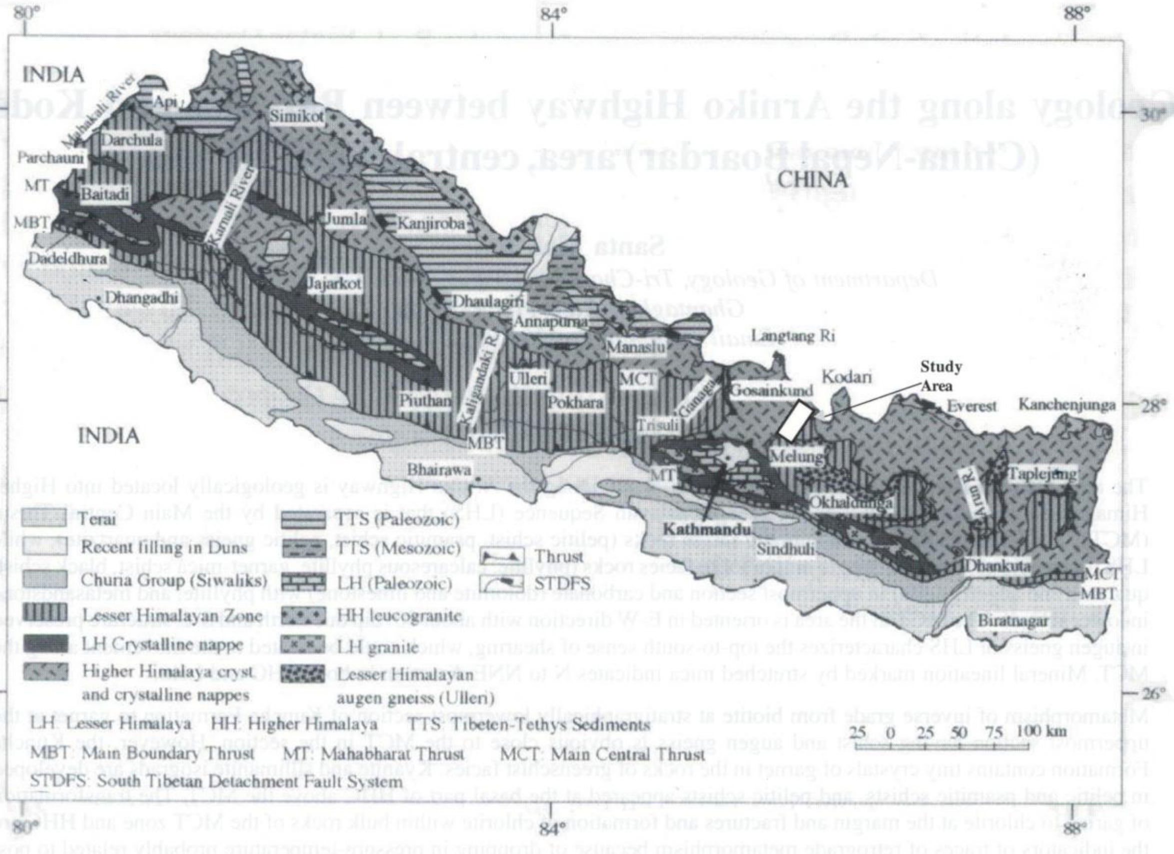

Fig. 1: Geological map of Nepal (Upreti and Le Fort 1999)

