MICROBIOTA FROM EARLY CENOZOIC SEDIMENTARY SEQUENCES OF INDUS SUTURE ZONE, LADAKH HIMALAYA

Ph.D. THESIS

by

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled "**MICROBIOTA FROM EARLY CENOZOIC SEDIMENTARY SEQUENCES OF INDUS SUTURE ZONE, LADAKH HIMALAYA**" in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Earth Sciences of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from July, 2011 to June, 2017 under the supervision of Dr. A. S. Maurya, Assistant Professor and Dr. Sunil Bajpai, Professor, Department of Earth Sciences, Indian Institute of Technology Roorkee, Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institution.

(SANJAY KUMAR VERMA)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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Date:

ABSTRACT

The zone of collision between Indian and Eurasian plate is known as Indus Suture Zone. Indus Suture Zone exposes thick succession of lower Cenozoic sedimentary sequences, which holds important clues to understand the early history of India-Asia collision and the final closure of the intervening Neo-Tethys. These sedimentary successions are broadly divided into two stratigraphic units, (a) Older stratigraphic unit, formally known as Indus Flysch/Indus Tar Group ,and (b) Younger Ladakh Molasse, formally designated as Indus Molasse/Indus Group. These sequences spread in a long arcuate belt along the southern margin of the Trans-Himalayan volcanic arc, extending eastwards from Kargil township through Nyoma in eastern Ladakh. Stratigraphically, these sedimentary rocks are folded, faulted and rest unconformably over the granitoids of the Ladakh. At places, these sequences also overlie unconformably over the Indian passive margin units, ophiolitic mélanges etc. However, in some areas, such as along Zanskar river, these horizons are believed to have a conformable relationship with the underlying Nindam Formation. Investigation of microbiota from these sedimentary sequences may provide useful information regarding change in landscape, regional biotic events. As a step in this direction, a putatively early Cenozoic sedimentary package, particularly terminal marine to early terrestrial sequences was studied.

During the course of this work, several forms of larger bethic foraminifera were recovered and represented by different species of *Assilina*, *Nummulite*s, *Discocyclina*, *Alveolina* etc. Systematic biostratigraphy of larger benthic foraminifera reveals that Sumdo Formation was deposited in earliest Eocene, while Nummulitc milestone was deposited in late Yepressian. Sumdo Formation can be correlated with the Upper part of Ranikot Formation of Pakistan, upper part of Patala Formation, while Nummulitic Limestone Formation can be correlated with upper part of Kong Formation of Zanskar Basin, Renging Formation of Arunachal Pradesh etc. Overall faunal assemblage (*Nummulite-Assilina* dominant and coral absences) of Sumdo Formation suggests a warmer climatic condition, in which deposition has taken place from fore to inner platform setting, while Nummulitic Limestone Formation is represented by *Assilina*, *Nummulites escheri, Alveolina* sp., micro gastropoda genus: *Turritella* sp., coral: *Coleilonus elongates* etc., suggest a backreef to lagoonal environment of deposition. Recovered bio assemblages from basal Molasse deposits of Ladakh includes vertebrates: fish teeth, fish scale and vertebra, representing Cyprinidae: *Barbus* sp., *Schizothorax* sp., *Cyprinus* sp., *Squalius* sp., rodents, crocodilian tooth

etc. Hence, the microfossils and their association suggests a typical fresh water environment of deposition for basal molasse horizons, which militates changes in landscape from marine to freshwater regime, a complete disappearance of Neo-Tethys due to the Himalayan tectonics, and final suturing between Indian and Asian plates. The occurrence of these fresh water fossil assemblages from basal molassic stratigraphic unit in eastern (Nyoma and Liyan areas), central (Taruche, Saspochey and Basgo areas) and western (Kargil area) Ladakh, along the Indus Suture Zone, also shows close similarity with stratigraphical arrangement, that suggests that fossiliferous molasse deposits of these areas may be homotaxial in nature. Presence of mammals *Juxia*, *Hyoboops*, *lberomeryx* rodents, charophytes, ostracods and palm leaf points that terrestrial link was established between the Indian and Asian landmasses by the time of deposition of Ladakh Molasse, that facilitated the dispersal of the above taxa from Asia to the Indian subcontinent.

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CHAPTER 1
INTRODUCTION

1.1 PROLOGUE

The Early Cenozoic sedimentary record has become the focus of considerable interest among geoscientist. This interval begins with one of the most destructive volcanic eruptions (Dreccan Volcalism) on earth surface. The Paleocene/ Eocene (P/E) transition of Cenozoic Era is now considered as one of the most critical turning points because it records highest atmospheric temperature and by enlarge earth's surface was free from any permanent ice-sheets. This warming episodes manifested itself in the form of several short lived hyperthermal events noted worldwide and commonly known as the Paleocene-Eocene Thermal Maximum or the PETM (~55.5 Ma), second Eocene Thermal Maximum or ETM2 (~53.7 Ma) and H2 event (~53.6 Ma) (Aubry et al., 1996; Gingerich, 2006; Lourens et al., 2005; Miller et al., 1991). The early Cenozoic time interval is also witnessed a gradual transformation from greenhouse to icehouse (Kennett and Stott, 1991; Nicolo et al., 2007; Stap et al., 2009; Zachos, 2001; Zachos et al., 2008). The noted shifting of climate from greenhouse to icehouse is also known as doubt-house world (Miller et al., 1991). The Cooling trend reversal has been noticed between ~40.6 to 40.0 Ma and this interval is known as Middle Eocene Climatic Optimum (MECO) (Zachos and Bohaty, 2003; Bohaty et al., 2009; Sexton et al., 2006). Further, a period of step-wise cooling occurred between ~33.5-34 Ma and popularly known as Eocene - Oligocene Transition (EOT) (Shackleton and Kennett, 1975; Coxall et al., 2007).

During the PETM, temperatures of sea surface increased ~ 5°C to 8°C. Several organisms including benthic foraminifers show extinctions and diversifications through P-E boundary (e.g., Pak and Miller 1992; Gibbs et al. 2006; Thomas 2007; Petrizzo 2007). However, beginning of the PETM include the rather sudden appearance of several modern orders of mammals, marked extinction of ~40% of benthic foraminifera in deep sea (BEE; Pak and Miller 1992) and a negative shift in Carbon Isotope. The larger benthic foraminifera (LBF) that evolved in late Paleocene and diversified through the lower to middle Eocene in a shallow marine ecosystem like gradual disappearance of Paleocene genera *Ranikothalia* and *Miscellanea* and the rise of genera *Nummulite*s and *Alveolina* during early Eocene (Scheibner et al., 2005). It is important to note that the biotic events are detrimental to life at the time; they can be extremely useful tools for biostratigraphy, which provides useful horizons for regional to local correlation. Additionally, certain biotic events are useful analogues to understand the future environmental perturbations.

1.2 DEFINITION OF PROBLEMS

The early Cenozoic interval in the history of the Earth is also noted for large-scale plate reorganisation believed to be associated with a change over from the Laramide tectonic regime ('Old' crustal configuration) to the Himalayan tectonic regime ('New' crustal configuration) (Jauhri and Agarwal, 2001). The manifestation of land mark features on the earth's surface the birth of Himalaya due to the continent-continent collision between Indian and Asian landmass and landmass considered as one of the largest orogenic event in ~500 Ma (Wu et al., 2007). Interestingly, it has also been suggested that the Himalayan Orogeny triggered some of early Cenozoic climatic and biotic changes (e.g. Beck et al., 1995), supposedly played a vital role in altering drainage pattern of major rivers (Brookfield 1998), ocean water chemistry, channels and currents (Richter et al. 1992). The upliftment of Himalaya was also responsible for establishment of Indian monsoon circulation system during the late Paleogene-early Neogene period. Despite this the understanding of lower Cenozoic evolution of the upliftment of Himalaya was also system is very scanty and patchy. Stratigraphy ascribed to the intervening span of late Paleocene-Eocene-Oligocene-early Miocene instills ambiguity to the sequence of events widely credited for Himalayan evolution. The precise understanding of the events and pace of deformation due Himalayan orogeny requires more data from many more section.

In India, the Indus Suture Zone of Ladakh Himalaya preserve excellent lower Cenozoic sedimentary sequences spread in approximately 2000 km long arcuate belt along the southern margin of the Transhimalayan magmatic arc, extending eastwards from Kargil Township through Nyoma in eastern Ladakh into South Tibet. Stratigraphically, these sedimentary rocks are folded and thrusted and consist of mainly carbonate and clastic sediments that locally rest unconformably on the granitoids of the Ladakh Batholith. At places, these sequences also unconformably overlie the Indian passive margin units (Lamayuru Group), ophiolitic mélanges, and the Cretaceous Dras/Kohistan Arc (Figure 2.1), In some areas such as the Zanskar Gorge, south of Sumda-Do these horizons are believed to have a conformable relationship to the underlying Nindam Formation of late Cretaceous-Paleogene age (Tonarini et al. 1993; Robertston and Dengan 1994; Robertston 2000; Clift et al. 2002a). These sequences includes the shallow Marine to terrestrial sediments, are deposited in the forearc to intermonate basin (Henderson et al, 2010). It is important to note that these sedimentary sequences represents the suture zone between Indian and Asian continent so study of micro biota from these sequences has a great significance in understanding the early history of India-Asia collision. Yet, the timing of the initiation of the collision remains poorly understood and range from the late Cretaceous to latest Eocene with little consensus. Therefore, the age of diagnostic microfossil particularly from marine to terrestrial transition facies allows to finesse the understanding towards the timing of final closure of the intervening Neo-Tethys ocean basin and timing of final suturing between India and Asia.

