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Tectono-lithostratigraphy of the outer Lesser Himalaya in the Barahakshetra-Tribeni area, Arun valley section, eastern Nepal

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ABSTRACT

Geological mapping was carried out in the outer part of the Lesser Himalaya in the Barahakshetra – Tribeni area of east Nepal along the Arun River valley. A revised and updated tectono-lithostratigraphic scheme of the area along with detailed description of each unit and their comparison with central and west Nepal has been presented in this work. The area is divided into three tectonic units named as the Chimra Thrust Sheet, the Dharapani Thrust Sheet and the Tribeni Paraautochthon from north to south, respectively, separated by the Chimra Thrust and the Dharapani Thrust. The rocks of the Chimra Thrust Sheet consist the Pre-Cambrian Phongsawa Group and is divided into the Mulghat Formation, Okhre Formation, Jyamire Gneiss and Belhara Formation, from bottom to top, respectively. The Jyamire Gneiss is comparable to the Ulleri Augen Gneiss and other formations are equivalent to the lower part of the Kuncha Formation. The Dharapani Thrust Sheet, comprising Pre-Cambrian Bhendetar Group, is subdivided into the Chiuribas Formation, Sangure Quartzite and Karkichhap Formation, from bottom to top, comparable with the upper part of the Kuncha Formation, Fagfog Quartzite and Dandagaon Phyllite, respectively. The Tribeni Paraautochthon is divided into the Late Pre-Cambrian Lukuwa Dolomite unconformably overlain by the Gondwana and post-Gondwana rocks of the Barahakshetra Group. The Barahakshetra Group is divided into the Kokaha Diamictite and Baraha Volcanics, Sapt Koshi Formation and Tamrang Formation, from bottom to top, comparable with the Sisne Formation, Taltung Formation and the Dumri Formation, respectively.

Keywords: Lesser Himalaya, east Nepal, tectono-lithostratigraphy, Gondwana, diamictite

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INTRODUCTION

Nepal Himalaya occupies the central arc of the Himalayan orogenic belt, the youngest orogenic event, which was resulted from the collision of the Indian continental mass with the Eurasian tectonic plate (Gansser, 1964; Upreti, 1999). The Sub-Himalaya, the Lesser Himalaya, the Higher Himalaya, and the Tethys Himalaya are the tectonic sheets within this arc separated by east-west trending intra-crustal fault systems, namely, the Himalayan Frontal Thrust (HFT), the Main Boundary Thrust (MBT), the Main Central Thrust (MCT) and the South Tibetan Detachment System (STDS), from south to north, respectively (Gansser, 1964; Frank and Fuchs, 1970; Upreti, 1999). In eastern Nepal, the Tethys Himalaya comprising the Cambrian to Cretaceous marine sedimentary sequence is exposed only on top of the snow-fed high-mountain peaks. Most of the area in eastern Nepal is covered by the medium to high-grade metamorphic rocks of the Higher Himalayan thrust sheets. The Lesser Himalaya comprising the metasedimentary and sedimentary rock sequences is exposed in two belts. In the inner part, it is exposed in the deep gorges of the Sunkoshi, Arun and Tamor Rivers as tectonic windows. In the outer part, it is exposed as a narrow stretch parallel to the mountain belt at the hanging wall of the MBT (Maruo et al., 1979; Fuchs, 1981; Shrestha et al., 1984) (Fig. 1).

The regional geological works covering the large areas of eastern Nepal have been carried out by several researchers (Auden, 1935; Bordet, 1961; Akiba et al., 1973; Maruo et al., 1979; Schelling and Arita, 1991; Schelling, 1992). A detailed review of regional geological work in eastern Nepal is given in Adhikari et al. (2021). The geology of the Lesser Himalayan sequence in the tectonic windows of the inner Lesser Himalaya in east Nepal has been presented by various authors such as Hagen (1969), Akiba et al. (1973), Maruo et al. (1979), Schelling and Arita (1991), Schelling (1992), Upreti et al. (2003), and Ambrose et al. (2015).

In the Arun valley section, the Lesser Himalayan sequence is exposed in the Barahakshetra-Tribeni area at the hanging wall of the MBT. The area belongs to the Nawakot Nappe of Hagen (1969). Akiba et al. (1973) provided regional geological map and sub-divided the area into the Dhankuta Autochthonous Zone, the Mulghat Autochthonous Zone, the Western Subzone of the South Marginal Zone, separated by the Dhankuta Thrust and Mulghat Fault, from north to south, respectively. Maruo et al. (1979) mapped the area as the Tribeni Stratigraphic Unit, the Dharan Stratigraphic Unit, and the Udayapur Stratigraphic Unit. Schelling and Arita (1991) placed the area within the Tumlingtar Group and Gondwana rock sequences. Regional studies of the area revealed that outer Lesser Himalayan sequence is comprised of two major sequences, the Proterozoic

to Precambrian low-grade metasedimentary sequences unconformably overlain by the Late Paleozoic-Mesozoic sedimentary sequence (Gondwana).

Bashyal (1980 a,b) provided first account of the Gondwana-type rocks (Barahakshetra Formation) in eastern Nepal. The lower part is of glacio-marine nature with pebbly shales (diamictites), radiolaria, glauconite and a penecontemporaneous trachyte-keratophyre volcanism. The upper part is of continental character and the regressive nature indicated by the detrital materials with coal and plant fossils. This formation is comparable with similar formation in Darjeeling-Sikkim area. Dhital (1992) compared the diamictites of the Barahakshetra area (Kokaha Diamictite) with that of the Sisne Formation in Tansen area and Salyan Diamictite of Dang area. He noticed that although the diamictites in three places show comparable lithologies, underlying and overlying rocks are quite different.

Dhital (1992) and Sunuwar (1993) provided a tectono-lithostratigraphic subdivision of the Tribeni–Barahakshetra area. They divided the Lesser Himalayan sequence into the Chhintang Group comprised of the Jyamire Gneiss and Belhara Formation; the Phongsawa Group comprised of the Ukhudanda Formation and Mulghat Formation; the Leoti Group comprised of the Raguwa Formation, Phalametar Quartzite and Chiuribas Formation; the Bhendetar Group comprised of the Sangure Quartzite and Karkichhap Formation; the Barahakshetra Group consisting of the Kokaha Diamictite, Sapt Koshi Formation, and Tamrang Formation. The Lukuwa Formation is the individual lithological unit disconformably underlying the Barahakshetra Group. Dhital (2015) placed the Ukhudanda Formation as member within Mulghat Formation and reestablished the Okhre Formation as separate unit overlying the Mulghat Formation. Further, he renamed the Belhara Formation as the Guthitar Formation and placed within the Phongsawa Group. He places the MCT at the base of the Jyamire Gneiss. He compared the Sapt Kosi Formation with the Amile Quartzite and the Tamrang Formation with the Dumri Formation of Tansen Area (Sakai, 1983).

Rai et al. (2016) mapped in the Dharan-Mulghat area. He renamed the Phongsawa Group as the Dandazar Group and the stratigraphic units within the Leoti Group were incorporated within the Bhendetar Group. He correlated the sequences with Nawakot Complex rocks of central Nepal (Stöcklin, 1980). Bhandari et al. (2018) correlated the Kokaha Diamictite and the Tamrang Formation with the Sisne Formation based on the analysis on characteristics of detrital zircon. The similar kind of study made by Baral et al. (2022) has correlated the Sapt Kosi Formation with the Taltung Formation and the Tamrang Formation with the Dumri Formation of western Nepal. Kobayashi et al. (2021) has correlated the Mulghat Formation and the Chiuribas Formation with the Kuncha Formation based on multichronological approach. The Sangure Quartzite has been correlated with the Naudanda Quartzite and the Raguwa Formation along with the Phalametar Quartzite has been correlated with the Heklang Formation (Sakai, 1985) of western Nepal.

Tamrakar (2021), Khatiwada (2022) and Gyawali (2022) have followed the stratigraphic classification of Dhital (1992) but placed the Belhara Formation and the Jyamire Gneiss in the MCT Zone within the Phongsawa Group of rocks.

A review of previous works presented above reveals that the researchers have adopted different schemes of stratigraphic nomenclature and correlation for lithological units present

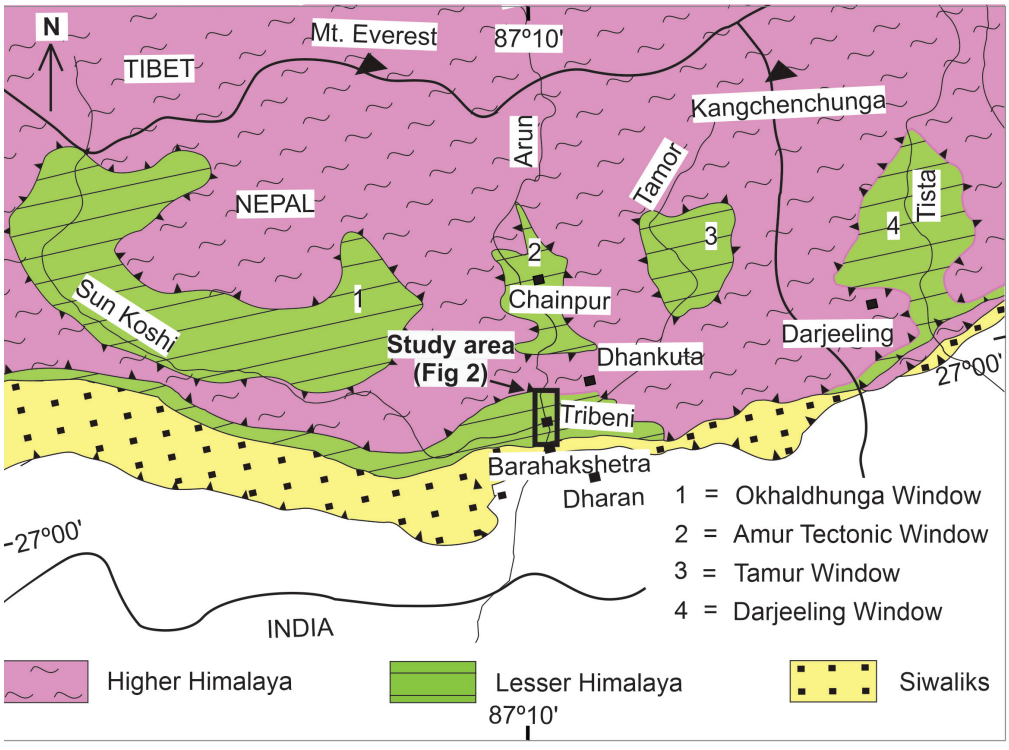

Fig. 1: Location map of the study area (modified after Fuchs, 1981; Meier and Hiltner, 1993).

in the area. One of the reasons for this could be the lack of large-scale mapping covering the complete section of the outer Lesser Himalaya combined with petrographic study of the lithological units. The main aim of the present study is to re-evaluate the lithology and stratigraphy of the area and to propose a unified tectono-lithostratigraphic scheme for the outer Lesser Himalaya. We have tried to compare the lithological units of the study area with that of similar sections of the Lesser Himalaya in central Nepal (Malekhu area).