MCT corresponds to the contact between the Greater Himalayan Crystalline gneisses and the upper Lesser Himalaya pelitic schists, whereas the MCT-I separates the mylonitic Phaplu augen gneiss from low-grade Lesser Himalayan metasedimentary rocks (Catlos et al. 2002). In the study area, the MCT zone produces a simple monoclinal structure trending E-W and dips about 30°N. Thickness of the MCT zone is 150 m and is divided into MCT-1 and MCT-2 around the Tatopani Village (Pradhananga and Duvadi 2006). According to Stöcklin and Bhattarai (1977), the MCT passes at the top of the augen gneiss very close to Tatopani Bazaar, south of Kodari (Fig. 3). Above the MCT two rock units namely Hadi Khola Schist on the upper section and Dhad Khola Gneiss on the upper section belonging to the Higher Himalayan Crystallines are divided. These two units are separated by a thrust. The zone between MCT-1 and MCT-2 is named as Hadi Khola Schist consisting of garnet-bioite schist, calcareous schist with quartzite and gneiss bands. Dhad Khola Gneiss is consisting of porphyroblastic gneiss, augen gneiss with quartzite and schist (Duvadi et al. 2005; Pradhanaga and Duvadi 2006). Marou et al. (1973) have also mapped the contact (MCT) between the Higher Himalayan Crystallines (their Himalayan Gneiss Zone) and the Midland Metasediments Group (Lesser Himalayan Sequence) south of Kodari near Tatopani Village. Pelitic schists having few fine-grained kyanite crystals appear on top of the highly sheared augen gneiss (Fig. 3). This boundary between two different lithologies can be considered as the Main Central Thrust, however, the effect of shearing can be seen in the augen gneiss or upper section of the LHS and the psamitic or pelitic schists of the HHC above the MCT. The present study shows that the occurrence of highly mylonitized coarse grained augen gneiss could be Ulleri type Lesser Himalayan granite. Such Ulleri type augen gneiss can be observed just below the MCT along Tadi Khola, Phalangu Khola, Langtang Khola north of Shivapuri Range (Rai et al. 1998; Rai 1998, 2001). In fact, the augen gneiss with pelitic schist belongs to the MCT zone. In the HHC, the rocks are essentially kyanite-garnet-biotite bearing pelitic schist to psamitic schist, kyanite-pelitic gneiss with subordinate quartzite (Figs. 4a to f). These rocks can be correlated with the Formation I of Tibetan Slab (Le Fort 1975) or Gosainkund Crystalline Nappe (Rai 1998, 2001; Rai et al. 1998).

Lesser Himalayan Sequence

According to Stöcklin and Bhattarai (1977) and Stöcklin (1980) the rocks along the Arniko Highway between Barabise and Tatopani belong to Nawakot Complex (Figs. 2 to 4). The Nawakot Complex have been subdivided into Lower and Upper Nawakot groups separated by an erosional unconformity (?) (Stöcklin and Bhattarai 1977). The present study follow the stratography prepared by Stocklin Bhattarai (1977).