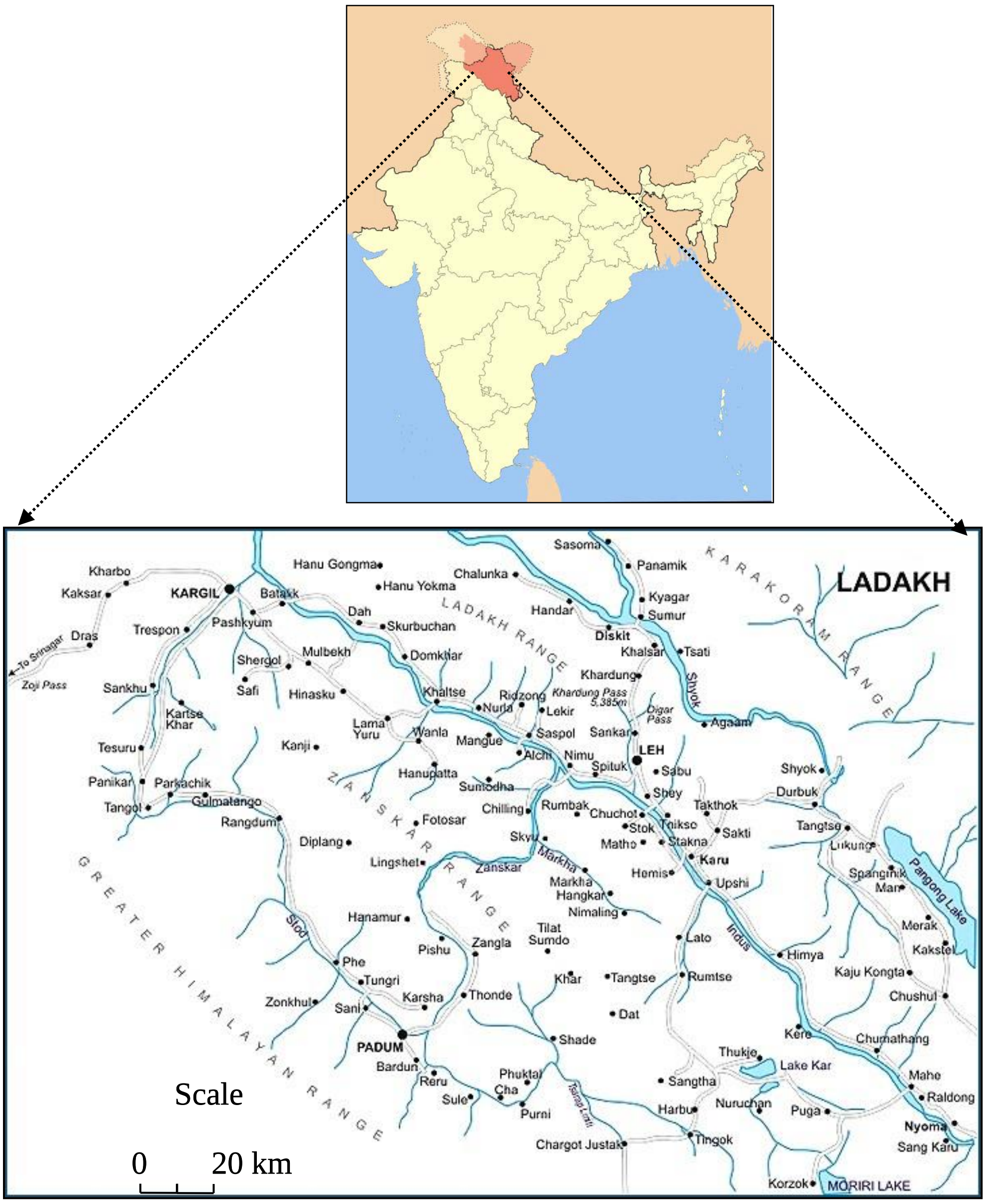

Figure 1.1. Geographical map showing the location of study area of Ladakh in NW India.

As a forward step in this direction, a putatively early Cenozoic sedimentary package, particularly terminal marine to early terrestrial/fluvial sequences within the suture zone, Indus basin, Ladakh Himalaya (Figs. 1.1 and 2.0). Present work was systematically investigated with emphasis on its biotic content to determine the regional biotic events, environment of deposition sedimentary sequences present in Indus Suture Zone (ISZ). Besides it, questions concerning i) correlation of molassic sequences in the eastern and western regions of Ladakh and ii) sub-aerial connections and faunal exchange between the contemporaneous terrestrial communities of the Indian and Asian landmasses in context of out-of-India or in-to-India hypothesis has also been also investigated on the basis of recovered fossil assemblages from the Indus Suture Zone (ISZ).

1.3 OBJECTIVES

Against the above background, the present work was carried out in a number of selected lower Cenozoic sections (see list below) across the Indus Suture Zone Ladakh, Himalaya, northwest India. The objectives pursued in this regard are as follows:

- To study systematic taxonomy of the recovered microbiota for proper identification and biochronologic implication.
- To reconstruct the paleoenvironment of studied sections based on the recovered microbiota.
- To understand the tectono-stratigraphic evolution of the lower Cenozoic sedimentary sequences to access the timing of the closure of the Neo Tethys Ocean and development of earliest land bridge between India and Asia.

1.4 METHODOLOGY

The present work is based on both field and laboratory work. A total of 425 kg of samples were collected from various localities and processed for recovery of microbiota (vertebrates and invertebrates).

1.4.1 FIELD PROTOCOL:

- Recognisance survey, demarcation of different stratigraphic units and selection of locality (Ridge, River, Road, Nala section etc).
- Delineation across and lateral tracing of Fossiliferous lower Cenozoic horizons in the selected sections of central, western and Eastern Indus Suture Zone of Ladakh Himalaya, NW India: Nimu-Sumdo-Chilling, Upshi-Lato,, Hemis, Trauche, Saspoche, Nyoma, Liyan (District Leh,); Kargil, Pashkyum (District Kargil); Jammu and Kashmir.
- Identification of litho-units, section measurement, making brief litholog and systematic bed rock sample collection at close stratigraphic intervals (up to 5cm) in different stratigraphic sections.

- Intensive surface prospection at promising localities for recovery of megafossil if any.

1.4.2 LABORATORY WORK:

- Screen washing of soft lithologies (e.g. clay/claystone) from promising sections for recovery of microfossils.
- Processing of relatively hard lithologies using chemical and mechanical methods in the lab.
- Random petrographic thin sections and selected oriented thin sections for the study of larger benthic foraminifera.
- Taxonomic identification using both Scanning Electron Microscopy (SEM) and optical microscopy.
- Palaeontological data integration and interpretation

1.5 LABORATORY METHODOLOGY FOR MICROFOSSIL RECOVERY:

All laboratory related work was performed in the Micropaleontology laboratory, Department of Earth Sciences, Indian Institute of Technology Roorkee and Microfaunal were recovered through maceration and thin section technique.

1.5.1 MACERATION TECHNIQUE:

The main aim of the sample processing technique is to separate the microfossils from the rock sample without damaging the fossils. Two methods were adopted for maceration. 1. For loose lithology such as claystone, mudstone samples were first soaked with kerosene for about of 7-8 hours. After this the kerosene was drained out and material was again immersed in tap water. This caused the kerosene to be forced out of the matrix and replaced by water. As a result, the material was disintegrated into a mud slurry. After about 24 hours the slurry was diluted by adding more water and the screening and washing process carried out under running water. 2. In the case of hard samples first, rock samples was taken in a labelled beaker. The sample were then treated with hydrogen peroxide (H_2O_2) and water in the ratio of 1:3 for 6 hours then Ammonia solution is added in addition to hydrogen peroxide (Quato solution). After nearly 6 hours the sample is boiled with water for about 20 minutes. All rock samples with a high siliceous content were treated with 30 % aqueous solution of hydrogen peroxide until most of the siliceous material is dispersed. The sample was then washed over standard sieves of ASTM 100, 200 and 230. As a result, the fine clay particles were washed off and a clear suspension of the sample was obtained. The screened sample was then transferred into the oven at 50^0C for drying. Once the sample were dried it had been taken into labelled sample bags according to their mesh size.

The examination of the samples begins with coarser fraction. It was spread carefully on the sorting tray and observed under the stereozoom microscope. An assemblage slide of 12 chambers was taken to keep the picked fauna using wet fine brush (000 size) and botanical needle.

1.5.2 Thin section preparation technique

The larger benthic foraminifer (LBF) identification and classification is largely based on their internal morphological features. Due to this reason, they were studied in thin section. The sections were generally studied mainly equatorial plane (horizontal) and the axial (vertical) plane. To prepare thin section for both vertical and equatorial plane frosted slide was placed upon a hot plate or hold over burning lamp and once it got warm a small piece of Canada Balsam (CB) was placed upon the slide. When CB melted the LBF was then placed onto the CB and the slide removed from the hot plate. Before the CB cooled the LBF was manipulated under the microscope using a mounted needle until CB came in horizontal position. The slide was then placed to cool and the CB sets. The thin section could be ground then on fine, wet, silicon carbide paper (800 to 1200 grade) over glass plate. Then slide were washed and progress had been checked frequently under the microscope to see how close the proloculus is. Once near the proloculus or when the proloculus/equatorial layer had been seen the slide was washed then dried and returned to the hot plate. When the CB has fully melted the LBF can be flipped using the pin or needle so that the flat side is "safe" against the slide and can be ground no further. Under the microscope the LBF was then gently pushed down into the CB using the pin to make sure it remains flat against the slide whilst the CB cools to room temperature. The precaution taken to avoid bubbles under the LBF. The grinding process was repeated on the new side until only a thin section through the equatorial/axial layer remains. If the original side was not close enough to the equatorial/axial plane the CB was melted and the LBF flipped again and ground on the original side, and this process were repeated until the equatorial/axial layer properly seen. The LBF position and orientation were also adjusted during the process by re-melting the CB. The slide was s labelled and studied under microscope for identification.

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1.6 SECTIONS UNDER STUDY

The General Geology of investigated lithosection in this work has been discussed in chapter-2 and Paleontology in chapter-3 However, a brief introduction to the sections investigated for this doctoral dissertation is as follows

1.6.1.0. Along the River Zanskar, District Leh (Jammu and Kashmir)

These sections located along the Zanskar river between the village Nimu and Chilling where stratigraphic horizons like Jurutze, Sumda, Chogdo and Nummulitic Limestone Formation of Tar Group and Nurla, Choksti, Nimu Formation of Indus Group. The locality of section is easily accessible from a metalled road that diverges from the Nimu village (Nimu 34° 12′ 0″ N, 77° 20′ 0″ E) from Leh-Srinagar highway and located 35 km away from Leh town, Jammu and Kashmir, India. Though in this region number of sections has been studied (table 1.1) but microfossils have been recovered from only Sumdo section-3 and Nummulitic limestone section-2.

Table 1.1. Measured section of different stratigraphic units along the River Zanskar, District Leh, and Ladakh.

GPS Locations	Name of studied section	Stratigraphic unit
N34° 02.459', E° 77 12.605'	Jurtze section-1	Jurtze Formation
N34° 04.43', E° 77 12.32'	Sumdo section-1	Sumdo Formation
N34° 06' 12.7", E 77 12' 49.6"	Sumdo section-2	
N34° 06' 12.9", E 77 12' 45.5'	Sumdo section-3	
N34° 07' 29.8", E 77° 14' 09.5"	Nummulitic limestone section-1	Nummulitic Limestone Formation
N34° 07' 29.8", E 77° 14' 09.5"	Nummulitic limestone section-2	
N34° 06' 45.8", E 77° 13' 05.3"	Chogdo section-1	Chogdo Formation
N34° 07' 43.1", E 77° 14' 27.1"	Nurla section-1	Nurla Formation
N34° 08' 14.4", E 77° 16' 48.5"	Chokasti section-1	Chokasti Formation
N34° 08' 33.9", E 77° 17' 18.6"	Chokasti section-2	
N34° 09' 12.1", E 77° 18' 15.9" ,	Nimu section-1	Nimu Formation
N34° 10' 28.4", E 77° 20' 13.1"	Nimu section-2	

Brief account of these fossiliferous section has been described as follow:

1.6.1.1. Sumdo section-3

This section is located just south west of village Sumdo at N34° 06' 12.9", E 77 12' 45.5" (fig. 2.4 and 2.5) along the left bank of Zanskar river. The rock unit exposed in this section belongs to Sumdo Formation and conformably overlain on underlying Jurtze

Formation and comprises fossiliferous limestone, calc-shale and medium-coarse grained sandstones and beds mainly dip subvertically.

