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Stratigraphy and structure of the inner Lesser Himalaya between Kusma and Syangja, Western Nepal

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ABSTRACT

The inner Lesser Himalayan rocks in the Kusma–Syangja area of Western Nepal comprise the Lower Nawakot Group, Upper Nawakot Group, Sirkot Group, and Tansen Group. The Lower Nawakot Group is made up of the Kuncha Formation (grey-green *gritty* phyllite and metasandstone), Naudanda Quartzite (very thick, pale yellow to white quartzite), Nayagaun Formation (grey-green phyllite and slate), Nourpul Formation (red-purple, grey, and green-grey phyllite, slate, and quartzite), and Dhading Dolomite (grey dolomite with columnar stromatolites), respectively from bottom to top. The Dhading Dolomite transitionally passes into the Benighat Slates (interlaminated black slate with sporadic carbonate bands) of the Upper Nawakot Group. The Sirkot Group succeeds the Benighat Slates and is represented by the Sorek Formation (grey-green and red-purple slate and orthoquartzite together with the Ripa Member of grey dolomite containing columnar and dome-shaped stromatolites) and the overlying Dhanpure Limestone (parallel-laminated grey limestone and shale). The Tansen Group disconformably overlies the above rocks, and is represented by the Sisne Formation (grey diamictite), Amile Formation (grey to brown orthoquartzite interbedded with brown and red-purple shale), and Dumri Formation (red-purple shale and grey-green sandstone), respectively in an ascending order.

The Lower Nawakot Group is equivalent to the Damtha Group and the Deoban Formation whereas the Benighat Slates are comparable with the Mandhali Formation in the Kumaon Himalaya, India. Similarly, the Sirkot Group is equivalent to the Kali Gandaki Supergroup and Gwar Group in the outer Lesser Himalaya of Nepal, and the Nagthat, Blaini, and Krol Formations of the Krol Belt in the Kumaon Lesser Himalaya of India.

The region underwent intense deformation resulting in the development of foreland- as well as hinterland-vergent imbricate faults. The Main Central Thrust (MCT) covered the entire inner Lesser Himalaya in the past and the Kusma–Syangja area was part of a complex duplex system. The MCT was the roof thrust of the duplex and its southward propagation was responsible for the development of south-vergent mesoscopic as well as small-scale folds near the anastomosing leading edge branch lines. A triangle zone was formed in the area bounded by two thrusts with opposite vergence and same basal detachment.

INTRODUCTION

Detailed geological mapping on a scale of 1:50,000 was carried out in the inner Lesser Himalaya of Western Nepal (latitudes 27° 55' N and 28° 15' N, and longitudes 83° 30' E and 83° 55' E) between the Kali Gandaki River to the west and the Siddhartha Highway to the east (Fig. 1). The region experienced intense deformation resulting in the development of a number of faults and folds. The deformation juxtaposed the rocks of various compositions and ages, and significantly obscured their stratigraphic sequence.

Various workers investigated the Lesser Himalayan rocks of Western Nepal and expressed quite diverse views on stratigraphy and structure. Hagen (1969) included the area into his Nawakot Nappes and correlated the rocks with those of the Krol Belt of Auden (1934) in the Kumaon Himalaya, India. Nanda (1966) classified the rocks of Western Nepal into the Bhimphedis, Grits, Quartzites, Grey Phyllites, Purples, Grey Dolomite, Carbonaceous Shales, Tansens (Khakis), and Siwaliks from bottom to top, respectively. Fuchs and Frank (1970) studied the area between the rivers Kali Gandaki and Thulo Bheri, and applied the stratigraphy of the Krol Belt. They also favoured the existence of nappes in the area. Stöcklin and Bhattarai (1977) and Stöcklin (1980) also made similar conclusions in Central Nepal. They subdivided the Lesser Himalayan rocks into the Nawakot Complex consisting of the Lower Nawakot Group (containing the Kuncha Formation, Fagfog Quartzite, Dandagaon Phyllite, and Dhading Dolomite, from bottom to top respectively) and the Upper Nawakot Group (containing the Benighat Slates, Malekhu Limestone, and Robang Formation, respectively in an ascending order). They also placed a disconformity between the Dhading Dolomite and the Benighat Slates.

On the other hand, Sako et al. (1973) as well as Ohta et al. (1973) denied the existence of any nappes in the area. Arita et al. (1982) identified the Baglung Zone and Bihadi Zone in this region. They gave more tectonic importance to their