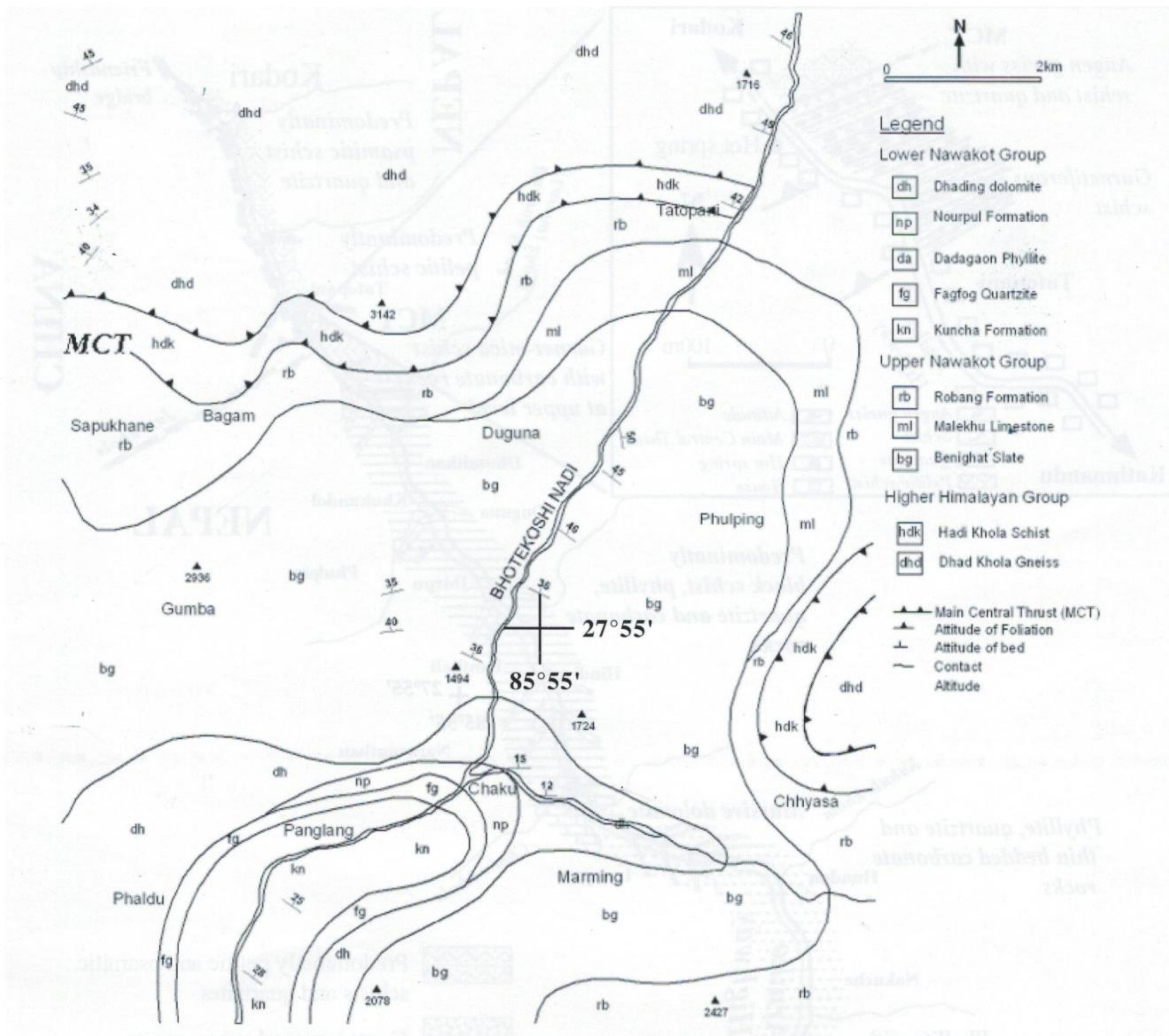

Fig. 2: Geological map of Sindhupalchok District, central Nepal (Duvadi et al. 2005)

Lower Nawakot Group

The Lower Nawakot Group is the oldest formation perhaps of the entire Lesser Himalaya of Nepal. Kuncha Formation is the base of the group, whose base is not exposed anywhere. The lower section of the formation consists of a monotonous sequence of flysch-like alternating phyllite, phyllitic quartzite and phyllitic gritstone. Strikingly, carbonate rock is missing except as cementing materials in some sandstone. The phyllite shows silky luster and yellowish, blue-gray to green-grey color. The phyllitic gritstones contain opal like milky-gray or bluish quartz, which is a diagnostic feature to the rock unit (Arita et al. 1973). The quartz grains are considered to be the elements of Indian Peninsular gneiss. Amphibolites are commonly associated within the formation. The Kuncha Formation contains sericite-chlorite metamorphic minerals.

In the type locality, the Kuncha Formation is overlain by Fagfog Quartzite consisting of coarse to fine grained white quartzite with frequently developed ripple and current bedding (Stöcklin 1980). The overlying Dandagoan Phyllite is comprised by green-gray phyllite, which is darker in color than the Kuncha Formation. Thin layers of dolomite and calc-phyllite appear first time in this sequence. The Dandagoan Phyllite passes upward to the Nourpul Formation having a mixed lithology of thinly banded purple slate, calcareous metasandstone and frequent intercalations of thick quartzite. Along the Kodari Highway these formations are not well represented (Fig. 3, present study). No certain equivalent, neither of the Dandagaon Phyllite nor of the Nourpul Formation could be identified (Stöcklin and Bhattarai 1977). In the type locality, the overlying ridge-forming Dhading Dolomite is massive to thickly bedded, finely crystalline to micritic dolomite. The dolomites are