1.6.1.2. Nummulitic Limestone section-2

This section is located 18 kms south of village Nimmu located at N34° 07' 29.8", E 77° 14' 09.5" (fig.2.4 & 2.6.). The rock unit exposed in this section belong to Nummulitic Limestone Formation and conformably overlain by Nurla formation and on underlain by Chogdo Formation and comprises fossiliferous to crystalline limestone, interbedded with sandstones, siltstone and pebble limestone.

1.6.2.0. Near the Village Basgo- Taruche and Saspoche

These sections located along the Road and Nala section between the village Basgo and Saspoche where stratigrphic horizon: Basgo and Temesgam Formations of Indus Group exposed. This section is easily accessible from an unmetalled road that diverges from the Village Basgo - Leh (Basgo is situated 42 km west of Leh along the way to Srinagar) road towards the Trauche-Saspoche area. The following sections has been studied in this area:

1.6.2.1. Basgo section-1

This section is located between the village Trauche and Saspoche at N34° 16.90', E 77° 10.496" (fig 2.7 and 2.8). The rock unit exposed in this section belong to Basgo Formation and unconformably overlain on Ladakh granitoid and consist of claystone, mudstone, siltstone, sandstone, conglomerate and conglomeratic sandstone. At this location beds are folded and the attitude of right limb bed is measured as 130°/35° dipping South-Westerly.

1.6.2.2. Trauche sections-1 and 2

These sections are located south of the village Trauche at N34° 16.30', E 77° 11.573" and N34° 16.266', E 77° 11.58" (fig 2.7 and fig 2.9) respectively. This section is easily accessible from an unmetalled road that diverges from the Village Basgo - Leh (Basgo is situated 42 km west of Leh along the way to Srinagar) road towards the Trauche-Saspoche area. The studied rock unit in these sections belongs to Basgo Formation and comprises claystone/mudstone/ siltstone, sandstone, conglomerate, conglomeratic sandstone etc.

1.6.3.0..Near the Hemis Monastery Section-1 and 2

These sections are located near Hemis Monastery at latitude-loggitude 33° 54' 48.96"N, 77°42'13.07"E (section-1) and 33° 54' 48.96"N, 77°43' 8.79"E (section-2) respectively. These sections are accessible from an unmetalled road that diverges from the Leh-Basgo road towards Hemis area. The studied rock unit in these sections belongs to Hemis Conglomerate Formation and comprises sandstone, conglomearte, conglometric sandstone, siltstone etc. Here fragmentary palm leaf is observed from sandstone unit of Section-1 and Section 2.

1.6.4.0. Near the Zingche area Section-1

These sections are located in Zingche area at 34° 7'10.39"N, 77°24' 50.74"E (section-1). The attitude of bed is measured as 135°/82° dipping westerly. The rock unit belongs to Choksti formation and comprises cross bedded sandstone, sandstone, carbonaceous shale, massive sandstone etc. The charcolyfied wood and wood burrows has been observed at this section.

1.6.5.0. Wakka Chu River and Kargil sections (district Kargil, Jammu and Kashmir)

1.8.5.1. Pashykum section

This section is located adjacent to Pashykum village near wakka chu river located at N34° 30' 29.05", E 76° 09' 19.77" (fig. 2.12 and 2.13). The rock unit exposed in this section belongs to Pashkyum Formation and comprises red shale, siltstone, conglomerate etc.

1.6.5.2. Kargil section:

This section is located along the Kargil-Batalik road near Kargil town at N34° 33' 29.05", E 76° 09' 19.77'77" (fig. 2.12 and 2.14). This rock unit belongs to Kargil formation and comprises brownish-grey shale, silstone/claystone, sandstone, conglomeratic sandstone, red-purple shale and attitude of bed is measured as 135°/21° dipping westerly.

1.6.6.0. Liyan Gompa Section (district Leh, Jammu and Kashmir)

This section is located 750 m to the north of the Liyan Gompa (figure 2.14 & 2.16) and is exposed in a dry riverbed at N33° 06' 26.3", E 78° 32' 43.7'. It is around 190 kms from Leh and can be accessible from a metalled road that diverges from 1 km before Nyoma village, (Leh-Nyoma road) towards Nidar-Liyan Gompa area. The exposed rock unit belongs to Liyan Formation and comprises clay/shale, sandstone/siltstone, sandstone and conglomeratic sandstone etc. and attitude of beds in the section measured as 180°/30^0 N.

1.6.7.0. East of Nyoma Sections (district Leh, Jammu and Kashmir

These sections located (fig. 2.14 and 2.15) in around Nyoma a small town and tehsil Nimu and Chilling where stratigraphic horizon Kargil Formation overlying above the Ladakh granitoid. These section can be easily accessible from a Leh- Nyoma metalled road. Total six sections measured at GPS location: N33° 10' 54.3", E 78° 39' 37.1", N33° 10' 51.7", E 78° 39' 26.9", N33° 11' 1", E 78° 39' 3.4", N33° 10' 59.5", E 78° 39' 4.4", N33° 11' 42.9", E 78° 33' 54.9" but only section at33°10'55.44"N, 78°39'35.05"E yielded fossil. The rock unit exposed in this section belong to Kargil Formation and unconformably overlain on Ladakh granitoid and comprises claystone/mudstone/siltstone, sandstone, and shale.

1.7. REPOSITORY

The entire fossil assemblage described in this dissertation is housed in the Micrpaleontology Laboratory, Department of Earth Sciences, Indian Institute of Technology, Roorkee under the acronym IITR/MF/ISZ/2011.

CHAPTER 2
GEOLOGICAL SETTING

The Himalayan orogenic belt is the result of Cenozoic Indo- Eurasian plate collision (Gansser 1974, Yin and Harrison, 2000; Aitchison et al., 2008) and represents one of the youngest and the highest mountain range in the world. In Indian Shield, it is bounded by the Indus in the west and Brahmaputra in the east, with diversity in lithology, stratigraphy and tectonic history. Himalayan mountain range spread along 2400 km from the Baluchistan Arc in the west to the ArakanYohna range in the east and across 240-325 km between the great Indo-Gangetic-Brahmaputra plains in the south and Tibetan Plateau in the north (Gansser, 1974).

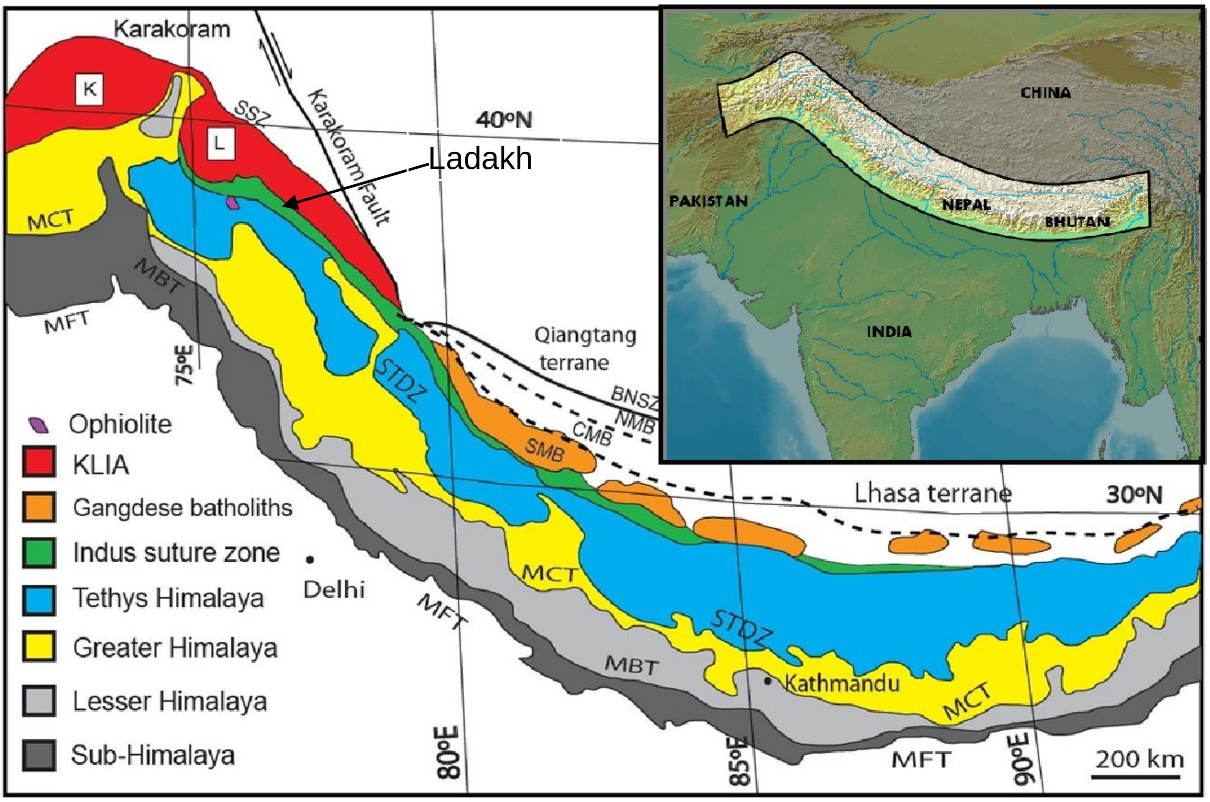
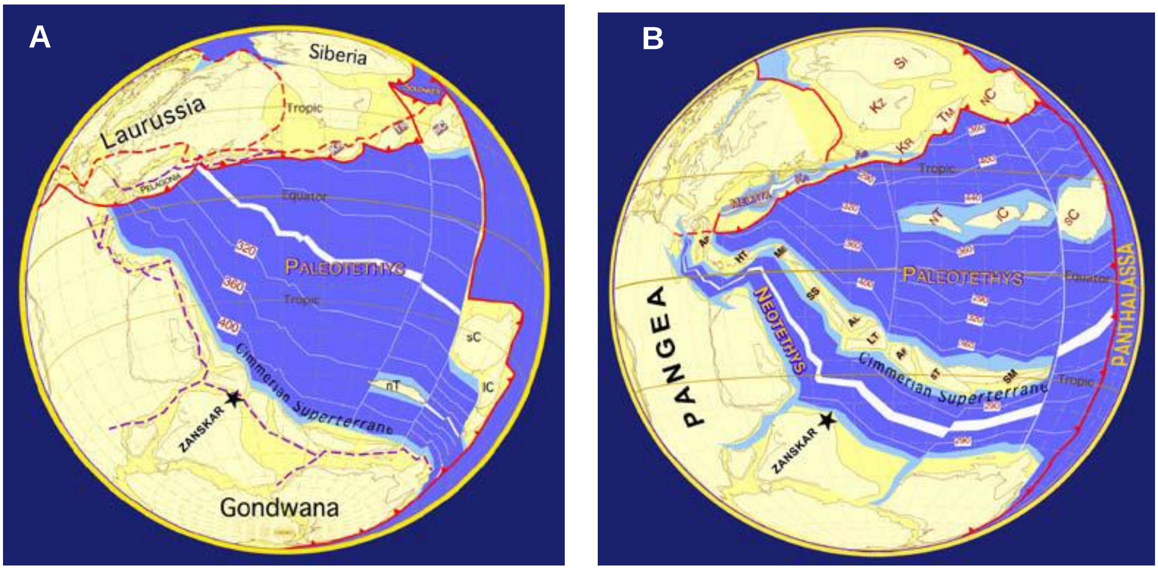


Figure 2.0. Geological map of the Himalaya showing Indus Suture Zone (ISZ) (modified from Najman et al. 2017). KLIA – Kohistan (K) and Ladakh (L) Oceanic Island Arc; STDZ = South Tibetan Detachment Zone; BNSZ = Bangong–Nujiang Suture Zone; MCT = Main Central Thrust; MFT = Main Frontal Thrust; MBT = Main Boundary Thrust; SSZ = Shyok Suture Zone; SMB = Southern Magmatic Belt of the Lhasa Terrane; NMB = Northern Magmatic belt of the Lhasa Terrane; CMB = Central Magmatic Belt of the Lhasa Terrane. Inset: location of the region in its: Showing Himalayan range.