TECTONO-LITHOSTRATIGRAPHY OF THE TRIBENI-BARAHAKHETRA AREA

Geological mapping was carried out at the scale of 1:25000 in the study area from Barahakshetra – Tribeni – Chhintang area comprising the Arun River valley. Geological route mapping was carried out at larger scale wherever necessary. Stratigraphic columns were prepared on the basis of route maps and direct measurements in the outcrops. Lithological characters were observed both in outcrop, hand specimens and thin sections. Sedimentary structures were observed to interpret the stratigraphic superposition of beds. On the basis of these studies, a revised and unified lithostratigraphy has been prepared for the outer part of the Lesser Himalaya in the Arun River valley. Lithostratigraphic classification and nomenclature adopted by the previous researchers have been followed as far as possible. Modification in the stratigraphy has been introduced based on new evidences found in the present mapping. Geological map, cross-section of the area prepared by Adhikari et al. (2023) and a generalized tectono-lithostratigraphic scheme of the area are given in Figures 2, 3, 4, respectively.

The rocks of the Barahakshetra - Tribeni area can be divided into various tectonic zones separated by thrusts and each tectonic zone can further be divided into various lithostratigraphic units based on unique lithology, stratigraphic position and age. A generalized lithostratigraphic division of the area is given in Figure 4.

The Lesser Himalaya in the study area is exposed as a narrow stretch (about 12 km wide) extending east-west and parallel to the mountain belt. In the south it is delimited by the MBT which brings the Lesser Himalayan rocks on top of the Siwalik. In the north, high-grade metamorphic rocks (kyanite grade gneiss and schists) of the Higher Himalaya are placed on top of the Lesser Himalaya by the MCT. The Higher Himalaya is allochthonous unit forming large-scale nappes in most parts of eastern Nepal.

Regional geological mapping reveals that the rocks of the Lesser Himalaya in the outer Lesser Himalaya of the Barahakshetra-Tribeni area are divided into three major tectonic zones by two major east-west extending regional thrusts named as the Chimra Thrust (CT) in the north and the Dharapani Thrust (DT) in the south. In the present study, the northernmost tectonic zone between the CT and the MCT is named as the Chimra Thrust Sheet and the intermediate tectonic zone is named as the Dharapani Thrust Sheet. Both the thrust sheets are allochthonous in nature where older Lesser Himalayan rocks are transported on top of the youngest sequence of the

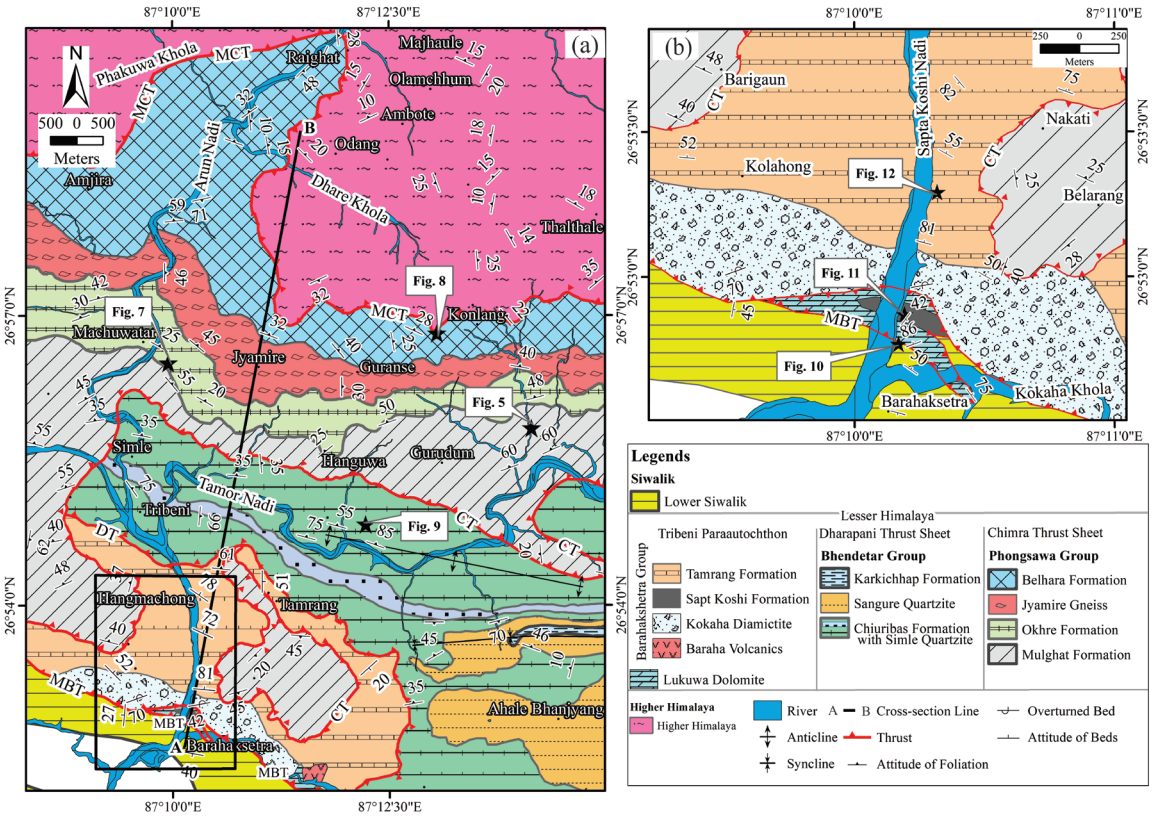

Fig. 2: (a) Geological map of the Barahakshetra - Tribeni area of the eastern Nepal Lesser Himalaya. A – B; line of cross-section in Fig. 3, (b) enlarged area of the map inside the inset in (a). MCT: Main Central Thrust, CT: Chimra Thrust, DT: Dharapani Thrust, MBT: Main Boundary Thrust.

Lesser Himalaya along the CT and DT. The tectonic zone between the CT and MBT is of parautochnonous in nature and has been named as the Tribeni Paraautochthon.

Lithostratigraphic sub-division

Generalized lithostratigraphy of each tectonic unit is given in the following sections.

Lithostratigraphy of the Chimra Thust Sheet

The rocks of the Chimra Thrust Sheet are named as Phangsawa Group of Dhital (2015) and can be further divided into four Proterozoic lithostratigraphic units as the Mulghat Formation, Okhre Formation, Jyamire Gneiss and Belhara Formation from bottom to top, respectively. It is equivalent to the Mulghat Autochthonous Zone of Akiba et al. (1973), the Udayapur Stratigraphic Unit and the Crystalline Thrust Nappe of Maruo et al. (1979), the Phyllite and Quartzite and the Augen Gneiss unit of Bashyal (1980a, 1980b), the Tumlingtar Group of Schelling and Arita (1991) and Schelling (1992), the Phongsawa and Chhintang Groups of Dhital (1992) and Sunuwar (1993), and the Dandabazar Group of Rai et al. (2016).

(a) Mulghat Formation

The Mulghat Formation is the oldest unit of the Chimra Thrust Sheet and most probably the oldest unit of the outer Lesser Himalaya in the study area. It was first named as Mulghat Formation by Rai (1991) and later followed by Dhital (1992, 2015), Sunuwar (1993) and Rai et al. (2016). This formation is distributed around Hanguwa, Akhuwatar, Hasanpur, Hangmachong, Beltar and Karkale Villages.

The Mulghat Formation consists of pencil grey to dark grey, thinly laminated (up to 5 cm) carbonaceous phyllite and schist, interbanded with thinly bedded (5–25 cm), fine-grained, grey quartzite and dolomite (Figs. 4, 5). The schist contains quartz lenses and occasionally exhibits crenulated structures. Grey to pale grey limestone and dolomite beds are found within this formation in the Gurudum Village. Sill-like bodies of metabasic rocks are found at the right bank of the Arun River near Haledetar and Pangnam Villages. The foliations in the rocks have variable dips ranging from 19º to 85º. West of the Sapta Koshi River, it has a thickness of over 1900 m, whereas, in the eastern section of the study area, it is narrower and has a thickness of less than 1150 m.

The lower boundary of this formation is defined by the CT, which separates it from the Bhendetar Group and the Barahakshetra Group (Fig. 6a). It has the sharp contact with the rocks of the overlying Okhre Formation.

