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Geological History of the Daling Formation of Himalaya, Bhutan

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Abstract:
The Daling Formation of Bhutan is a significant Precambrian lithostratigraphic unit of the Lesser Himalayan Sequence of the eastern Himalaya, which holds important geological records concerning the tectono-sedimentary history of the northern continental margin of India. The Daling Formation is made up primarily of low to moderate grade metamorphosed rocks such as phyllite, quartzite, quartz-mica schist, slate, and occasional carbonaceous beds. Geologic and stratigraphic studies have established that the Daling Formation is a part of the Daling-Shumar Group, formed in the Paleoproterozoic in the shallow marine shelf settings on the passive northern margin of the Indian continent. Evidence of sedimentary features such as ripple marks and cross bedding present in the quartzitic beds suggests deposition in a stable tectonic setting prior to Himalayan deformation. The detrital zircon geochronology of sediment deposition ranges from 1.8 to 1.9 Ga, indicating the continental crust origin related to the Indian shield. Geological history of the Daling Formation was greatly altered due to the Himalayan orogenesis resulting from India–Asia continental collision event. Regional tectonic compression has led to folding, thrusting, development of schistosity and regional metamorphism. The formation is tectonically connected with major Himalayan tectonic zones, especially the Main Central Thrust (MCT) that had a major role in crustal shortening and tectonic stacking. Petrographic study of thin sections shows extremely deformed and recrystallized quartz–mica schist that is highly foliated and schistic under crossed polars. The quartz has undulose extinction and dynamic recrystallization, whereas the micas have lepidoblastic to granolepidoblastic texture. Feldspar, amphibole and opaque minerals are present in small amounts, which implies medium to high-grade regional metamorphism under directed pressure. The formation is correlated with comparable Lesser Himalayan sequences in India, Nepal, and Sikkim.

Keywords: *Geology, Himalayan, Bhutan, Stratigraphy, Daling formation, MCT*

1. INTRODUCTION

The Himalayan mountain range is considered to be among the most recently and actively forming mountain ranges in the world, and it was formed as a consequence of collision between Indian and Eurasian plates. Bhutan is situated at a key location in the eastern part of the Himalayas where there are well-exposed lithotectonic complexes. One of these units is Daling Formation, which is a member of the Lesser Himalayan Sequence that records the history of ancient sedimentation and tectonic deformation. The Daling Formation is of particular interest for geology because it contains important information about the Precambrian geologic evolution of the Indian

Plate and Himalayan Orogenesis (Bhargava, 1995). The Daling Formation is widely spread in Bhutan and neighboring areas of the Himalaya. Geologically, the formation occurs as a cover of quartzitic Shumar Formation, being overlain by Jaishidanda meta-sedimentary formation. According to the studies conducted in the area, the rocks of the Daling Formation experienced metamorphism and deformation during the process of formation of the Himalayan mountains (Long et al., 2011). The formation is interpreted as a shallow marine sedimentary succession deposited along the passive northern margin of the Indian craton prior to the India–Asia continental collision (Gansser, 1983).

2. REGIONAL GEOLOGICAL SETTING

The Bhutan Himalaya is made up of a number of different tectonic zones such as the Sub-Himalaya, Lesser Himalaya, Greater Himalaya, and Tethyan Himalayan Sequence. Different tectonic zones of Bhutan Himalaya are bounded by important thrusts such as the Main Boundary Thrust (MBT), Main Central Thrust (MCT) and South Tibetan Detachment System (STDS) (Gansser, 1983). Daling Formation is mostly restricted to the Lesser Himalayan region. The Lesser Himalaya of Bhutan is mainly composed of Proterozoic metasediments that were formed on the passive continental margin of the Indian plate. These rocks were subjected to compressive deformation, metamorphism, and southward transportation during the Himalayan orogenesis period. The Daling Formation belongs to the Daling-Shumar Group, which was formed during the Paleoproterozoic age (Long et al., 2011).