It has been divided into the western, central and eastern Himalaya along strike length and Sub, Lesser, Greater and Tethys Himalayan zone from south to north across the Himalayan trend (Fig. 2.0). Present work is confined to the north of Trans Himalaya within the Indus Suture Zone (ISZ), which represents a zone of collision between the Indian plate and Asian plate, along which the oceanic crust of Neo-Tethys was subducted beneath the Trans-Himalayan Arc. Ladakh granite range in north and the Precambrian- Eocene Zanskar passive margin sediments in south bound ISZ. ISZ extends for about 2500 km from the west to the east, separating the Himalaya from the Tibet Plateau, representing Indian and Asian (Eurasian) plates respectively

2.1 EVOLUTION OF HIMALAYA



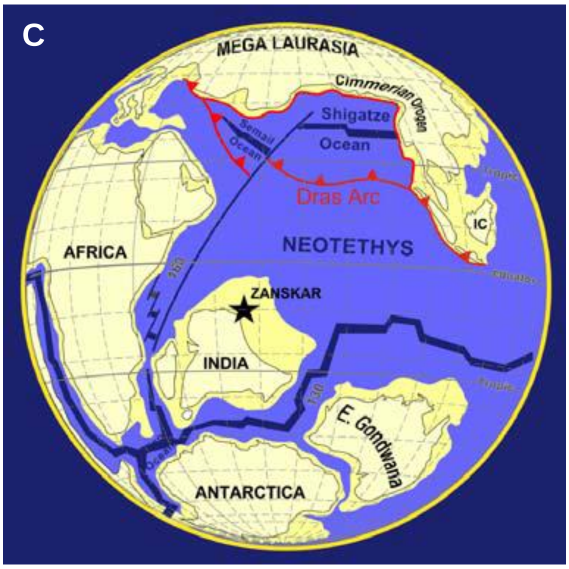


Figure 2.1. Paleogeographic reconstruction of Indian plate: **(A)** Position of India in early Permian **(B)** Position of India at Permian-Triassic boundary **(C)** India in the Cretaceous when it was separated from Africa and East Gondwana (based on Dèzes 1999; Patriat and Achache 1984, Brookfield, 1993; Ricou, 1994; Rowley, 1996; Stampfli et al. 1998 and

The Indian subcontinent was a part of Gondwana, bounded by Cimmarian superterranes towards the North in late Precambrian and early Paleozoic (Fig. 2.1A). At Early Carboniferous time period, rifting started between the Indian continent and the Cimmerian Superterranes. The Cimmerian Superterranes drifted away from Gondwana towards the north and Neo-Tethys formed between them (Figure 2.1B). The Indian continent, along with Australia and Antarctica, was split from the rest of Gondwana by a major rifting event in the Norian, around 210 Ma, to form East Gondwana (Figure 2.1C). East and West Gondwana separated from one another, with the creation of an oceanic crust between them, in the Callovian (160-155 Ma), and the Indian plate broke off from Australia and Antarctica in the Early Cretaceous (130 - 125 Ma) with the opening of the "South Indian Ocean" (Dèzes 1999). The Indian continent moved northward at an average speed of 15 cm/year, covering a distance of 6000 km (Figure 2.2A; Dèzes 1999), leaving behind pronounced spreading ridge at the trailing edge of India (Figure 2.2 B). Meanwhile a series of volcanic arcs, including the Ladakh-Kohistan arc terrane, had formed in the northern part of the Neo-Tethys. As the Indian plate continued to move northward, the Neo-Tethys crust was subducted beneath Ladakh-Kohistan and the Asian plate.

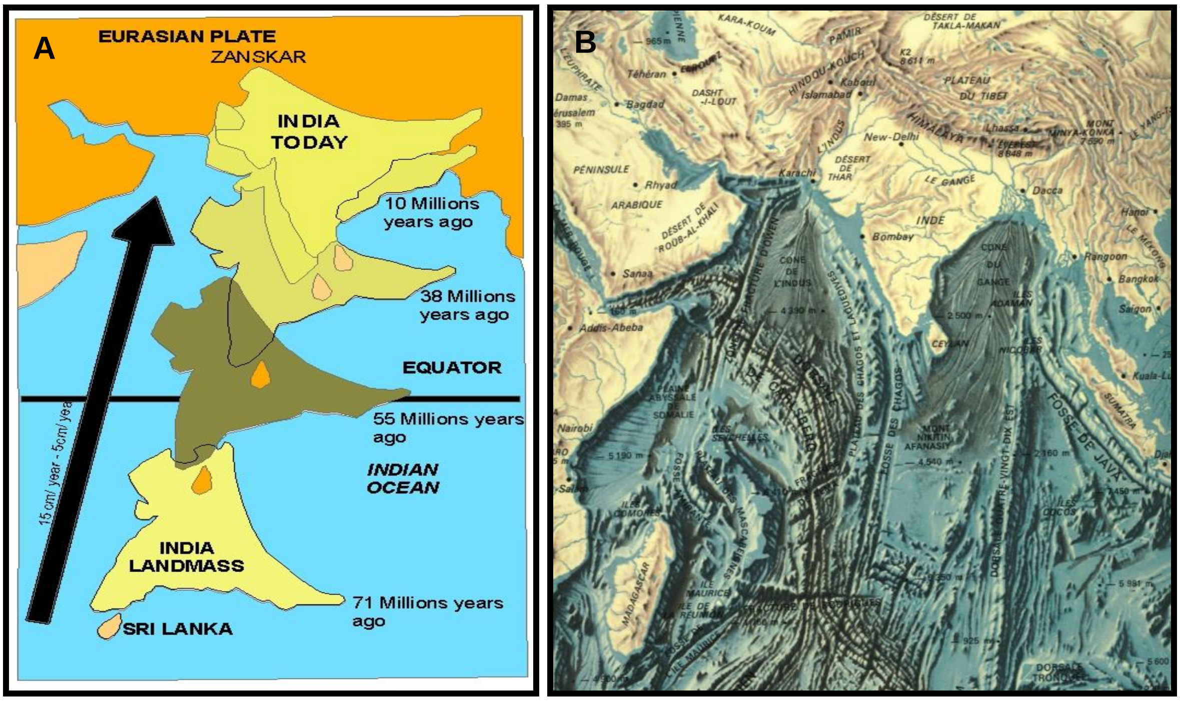


Figure 2.2 A. Northward drift of India through time (in million years,ago), **B.** The new Indian Ocean at the trailing edge of India. The Mid-Ocean spreading ridge forms a prominent topographic high dissected by transversal faults (after Patriat and Achache 1984).

The Indian continental lithospheric plate crashed into the Eurasian continental lithospheric plate between 70 and 50 Ma created the Himalayas (Weinberg and Dunlap 2000; Yin and Harrison, 2000).

2.2 GEOLOGICAL SETTING OF STUDY AREA

Study about geology of Ladakh, NW Himalaya has been started since middle of the 19th century (Stoliczka, 1866; Drew, 1875; Lydekker, 1883; Oldham, 1888; Mc Mohan, 1901; Hayden, 1909; Dainelli, 1922, 1933-1934; De Terra, 1932, 1935; Wadia, 1935, 1937; Heim and Gansser, 1939; Berthelson, 1951, 1953) and the work of these researchers provided a foundation to the general geology of the Ladakh region. There are huge list for the contribution in geological account of the Ladakh area. However, some of major work is summarised in (table no. 2.1).

Table 2.1. List of key authors who have contributed stratigraphical and Palaeontological information for the Indus Suture zone , Ladakh**.**

Author/s	Contributions
Stoliczka (1866)	Recorded fresh water gastropod genus Melania from the Paleogene (earlier used as Tertiary) sediments of Kargil formation Kargil area.
Drew (1875)	Documented a palm leaf of Sabal along with fresh water mollusc genus Unio from the Kargil area.
Lydekker's (1883)	Recorded the Nummulites from Paleogene rock of Kargil area and referred the Paleogene (earlier used as Tertiary) Rocks of the area to Indus Flysch and produced first geological map of the Ladakh area.
Middlemiss (1921)	Mapped the area between Kargil and Hamboting La and assigned an upper Paleogene (upper Tertiary) age for the sedimentary sequence falling in this belt.
Dainelli (1933-1934).	A geological map on the scale of 1:100000 based on the results of the Italian expedition to Ladakh by Filippi between 913-1914 and partly based on Lydekker's (1883) work.
De Terra (1935)	Provided detailed account of the geology of the area along with a geological map and referred Paleogene sequences to Indus Flysch although he noticed some fresh water plant fossils in the Hemis Conglomerate located south of Leh town.
Wadia (1928, 1937)	Mapped the area and contributed more information on the geology of this belt.
Pascoe (1959)	Recovered gastropod fauna of Upper Cretaceous (Senonian- Maastrichtian) age from the western slope of Kargil basin, western part of suture zone of Ladakh in the supposed Upper Cretaceous Flysch.