(b) Okhre Formation

The Okhre Formation is named after Okhre village in the Bhendetar-Rajarani road section by Rai (1991), and followed by Rai (2012), Dhital (2015) and Rai et al. (2016). Previously it was mapped under the Mulghat Formation by Dhital (1992) and Sunuwar (1993). The Okhre Formation has distinct lithological characteristic and can be mapped as separate unit as proposed by Rai (1991). It is well-exposed around Machuwatar, Bartang, Pangnam Villages and along the Khari Khola section.

The Okhre Formation comprises of grey, dark grey, green to dark green, thinly laminated pelitic and psammatic phylite and schist with abundant quartz veins and boudins, grey, dark grey to green, medium- to coarse-grained, thinly-bedded (2–20 cm) quartzite with schist partings, and grey to creamy grey, thinly bedded (5–25 cm) dolomite beds (Figs. 4, 7). At some exposures the schist exhibits calcareous nature. In the Khari Khola region, patches of copper ore malachite and azurite can be observed. The hematite band, 15 m thick, can be observed along the left bank of the Arun River, approximately 200 meters upstream from the confluence of the Nankhuwa Khola and the Arun River. Additionally, a dark green sill-like band of metabasic rock is present near Machuwatar Village.

The foliation in the Okhre Formation is primarily oriented to northeast to northwest direction with varying dip amount (20º–56º). The average thickness of the Okhre Formation is about 750 meters. The contact with the overlying Jyamire Gneiss is very sharp.

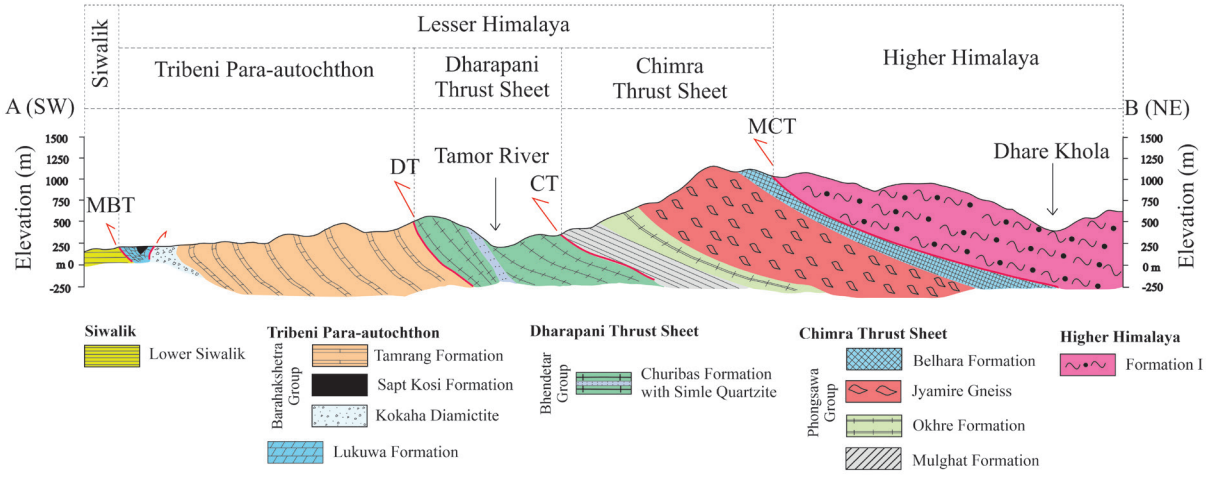

Fig. 3: Geological cross-section of the present study area along A-B in Fig. 2. MCT: Main Central Thrust, CT: Chimra Thrust, DT: Dharapani Thrust, MBT: Main Boundary Thrust (redrawn after Adhikari et al., 2023).

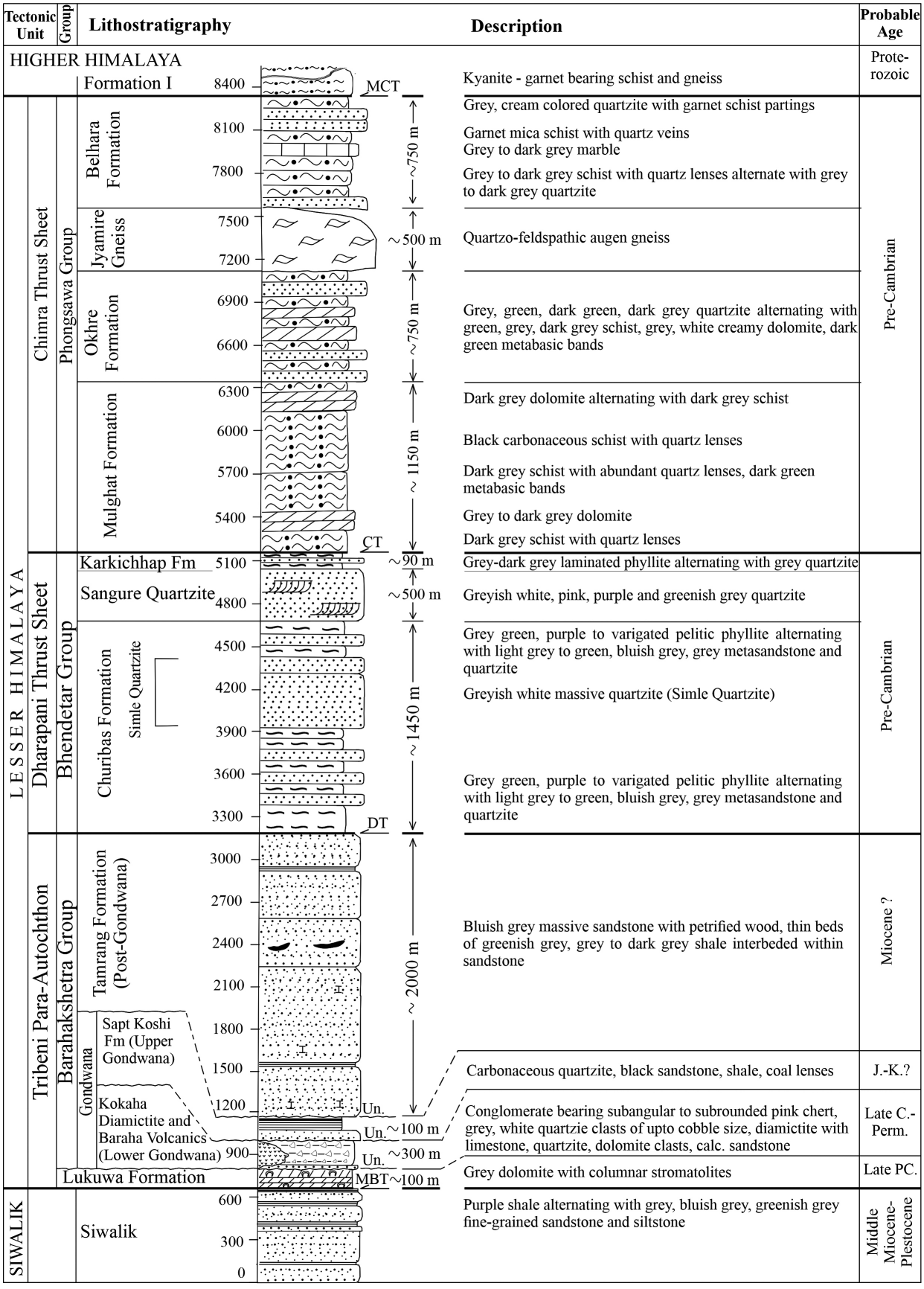

Fig. 4: Generalized tectono-lithostratigraphy of the outer Lesser Himalaya in the Barahakshetra area, east Nepal.

(c) Jyamire Gneiss

The Jyamire Gneiss was first named by Dhital (1992) after the village Jyamire. The same unit was mapped as the Augen Gneiss Zone by Maruo et al. (1979), the Augen Gneiss by Bashyal (1980a,b). This unit is exposed in the vicinity of Guranse, Jyamire and in the lower parts of the Roktang Khola.

The Jyamire Gneiss comprises 10 cm to 1.5 m thick augen gneiss with a few intercalations of metaquartzite bands. The augen gneiss is composed of quartz, feldspar, muscovite, biotite. It is well-foliated with foliation defined by preferred orientation of muscovite and biotite. The size of the feldspar augen reaches up to 2 cm. The gneiss shows mylonitic character with well-formed foliation with higher percentage of mica at the margins (top and bottom part), while it is quite massive with higher percentage of quartz and feldspar at the middle part (Fig. 6b). The foliation of this unit monotonously dip towards north at variable angle (15º to 45º). This unit is approximately 500 m thick. It is sharply overlain by the Belhara Formation.