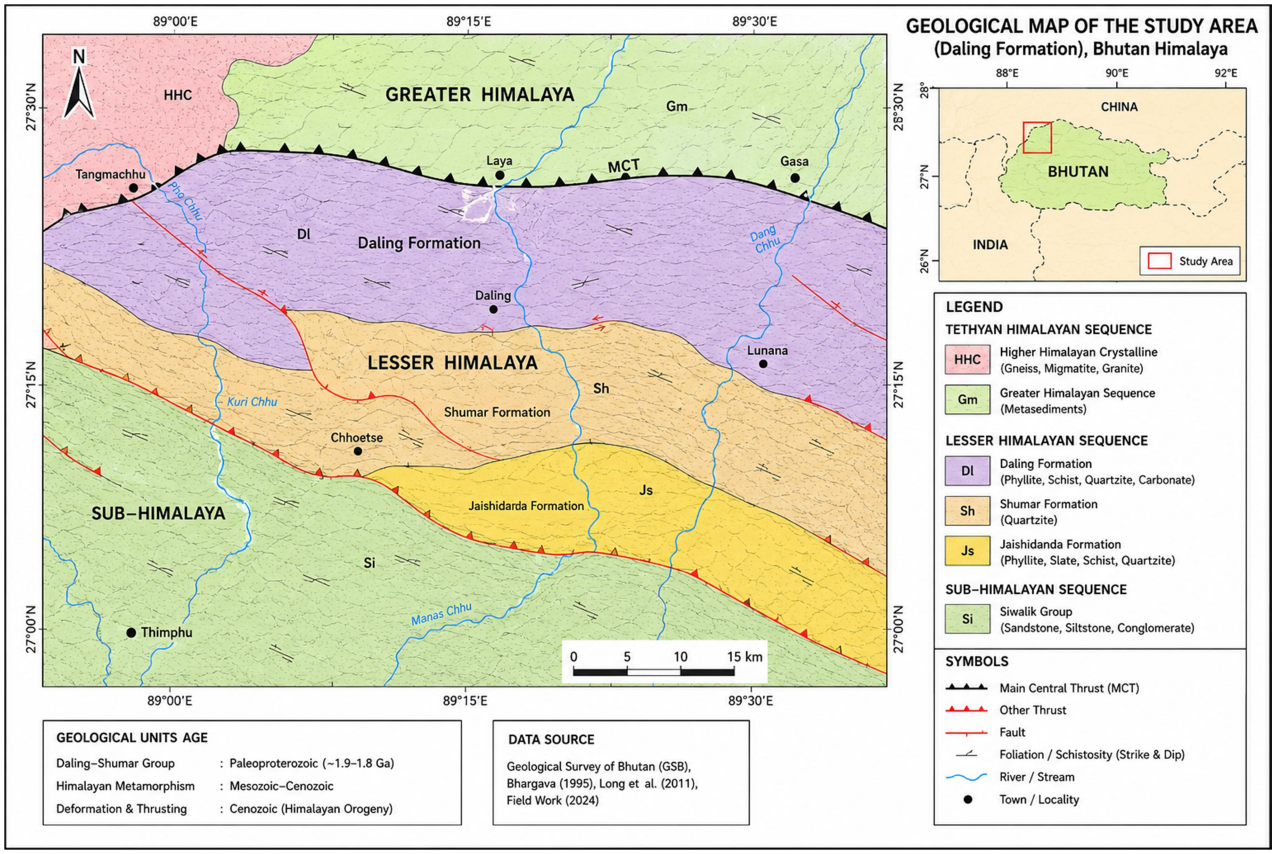

Figure 1: Geological Map of the study area

3. LITHOLOGY OF THE DALING FORMATION

The Daling Formation consists of a thick sequence of meta-sediments composed mainly of phyllite, quartz-sericite schist, quartzite, slate, and some carbonates. Garnet-rich schists and calc-silicate rocks occur locally in structurally deep zones (Ray, 1989). The rocks consist of fine-grained materials that exhibit pronounced foliations due to regional metamorphism. Veined quartzites, folded quartzite beds, and boudinage features are common in the formation. Sedimentary features like ripples and cross-beddings occurring in quartzites point out to their deposition. These features are also used to find the younging direction of deposits (Long et al., 2011). The greenschist facies metamorphism is the dominant process in the Daling Formation, but there are local zones of higher metamorphism close to structural zones like the Main Central Thrust. The deformation has led to the development of schistosity, crenulation cleavage, and isoclinal folding (Trichal & Jayaram, 1989).