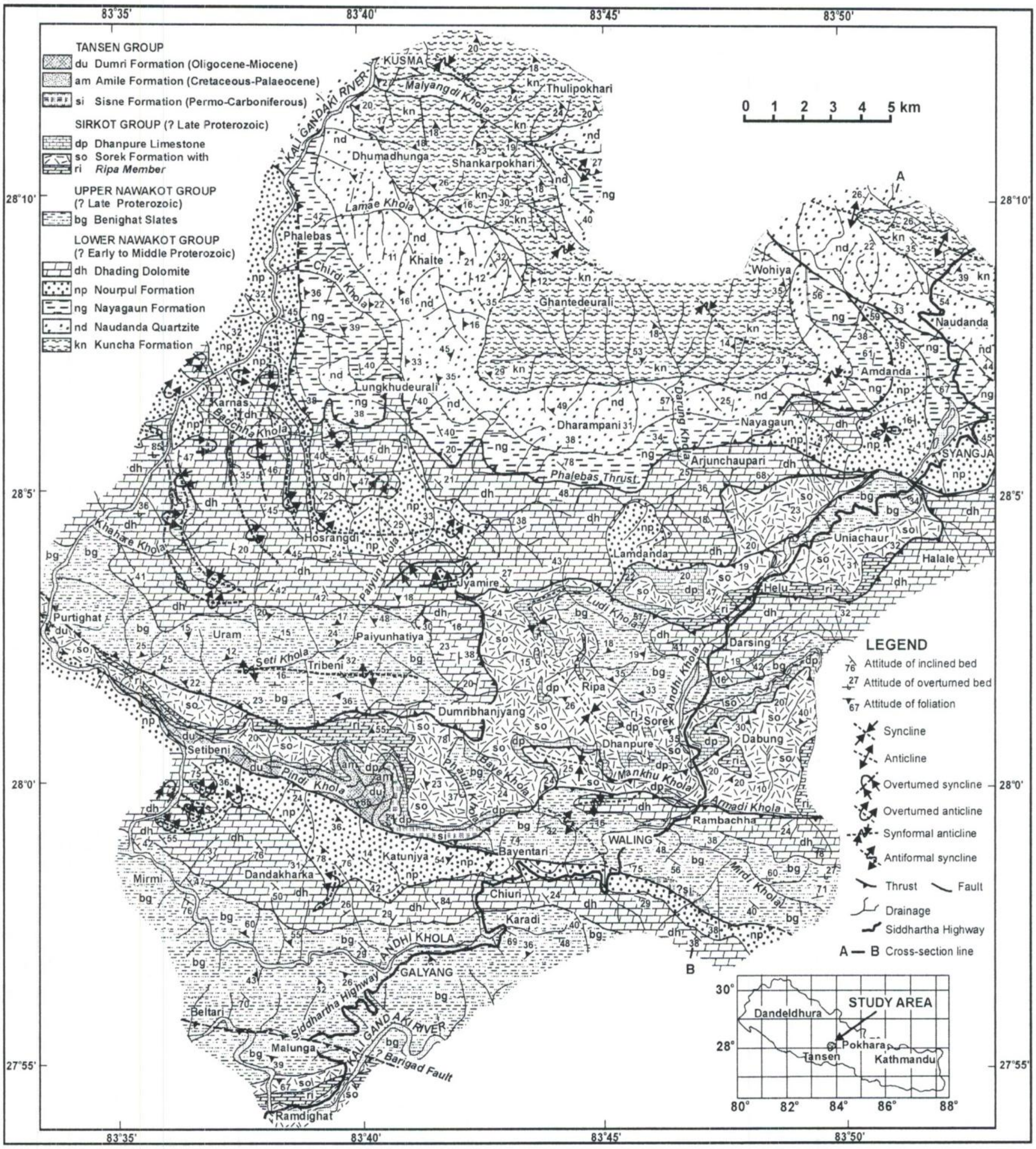

Fig. 1: Geological map of the inner Lesser Himalaya between Kusma, Syangja, and Galyang.

Kali Gandaki Fault and its northwestern extension (i.e. their Bari Gad Fault) than the Phalebas Thrust identified by Sharma and Merh (1978) and Upreti et al. (1980).

Sakai (1983, 1985, 1986a, 1986b) carried out a detailed investigation in the Lesser Himalaya of the Palpa–Syangja area. He divided the rocks into the Tansen Group and the Kali Gandaki Supergroup. In the study area, he identified the Belbas Slates, Syangja Beds, Darsing Dolomite, and Andhi Khola Formation belonging to the Kali Gandaki Supergroup, and the Sisne Formation, Amile Formation, and Dumri Formation belonging to the Tansen Group.

PROBLEMS IN GEOLOGICAL INTERPRETATION

In the Lesser Himalaya of Central and Western Nepal, some workers have mapped more than one quartzite band within the upper part of the *gritty* phyllite (i.e. the Kuncha Formation) succession (e.g. Tater et al. 1984; Jnawali and Tuladhar 1996a, b). Other researchers (e.g. Shrestha 1981; Paudel and Dhital 1996) have traced two *gritty* phyllite successions with only one intervening quartzite band, whereas some others (e.g. Hirayama et al. 1988) have put a series of thrusts or vertical faults between the *gritty* phyllite and quartzite successions.

Owing to the above uncertainties in structural position of the quartzite and the adjoining grey phyllite successions, the name Naudanda Quartzite is retained following the earlier workers whereas the Nayagaun Formation is introduced here as a new formation. The two units are believed to be equivalent respectively to the Fagfog Quartzite and the Dandagaon Phyllite (Stöcklin and Bhattarai 1977) in Central Nepal.

There are many similarities between the southwestern quartzite band that lies above the Phalebas Thrust and the northeastern quartzite band, which occupies the left bank of the Andhi Khola around Naudanda (Fig. 1). Both of them contain amphibolites (Paudel and Dhital 1996), are identical in composition, and exhibit transitional contacts with the adjoining *gritty* phyllites containing sporadic conglomerate lenses and amphibolite bands.

The northeastern quartzite band of Naudanda dips due south and the *gritty* phyllites occur in the core of a westerly plunging anticline, whereas the southwestern quartzite band constitutes a synform with the *gritty* phyllites in the core (Fig. 1). In other words, the latter quartzite band is apparently overturned. This fact is further supported by the development of transposed foliation and numerous mesoscopic (Fig. 2) and small-scale folds (Fig. 3) as well as folded quartz veins in the Darung Khola. Overturned ripples and cross-laminae are observed in the Andhi Khola northwest of Naudanda and elsewhere. Even though there are some trough cross-laminae in the Darung Khola and wave ripples in the Lamae Khola indicating the right-side-up position, the overall regional structure of the southwestern quartzite band above the Phalebas Thrust is interpreted as a synformal anticline (Fig. 1).

Many previous workers (e.g. Nanda 1966; Fuchs and Frank 1970; Tater et al. 1984; Sakai 1986a; Hirayama 1988; Jnawali and Tuladhar 1999; Shrestha et al. 2000a, b) have correlated the stromatolitic carbonate bands of the Lesser Himalaya with the Dhading Dolomite in Central Nepal. This study revealed that the stromatolitic carbonate rocks in the Kusma–Syangja area occur in two different stratigraphic positions. The Dhading Dolomite represents the first horizon and lies below the Benighat Slates, whereas the second one is found above the slates. Hence, the rocks younger than the Benighat Slates are classified into the Sirkot Group consisting of the Sorek Formation (with the Ripa Member of stromatolitic dolomite) and the Dhanpure Limestone.

LITHOSTRATIGRAPHY

The rocks of the study area belong mainly to the Nawakot Complex (represented by the Lower Nawakot Group and the Upper Nawakot Group) and the Sirkot Group (Fig. 4). A narrow belt comprising the rocks of the Tansen Group (Sakai 1985) lies in the Pindi Khola area (Fig. 1).

Lower Nawakot Group

The Lower Nawakot Group constitutes a thick (more than 6 km) sequence of *gritty* phyllites and quartzites followed by grey dolomites and slates in the south. It is divided into the Kuncha Formation, Naudanda Quartzite, Nayagaun Formation, Nourpul Formation, and Dhading Dolomite, respectively in an ascending order.

Kuncha Formation

The Kuncha Formation (Fig. 1, 4) is distributed only in the northern part of the study area and crops out in two separate zones, i.e. 1) around Naudanda and 2) around Kusma, Shankarpokhari, and Ghantedeurali (Fig. 1). The Kuncha Formation is composed of very thick, rather monotonous sequence of alternating green-grey phyllite, green-grey to light grey *gritty* phyllite, quartzose phyllite,

Fig. 2: A mesoscopic antiform in the Naudanda Quartzite near Darung. View to NE.