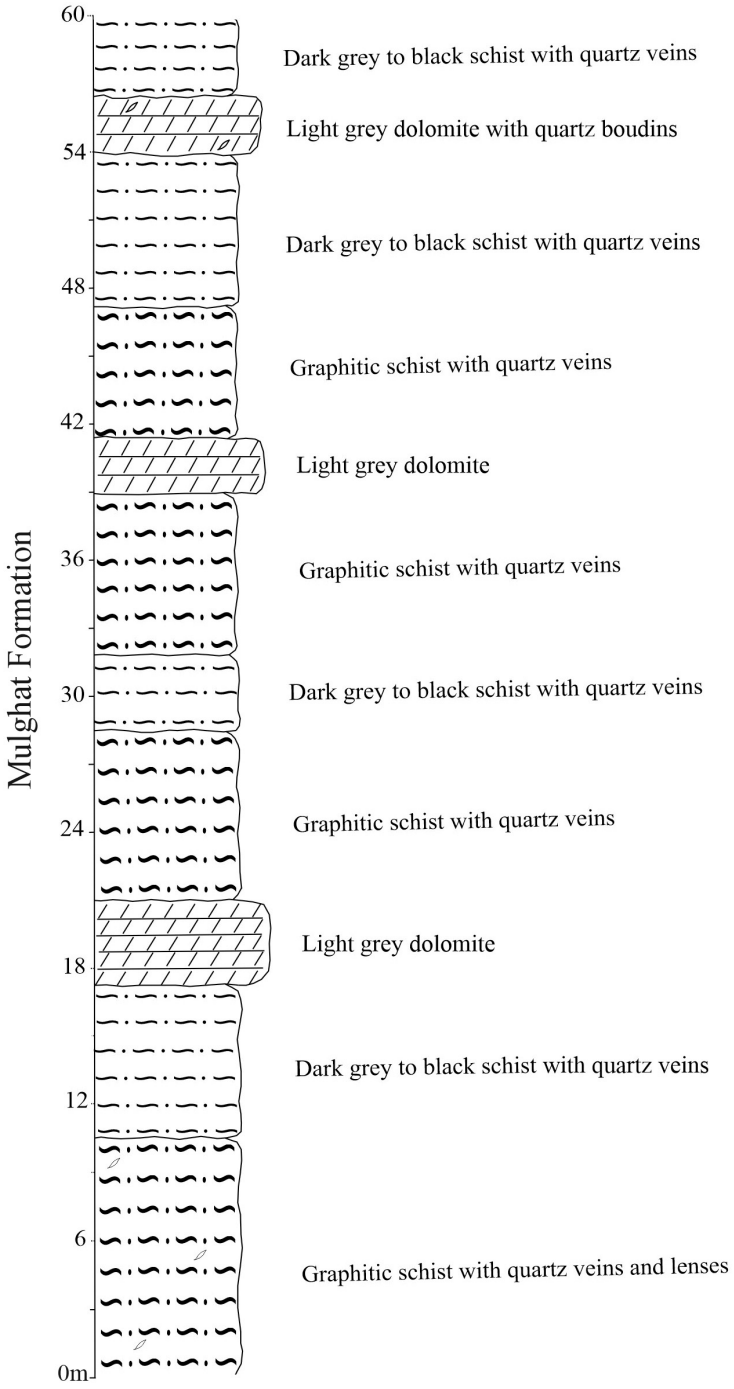

Fig. 5: Representative columnar section of the middle part of the Mulghat Formation the Khani Khola – Chhintang Road section near Beltar Village. See in Fig. 2 for the location of the column.

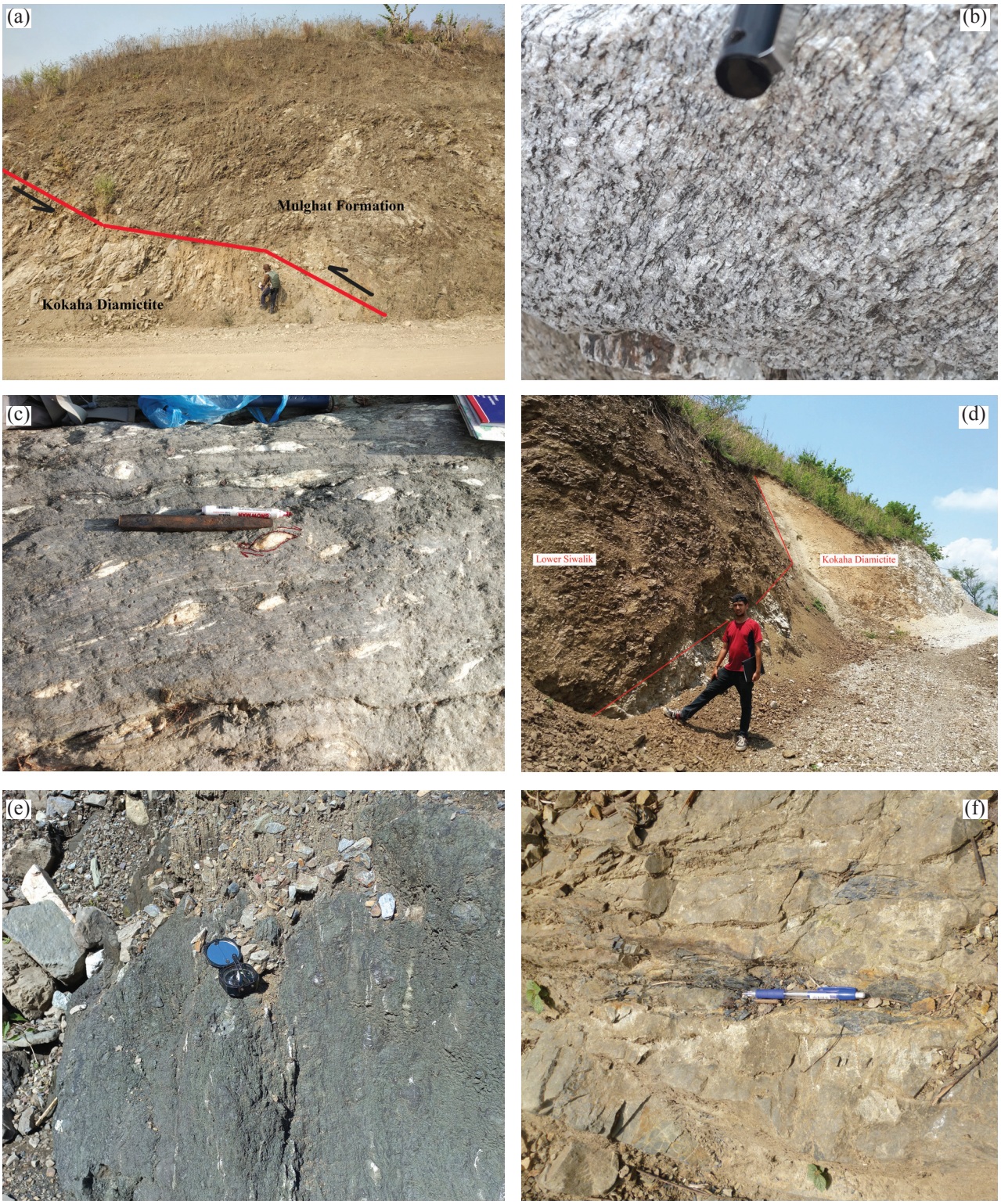

Fig. 6: Field photographs (a) Chimra Thrust separating the rocks of the Mulghat Formation and the Kokaha Diamictite along the Tamor Corridor road section about 2 km towards Mulghat from the Kokaha Khola, (b) Jyamire Gneiss observed along the left bank of the Arun River about 200 m upstream from the Piliatar Village, (c) asymmetrical quartz lenses showing top to the south sense of shearing in the garnet schist of the Belhara Formation along the right bank of Dhare Khola near its confluence with the Arun River, (d) the boundary between the conglomerate of the Kokaha Diamictite and the Lower Siwalik rocks near Dhakmalun village, (e) Baraha Volcanics at the confluence of Koakaha Khola and the Latare Khola, (f) petrified wood pockets observed within the sandstone beds of the Tamrang Formation along the left bank of the Sapta Koshi River about 2 km upstream from its confluence with the Kokaha Khola.

(d) Belhara Formation

The Belhara Formation, named after Belhara Village in Dhankuta District (Dhital 1992), is the uppermost unit of the Chimra Thrust Sheet. It is equivalent to the Guthitar Formation of Dhital (2015) and Patigaun Formation of Rai et al. (2016) in the adjacent region of the present study area. It can be observed in Kagune, Lalhanitar, and Aamjira villages, as well as in the lower reaches of the Dhare Khola and the upper reaches of the Roktang Khola.

The Belhara Formation comprises of grey, dark grey and greenish grey, laminated fine-grained pellitic and psammatic schists alternating with grey to dark grey medium-grained quartzite (Figs. 4, 8). In the upper part (northern part), it is composed of almandine garnet-bearing schist. The grain size of garnet increases northwards and reaches upto the 1 cm diameter. The schist contains asymmetrical quartz lenses and drag folds formed by quartz veins (Fig. 6c). The crenulation cleavage and S-C structures are seen in the schists. The uppermost part of the Belhara Formation consists of grey, white to creamy white, laminated quartzite with schist partings. At the lower reaches of Dhare Khola, a metabasic band containing actinolite crystals was observed. Traces of malachite and pyrite grains are also visible near Guranse Village. Foliation in this unit also monotonously dips to the north with angles varying from 28º to 45º. The Belhara Formation is about 750 m thick. The Belhara Formation is sharply overlain by the kyanite-bearing schists and gneiss of the Higher Himalaya along the MCT.

Lithostratigraphy of the Dharapani Thrust Sheet

The rocks of the Dharapani Thrust Sheet are named as Bhendetar Group (Dhital, 1992; Sunuwar, 1993; Rai et al., 2016). It was named as the Western Subzone of the South Marginal Zone by Akiba et al. (1973), Dharan Stratigraphic Unit by Maruo et al. (1979), Sanguri Formation by Bashyal (1980a,b), Tumlingtar Group by Schelling and Arita (1991) and Schelling (1992). Dhital (1992), Sunuwar (1993) and Dhital (2015) have divided rocks of this thrust sheet into two groups namely Bhendetar Group and Leoti Group based on the place of the rock's exposure.

The Pre-Cambrian rocks of the Bhendetar Group have been subdivided into the Chiuribas Formation with the Simle Quartzite Member, Sangure Quartzite and Karkichhap Formation, from bottom to top, respectively.

(a) Chiuribas Formation

The Chiuribas Formation was first named by Rai (1991) after Chiuribas Village in Sunsari District, and was subsequently followed by Dhital (1992), Sunuwar (1993), Dhital (2015) and Rai et al. (2016). The rocks of the Chiuribas Formation are exposed in and around the Tribeni, Ghangaru, Ghangari, Simle Villages, as well as along the Tamor River. It is truncated by the rocks of the Mulghat Formation in the west of the Arun River.