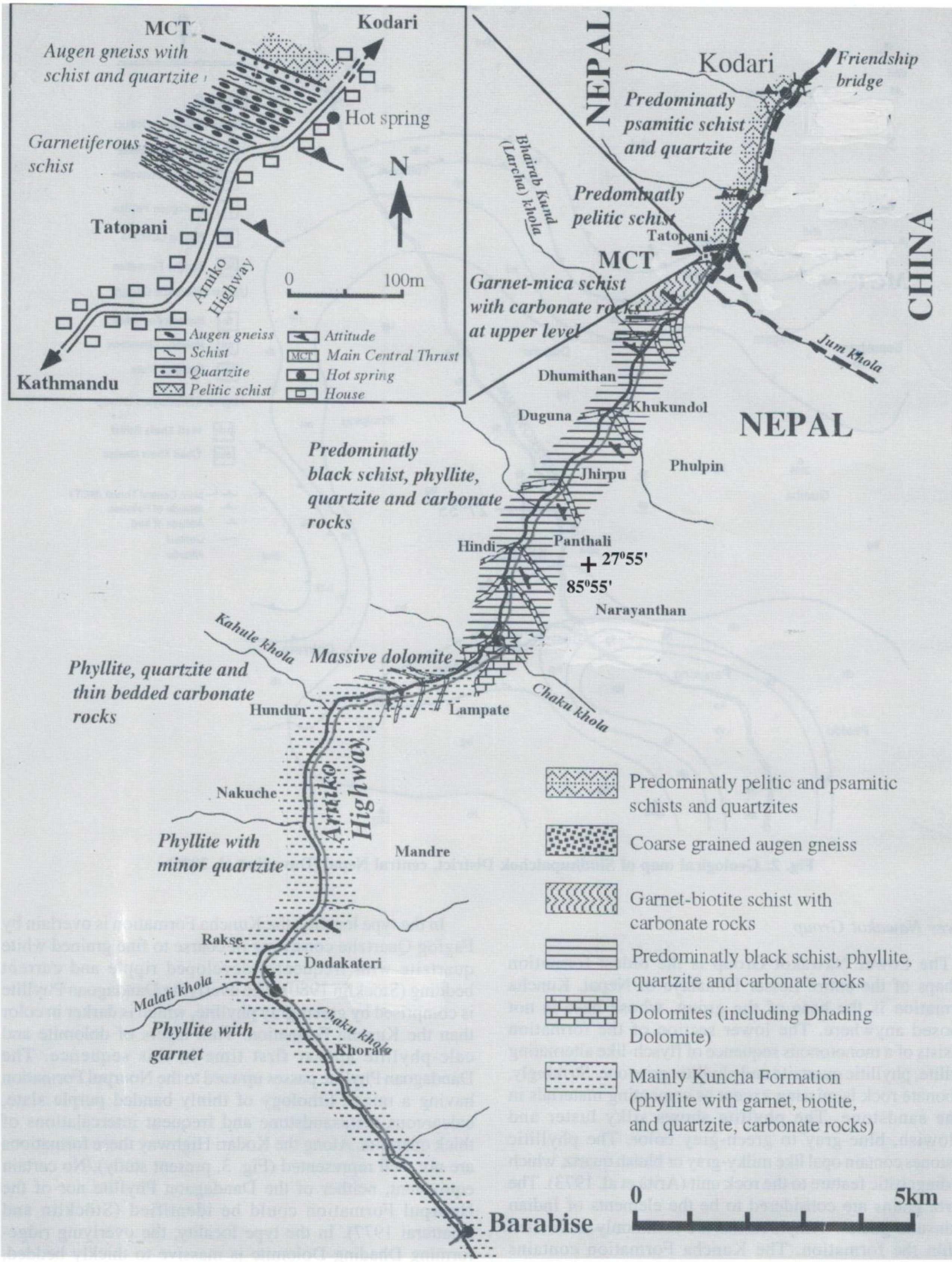

Fig. 3: Geological map along the Arniko Highway between Barabise and Kodari villages (present study)