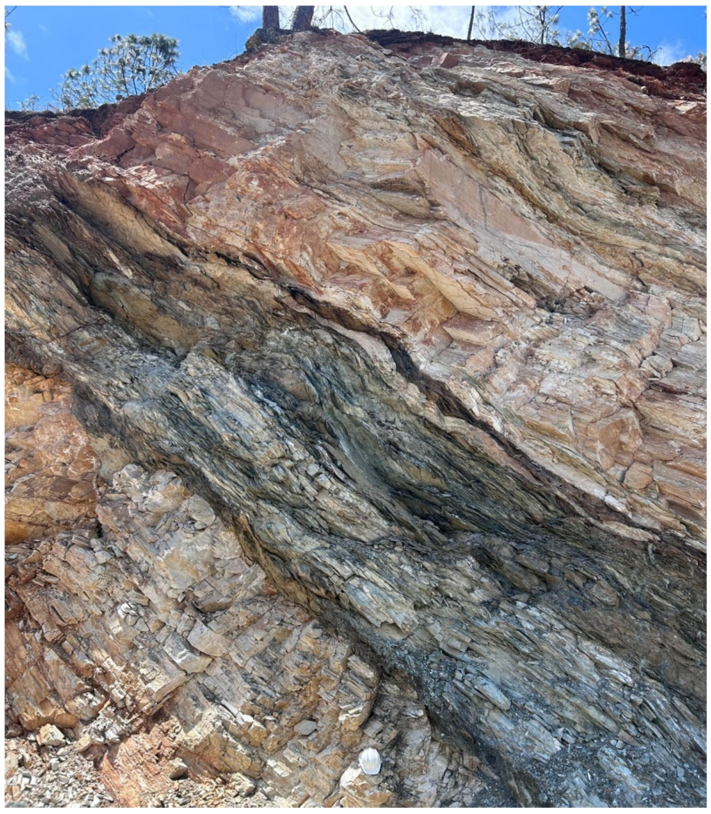

Figure 2: Field Photograph of the Study Area

4. STRATIGRAPHY AND AGE

The Daling Formation is an entity of the Daling–Shumar Group in Bhutan Himalayas. The stratigraphy of the Daling Formation includes quartzite-rich Shumar Formation below and Jaishidanda Formation above underlain by the Main Central Thrust (Bhargava, 1995). Geochronology based on detrital zircons reveals that the Daling Formation was formed in the Paleoproterozoic period. Age distribution of zircons often varies between 1.8 and 1.9 Ga, pointing out that the source rocks are derived from the continental crust of Indian shield (Long et al., 2011). All of these facts suggest that the Daling basin was formed along the passive continental margin of northern India in the Precambrian period. The sediments of the Daling Formation were probably formed in the shallow shelf marine environment with periodic influx of siliciclastic materials. The sedimentary structures in the quartzites suggest relatively stable tectonics prior to the Himalayan deformation (Gansser, 1983).

5. DEPOSITIONAL ENVIRONMENT

Daling sediments were formed on the passive margin of the Indian craton in the Precambrian era. From geological studies, it can be deduced that deposition occurred in shallow marine shelf or coastal settings, and fine clastic sediments were supplied from continents (Ray, 1989). Quartz-rich beds denote high-energy sedimentation, while phyllite beds imply low-energy sedimentation in the form of mud and silt deposits. Chemical sedimentation in carbonate interbeds is implied by the lithological combination. It signifies deposition in a stable setting of the continental margin before tectonic transformation of the northern Gondwana margin. Daling basin could have been developed through extensional tectonic activity related to Proterozoic crustal evolution (Long et al., 2011).

6. HIMALAYAN OROGENY AND TECTONIC EVOLUTION

The geologic history of the Daling Formation is related to the Himalayan orogenesis. In the Mesozoic and Cenozoic eras, the Indian plate moved towards the north and collided with the Eurasian plate some 55-50 million years ago; this led to the formation of the Himalayan mountain chain (Gansser, 1983). The Daling Formation experienced strong tectonic deformation in this collision event. The rocks were subjected to folding at a regional scale into anticlines and synclines and movement southward via major thrust systems. Regional metamorphism caused the sedimentary rocks to transform into phyllites and schists (Trichal & Jayaram, 1989). The MCT was responsible for the juxtaposition of higher grade Greater Himalayan rocks over the lower grade Lesser Himalayan rocks, such as the Daling Formation.