Sahni and Bhatnagar (1958)	Described fresh water molluscs - Melania kargilensis, Viviparus sp., Planorbis sp and plant remains palm impressions to Sabal or Tachycarpus collected by G. Kohli, geologist of the Geological Survey of India, from Paleogene (Tertiary) beds exposed near Kargil town and assigned an Eocene age for the fossil-bearing horizons.
Tewari (1964)	Mapped the suture zone and came out with one landmark observation for recognizing the post-Eocene sediments of Kargil basin as molasse rather than flysch. Compared these sedimentary beds with those of Hundes region (Tibet), Kailas Conglomerate series of Trans Himalaya and assigned a Miocene-Pliocene age for the molasse sequence of Kargil.
Dixit et al. (1971)	Carried out work within the suture zone molassic sequences and reported a mammalian cheek tooth and fragmentary bone from the basal part of Ladakh Molasse and a large number of plant fossils from the overlying and underlying horizons.
Dixit et al. (1971)	Identified the mammalian tooth as Hyoboops, an anthracotheriid known from the Miocene of East Africa, and similar age was suggested for the fossiliferous bearing strata. Also documented gastropod Subzebrinus gudei from 1500 m thick Wakka Chu river section, at Kargil-Shanko road and designated this section as a stratotype section for the Wakka River Formation and replaced the previous Ladakh Molasse Group nomenclature.
Tewari and Sharma (1972)	Documented fresh water charophytes: Grambastichara cf. tornata, Grambastichara cf. cylindrica, Harrisichara cf. vasiformis, from the same bed which yielded Subzebrinus gudei and angiosperm leaves and suggested an Oligo-Miocene age for the Wakka River Formation.
Shanker et al. (1974)	Identified two contrasting sequence of rocks ranging in age from Cretaceous to Eocene from the northern and southern sides of the lower Indus basin. Designated northern side sequence of thick pile of coarse clastic sediments as “Indus Formation”, resting over the Ladakh Granite, whereas the typical ophiolite sequence of southern side is referred to as "Samdo Formation/Dras Volcanics". Also assigned Mio-Pliocene age to Indus Formation.
Bhandari et al. (1977),	Given stratigraphic classification for section exposed along the Wakka Chu river between Kargil and Pashkyum into Kargil Formation, Tarumsa Formation and Pashkyum Formation in this order of superposition.

Guleria et al. (1983)	Reported plant Prunnus from the Liyan Formation and suggested a Miocene age for the plant bearing horizon.
Lakhanpal et al. (1984)	Reported the occurrence of leaf impression and palms (Tachycarpus ladakhensis) from the Liyan Formation (Kargil Molasse).
Sahni et al. (1984a)	Described fish remains (Siluridae, Cyprinidae, Channidae), pelecypods (Unio kohlii) and gastropods (Bullinus sp.) from a siliceous siltstone of Kuksho Formation cropping out northeast of Nyoma Gompa.
Garzanti and van Haver (1988)	Suggested, Indus basin of Ladakh as a fore-arc basin till Mid-Cretaceous age that overlapped the Ladakh Granite to the north and evolved into an intermontane depression in the Early Eocene. And reported the occurrence of freshwater ostracods Bhythoceratina sp. and Platycytheris sp. from the Basgo Formation and suggested Maastrichtian age for the basal unit of Ladakh molasse.
Nanda and Sahni (1990)	Reported vertebrate fossils including an indeterminate boid snake and mammals represented by Cryptomeryx savagei (Tragulidae), Lophiomeryx kargilensis (Gelocidae) from the Wakka Chu river section of the Kargil Formation, about 3.5 km WNW of Kargil town and suggested a Late Oligocene age for fossiliferous unit.
Kumar et al. (1996)	Documented a rodent fauna comprising of Fallomous razae, F. ladakhensis (Chappattimyidae), Wakkamys hartenbergeri (subfamily Baluchimyinae) and Zindapira (Baluchimyinae) from the Wakka Chu river section of Kargil Formation and suggested an Oligo-Miocene age for Kargil formation.
Kumar and Virdi (1997)	Interpretated three fluvial stages for molasse sedimentation in Kargil area.
Tiwari (2003)	Reported rhinoceratid skull: Juxia sharmurens from the Liyan Formation (sensu Shanker et al., 1982) exposed near Liyan village and assigned a Late Eocene age for the fossiliferous Liyan Formation.
Bajpai et al. (2004)	Recorded Cypridacean ostracods from the Basgo Formation of the Ladakh Molasse which include three species, viz.: Dongyingia sannionis, Candona himalacia and Eucypris alpina. Assigned a Late Oligocene age to the Basgo Formation.
Prasad et al. (2005)	Reported the cricetid rodent, Democricetodon sp. from the basal part of the Ladakh Molasse (Basgo Formation), exposed 3 km west of Taruche village,

	and assigned Early to Middle Miocene age for the rodent yielding stratigraphic level of the Basgo Formation.
Mehrotra et. al. (2007)	Reported new palm leaves Amesoneuron ladakhensis (Mehrotra et al., 2007) near Shingbuk near Tsokar in the eastern Ladakh Himalaya.
Paul et. al. (2007)	Reported palm leaves Palmacites tsokarensis from the same area of Mehrotra et al. (2007)

Recently the Stratigraphy and structure of the Indus Suture Zone (ISZ) has been described and interpreted by (e.g. Thakur 1983; Searle, 1983; Brookfield and Andrews-speed 1984; Corfield et al.1999; Van Haver 1984; Garzanti and Van Haver 1988; Sinclair and Jaffey 2001; Clift et al. 2002 a &b; Aitchison et al., 2000 & 2007; Searle et al. 1987, 1990& 1997b; Steck et al. 1993& 2003; Rowley 1996; Sinclair et al. 2001; Wu et al. 2007; Green et al., 2008; Najman et al., 2010; Henderson et al. 2010, 2011). There work suggest that ISZ exposes a variety of rock sequences which can be divided as follows :

Table No. 2.2 Major rock sequences within the Indus Suture zone

Sl. No.	Stratigraphic unit
4	Indus molasse/ Ladakh molasse/ Karu molasse/Indus Group
3	Indus flysch/Indus formation/ Serie verte de Tar/Tar Group
2	Ophiolitic melange and deep sea sediments
1	Indus volcanics (Dras Volcanics) and associated sediments

Out of these (Table 2.2**)** stratigraphic units, Tar Group/Indus Flysch and Indus Group/Indus Molasse make up the dominant unit within the Indus Suture Zone, Ladakh Himalaya, recording the Lower Cenozoic marine to terrestrial sedimentary deposition and termed as Indus Basin Sedimentary Rocks (IBSR) (Henderson et al., 2010a). This thesis is concerned with IBSR. IBSR has acquired a variety of nomenclatures such as Tar Group, also referred as Indus Flysch or Indus Formation, etc. (Table 2.3).

Table 2.3: Different nomenclature adopted by workers for Ladakh Flysch in different localities.

Group/Formation	Locality	Author/s
Indus Flysch	All Flysch horizons of Ladakh	Dainelli 1934; Fuchs, 1979 and 1981; Gansser, 1977

Indus Formation	Upshi-Nyoma area	Sharma and Kumar, 1978; Pal et al., 1978
Tar Group	Nimu- Upshi area	Searle et al., 1990; Sinclair and Jaffey, 2001; Henderson et al. 2010a
Serie verte de Tar	Nimu- Chilling area	Van Haver, 1984

Table. 2.4. Nomenclature and classification of Ladakh Molasse at different localities by different author

Group/Formation			Locality/Area	Author/s
Wakka Chu Molasse	U. Taramsu	Pashkyum	Kargil	Brookfield and Andrews-Speed, 1984
	Taramsu	Taramsu		
	Kargil	Kargil		
Indus Molasse			Wakka Chu section, Kargil	Tewari, 1964
Kargil Formation			Kargil	Shah et al., 1976
Indus Molasse and Hemis Conglomerate			Kargil-Upshi	Frank et al., 1977
Karu Formation			Hemis	Pal et al., 1978
Liyan Formation			Liyan Gompa	Shankar et al., 1982
Indus Group	Karit Formation		Kargil to Nyoma	Srikantia and Razdan, 1980 and 1985
	Makishun Formation			
	Kushko Formation			
	Skinding Formation			
Wakka Chu Formation			Kargil	Brookfield and Andrews-Speed, 1984
Indus clastics	Temesgam		Kargil-Leh	Garzanti and Van Haver, 1988
	Basgo			
Ladakh Molasse Group	Kargil Formation		All molasse horizons of Ladakh	Nanda and Sahni, 1990
	Liyan Formation			

Table. 2.5. Lithostratigraphy of Indus Flysch (after Pal and Mathur, 1977).

Stratigraphic unit	Member	Lithology	Thickness (in meters)
Indus Flysch	V	Interbedded slate and conglomerate	259
	IV	Red shale	200
	III	Grey shale	250
	II	Sandstones	150
	I	Red and green slates with basic rocks	400

Similarly the younger Ladakh Molasse is designated as Indus Molasse/Indus Group/Kargil Molasse/ Hemis Conglomerate/Karu Molasse etc. (Table 2.4). The older stratigraphic unit, Indus Flysch/Indus Formation/Tar group, constitutes a NE-SW trending belt about 5-10 km wide and a thickness of over 5000 meters. The belt is separated from the Ladakh granite and Karu molasse/Ladakh molasse/ Indus molasse/Indus group in the north by the south dipping Upshi Thrust. Towards the south, the belt is in tectonic contact with the Zaskar sediments, the Tso Morari crystalline, the Nidar ophiolites and Sumdo ophiolitic mélange. Pal and Mathur (1977) divided (Table 2.5) the Indus flysch into five members. Srivastava (1978-79) carried out sedimentary work and identified seven megacycles: I. Conglomerate-sandstone-shale, II. Sandstone-shale, III. Conglomerate-sandstone, IV. Sandstone-shale-conglomerate, V. Shale-sandstone-limestone, VI. Shale-sandstone, and VII. Conglomerate-shale-sandstone and suggested that the Indus Flysch shows typical flysch characteristics. In most of the area, the current direction is from SSE to NNW. Though in the northern part of the area a NW-SE current direction has been noted, thus indicating two source areas. According to Thakur and Bagati (1983) statigraphically the sequences of the Indus Formation are not continuous and having indefinite contacts. According to them, three principal stratigraphic units are recognized in the Indus Formation. These are: (a) conglomerate, sandstone and shale with Hippurites bearing calcareous rock of Cretaceous; (b) Nummulitic limestone and calcareous shale of lower to middle Eocene and (c) *Livistona wadiai*, a fossilized palm tree and some other plants bearing horizons of conglomerate, sandstone and shale of late Eocene-Oligocene interval.

Younger Indus Molasse/ Ladakh Molasse/ Indus Group/Kargil Molase/Karu Molasse stratigraphic unit, exposed at Kargil having maximum thickness up to 1500m. It extends in an eroded belt along the Indus valley, overlying the southern margin of the Ladakh Batholith diping gently towards south (Fig. 2.3). At localities lke Kargil, Karu, Chumathang and Nyoma the conglomeratic bed of the Kargil Formation seems to rest on the eroded surface of the ultra mafics (Thakur and Bagati, 1983).

The deep sea carbonates and radiolarian cherts yielding Permian to Cretaceous and middle Eocene faunal elements. The molasse conformably overlies the Tar Group in Nimu-Chilling area, while it directly rests unconformably over the Indus Formation, Nidar ophiolitic sequences and Tso Morari plutonic complexes.