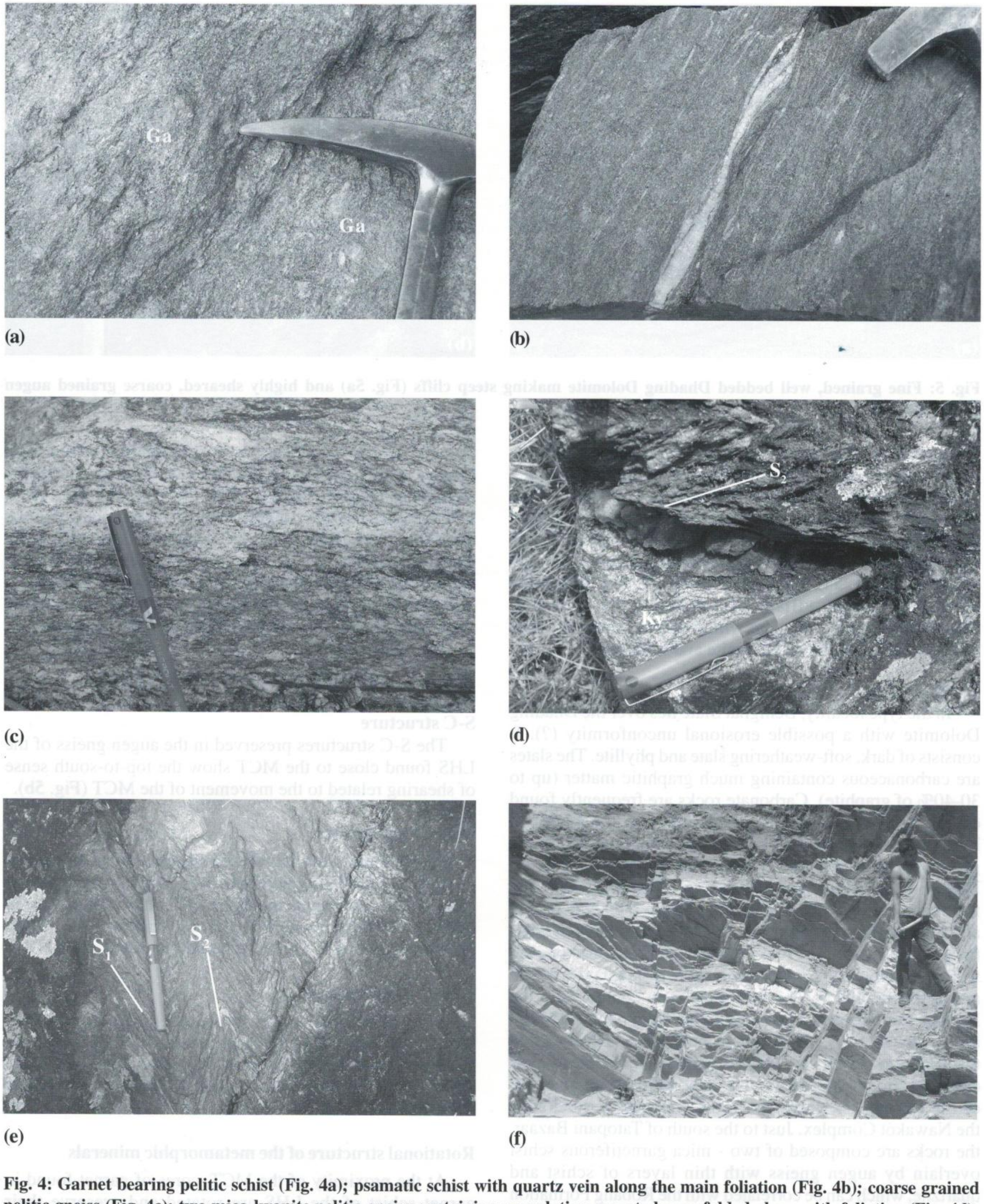

Fig. 4: Garnet bearing pelitic schist (Fig. 4a); psamatic schist with quartz vein along the main foliation (Fig. 4b); coarse grained pelitic gneiss (Fig. 4c); two mica-kyanite pelitic gneiss containing crenulation, quartz lenses folded along with foliation (Fig. 4d); crenulation in pelitic gneiss with folded quartz lenses (Fig. 4e) and fine grained quartzite (Fig. 4f)

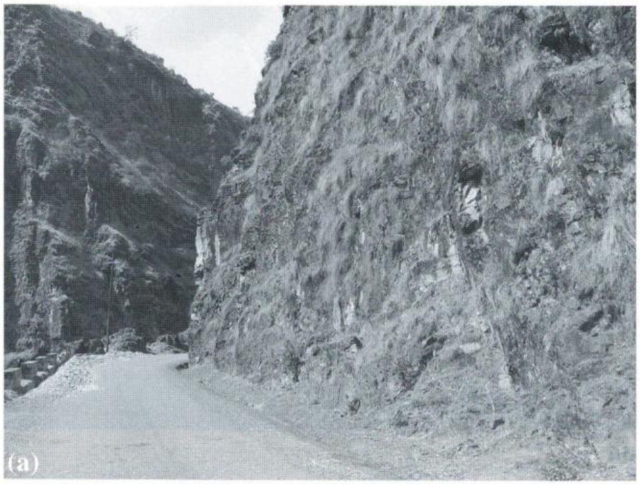

Fig. 5: Fine grained, well bedded Dhading Dolomite making steep cliffs (Fig. 5a) and highly sheared, coarse grained augen gneiss (Fig. 5b)

characterized by bluish-gray colour and splintery fracture. Black slates are commonly interbedded within the dolomite. Stromatolites are profusely developed in the formation. The formation can be recognized however, much reduced thickness with somewhat facies change at Chaku Khola where it forms conspicuous cliffs on both sides of the Sun Kosi River (Fig. 5a). The rocks between Chaku Khola and north of Barabise village are comprised by phyllite, calcareous phyllite, quartzite with frequent intercalation of thin beds of amphibolite, dolomite and limestone.