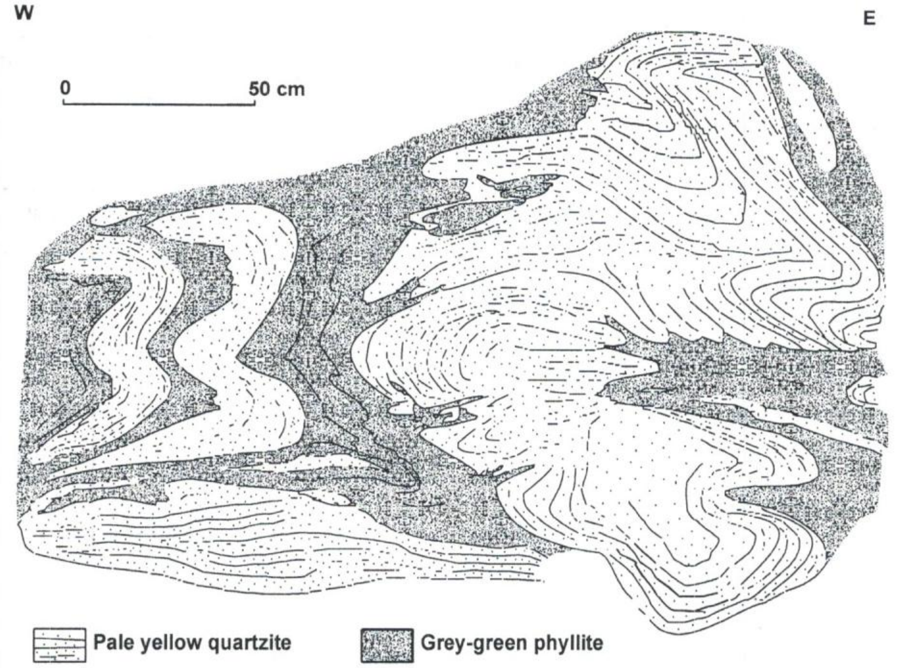

Fig. 3: Small-scale folds in the Naudanda Quartzite north of Lungkhudeurali.

fine-grained, massive, olive green quartzite, grey-green metasandstone and sporadic interbanding of coarse-grained metaconglomerate and thick (up to 5 m) lenses of massive, dark green amphibolites. The grey-green phyllite is extremely fine-grained, thinly foliated and crenulated. Sometimes, tiny (0.5–1 mm) muscovite flakes are observed along the foliation plane in the phyllite and metasandstone. Sporadically, pebbly phyllite with stretched clasts is also encountered.

The feldspar and bluish-grey and smoky quartz grains frequently found in the Kuncha Formation were probably derived from the Achaean charnockites of India. These rocks are of wide prevalence in Tamilnadu, and constitute the hills of Nilgiris, Palnis, and Shevaroys (Wadia 1957). Charnockite is a coarse-grained rock of approximately granitic composition and granoblastic texture, containing feldspar, orthopyroxene, and quartz. Quartz and feldspar often contain inclusions of minute needles of rutile (Krishnan 1956). The quartz characteristically has a blue opalescence due to the presence of exsolved needles of rutile, while the feldspar may be brownish in colour (Lapidus 1990).

The Kuncha Formation passes into the overlying Naudanda Quartzite with a rapid transition, and it is more than 2000 m thick in the study area.

Naudanda Quartzite

The Naudanda Quartzite (Fig. 4) is confined to the northern part of the study area where it makes steep and bare rock cliffs. It lies above the Phalebas Thrust in the Lamae Khola, in the Darung Khola, around Khalte, and at Dharampani. It also forms the southern limb of the anticline at Naudanda. The Naudanda Quartzite comprises medium- to coarse-grained, medium- to very thick-bedded (50 cm to 5 m), massive, pale yellow, light grey, white, and light green quartzite alternating with thin-banded, blue-grey to green-grey phyllite and thick (sometimes up to 20 m), massive, coarse-grained, dark-green amphibolite. The quartzite preserves various types of wave as well as current ripples and cross-laminae. The cliff north of Naudanda is notable for the spectacular ripple marks. By the decrease of quartzite, the Naudanda Formation transitionally passes into the overlying Nayagaun Formation and is about 800 m thick at Naudanda.

Nayagaun Formation

The Nayagaun Formation constitutes the hanging wall of the Phalebas Thrust between Phalebas and the Andhi Khola (Fig. 1). It is extensively distributed in the Chirdi Khola, at Nayagaun, and north of Syangja. The Nayagaun Formation is represented by grey, dark grey, and green-grey phyllite and slate. Generally, the phyllite is fine-grained and alternates with 1–2 m thick bands of fine-grained metasandstone. The phyllite is strongly deformed and exhibits crenulation cleavage. In the Darung Khola, small folded quartz veins are also present. A few sporadic dark grey to black calcareous quartzite and lenticular carbonate bands are observed southeast of Naudanda and in the Darung Khola. The Nayagaun Formation is about 1000 m thick in the Darung Khola.

Nourpul Formation

The Nourpul Formation lies in the core of an overturned anticline in the upper reaches of the Paiyun Khola. It also crops out around Syangja and forms a continuous band