7. METAMORPHISM AND STRUCTURAL GEOLOGY

The Daling Formation preserves evidence of low to moderate levels of regional metamorphism through the presence of mineral assemblages like chlorite, muscovite, biotite, garnet, and quartz (Ray, 1989). Metamorphic gradation occurs at higher levels where the structural depth is closer to the tectonic shear zone. The prominent structural characteristics in the formation are foliation, schistosity, isoclinal folding, cleavage development, quartz vein boudins, and shear zones. These structures have developed through the process of Himalayan compression and deformation (Trichal & Jayaram, 1989). The direction of the foliation and folds indicate strong shortening along the north–south direction due to Himalayan convergence. Thrust tectonics are common in Bhutan Himalaya and have played an important role in the structural history of the Daling Formation (Long et al., 2011).

Figure 3: Structure feature from Field Photograph of the Study Area

8. CORRELATION WITH OTHER HIMALAYAN SEQUENCES

The Daling formation has been correlated to other Proterozoic metasedimentary series of the Himalayan region, such as the Daling group of Sikkim and Darjeeling, the Lesser Himalayan series of Nepal, and the equivalent formations of the Baxa group of northeastern India (Bhargava, 1995). The correlation has been made on the basis of similarities in lithology, age distribution of zircons, and metamorphic history of these formations. These correlations also suggest that the sedimentation was continuous within the northern continental margin of India during Proterozoic time (Long et al., 2011).

Figure 4: Hand-specimen of the Sample

9. PETROGRAPHIC REPORT OF STUDY AREA

In the current study, a scientific approach has been adopted to find out the geological and petrographical aspects of the study area. At first, the process started with carrying out an extensive review of the literature where all the relevant geological data and regional tectonic information have been gathered. After that, geological field survey has been done to make an observation of different lithology, structures, and rocks in the field. Appropriate rock samples have been collected for the laboratory examination. All these rock samples have been processed and prepared in the laboratory using various geological techniques**.**

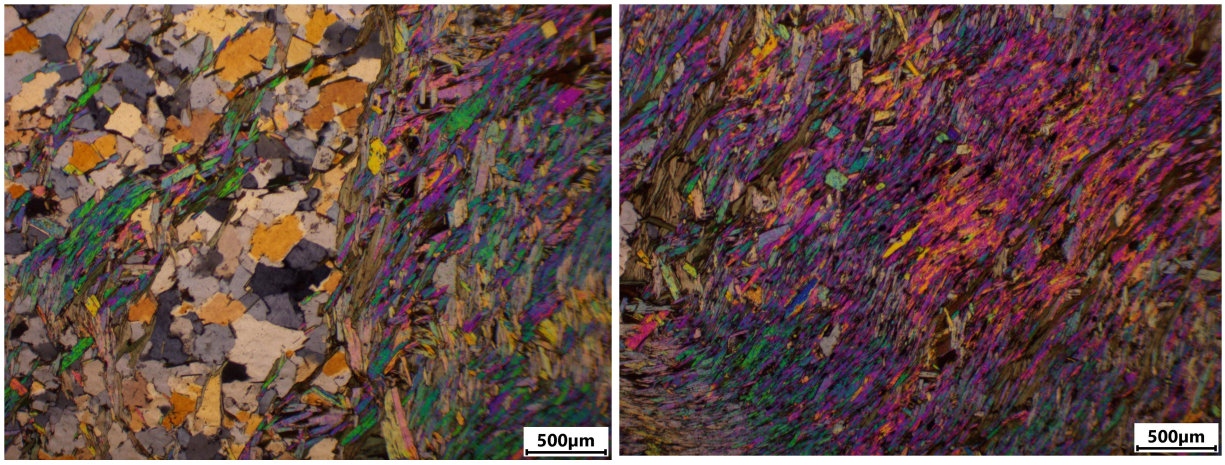

Figure 5: Micro-photographs

9.1. General Description

The thin sections reveal a well-deformed and recrystallized metamorphic rock in XPL. There is a well-developed foliation resulting from the orientation of plate-like minerals. The texture is inequigranular.

9.2. Mineralogical Composition (Estimated)

Quartz: 30-40%
Feldspar: 10-20%
Mica (Biotite ± Muscovite): 25-40%
Amphibole: 5-15%
Opaque minerals: 2-5%

9.3. Optical Properties

Quartz: Low first-order grey interference colors, undulose extinction, recrystallized grains.
Feldspar: Low-order colors, twinning locally present, altered.
Mica: Bright high-order colors, strong foliation, perfect cleavage.
Amphibole: Moderate-high birefringence, elongate grains.
Opaque minerals: Black under XPL.