Upper Nawakot Group

In the type locality, Benighat Slate lies over the Dhading Dolomite with a possible erosional unconformity (?). It consists of dark, soft-weathering slate and phyllite. The slates are carbonaceous containing much graphitic matter (up to 30-40% of graphite). Carbonate rocks are frequently found on top of the section that corresponds to the Malekhu Limestone. This Malekhu Limestone is well marked in the geological map prepared by Stöcklin and Bhattarai 1977; Duvadi et al. 2005; Pradhanaga and Duvadi 2006. The formation consists of a thin to thick-bedded, platy dolomite and siliceous light grey limestone and it conformably overlies the Benighat Slate. The rocks of the Malekhu Limestone are well exposed along Chaku Khola near Dolalghat (Stöcklin and Bhattarai 1977). The formation is in contact with the Kuncha Formation at a high angle Sun Kosi Fault (Stöcklin and Bhattarai 1977). In contrast, in the Sun Kosi River section this formation is not very well recognizable. The green-grey colored sericite-chlorite phyllite interbedded with quartzite of the Robang Formation form the youngest formation of the Nawakot Complex. Just to the south of Tatopani Bazaar, the rocks are composed of two - mica garnetiferous schist overlain by augen gneiss with thin layers of schist and quartzite, which can be correlated with the Robang Formation (Stöcklin and Bhattarai 1977; Duvadi et al. 2005; Pradhanaga and Duvadi 2006). These rocks are comparatively high-grade metamorphic rocks (garnet grade) produced due to the MCT. The upper stratigraphic section of the LHS in the vicinity of the MCT has undergone strong deformation and metamorphism producing garnet ± kyanite as a result of the movement along the MCT (Le Fort 1975, 1981; Pêcher 1978, 1989). A coarse grained highly sheared augen gneiss of about 80-100 m thick (Figs. 3 and 5b) occurs at Tatopani Bazaar. This Precambrian gneiss belongs to the Lesser Himalayan augen gneiss (Ulleri type augen gneiss), which is essentially composed of feldspars and quartz with biotite. Feldspars show myrmekitic structures. It looks like an orthogneiss.

GEOLOGICAL STRUCTURES

S-C structure

The S-C structures preserved in the augen gneiss of the LHS found close to the MCT show the top-to-south sense of shearing related to the movement of the MCT (Fig. 5b).

Stretching lineation

Platy minerals like muscovite and biotite show orientation along N or NNE direction, which is a stretching lineation related to the movement along the MCT. It is well marked in the rocks of the Kuncha Formation, Benighat Slate, Ulleri type augen gneiss of the LHS and pelitic schist of the HHC.

Crenulation cleavage

Crenulated folds have developed cleavage in rocks, which can be observed in the garnet schist of the LHS (Fig. 6a) proximity to the MCT and pelitic gneiss of the HHC (Figs. 4d and 4e). These structures show the different phases of deformation.

Rotational structure of the metamorphic minerals

At the proximity of the MCT, cores of garnet found in garnet schist of the LHS are rotated and preserve their internal schistosity (Fig. 6c). This internal schistosity is oblique to the main metamorphic schistosity. The rotational garnets show the top-to south sense of shearing along the MCT.