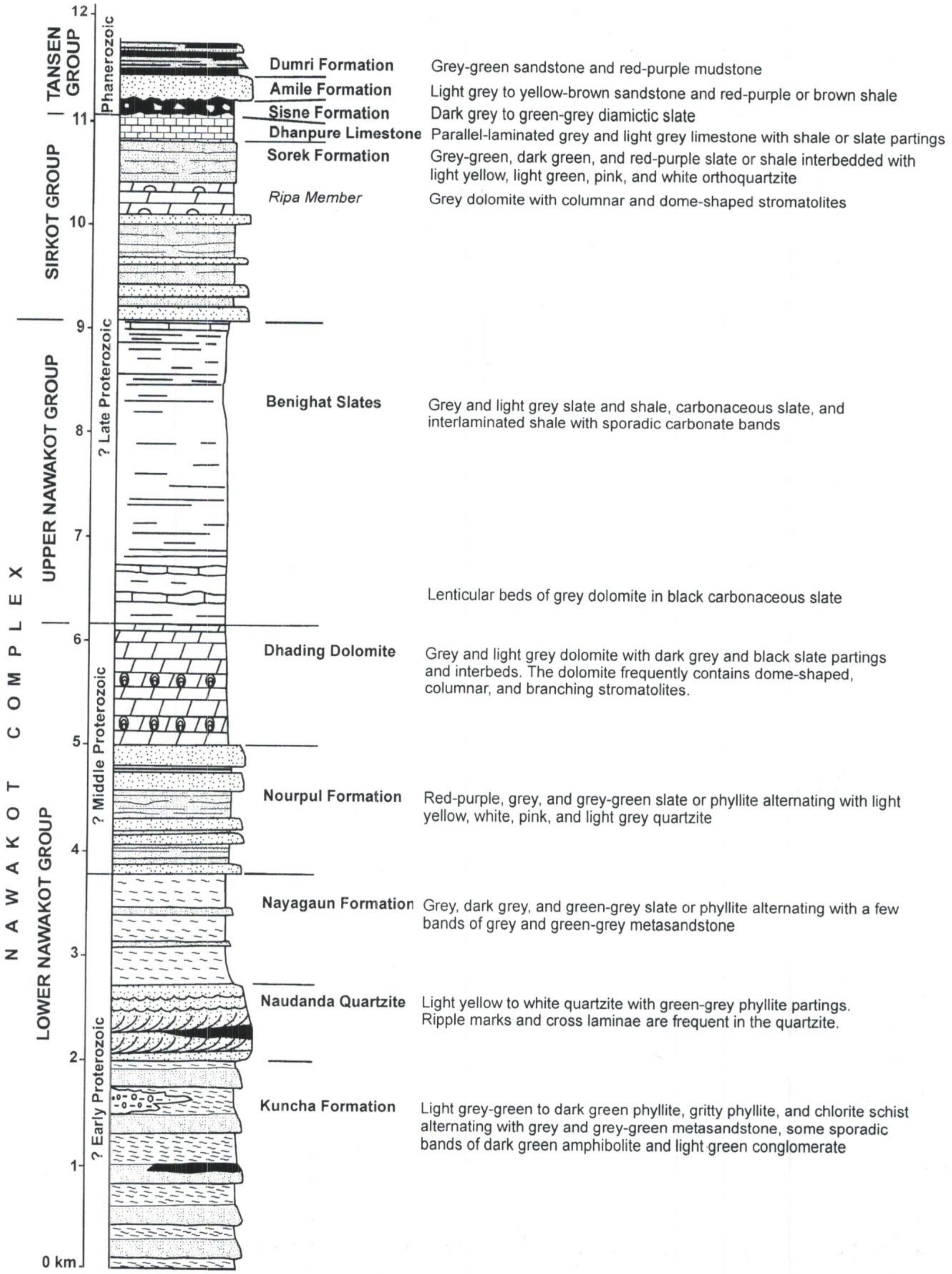

Fig. 4: Generalised lithostratigraphic column of the Kusma–Syangja area in the Western Nepal Lesser Himalaya.

between Setibeni and Bayentari (Fig. 1). The Nourpul Formation succeeds the Nayagaun Formation with a rapid transition. It has a variable lithology of slate, phyllite, and quartzite. The lower part contains medium- to thick-bedded, medium- to coarse-grained, light grey, grey-green, pink, and white quartzite alternating with red-purple phyllite and grey-green slate. The middle part comprises mainly thin-banded (5–15 cm) purple slate, parallel-laminated black slate, and blue-grey and blue-green phyllite. In the upper part, the pink, light grey and white quartzites become prominent, and in them cross-laminae and ripples are frequent. By the decrease of slate and phyllite, the Nourpul Formation passes into the overlying Dhading Dolomite. The Nourpul Formation exposed south of Syangja is about 1200 m thick.

Dhading Dolomite

The Dhading Dolomite crops out around Dumribhanjyang, Jyamire, Dandakharka, and south of Syangja, where it forms many prominent peaks and ridges. It is composed of a sequence of calcareous quartzite at the bottom, followed by purple siliceous dolomite and massive blue-grey dolomite. The main lithology of this formation is very thick-bedded, light grey to blue-grey dolomite interbedded with dark grey to black slate. A dolomite band is from 1 to 5 m thick and a slate band is generally from 1 cm to 1 m thick. In some dolomite bands, detrital quartz grains can be viewed with the unaided eye. Columnar and branching stromatolites (about 1 m long and 10 cm wide) prevail in the dolomite. In the middle part of the succession, some small dome-shaped stromatolites are also present together with intraclasts and chert nodules (Fig. 6). The dolomite consists mainly of micrite and pseudospar, which frequently contain cavities and vugs filled with chert and quartz (Fig. 5). A number of mesoscopic and small-scale folds abound in the Dhading Dolomite (Fig. 7). The Dhading Dolomite succession cropping out north of Karadi is about 1200 m thick and its thickness varies considerably from place to place.

Upper Nawakot Group (Benighat Slates)

In the study area, the Upper Nawakot Group is represented by the Benighat Slates. They are widespread in

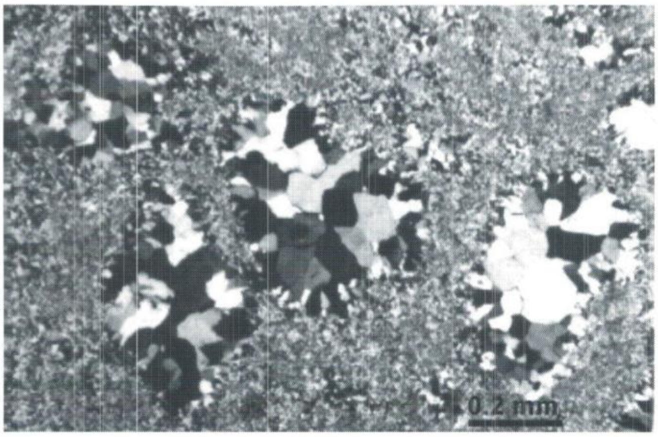

Fig. 5: Vugs filled with chert and quartz in the Dhading Dolomite at Chiuri.

the southern part of the mapped area (Fig. 1), i.e. in the Seti Khola, around Malunga and Galyang, and in the Mirdi Khola. The slates reappear in the northern part of the study area, where the Phalebas Thrust overrides them east of Nayagaun and south of Lungkhudeurali. The Benighat Slates have a conformable contact with the underlying Dhading Dolomite. In the vicinity of Uram and Paiyunhatiya, a carbonate succession is observed about 200 m above the contact with the Dhading Dolomite and it continues for more than 5 km along the strike. Such carbonate bands are also frequent at Karadi and in the Mirdi Khola (Fig. 1).

This formation consists mainly of very thinly (less than 1 cm) cleaved black slates. The slates look typically green-grey to brown on weathered outcrops. They contain thin strips of carbonaceous matter, which are best observed on fresh outcrops. One of the characteristic features of the slates is that they exhibit well-developed lamination (especially in the upper part of the formation). The thickness of a lamina varies from 0.5 mm to 2 cm. Generally, the laminae are plane, continuous, and parallel. The conspicuous colour banding in the laminated slate is due basically to the micro-grading in a lamina containing very fine sand (light grey), silt (grey), and clay (dark grey), respectively from bottom to top. The slates are intensely sheared and fractured, and show many small-scale chevron and polyclinal folds. The Benighat Slates transitionally pass into the overlying Sorek Formation of the Sirkot Group and are about 3000 m thick.

Sirkot Group

The rocks of the Sirkot Group crop out in the central part of the study area and frequently comprise the footwalls of north-vergent imbricate faults. The Sirkot Group is subdivided into the Sorek Formation and the Dhanpure Limestone in an ascending order.

Sorek Formation

The transitional contact between the Benighat Slates and the overlying Sorek Formation is well seen north of Sorek, in the Baye Khola, and south of Malunga (Fig. 1). The Sorek Formation begins with an intercalation of grey-green laminated slate and fine-grained grey quartzite. This succession is followed by an interbedding of red-purple, grey-green slate and pale yellow, pink, and grey quartzite. Towards the upper part, the stromatolitic dolomite of the Ripa Member is intercalated (Fig. 9) with the slate and quartzite.

The Ripa Member (Fig. 8) differs significantly in thickness (200–500 m), lithology (interbedded dolomite and calcareous quartzite) and kinds of stromatolite from the Dhading Dolomite. The Dhading Dolomite predominantly contains columnar stromatolites, whereas the Ripa Member contains small columnar (in the lower part) and relatively wide dome-shaped (in the upper part) stromatolites. The Sorek Formation is about 1700 m thick and transitionally passes into the overlying Dhanpure Limestone.