9.4. Texture and Fabric

Lepidoblastic to granolepidoblastic texture. Strong foliation and schistosity. Evidence of dynamic recrystallization in quartz.

9.5. Metamorphic Grade

Medium to high-grade metamorphism (amphibolite facies likely).

9.6. Interpretation

Rock formed under regional metamorphism with directed pressure. Likely derived from pelitic or greywacke protolith.

9.7 Final Rock Name

Mica Schist (Quartz-Mica Schist)

10. RESULTS AND DISCUSSIONS

This study suggests that the Daling Formation in Bhutan is an important sequence of Paleoproterozoic metasediments in the Lesser Himalayan Sequence. From lithological data, it appears that the formation consists of mainly phyllites, quartzites, quartz-mica schists, slates, and minor carbonates indicating that the

sediments were deposited in a shallow marine shelf environment at the passive continental margin of India. The sedimentary structures such as ripple marks and cross-bedding in quartzites provide more insight into marine environment with alternating sedimentation of low and high energy regimes. The geochronological data from the detrital zircons shows that the sediments were deposited during the Paleoproterozoic period, 1.8–1.9 Ga. It confirms the continental crustal source of the sediments related to the Indian shield. Lithostratigraphic, structural, and geochronological data show that the Daling Formation is part of the larger Daling–Shumar Group and correlates with other Lesser Himalayan sequences in the Himalaya (Long et al., 2011).

Metamorphic and structural studies show that the Daling Formation witnessed extreme tectonic deformation due to the Himalayan orogenic event. Tectonic compression from the India-Asia collision caused folding, faulting, schistosity formation, and regional metamorphism of the rocks. There is clear foliation, crenulation cleavage, boudinage of quartz veins, and isoclinal folding of the rock formations, suggesting repeated phases of deformation related to crustal shortening and tectonic stacking. The petrographic study of the thin sections shows highly deformed and recrystallized quartz-mica schist having lepidoblastic to granolepidoblastic textures. Quartz has undulose extinction and dynamic recrystallization while aligned mica minerals form schistosity and foliation of the rock formation. Mineral assemblage of quartz, feldspar, biotite, muscovite, amphibole, and opaque minerals implies medium to high-grade regional metamorphism, likely to amphibolite grade in the vicinity of the Main Central Thrust. The rocks have been correlated to the similar Proterozoic sedimentary sequences of the Lesser Himalaya of India, Nepal, and Sikkim.

11. ECONOMIC AND SCIENTIFIC IMPORTANCE

Scientific significance is associated with the Daling Formation due to the preservation of records that pertain to the issues of Precambrian sedimentation, tectonic development, and Himalayan metamorphism. Scientific research into the Daling Formation allows for obtaining knowledge concerning the evolution of the Indian continental margin, crustal deformation, and Himalayan tectonics (Gansser, 1983). Also, the formation possesses some economic value in the form of resources like quartzite, carbonates, and metallic minerals. Studies on the structure of the Daling Formation have practical value in engineering geology and geological mapping of mountain regions (Ray, 1989).

12. CONCLUSION

The Daling Formation from Bhutan is a significant Precambrian metasedimentary sequence from the Lesser Himalayan Sequence. Being deposited in the Paleoproterozoic period on the passive northern margin of the Indian craton, the Daling Formation consists of shallow marine sediments, which then underwent Himalayan deformation and metamorphism. Based on lithological, structural, and geochronological data, the Daling Formation belongs to the larger Daling-Shumar Group, which corresponds to the Lesser Himalayan sequences in the Himalaya region. It should be noted that the process of Himalayan orogeny caused substantial changes to the original basin, including folding, thrusting, metamorphism, and stacking. As a result, the Daling Formation is an essential geological unit for studying the tectonic and crustal evolution of Bhutan Himalaya. Future research, which will use isotopic dating, structural, and metamorphic techniques, will further develop knowledge about the formation and its significance for the Himalayan geodynamics. According to the thin section analysis, the rock is a heavily deformed and recrystallized quartz-mica schist with pronounced foliation and schistosity in XPL. Undulose extinction and dynamic

recrystallization characterize quartz, whereas mica grains form a lepidoblastic to granolepidoblastic texture. Minor feldspar, amphibole, and opaque minerals testify to medium- to high-grade regional metamorphism under directed pressure.

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