The Chiuribas Formation consists of grey, green, purple to variegated, phyllite alternating with grey, light green to green metasandstone and white, grey to bluish grey quartzite (Figs. 4, 9).

In the Simle Village area, there is up to 250 m thick band of white to greyish white massive quartzite within this Formation. It pinches out towards east and west. It has been mapped as a Simle Quartzite (Adhikari et al., 2023) member of the Chiuribas Formation in the area.

In the Tribeni and Tamrang villages, a dark green band (about 7 to 12 cm thick) of metabasic rock was observed. At Tribeni, the metabasic rock is sheared and forms boudins. The Chiuribas Formation is about 1450 m thick,

The lower boundary of the Chiuribas Formation is delimited by the Dharapani Thrust and the upper boundary with the Sangure Quartzite is transitional.

(b) Sangure Quartzite

The name of this formation is derived from the Sangure Ridge (Tater, 1964; Maskey, 1987; Dhital, 1992). The rocks of this formation can be observed at and around the Ahale Bhanjyang, Ahale and the Hardiya Villages and at the upper reaches of the Khaire Khola. The Sangure Quartzite repeated in the area by the Ahale Syncline.

The Sangure Quartzite comprises of greyish white, pink, purple and greenish grey massive to cross-laminated quartzite. The average thickness of this formation is 500 m. The formation is sharply overlain by the Karkichhap Formation.

(c) Karkichhap Formation

The formation is named after the village Karkichhap of Dhankuta District along the Koshi Highway (Dhital, 1992). It is exposed at the Ahale village area.

The Karkichhap Formation comprises of grey to dark grey laminated phyllite alternating with dark grey quartzite. It is present as small band in the present study area with thickness averaging 90 m. It is situated at the core part of the Ahale Syncline.

Lithostratigraphy of the Tribeni Paraautochthon Zone

The Tribeni Paraautochthon Zone extending from Barahakshetra to Tribeni comprises Late Pre-Cambrian metasedimentary rocks (Lukuwa Dolomite) disconformably overlain by Permo-carboniferous to Miocene Gondwana and Post-Gondwana-type sedimentary rocks of the Barahakshetra Group (Dhital 1992; Sunuwar, 1993).

(a) Lukuwa Dolomite

The Lukuwa Dolomite was named after Lukuwa Khola by (Dhital, 1992). Although Dhital (2015) named it as Lukuwa Formation, we argue that Lukuwa Dolomite is appropriate name for this formation as it contains monotonous sequence of dolomite. The dolomite beds of this unit are exposed along the Sapta Koshi River, approximately 50 meters upstream from its confluence with the Kokaha Khola. It is also observed in some parts of Kokaha Khola section. The dolomite occurs as a number of tectonic slices in the area.

The formation consists of light to grey, highly deformed dolomite (Figs. 4, 10). It comprises columnar stromatolites and algal mats. The dome-shaped stromatolite indicates that the rocks are in normal stratigraphic position. The dolomite bed generally dips towards the northwest, with a dip angle exceeding 70 degrees. Multiple shear zones can be observed along the formation. The average thickness of this formation is 100 m.

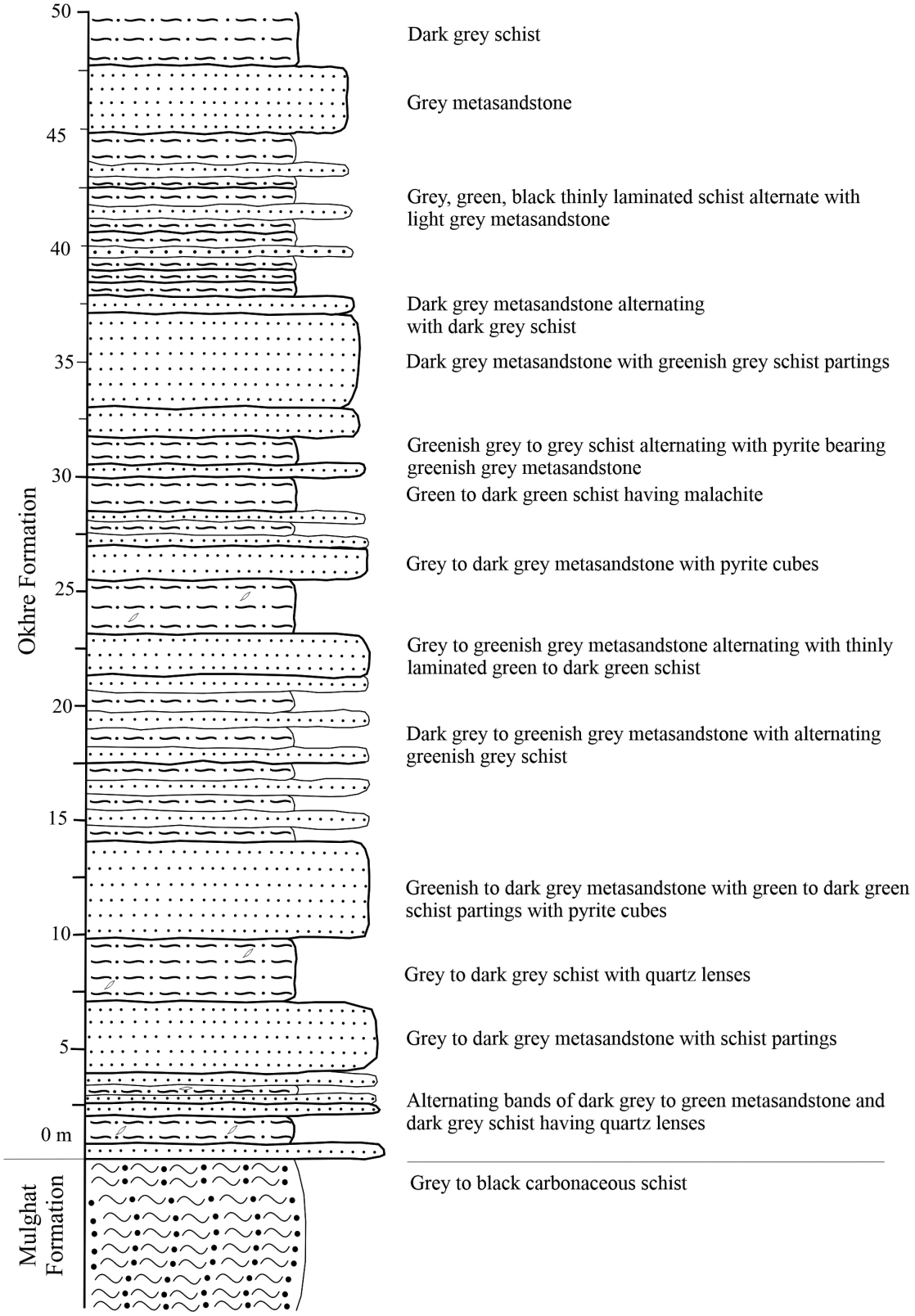

Fig. 7: Representative columnar section of the lower part of the Okhre Formation at the Khari Khola (see Fig. 2 for the location of the column).

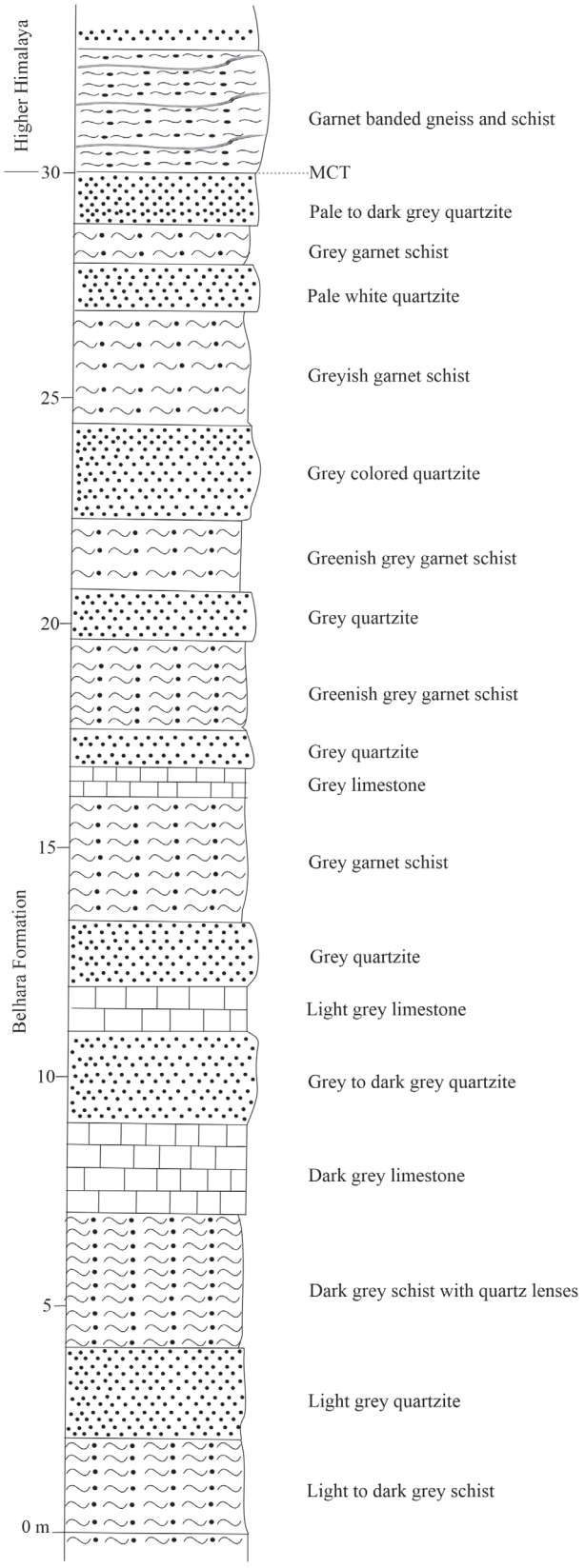

Fig. 8: Columnar section of the upper part of the Belhara Formation along the Gurase-Ghangaru road section. See Fig. 2 for the location of the column.