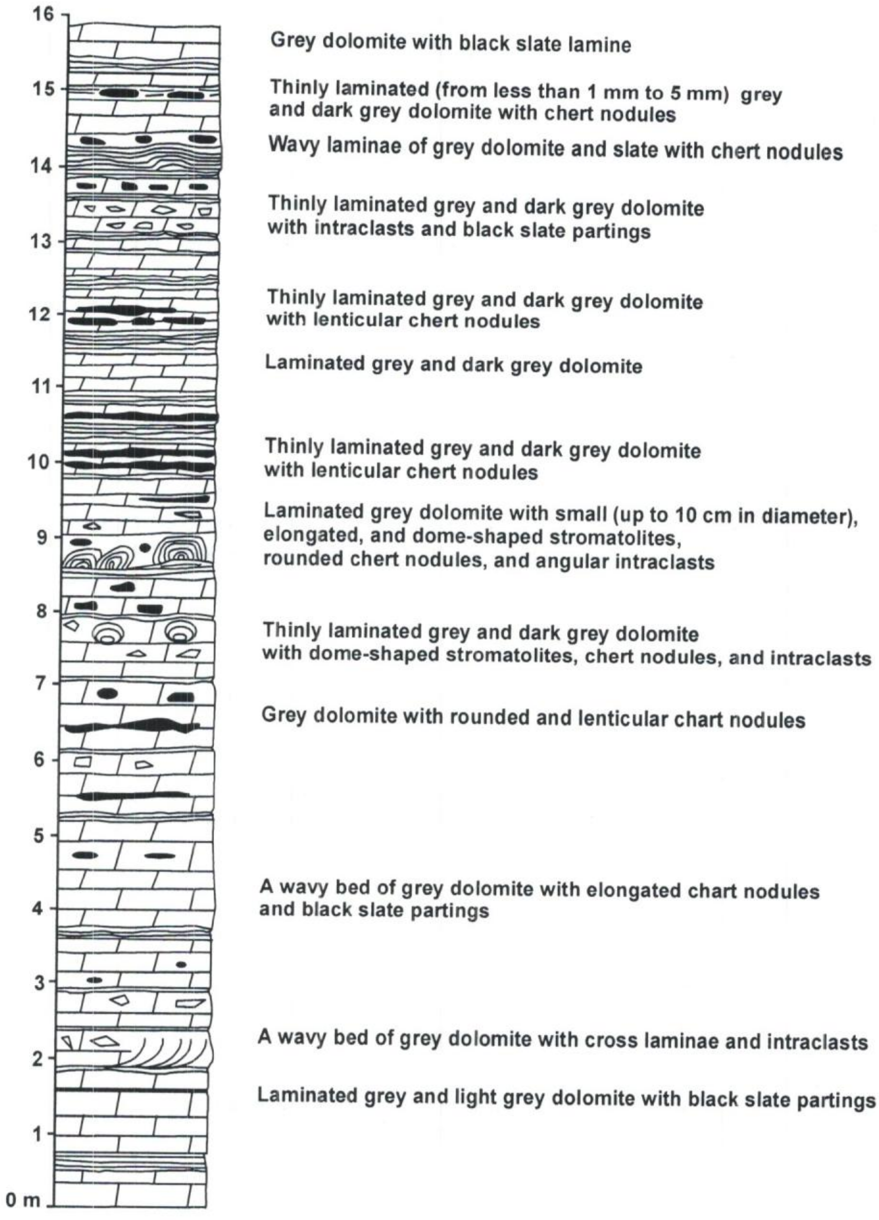

Fig. 6: Detailed columnar section depicting intraclasts, chert, and stromatolites in the middle portion of the Dhading Dolomite at Chiuri.

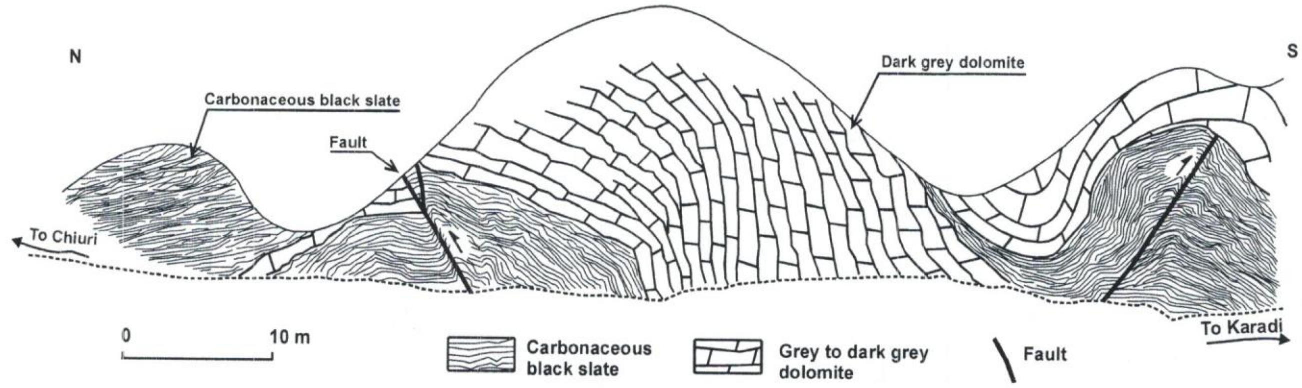

Fig. 7: Folded dolomite and slate (upper part of the Dhading Dolomite) exposed on the cut slope of the Siddhartha Highway north of Karadi.

Dhanpure Limestone

The Dhanpure Limestone crops out as a marker horizon in the central and southern parts of the study area (Fig. 1). It is intensely deformed and various chevron folds are seen in the Mankhu Khola, around Dhanpure, and in the upper reaches of the Ludi Khola. The Dhanpure Limestone is composed of grey to green-grey parallel-laminated limestone with slate partings and interbeds. Towards the top a few pale yellow to light grey quartzite beds are also intercalated in the Phaudi Khola. The Dhanpure Limestone is about 200–400 m thick.

Tansen Group

A narrow belt of rocks belonging to the Tansen Group is observed around Setibeni (Fig. 1) where it is represented by the following formations in an ascending order.