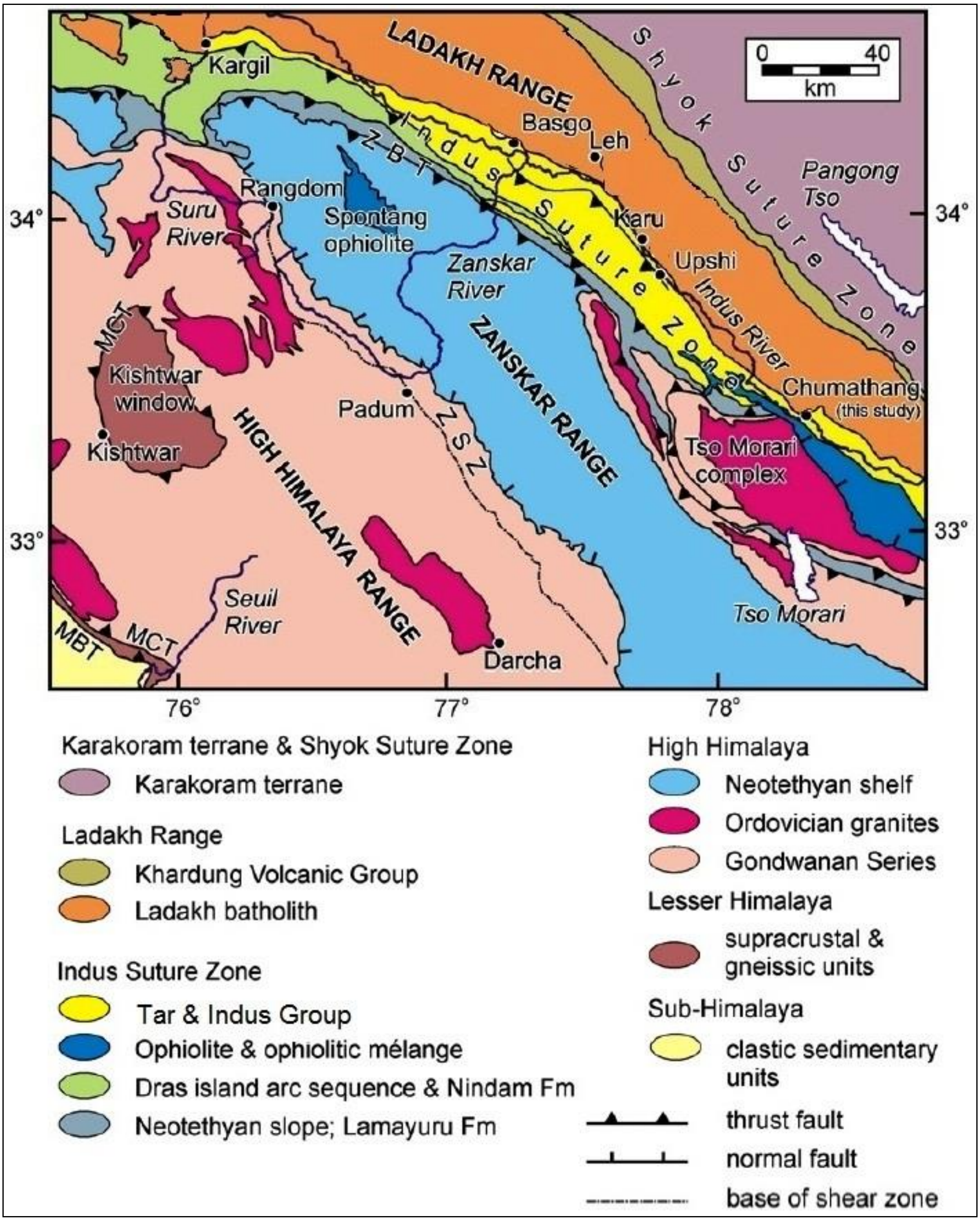


Fig.2.2 Geological map of Ladakh (modified after St-Onge et al. 2010)

These molasse deposits occur in a long arcuate belt along the southern margin of the Trans-Himalayan magmatic arc, extending eastwards from Kargil Township through Nyoma in eastern Ladakh to Hanle. This sequence was initially referred to as 'Indus Flysch' by De Terra (1935). It was later termed 'Ladakh Molasse Group' by Tewari (1964), who separated them from the Indus Flysch. Subsequently, the molasse in different areas assigned different formal and informal local names by different workers (Tables 2.1 and 2.4).

Table: 2.6 The sequences of rock types of Indus molasse occurring between the Ladakh plutonic complex at North and Dras Volcanics on the south (after Tewari, 1964)

(SOUTH)
Dras volcanic unit
-------------------------------------- Thrust--------------------------------
1- Alternating Sandstone and Shale
2- Greenish shale and sandstone
3- Greyish sandy shale
4- Bedded sandstone
5- Greyish sandstone and arkosic sandstone
6- Greenish sandstone and red shale
7- Conglomerate unit
----------------------------------Unconformity----------------------------
Ladakh Batholith
(NORTH)

Lithologically, this sequence comprises greenish sandstones with intercalated greenish, reddish shales and conglomerates. The Ladakh Molasse Group, extending from Kargil in the west to Hanle in the east, has been provisionally divided into two formations: (i) Liyan Formation, which consists of three large outliers of the molasse deposits, located at north of Tsokar and near Liyan Gompa in eastern Ladakh (Shankar et al 1976), and occurs above the volcano-sedimentary Sumdo Formation, consisting of conglomerate, grits, sandstone and greenish to grey coloured shale, and (ii) Kargil Formation, which includes mostly of the northern molasse horizons that unconformably overlie the southern flank of Ladakh Granitoids/Indus Formation. The northern and southern contacts of Kargil Formation are well exposed near Karu. It is confined to a narrow linear belt from Kargil in the west through Hagnis, Dumker, Saspol, Nimmu, Karu, Upshi, to south of Kiari. In the eastern sector this unit is well exposed, resting on the Indus flysch and the associated volcanics and ophiolitic mélange (Fig. 2.3 and Table 2.6) in the Chunglung-Liyan area. The molasse near Kargil occurs widely but tapers out in a thin belt towards the east where it forms detached outcrops unconformably overlying the Samdo Formation. Locally, the underlying contact between the Ladakh granite and the Indus flysch has been exposed and is generally unconformable and well observed in the Mahe-Nyoma section.

2.5 GEOLOGY OF THE MEASURED STRATIGRAPHIC SECTIONS

The geology of Ladakh area can be set with multiplicity of stratigraphic nomenclatures and their usage for practical purpose. It can be divided in three sectors, namely Western, Central and Eastern Ladakh.

2.5.1 Central Ladakh

In central Ladakh, best representative stratigraphy of these sequences is exposed in central Ladakh around Nimu- Chilling, Basgo Trauche area. The IBSS deposited in two domains:

(1) Southern flank of Indus Basin, where it is stratigraphically divided into two groups:

(a) Tar Group: A 1500 m thick predominantly marine sequence of Late Albian- Early Eocene age, formed in a fore-arc setting of the Trans-Himalayan arc, documented from the south of the ITSZ.

(b) Indus Group: A 1200 m thick post-Early Eocene continental sediments, conformably overlying the Tar Group, which represents a gradual shift from fore-arc to intermontane basin sedimentation referred to as Indus Group (Table 2.7).

(2) Northern flank of Indus Basin: The basal part of the northern sequence resting unconformably over the Ladakh batholith, shows considerable lateral facies variation from alluvial fan conglomerates to braided-plain sandstones to lacustrine marls and limestones. This sequence has been designated as Basgo Formation and a Maastrichtian age has been assigned on the basis of ostracod fauna (van Haver, 1984). Overlying the Basgo Formation is a sequence of fine-grained, yellow colored pelites alternating with reddish sandstones, referred to as Temesgam Formation by Garzanti and van Haver (1988). The Temesgam Formation has been dated as Palaeocene-Early Eocene in age (Garzanti and van Haver, 1988). In the Kargil area, about 75 km west of Garzanti and van Haver's (1988) study area and in strike extension of Basgo/Temesgam formations, a belt of clastic sediments represented by conglomerate, sandstone, siltstone and shale, rests directly and transgressively over the Ladakh batholith, which has often been referred to as Kargil Molasse or Wakka Chu Molasse or Kargil Formation (Thakur, 1981). In the eastern part of the Indus Suture Zone, similar molasse sediments occurring as outliers over the Shergol mélange and Nidar Complex are designated as Liyan Formation by Shankar et al. (1982) and same was considered to be a part of Kargil Formation by Thakur (1981).

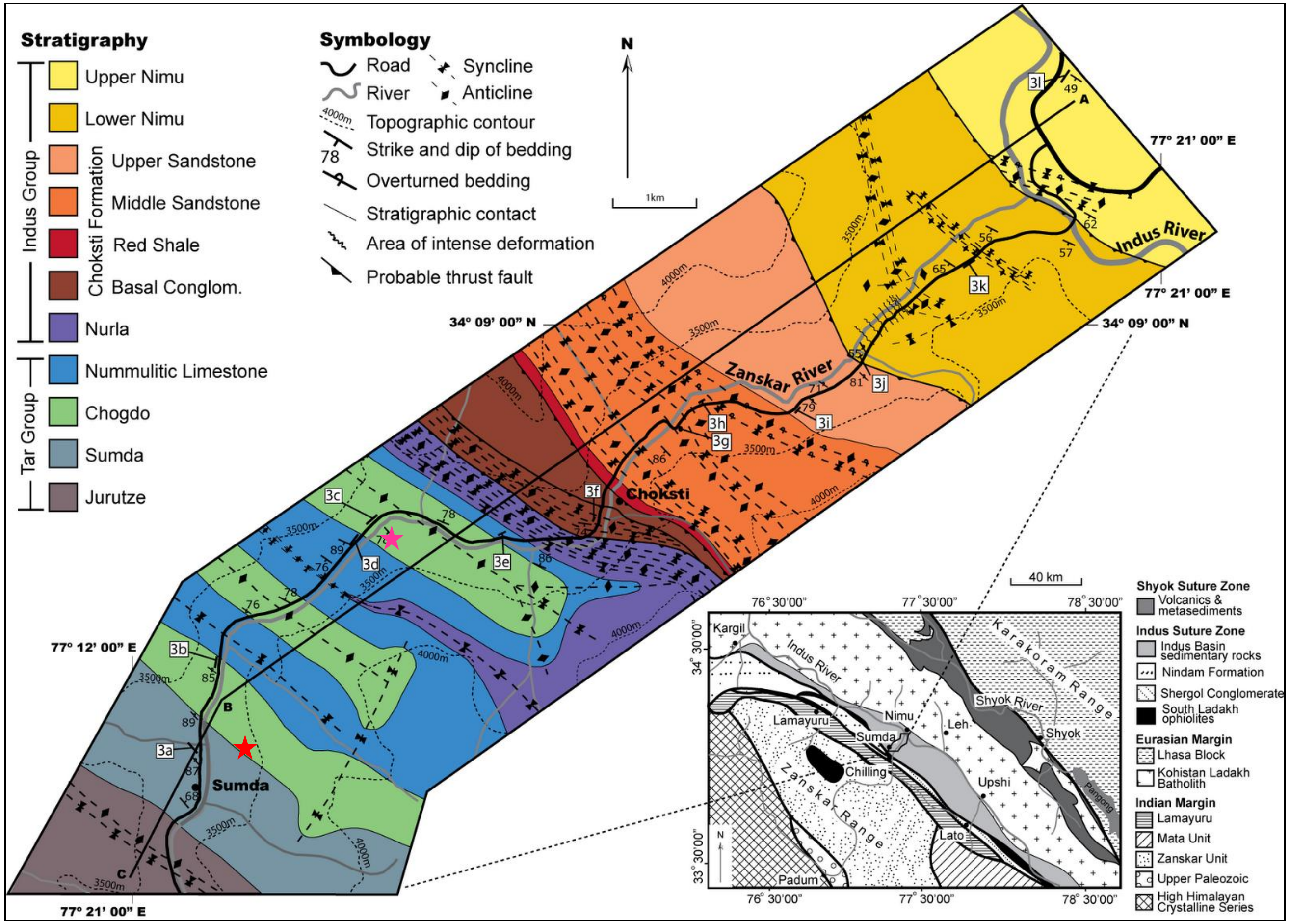


Fig.2.4 Geological map along the river Zaskar (between the village Nimu and Sumdo) after the Henderson et al., 2010 showing Location of Sumdo (★)and Nummulitic limestone (★)section indicated by a star.