The Lukuwa Formation is bounded by the MBT to the south. It is unconformably overlain by the Barahakshetra Group (Gondwana-type rocks).

(b) Barahakshetra Group

The Barahakshetra Group has been previously mapped as the Tribeni Stratigraphic Unit by Maruo et al. (1979), Barahakshetra Formation by Bashyal (1980a,b), the Gondwana unit by Schelling and Arita (1991). The Barahakshetra Group can be divided into three lithostratigraphic units as the Kokaha Diamictite and Baraha Volcanics, Sapt Koshi Formation, and the Tamrang Formation, from bottom to top, respectively (Dhital, 1992).

(c) Kokaha Diamictite and Baraha Volcanics

The name Kokaha Diamictite was given after the Kokaha Khola by Dhital (1992). It is equivalent to the Unit III of the Barahakshetra Formation of Bashyal (1980a). It is exposed along the Kokaha Khola, approximately 150 meters upstream from the suspension bridge at Barahakshetra village, and along the Sapta Koshi River, about 1 kilometer upstream from the confluence of the Kokaha Khola and the Sapta Koshi River.

The Kokaha Diamictite consists of dark grey laminated diamictite beds, reaching upto 30 cm in thickness. It contains angular to subangular clasts of dolomite, limestone, quartzite, and gneiss. These clasts range in diameter from a few millimeters to 70 cm. The upper part of this formation consists of a white to greyish white matrix-supported conglomerate (pebbly quartzite of Dhital, 2015). The conglomerate consists of pink chert, grey to black fine quartzite, and white quartzite clasts embedded in siliceous matrix. The clasts range in size from a few millimeters to 12 centimeters. Graded pebble beds are observed along the Sapta Koshi River at some places indicating overturning of the sequence. On average, the formation has a thickness of 300 meters.

The Kokaha Diamictite is place on top of the Tamrang Formation in the study area by an unconfirmity. To the west of Sapta Koshi River, it directly overlies the Siwalik along the MBT (Fig.6d).

The Baraha Volcanics has been derived from the Barahakshetra village of the Sunsari District (Dhital, 1992; Dhital, 2015). The exact stratigraphic position of this unit is quite debated. It was mapped within the Kokaha Diamictite by Dhital (1992). Dhital (2015) placed it between the Lukuwa Dolomite and the Tamrang Formation. However, Baral et al. (2022) placed it within the Lukuwa Dolomite and the Sapt Koshi Formation. Present study reveals that it overlies the Lukuwa Dolomite and underlain by the Tamrang Formation. The exposure consisting these rocks is confined in the right bank of the Kokaha Khola, approximately 2500 m upstream from the confluence of the Kokaha Khola and the Sapta Koshi River.

The Baraha Volcanics consists of brown grey layered tuff and agglomerates (Fig. 6e). Feldspar phenocrysts can be observed within these layers. The thickness of this band is approximately 25 m.

(d) Sapt Koshi Formation

The Sapt Koshi Formation is named after the Sapta Koshi River in eastern Nepal (Dhital, 1992). This unit was mapped as

Unit IV of the Barahakshetra Formation by Bashyal (1980a). It is exposed along the left bank of the Sapta Koshi River, approximately 750 meters upstream from the confluence of the Kokaha Khola and the Sapta Koshi River.

The Sapt Koshi Formation consists of carbonaceous quartzite, lenticular beds of grey to dark grey shale, sandstone and occasional coal lenses (Figs. 4, 11). The beds of this formation mostly dip steeply to the south (50º to 70º). This formation is about 100 m thick.

(e) Tamrang Formation

The Tamrang Formation is the youngest unit in the study area. It was named after Tamrang village by Dhital (1992). It can be traced along the Sapta Koshi River from the confluence of Ghumti Khola to that of Tankera Khola. It is also exposed in the Sankama, Kolahon, and Tamrang villages

The Tamrang Formation primarily consists of bluish grey, brown grey and greyish black massive sandstone beds (Figs. 4, 12). These sandstone beds often exhibit calcareous nature. The greenish grey, grey to dark grey, laminated to 6 cm thick shale beds are interbedded between these sandstone beds. In some locations, small pockets of petrified woods can be observed within the sandstone beds (Fig. 6f). The average thickness of the Tamrang Formation is about 2000 meters. It is truncated by the CT to the west of Sapta Koshi River.

DISCUSSION

Tectono-lithostratigraphy

Present lithostratigraphic classification mostly follows the works of Rai (1991), Dhital (1992), Sunuwar (1993), Dhital (2015) and Rai et al. (2016). However, we have introduced

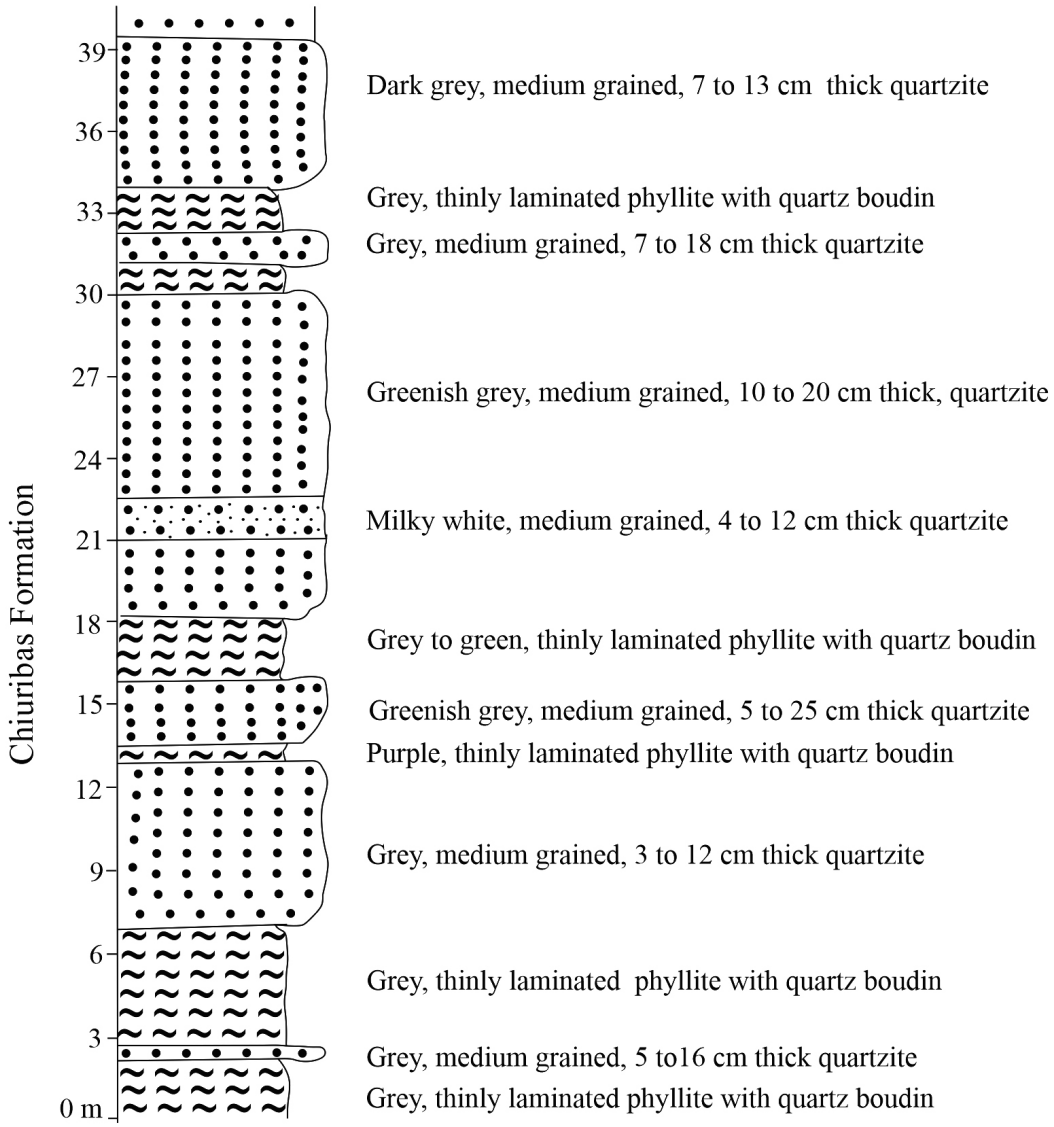

Fig. 9: Representative columnar section of middle part of the Chiuribas Formation at Ghangaru Village. See Fig. 2 for the location of the column.

slight modifications in certain units based on new evidences. Previous researchers (Dhital, 1992; Sunuwar, 1993) have classified the rocks of the Chimra Thrust Sheet into two separate groups based on the thrust contact (Dhankute Khola Thrust) between the Okhre Formation and Jyamire Gneiss. Dhital (2015) placed the MCT on top of the Okhre Formation and the Jyamire Gneiss and Belhara Formation were regarded as the rocks of the Higher Himalaya. We argue that the contact between the Okhre Formation and the Jyamire Gneiss is not a thrust contact, rather it is a granitic intrusion later deformed and metamorphosed to orthogneiss. In the present study, the MCT is placed on top of the Belhara Formation where rock type sharply changes from garnet schist to kyanite schist exhibiting inverted metamorphism as in central Nepal (Le Fort, 1975; Arita, 1983; Paudel and Arita, 2000).