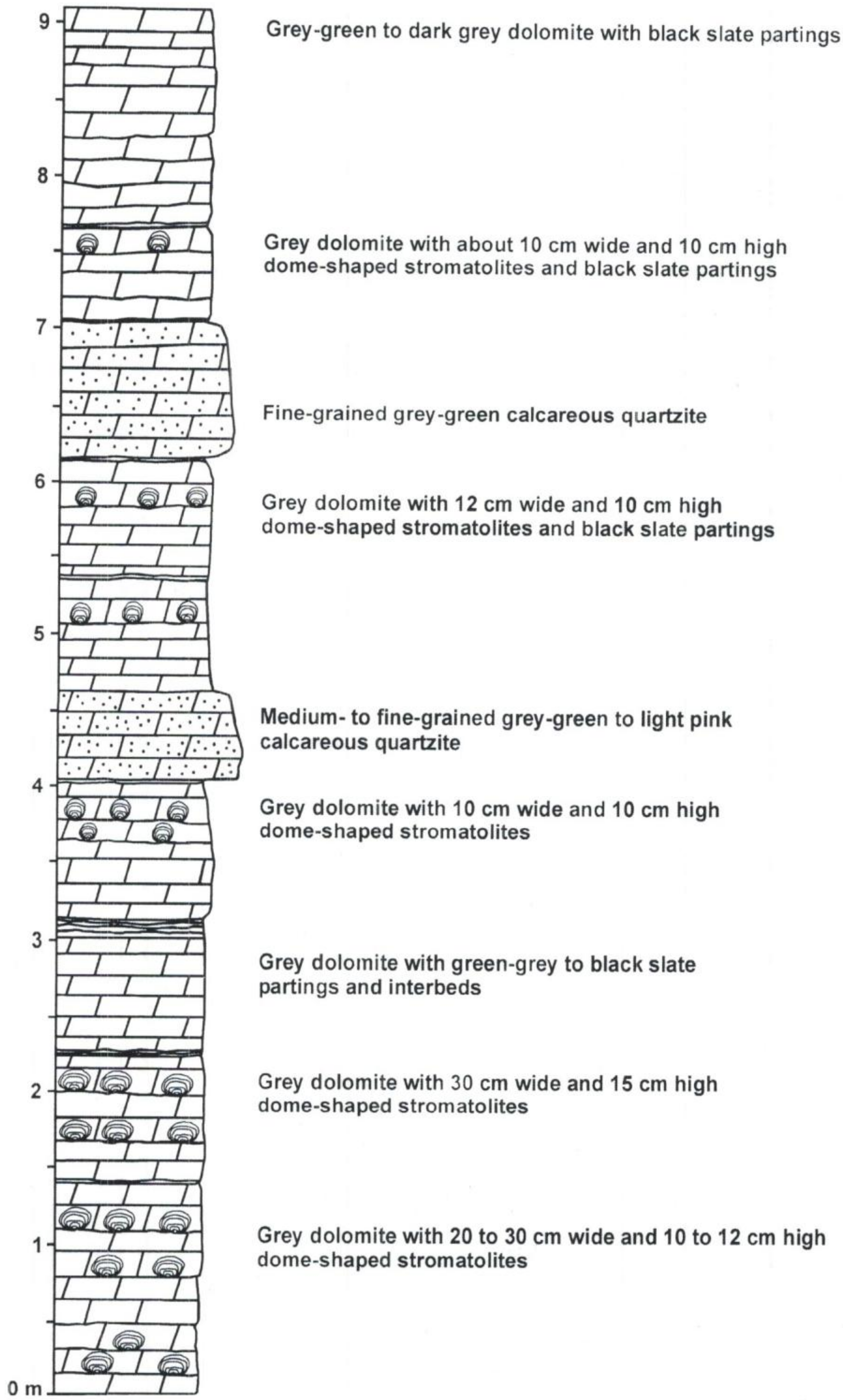

Fig. 8: Detailed columnar section of the Ripa Member exposed at Ripa.

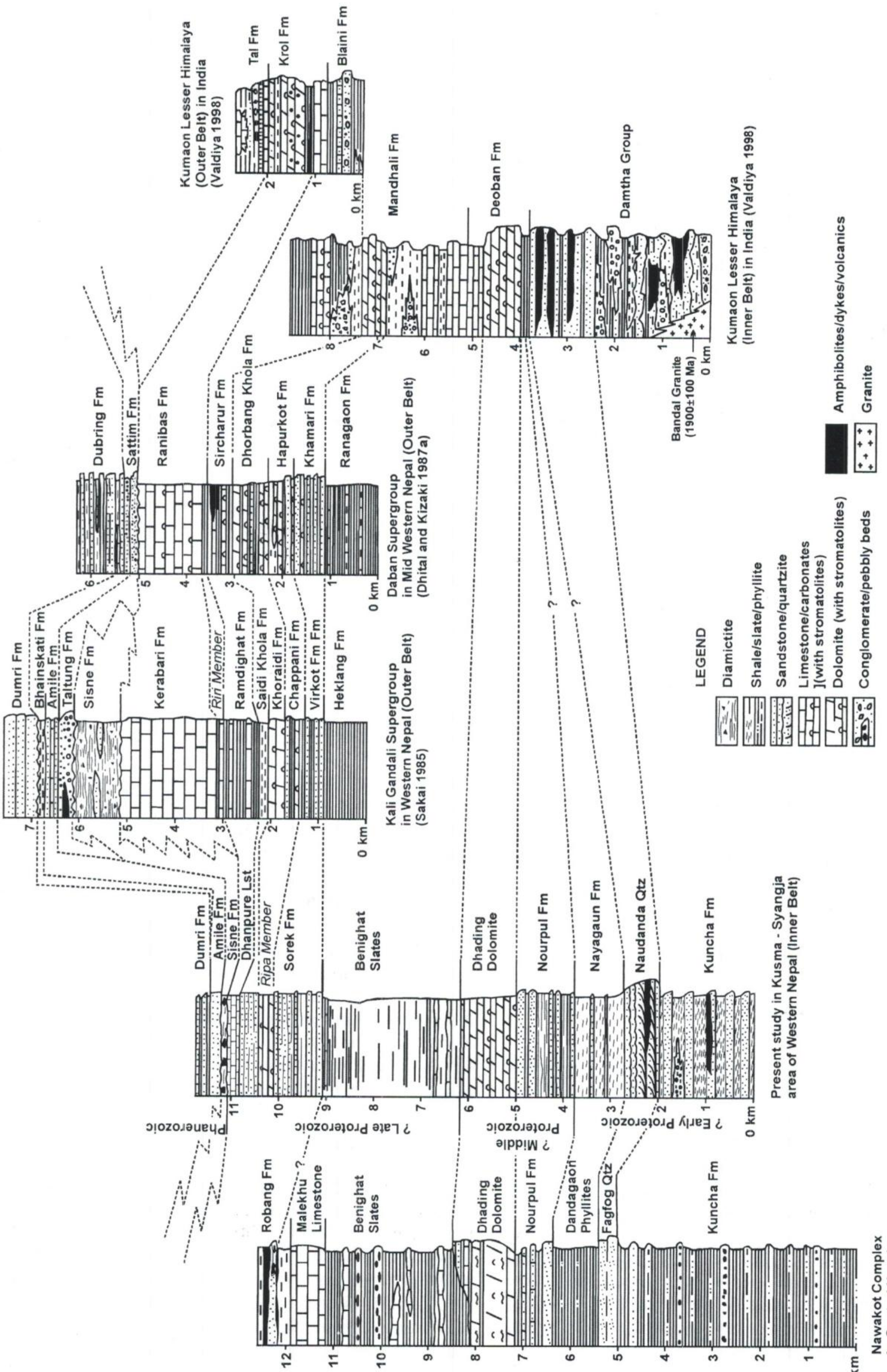

Fig. 9: Correlation scheme for the Lesser Himalayan rocks of Nepal and Kumaon, India.

Sisne Formation

The Sisne Formation is observed between Setibeni and Bayentari in the southern part of the study area. It overlies the Dhanpure Limestone with a sharp contact (? disconformity) in the Phaudi Khola. The Sisne Formation is represented by grey-green and dark grey diamictic slate with angular clasts (from 2 mm to 20 cm) of grey dolomite, dark grey to black slate, and light yellow to grey quartzite. An isolated outcrop lying southeast of Waling in a southern tributary of the Mirdi Khola shows a rather transitional contact with the underlying black Benighat Slates. It consists of small (less than 2 cm) clasts of quartzite and slate, and is tentatively mapped as the Sisne Formation. The Sisne Formation is about 200 m thick in the Phaudi Khola.