Table 2.7. The sequences of rock types IBSR occurring between the Nimu in north and Chilling in south (after Henderson et. al., 2010a).

Group	Formations		Lithology
Indus	**Nimu**	**Upper**	Blue grey silt muds and shale, black grey yellow sandstone, organic rich coal
		Lower	Conglomerate, grey black shale, green grey phyllites red shale, green black fine coarse sandstone
	Chokski	**Upper sandstone**	Grey-green sandstone, black red green shale and grey phyllite, conglomerate
		Middle sandstone	Grey-green yellow fine coarse sandstone and black shale
		Red shale	Red shale, green yellow fine medium sandstone
		Basal conglomerate	Clast supported pebble conglomerate and grey–green sandstone
	Nurla		Conglomerate, green red coarse to fine sandstone and black shale
Tar	**Nummulitic limestone**		Nummulitic bioclastic packstone and well laminated black crystalline carbonates, pebble conglomerate and black shale
	Chogdo		Conglomerates, green gritstone, coarse-fine sandstone and well cleaved maroon shale
	Sumdo		Brown silver grey phyllites and fine coarse sandstone. Brown nummulitic bioclastic packstone and wackstones and black crystalline carbonates, mudstone supported breccia with carbonate intraclast
	Jurutze		Black grey green shale, volcanic lithic rich sandstone, black crystalline carbonates, grey-blue phyllites
Nindam Formation			

In the eastern part of the Indus Suture Zone, similar molasse sediments occurring as outliers over the Shergol mélange and Nidar Complex

In the present work, for the southern flank of Indus Basin, the nomenclature and lithostratigraphic classification given by Sinclair and Jaffey (2001) and Henderson *et al.* (2010a) (Table 2.7) has been followed and used for section studied along Zanskar river, Nimu Chilling road (Chapter-1, Section 1.61.0) and Zingche section (Chapter-1, Section 1.6.4.0), while northern flank stratigraphy, given by Garzanti and van Haver (1984), has been followed and used for Trauche and Basgo section (Chapter-1, Section 1.6.2.0). Stratigraphic nomenclature of Frank et al. (1977) has been followed for section studied at Hemis Gompa.

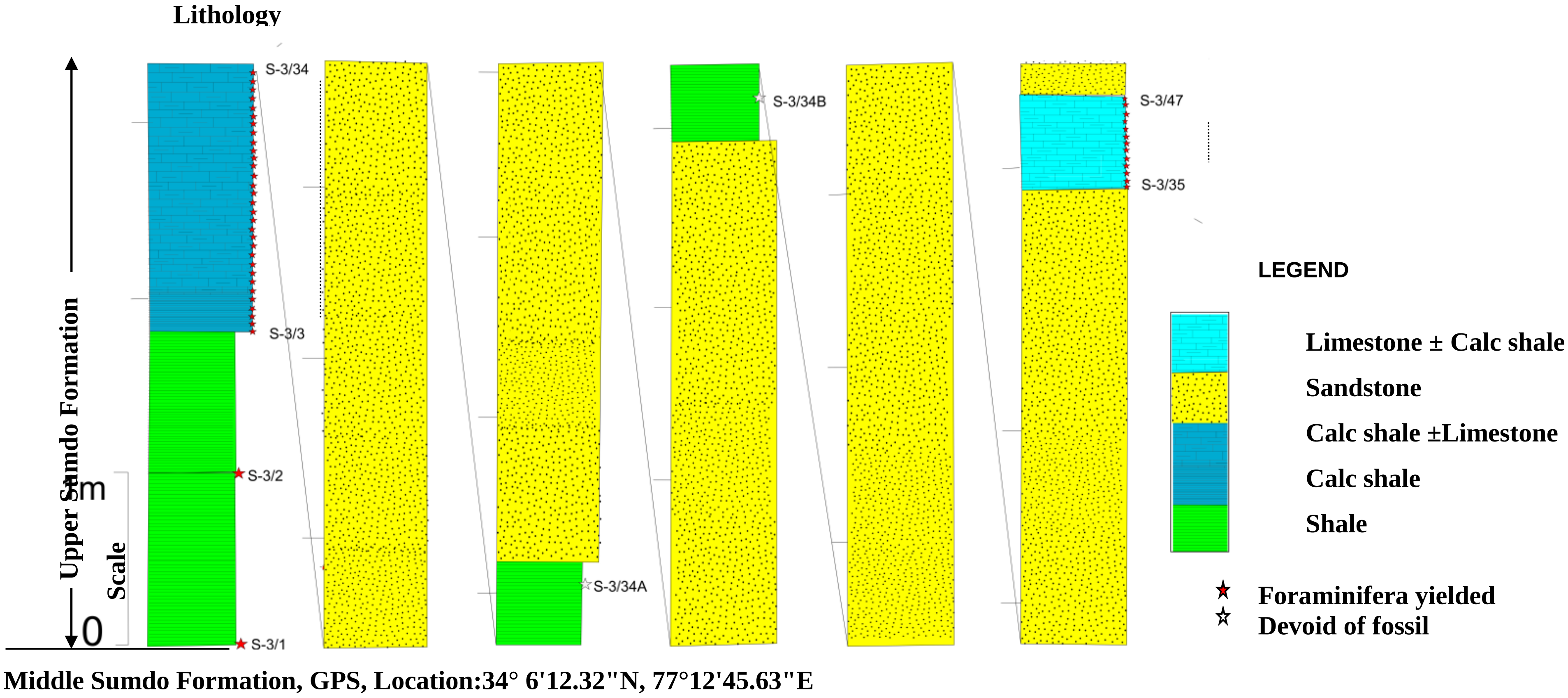


Fig. 2.5 Litholog of measured Sumdo Formation section-3, at Nimu-Chilling road showing foraminifers yielded levels

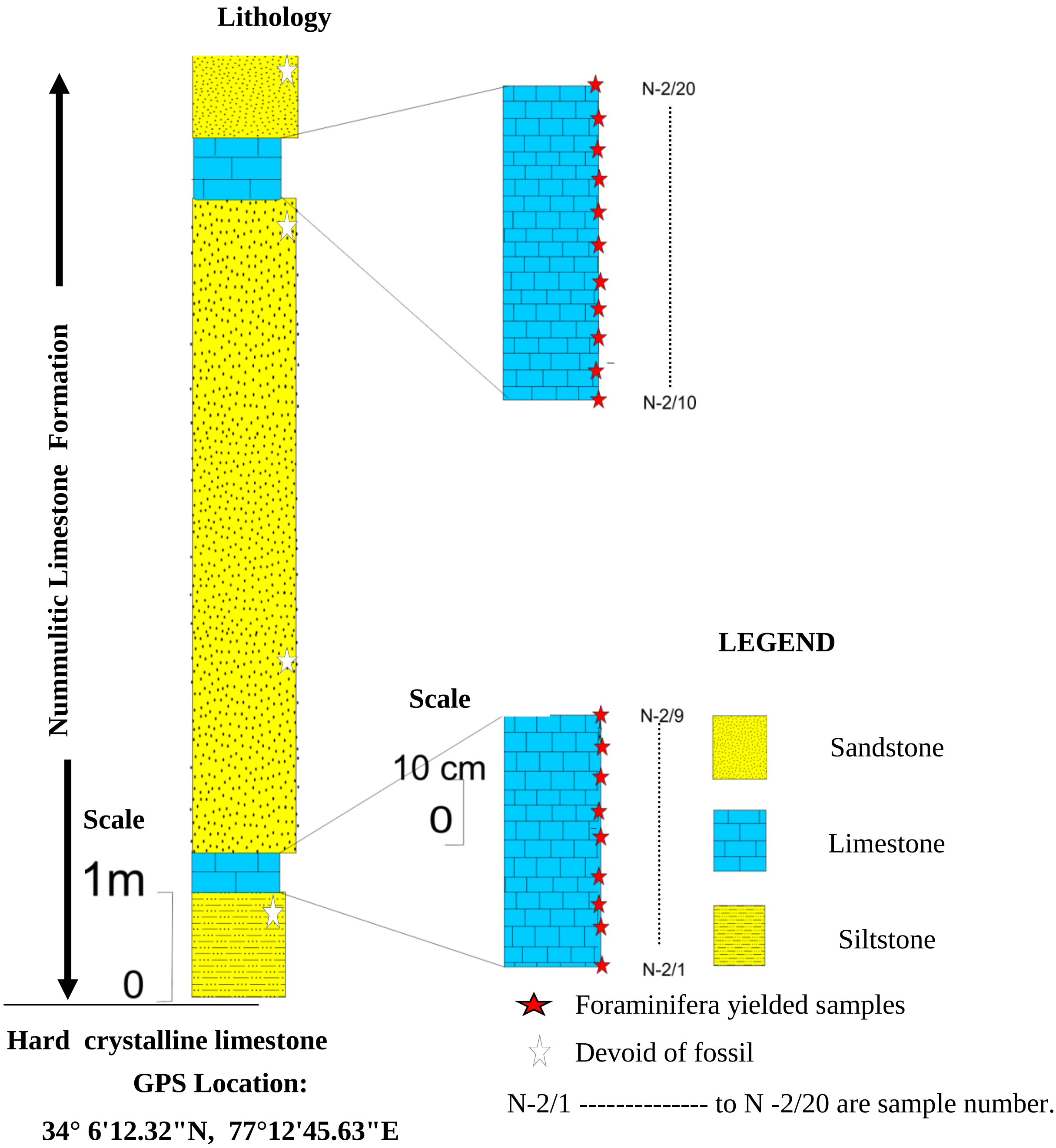


Fig. 2.6 Litholog of measured Nummulitic Formation section-, at Nimu-Chilling road showing formaminifers yielded levels