Furthermore, the Belhara Formation comprises the rock sequence equivalent to the Guthitar Formation (Dhital, 2015) of Mulghat–Dhankuta section and Patigaun Formation (Rai et al., 2016) of Dandabazar section. Therefore, these units are placed within the Chimra Thrust Sheet or the Phongsawa Group as they are stratigraphically continuous lithological units.

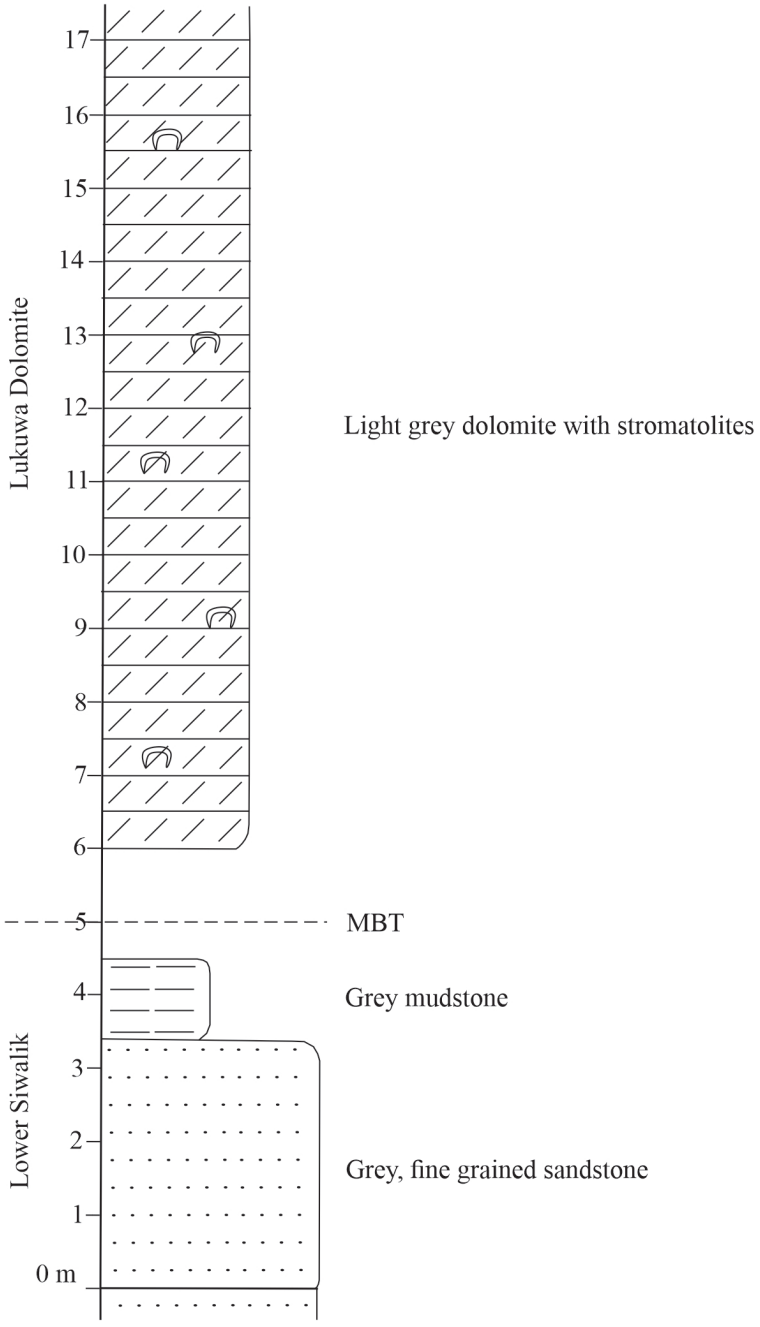

Fig. 10: Columnar section of boundary region of the Lukuwa Formation and the Siwalik observed along the left bank of the Sapta Koshi River about 400 m upstream from its confluence with Kokaha Khola. See Fig. 2 for the location of the column.

A major quartzite band occurs within the Chiuribas Formation. Previously, this quartzite was mapped as a separate formation namely Phalemetar Quartzite (Dhital, 1992; Sunuwar, 1993). However, present study shows that the quartzite band is not continuous throughout the study area, rather it pinches-out to the east of the study area. Therefore, it has been mapped as a member of the Chiuribas Formation named as the Simle Quartzite.

In the Tribeni Paraautochthon, the conglomerete containing the subangular to subrounded clasts of pink chert and black quartzite (Fig. 13a), was previously mapped within the Sapt Koshi Formation (Dhital, 1992; Sunuwar, 1993; Dhital, 2015). In the present study, it is mapped within the Kokaha Diamictite as it was observed alternating with diamictite beds at the fresh road cut of the Tamor Corridor Road section (Fig. 13b).

The interlayered tuff and agglomerates of the Baraha Volcanics was mapped at the top of the Sapt Koshi Formation in eastern section of the Barahakshetra area and interpreted as volcanic activity within the Kokaha Diamictite (Dhital, 1992; Sunuwar, 1993). Bhandari et al. (2018) argued its eruption after the cessation of the deposition of the Upper Lesser Himalaya, before the deposition of the Permian Kokaha Diamictite based on the U-Pb age of zircon. Baral et al. (2022) reported it stratigraphically erupted within the rocks of the Sapt Koshi Formation. They assume it penetrated the rocks of the Tamrang Formation. In present study, the volcanics has been observed between the Lukuwa Dolomite and the Tamrang Formation. The exact boundary of these volcanics were unable to trace. This has created difficulty in interpretation on its stratigraphic position. Intense field in larger scale, focusing the boundary condition and petrological behavior of the volcanics is recommended to delineate its stratigraphic position.

Probable age and lithostratigraphic comparison

Majority of the rock sequence in the study area is devoid of fossils except the presence of stromatolite in the Lukuwa Formation and petrified wood in the Tamrang Formation. Therefore, it is very difficult to assign exact age for each formation. However, it is possible to assign approximate age of each unit based on available fossils, age of intrusive rocks within the lithostratigraphic units and cross-cutting relations.

Stromatolite-bearing dolomite in central Nepal is named as the Dhading Dolomite and its age has been assigned to Riphean (about 850 Ma) (Stöcklin, 1980; Baral et al., 2022). The stromatolite-bearing Lukuwa Dolomite is similar to the Dhading Dolomite. Therefore, it can be compared with the Dhading Dolomite and age is assigned as Late Precambrian. The Bhendetar Group of rocks are placed on top of the Lukuwa Dolomite and Barahakshetra Group along the DT. Similarly, Phongsawa Group of rocks are placed at the top of the Bhendetar Group along the CT. Therefore, they should be much older than Riphean. However, it is difficult to assign exact age of those rocks.

The Mitlung Augen Gneiss similar to Jyamire Gneiss have been reported from the Taplejung Tectonic Window (Upreti et al. 2003; Sakai et al., 2013). The emplacement age of its protolith (i.e., granite) has been estimated to be about 1809 (Sakai et al., 2013). Maruo et al. (1979) mapped this augen gneiss as equivalent to the Ulleri Gneiss in the Modi Khola section of central Nepal (Le Fort, 1975). The crystallization ages of the Ulleri Augen Gneiss have been estimated to be about 1880-1800 Ma (Célérier et al., 2009).

Rai et al. (2016) presented the lithological correlation of the Chiuribas Formation with the rock sequences of the Dandagaon Phyllite, Sangure Quartzite with the Purebesi Quartzite member of the Nourpul Formation and Karkichhap Formation with the Benighat Slate. However, Purebensi Quartzite is the basal member of the Nourpul Formation and the contact between the Karkichhap Formation and the Sangure Quarzite is reported gradational (Rai et al., 2016). Hence, the correlational proposition made didn't match the stratigraphic continuity as the Dhading Dolomite above the Nourpul Formation hasn't been reported in between these rock units. The maximum depositional age of the Sangure Quartzite of the Bhendetar Group were constrained to be about 1795 Ma by Kobayashi et al. (2022). This sequence is comparable with the Naudanda and Fagfog Quartzites in central Nepal (Kobayashi et al., 2022). Based on the above facts it can be argued that the metasedimetary rocks of the Phangsawa Group are older than 1800 Ma and are probably equivalent to the lower part of the Kuncha Formation. It is supported by the fact that the Ulleri Gneiss in central Nepal is found within the Kuncha Formation (Upreti, 1999; Le Fort and Rai, 1999; DeCelles et al., 2001; Pearson and DeCelles, 2005; KC and Paudyal, 2019) and U-Pb dating zircon in the Kuncha Formation yields its age to be about 1900 Ma (Martin et al., 2011). The Karkichhap Formation overlying the Sangure Quartzite can be compared with the Dandagaon Phyllite and the Chiuribas Formation underlying the Sangure Quartzite can be compared with the upper part of the Kuncha Formation in central Nepal.

The Barahakshetra Group unconformably overlies the Lukuwa Dolomite. The oldest unit of the Barahakshetra Group is the Kokaha Diamictite. Based on its lithological similarity, the Kokha Diamictite can be compared with the Sisne Formation of Tansen area in western Nepal (Sakai, 1983; Dhital, 1992; Sitaula, 2009; Bhandari et al., 2018; Baral et al., 2022). The Sisne Formation is regarded as the Late Carboniferous to Permian (Lower Gondwana) sedimentary sequence.