Amile Formation

The Amile Formation is confined to the upper and middle reaches of the Pindi Khola in the southern part of the study area. It rests disconformably over the Sisne Formation and is represented by yellow to grey, medium- to coarse-grained, massive quartzite with a few beds of grey to brown shale. The Amile Formation is about 200 m thick in the Pindi Khola.

Dumri Formation

The Dumri Formation is the youngest unit of the study area. It is observed in the vicinity of Setibeni and along the Pindi Khola as a continuous band. An isolated small outcrop of the Dumri Formation is also seen at Purtighat. The Dumri Formation transitionally follows the Amile Formation and is represented by green-grey sandstone and red-purple shale. The rock is highly crushed. Its thickness reaches up to 300 m in the Pindi Khola.

CORRELATION AND AGE

Many previous workers have correlated the outer and inner Lesser Himalayan successions of red-purple slates, phyllites, and quartzites with the Nourpul Formation, and the overlying carbonates with the Dhading Dolomite of Stöcklin and Bhattarai (1977) in Central Nepal. The correlation was based on the lithological similarity and occurrence of stromatolites. Present study refutes this correlation, since most of the outer Lesser Himalayan rocks are younger than the Benighat Slates.

A correlation scheme for various Lesser Himalayan formations of Nepal and Kumaon is given in Fig. 9. Based on stratigraphic position and radiometric dating of igneous rocks, Valdiya (1998) assigned some age limits to the Precambrian rocks in the Kumaon Himalaya (Table 1). He described the Mandhali Formation as a sequence consisting of black shales and black limestones with marlites and intraformational conglomerate. This sequence is quite similar to the Benighat Slates. The columnar and branching stromatolite-bearing Deoban Formation lying below the Mandhali Formation is akin to the Dhading Dolomite, whereas the Damtha Group is equivalent to the Kuncha Formation, Naudanda Quartzite, and Nayagaun Formation (Table 1; Fig. 9).

Auden (1934) described the rocks of Krol Belt as follows: Mandhalis (quartzites, limestones, slates, phyllites, and boulder beds), Chandpur (laminated green phyllite and quartzites), Nagthat (current-bedded red-purple and green sandstones, quartzites, grits, conglomerates, and clay-slates), Blaini (dark grey to brown boulder beds and pink limestone), Infra-Krol (soft dark shales and slates), Krol Sandstone (crumbling sandstone without good bedding and containing well rounded quartz grains and cemented by silica), and Krol Limestone (Krol A: blue-grey limestones and shales, Krol B: thinly laminated purple-red shales and limestones, Krol C: dark blue crystalline limestone, Krol D: intercalation of dark grey cherty limestone and variegated shale, and Krol E: grey and pale cream-white microcrystalline limestone), respectively from bottom to top. Evidently, the Krol Belt is similar in lithostratigraphy to the outer Lesser Himalayan rocks of Nepal, i.e. the Kali Gandaki Supergroup (Sakai 1985) in the Kali Gandaki area and the Gwar Group (Dhital and Kizaki 1987a) in the Northern Dang area (Fig. 9).

The inner Lesser Himalayan Sirkot Group is similar to the inner Lesser Himalayan rocks of Kumaon, India (Fig. 9). However, it is considerably thinner than the outer Lesser Himalayan rocks of Nepal and Kumaon. This fact is attributable probably to the changes in the depositional environment and absence of the uppermost thick carbonate succession (i.e. Krol Limestone) in the Kusma–Syangja area as well as the slower sedimentation rates in the inner belt.

The K/Ar age determination (Bordet et al. 1964) on muscovite from sandstone and uralite from a basic rock of the Kuncha Formation in the Kali Gandaki region gave 872 Ma and 1,150 Ma, respectively. Radiometric dating of detrital zircons in the Lesser Himalayan rocks of the Langtang area (Parrish and Hodges 1996) revealed that the unfossiliferous portions of the Lesser Himalayan sequence just below the MCT are of Middle Proterozoic age. Hence, based on the radiometric ages and the stratigraphic position, an early Proterozoic age is assigned to the Kuncha Formation, Naudanda Quartzite, and the Nayagaun Formation whereas a middle Proterozoic age is allocated to the Nourpul Formation and the Dhading Dolomite, and a late Proterozoic age is inferred for the Benighat Slates and the Sirkot Group. Similarly, the Sisne Formation is believed to be of Permo–Carboniferous, the Amile Formation of Cretaceous–Palaeocene, and the Dumri Formation of Oligocene–Miocene age (Sakai 1983, 1985).

IMBRICATE THRUSTS

The Kusma–Syangja area underwent intense deformation resulting in the development of many north- as well as south-vergent listric imbricate thrusts. Fuchs and Frank (1970) regarded the Phalebas Thrust as a large-scale nappe bringing with it the Chail Unit over the Tansen Unit. Nadgir and Nanda (1966), and Ohta et al. (1973) described it as a steeply dipping fault related to the vertical block movement. Dhital and Kizaki (1887b) recognised a duplex in the outer Lesser Himalaya of Mid Western Nepal.

Table 1: Lithostratigraphic units in Kumaon, India and their equivalents in Nepal.

Lithostratigraphic units in Kumaon (Valdia 1980, 1998)	Equivalent lithostratigraphic units in Nepal	Age (Valdiya 1998)
Krol Fm, Blaini Fm, Nagthat Fm, and Chandpur Fm	Sirkot Group in inner Lesser Himalaya; Kali Gandaki Super group and Gwar Group in outer Lesser Himalaya	Neoproterozoic-Verdian (1000-570 Ma)
Mandhali Fm	Benighat Slates	
Deoban Fm	Dhading Dolomite and Nourpul Fm	Mesoproterozoic (1400-1000 Ma)
Damtha Group	Nayagaun Fm, Naudanda Qaurtzite, and Kuncha Fm	(2050-1400 Ma)

The Main Central Thrust (MCT) covered the entire inner Lesser Himalaya of Western Nepal in the past and acted as a roof thrust of a complex duplex system. The Kusma–Syangja area was part of it and the imbricate faults observed at present were exposed after erosion of their leading branch lines. There are mainly two imbricate thrust systems in the area: 1) a foreland-vergent imbricate fan and 2) a hinterland-vergent imbricate fan.

Foreland-vergent imbricate fan

The foreland-vergent imbricate fan occupies the northwestern half of the study area and comprises the Phalebas Thrust and other south-vergent faults (Fig. 1). In the study area, the Phalebas Thrust passes through Phalebas, Lungkhudeurali, Nayagaun and Amdanda, and terminates in the Andhi Khola south of Naudanda against a steep fault (Fig. 1 and 10), which is seemingly a breaching thrust (Butler 1987). The Phalebas Thrust brings with it intensely folded rocks of the Kuncha Formation, Naudanda Quartzite, and the Nayagaun Formation over the younger rocks. Apparently, it is a folded horse consisting of two en-echelon antiformal synclines (Fig. 1).