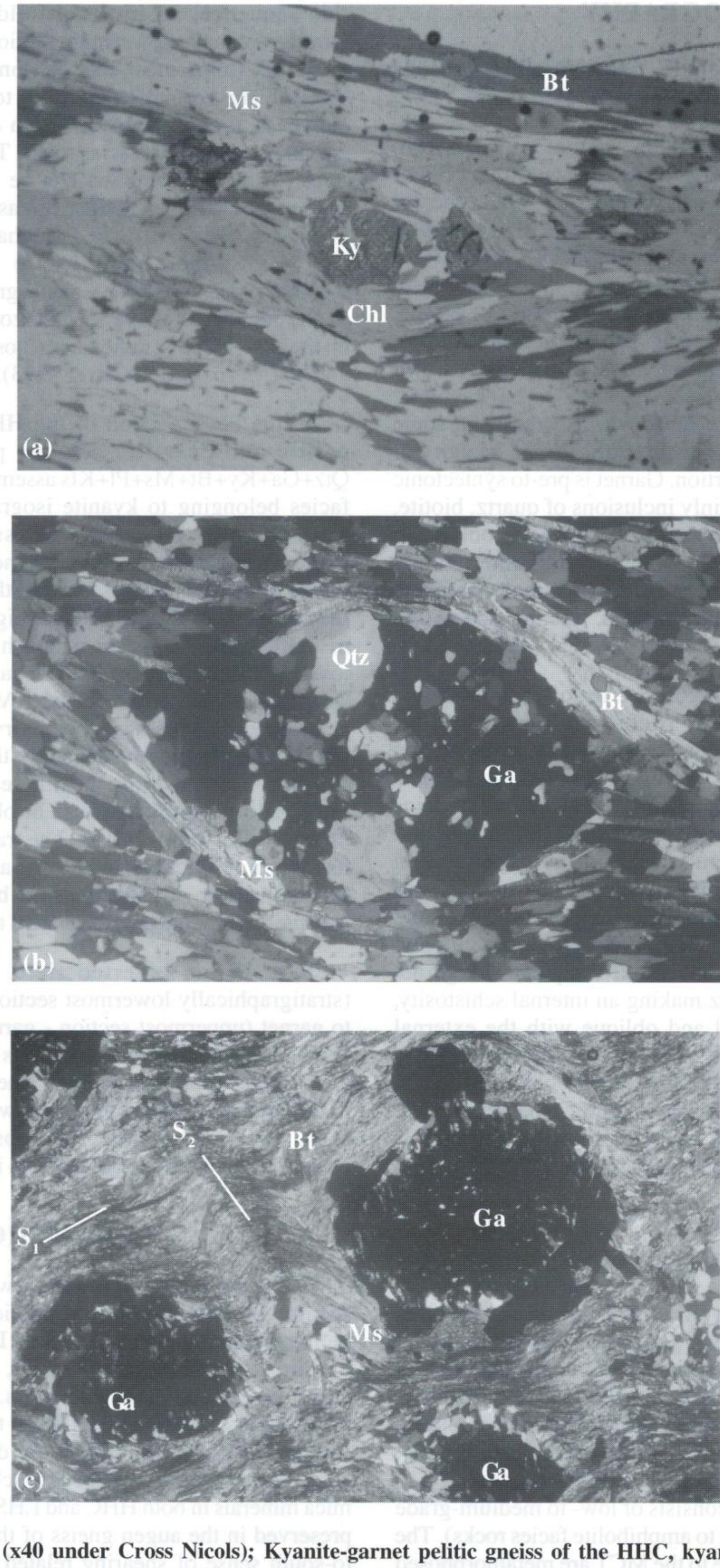

Fig. 6: Photomicrograph (x40 under Cross Nicols); Kyanite-garnet pelitic gneiss of the HHC, kyanite and garnet contain the inclusion of quartz, biotite and muscovite (poikiloblastic texture) (Figs. a and b) and poikiloblastic garnet in schist of the LHS with crenulation cleavage (Fig. c)

PETROGRAPHY

The rocks of the HHC in the study area are essentially the garnet-biotite bearing pelitic schist to psamitic schist, pelitic gneiss with subordinate quartzite. The pelitic and psamitic schists, pelitic gneiss contain Qtz+Ga+Ky+Bt+Ms+Pl+Kfs±Sill assemblage with accessory minerals as Fe-Ti, tourmaline and chlorite. Such types of assemblages are reported between the Manaslu and Dhaulagiri areas (Colchen et al. 1980, 1986; Le Fort et al. 1986, Vanny and Hodges 1996, Rai et al. 2004). The main foliation is defined by the preferred orientation of biotite, muscovite, kyanite, and quartz (Fig. 6a). Sillimanite is fibrous. Kyanite crystals are fine grained, some of which show two sets of cleavage and some of them seem to be fractured. Inclusion of quartz, biotite, muscovite is present in some crystals of kyanite (poikiloblastic texture). The quantity of this mineral is in low proportion. Garnet is pre-to syntectonic porphyroplast showing mainly inclusions of quartz, biotite, kyanite (Fig. 6b). Internal schistosity of garnet is oblique to external schistosity, while in some crystals internal and external schistosity are parallel. Transformation of garnet to chlorite can be observed at its margin, fracture and within the crystal.

The LHS consists of greenschist to lower amphibolite facies type metamorphic rocks such as phyllite, metasandstone, carbonaceous schist, garnet schist, augen gneiss and carbonate rocks (dolomite and limestone). The phyllite at the lower section (Kuncha Formation) contains Qtz+ Bt+Ms as principal minerals and Fe-Ti, tourmaline and garnet are accessory minerals while in the upper section proximity of the MCT, the minerals assemblage in schist and augen gneiss is Qtz+Bt+Ms±Kfs±Ga±Cal and Fe-Ti and tourmaline as accessory minerals. Biotite, muscovite and quartz make a major foliation in all samples. The garnet contains inclusion of quartz making an internal schistosity. This schistosity is parallel and oblique with the external schistosity (Fig. 6c). The garnet is pre-to syntectonic porphyroblast. Traces of chlorite can be observed in the margin or fracture of garnet due to retrograde metamorphism. In some samples of garnet schist crenulation cleavage is well developed denoting different phases of deformation (Fig. 6c).