The age and correlation of the Sapt Koshi Formation and Tamrang Formation is much debated. Similarly, the position of the Baraha Volcanics is also controversial. Dhital (1992) regarded the Sapt Koshi Formation as Lower Gondwana based on the Lower Gondwana-type fossil (*Schizoneura gondwanensis* FEISTMANTEL) finding in the carbonaceous shales by Bashyal (1980a). However, Bhandari et al. (2016) and Baral et al. (2022) reported zircons of younger ages in the Sapt Koshi Formation and argued that it should be younger than Permian. Lithologically, the Sapt Koshi Formation is comparable with that of the Taltung Formation of Sakai (1983). Both the units contain carbonaceous shales with frequent coal seams. However, Dhital (2015), Sitaula (2009) and Bhandari et al. (2018) compared it with the Amile Quartzite based on lithology, model composition of sandstone and heavy mineral analysis, and analysis of detrital zircon age pattern, respectively. Later on, the analysis on detrital zircon by Baral et al. (2022) predicted the age the Sapt Koshi Formation not older than Cretaceous and compared it with Taltung Formation. The mean depositional age of the Sapt Koshi Formation was calculated to be 119.7 ±4.8 Ma (Baral et al., 2022).

Similarly, the Tamrang Formation has lithological and geochronological similarity with the Miocene Dumri

Formation (Dhital, 1992, 2015; Sakai et al., 2013; Baral et al., 2022). However, Sitaula (2009) correlated this formation with the Bhainsekati Formation. On the other hand, Bhandari et al. (2018) compared it with the Permian Sisne Formation. However, Bhandari et al. (2018) themselves are not sure about their interpretation suggest for further investigations using paleomagnetic and metamorphic studies.

The comparison of the rocks of the outer section of the Lesser Himalaya with that of central and western Nepal found difficult as these sequences bears unique lithocharacters and devoid of fossil content and primary structures. The advance analytical techniques using detrital zircon carried out in previous researches has presented different sets of arguments in stratigraphy of Lesser Himalaya of the area. New routes for geological field work using larger scale mapping has been recommended as the area bears slices of lithological units in close spatial distribution. The field data should be coupled with structural analysis, petrography, basin analysis, interpretations of tectonic events using paleomagnetic and metamorphic studies are recommended for future to resolve the stratigraphic positions of the lithological units.

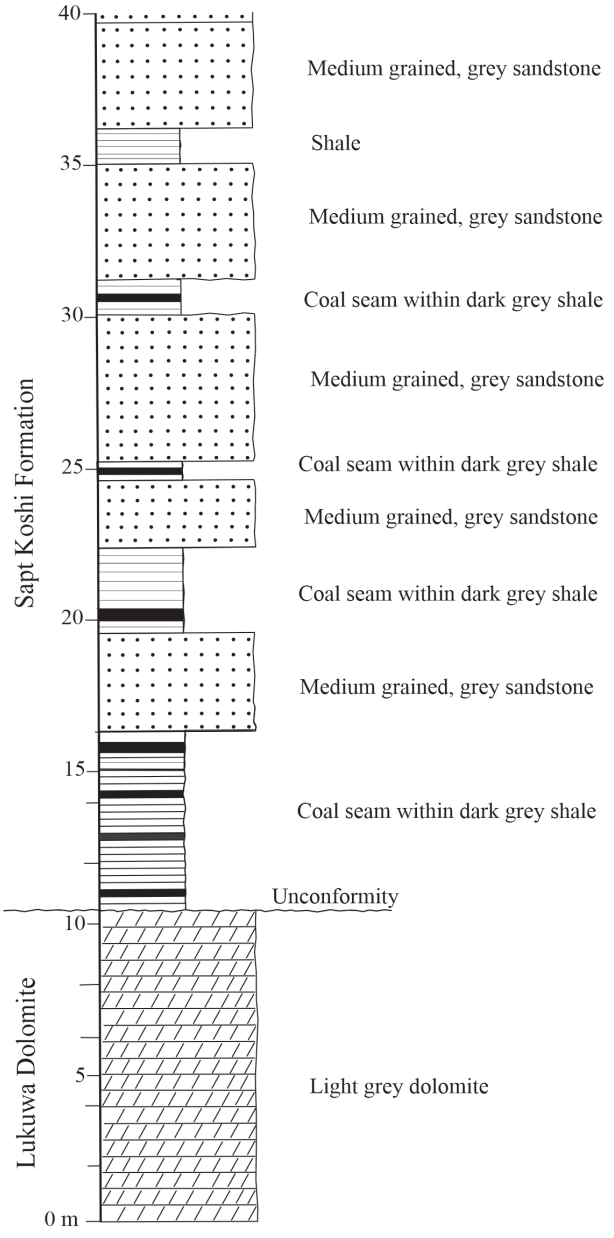

Fig. 11: Columnar section of the lower part of the Sapt Koshi Formation along the left bank of the Sapta Koshi River about 500 m upstream from its confluence with Kokaha Khola (See Fig. 2 for the location of the column).

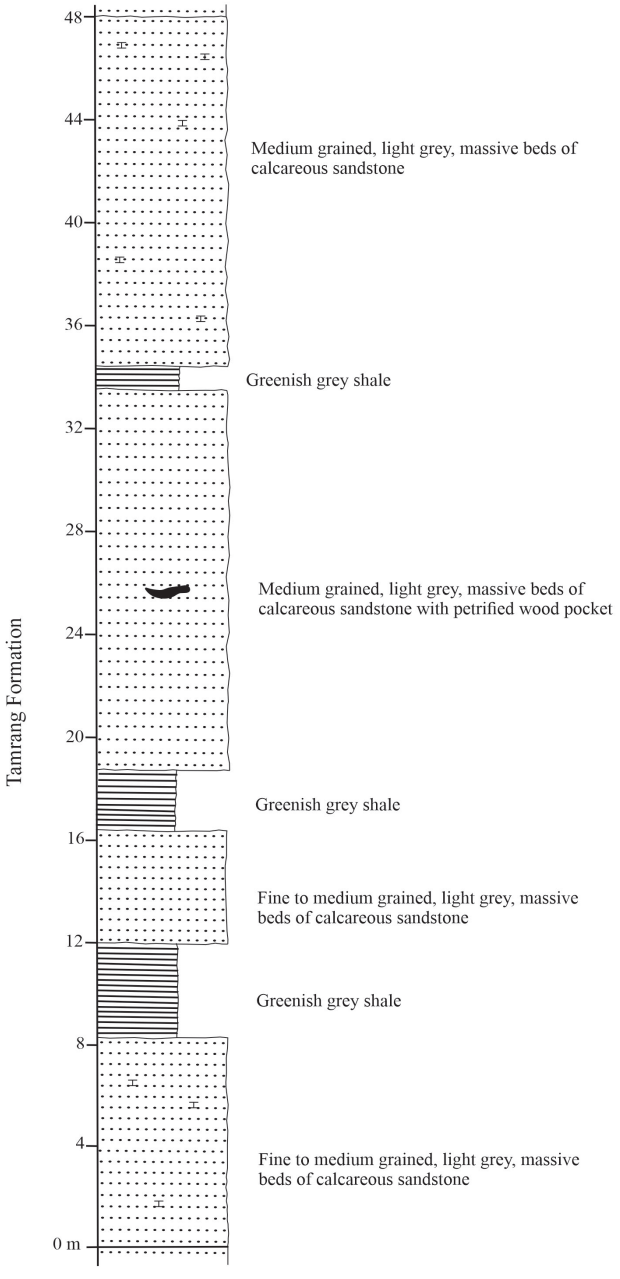

Fig. 12: Representative columnar section of the middle part of the Tamrang Formation observed along the left bank of the Sapta Koshi River about 2 km upstream from its confluence with Kokaha Khola (see Fig. 2 for the location of the column).

Fig. 13: Field photographs (a) conglomerate of Kokaha Diamictite observed along the left bank of the Sapta Koshi River about 800 m upstream from its confluence with the Kokaha Khola, (b) alternating beds of conglomerate and diamictite observed near the Belarang Village along the Tamor Corridor Road section, about 2 km towards Tribeni From Kokaha Khola.

CONCLUSIONS

The outer part of the Lesser Himalaya in the Barahakshetra–Tribeni area of eastern Nepal can be sub-divided into three tectonic units from north to south as the Chimra Thrust Sheet, the Dharapani Thrust Sheet and the Tribeni Paraautochthon. They are separated by two regional thrusts; the Chimra Thrust and the Dharapani Thrust. The rocks of the Chimra Thrust Sheet are named as Phongsawa Group and can be further subdivided into the Mulghat Formation, Okhre Formation, the Jyamire Gneiss and the Belhara Formation from bottom to top, respectively. The Jyamire Gneiss is quartzo-feldspathic orthogneiss and can be compared with the Ulleri Gneiss in central Nepal. The metasedimentary rocks of the Mulghat Formation, Okhre Formation and the Belhara Formation are equivalent to the lower part of the Kuncha Formation.

The rocks of the Dharapani Thrust Sheet are named as the Bhendetar Group and can be further subdivided into the Chiuribas Formation, Sangure Quartzite and Karkichhap Formation, from bottom to top respectively. They are comparable with the upper part of the Kuncha Formation, Fagfog Quartzite and the Dandagaon Phyllite respectively. The Chiuribas Formation comprises a prominent quartzite member (Simle Quartzite) in its upper part.

The Tribeni Paraautochthon is divided into the Lukuwa Dolomite unconformably overlain by the Gondwana and post-Gondwana Barahakshetra Group. The Lukuwa Dolomite is equivalent to the Dhading Dolomite in central Nepal. The Barahakshetra Group is sub-divided into the Kokaha Diamictite and Baraha Volcanics, Sapt Koshi Formation and Tamrang Formation from bottom to top, respectively. The Kokaha Diamictite is comparable with the Permo-Carboniferous Sisne Formation. Similarly, the Sapt Koshi Formation can be compared with the Jurassic to Cretaceous Taltung Formation and the Tamrang Formation with the Miocene Dumri Formation of western Nepal.

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