The foreland-vergent imbricate fan is essentially a forward-breaking sequence. The southward propagation of the roof thrust was responsible for the development of south-vergent mesoscopic as well as small-scale folds near the anastomosing leading edge branch lines (Fig. 2, 3 and 10).

A large area lying between the Phalebas Thrust to the north and the thrust passing through Purtighat, Dumribhanjyang, Jyamire, Lamdanda, and south of Syangja includes a series of steeply to gently plunging, non-cylindrical, tight, isoclinal, and overturned folds. An individual fold extends from tens of metres to over 10–15 km. Most of the folds have asymmetrical profiles with steep axial surfaces. Their wavelength varies from 100 m to 2–3 km and the amplitude ranges from less than 100 m to 2 km. In the vicinity of the Kali Gandaki River, their axial traces change the trend from east to north. Evidently, most of the folds were initiated as fault-propagation folds and were subsequently modified due to superposed folding.

Hinterland-vergent imbricate fan

The hinterland-vergent imbricate fan consisting of backthrusts occupies the southeastern half of the study area (Fig. 1). One of the prominent backthrusts passes through Purtighat, Setibeni, the Pindi Khola, and Bayentari. Since the backthrusts lying in the north are comparatively more deformed (e.g. their leading edges show intensely folded and overturned beds) than those lying in the south, and the southern backthrusts crosscut the northern ones (Fig. 1), it is evident that the hinterland-vergent imbricate fan is basically a break-back sequence, where the individual thrusts propagated from north to south. During this process, the roof thrust continued to propagate to the south giving rise to the deformed leading edges of the backthrusts (Fig. 10). 0Since the backthrusts contain younger rocks and they are relatively less deformed than the foreland-vergent thrusts (which contain S-shaped fold axial traces towards the northwest), it is apparent that the hinterland-vergent imbricate fan developed subsequently to the foreland-vergent one.

Most of the foreland-vergent thrusts merge (i.e. form branch lines) towards the northeast and diverge towards the west, whereas the backthrusts merge towards the west and diverge towards the east or northeast (Fig. 1). This type of opposing arrangement of branch lines in the two imbricate fans was probably responsible for the uneven intensity of folding within an imbricate slice. Moreover, during the movement of the hinterland-vergent imbricate fan, the obliquely lying foreland-vergent imbricate fan underwent further deformation, giving rise to the superposed folds.

Triangle zone

There are two triangle zones in the region bounded by the two types of imbricate fan with opposite vergence and same basal detachment. The first one contains the youngest

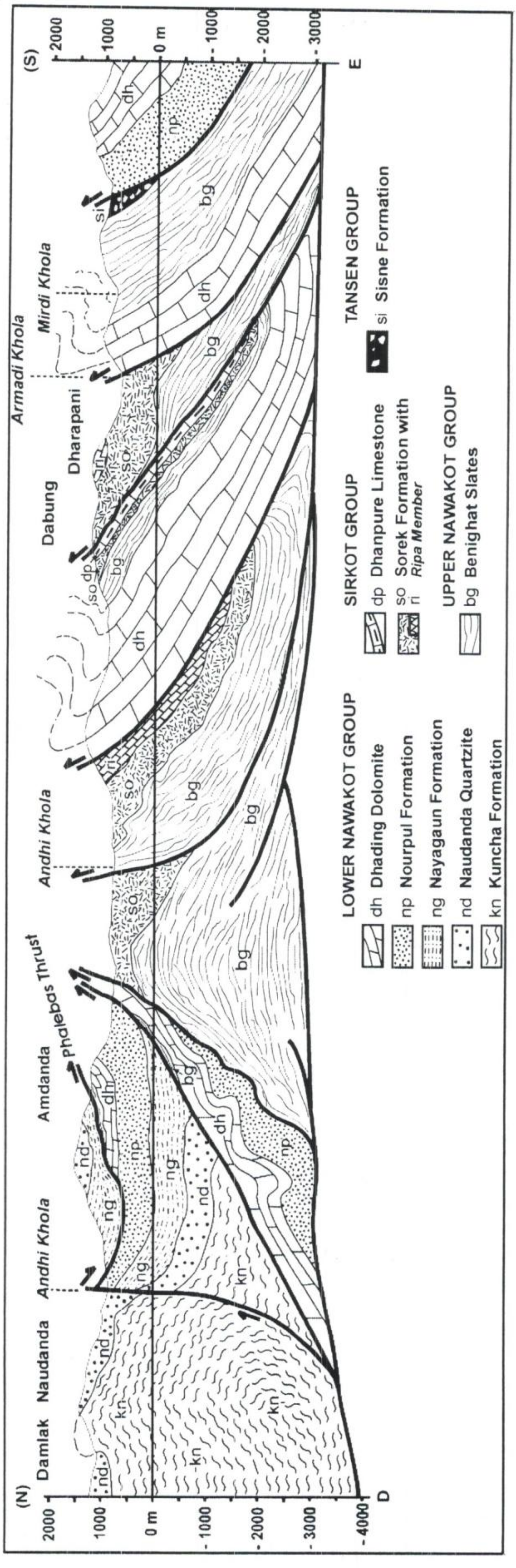

Fig. 10: Geological cross-section of the study area showing a triangle zone between the two sets of imbricate fan (see Fig. 1 for the section line AB).

rocks (i.e. the Dumri Formation) of the study area and lies between Purtighat, Setibeni, the Baye Khola, and the Ludi Khola where it terminates against the hinterland-vergent imbricate fault passing through Helu and Halale. Another triangle zone lies on the right bank of the Andhi Khola west of Uniachaur (Fig. 1 and 10).

CONCLUSIONS

Hitherto correlated carbonate rocks from the inner and outer belts of the Lesser Himalaya in Western Nepal belong to two different stratigraphic rungs. Despite their somewhat similar lithology and presence of columnar stromatolites, the Dhading dolomite lying below the Benighat Slates is older than the Sorek Formation lying above the Slates.

The Benighat Slates are comparable with the Mandhali Formation whereas the Sirkot Group is equivalent to the overlying inner Lesser Himalayan rocks of Kumaon, India. The Sirkot Group is considerably thinner than the equivalent outer Lesser Himalayan rocks of Nepal and Kumaon. This fact is primarily related to the changes in the depositional environment and absence of the uppermost thick carbonate succession. It is inferred that the Kuncha Formation, Naudanda Quartzite, and the Nayagaun Formation are of early Proterozoic age, whereas the Nourpul Formation and the Dhading Dolomite are of middle Proterozoic, and the Benighat Slates together with the Sirkot Group are of late Proterozoic age.

The MCT acted as a roof thrust covering the entire inner Lesser Himalaya of Western Nepal, and the Kusma–Syangja area was part of a complex duplex system. The imbricate faults were exposed after erosion of the roof thrust. Though there are foreland- as well as hinterland-vergent imbricate fans, the direction of tectonic transport remained essentially the same – i.e. towards the foreland.

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