DISCUSSIONS

Himalayan region is well known region for inverted metamorphism field gradient, generally characterized by a gradual progression from chlorite to sillimanite from base of the LHS to the top of the HHC (Le Fort 1975; Arita 1983; Caby et al. 1983; Brunel and Kienast 1986; Pêcher and Le Fort 1986; Hubbard 1989; Pêcher 1989; Rai et al. 1998, 2004; Guillot 1999; Paudel and Arita 2002; Chamlagain et al. 2003). In the study area, the LHS consists of low- to medium-grade metasediments (greenschist to amphibolite facies rocks). The rocks of the LHS lying close to the MCT are metamorphosed under higher-grade condition up to amphibolite facies. In this sequence, an inverted field gradient from biotite (stratigraphically lowermost section at Kuncha Formation) to garnet (uppermost section containing garnet schist of the Robang Formation) closing to the MCT is observed. However, the Kuncha Formation contains tiny crystals of garnet in greenschist facies rocks. The occurrence of garnets in the Kuncha Formation can be also observed along the section of Dudh Kosi River of eastern Nepal (Catlos et al. 2002, Rai et al. 2010). The Benighat Slate at the proximal of the MCT zone is phyllonite zone where grade of metamorphism is chlorite-epidote grade i. e., lower than either of the sequences above kyanite zone or below garnet zone on the basis of index mineral, phyllosilicates, illite crystallinity and b0 (Morrison and Oliver 1993).

In the basal section of the HHC above the MCT the pelitic and psamitic schists, pelitic gneiss contain Qtz+Ga+Ky+Bt+Ms+Pl+Kfs assemblage (amphibolite grade facies belonging to kyanite isograde). Larger crystals of kyanite up to 1 cm long in association with quartz-plagioclase-garnet-two mica in medium to coarse grained pelitic gneiss can be observed in the step terrain located to the northwest of Kodari Village (Fig. 4d). Fibrous sillimanite in peltic gneiss appears in the higher structural section towards Friendship Bridge (Kodari Village) or northwest steep topographic terrain of Kodari Village. Fibrous sillimanite bearing pelitic gneiss can be observed in the rock blocks of the streams. In the present study these fibrous sillimanites can be observed only in thin section study. A trace of retrograde metamorphism can be observed both in the rocks of the MCT zone and HHC. The transformation of garnet at its margin or fractures to chlorite and within bulk rocks are the indicators of retrogression because of dropping of pressure-temperature probably related to post deformational event.

In LHS, an inverted field gradient from biotite (stratigraphically lowermost section at Kuncha Formation) to garnet (uppermost section - garnet schist of the Robang Formation) closing to the MCT is observed indicating the inverse metamorphic gradient. The P-T condition recorded in the LHS in Kathmandu region, west of the study area (Rai et al. 1998) and present field observations exhibit well-preserved inverted metamorphism in the LHS.

CONCLUSIONS

Along the Arniko Highway between Barabise and Kodari section the HHC consists of pelitic schist, psamitic schist, pelitic gneiss and quartzite, while LHS consists of phyllite, calcarous phyllite, garnet schist, black schist, quartzite, augen gneiss and carbonate rocks. The MCT is the major thrust fault separating the HHC to the north and LHS to the south, which orients along E-W direction and dips about 30°N. The N or NNE oriented stretching lineation marked by mica minerals in both HHC and LHS rocks, and S-C structure preserved in the augen gneiss of the LHS indicate the top-to-south sense of shearing related to the movement along the MCT. In the LHS, an inverted field gradient from biotite (stratigraphically lowermost section at Kuncha Formation) to garnet (uppermost section - garnet schist of the Robang Formation) closing to the MCT is observed indicating the inverse metamorphic gradient. The rocks of the HHC above the MCT belong to kyanite and sillimanite isograds. The transformation of garnet at its margin and fractures to chlorite and formation of chlorite within bulk rocks of the MCT zone and HHC are the indicators of trace of retrograde metamorphism because of dropping of pressure-temperature probably related to post deformational event.

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