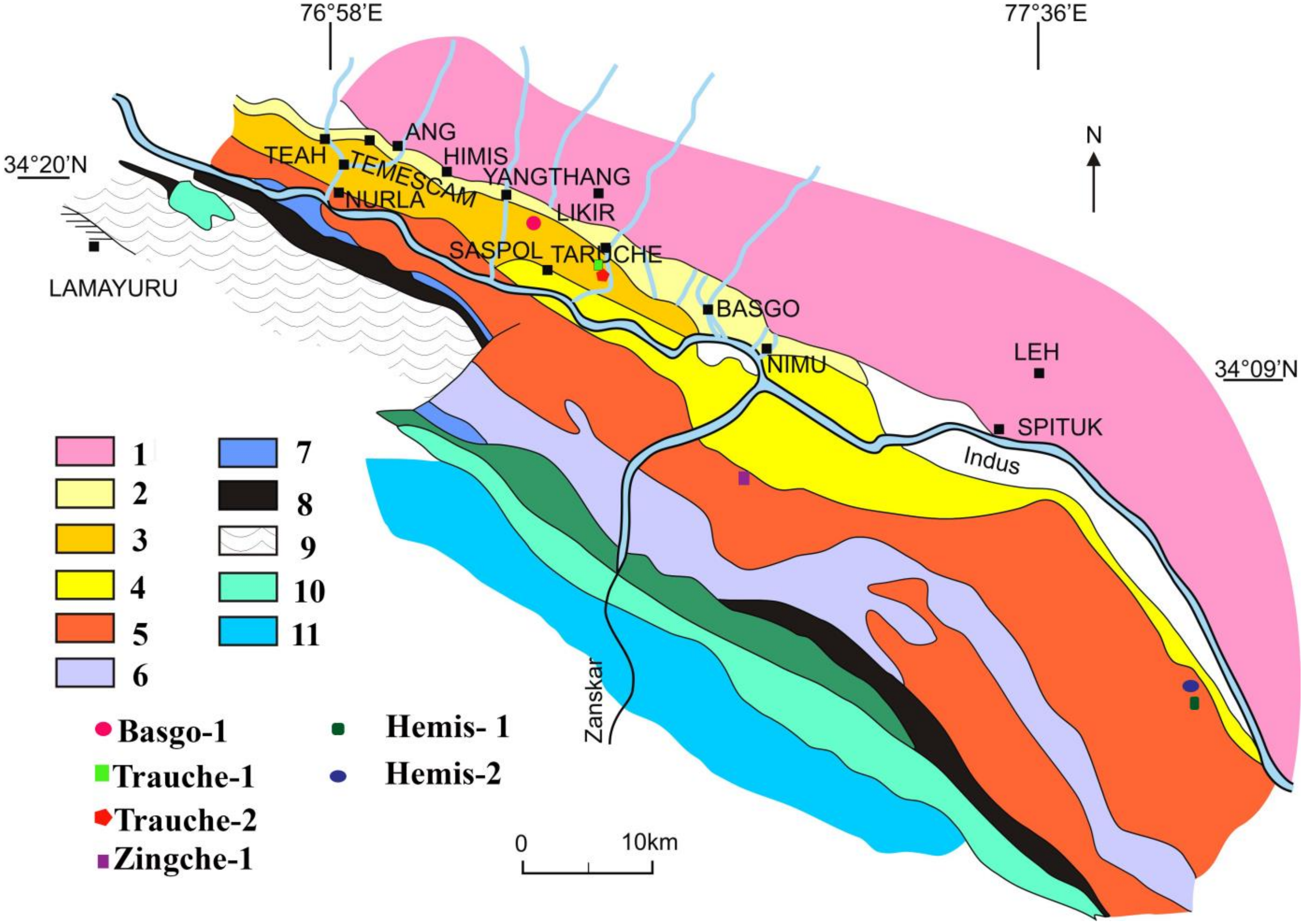


Fig. 2.7. Geological map of part of central Ladakh, Ladakh, Jammu and Kasmir State, India (modified after , Bajpai, et al., 2004 and Garzanti & Van Haver, 1988), showing the studied section localities. 1= Ladakh batholith; 2=Basgo Formation; 3=Temesgam Formation; 4=Nimu Formation; 5= Nurla Formation; 6= Nummulitic Limestone 7=Khalsi Limestone; 8=ophiolites and mélanges; 9=Nindam Unit; 10=Lamayuru Unit; 11=Zanskar carbonates.
Hemis-1= Hemis section -1
Hemis-2= Hemis section-2
Basgo-1= Basgo section-1,
Trauche-1= Trauche section-1
Trauche-2= Trauche section-2

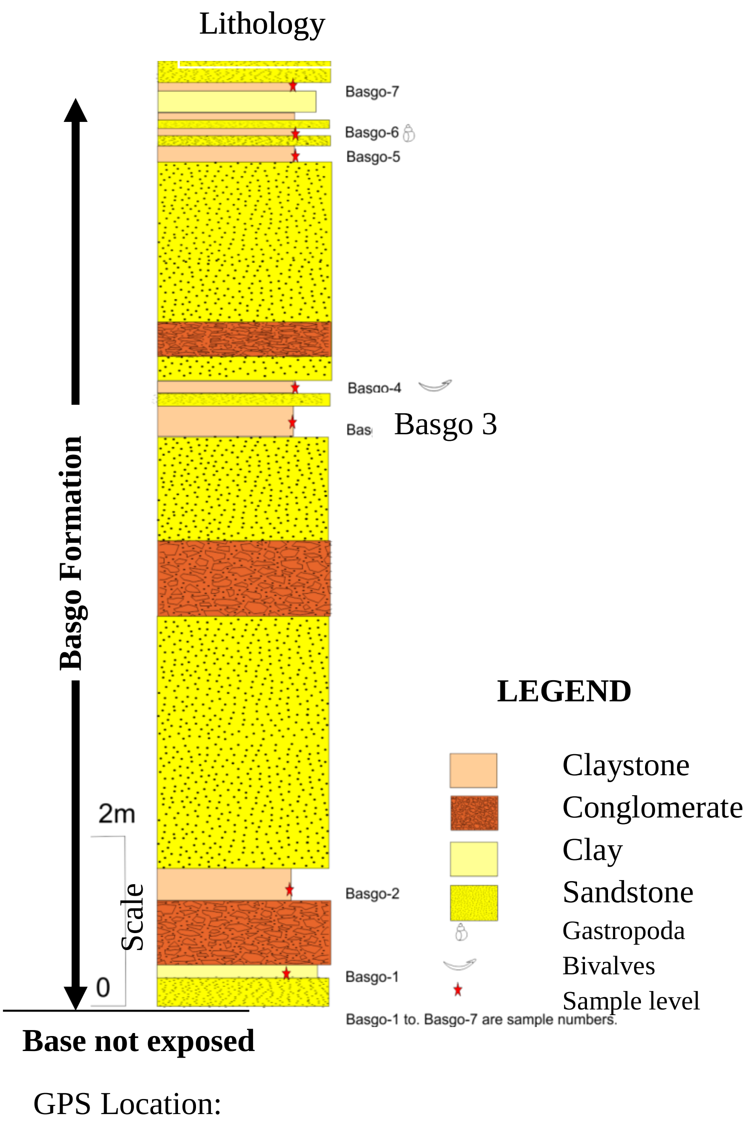


Fig. 2.8 Litholog of measured Basgo Formation section-1, between village Yangthang and Saspoche

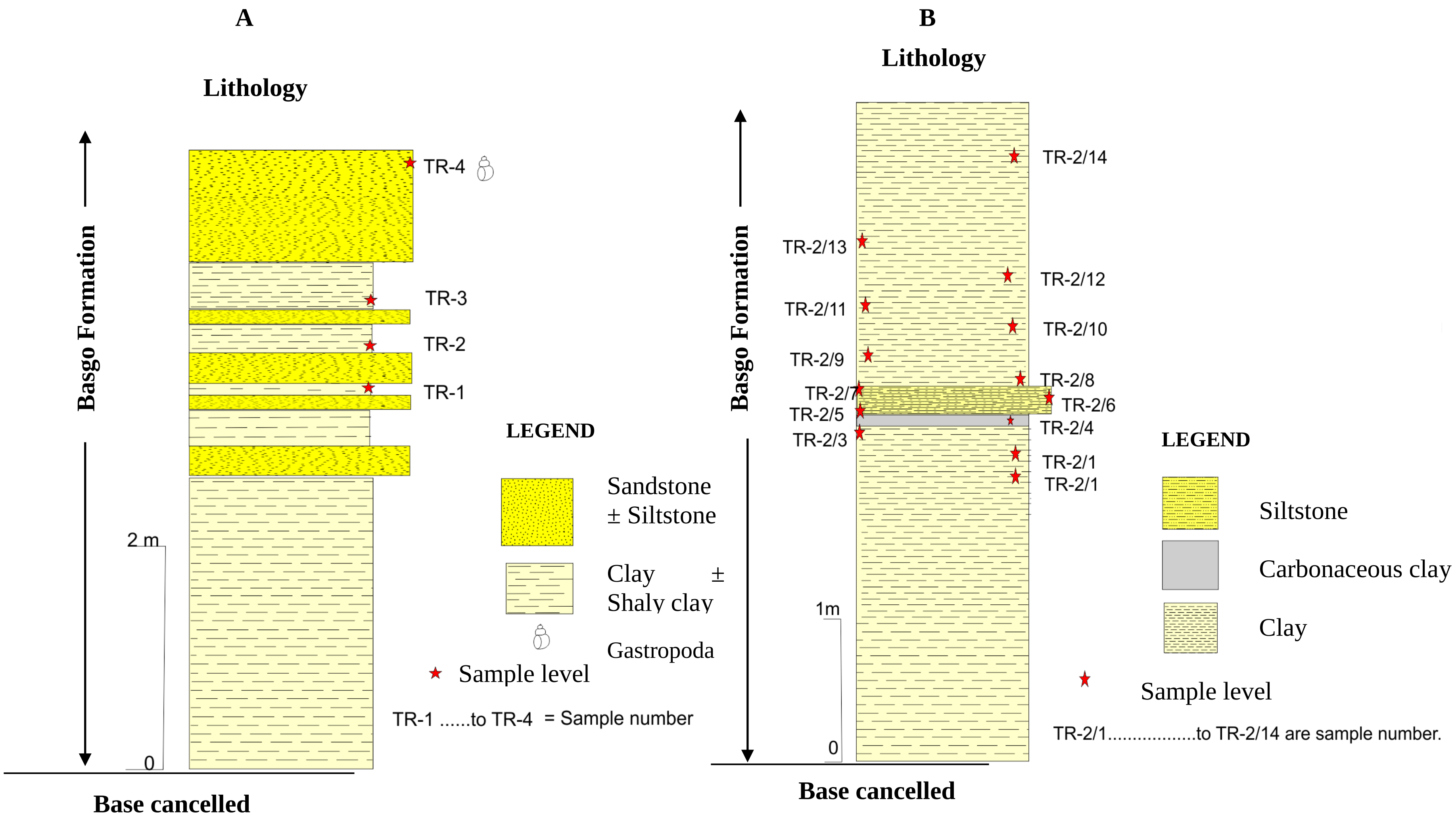


Fig. 2.9 Litholog of measured Trauche section-1 (a), and Trauche section-2 (b), between village Yangthang and Saspoche.

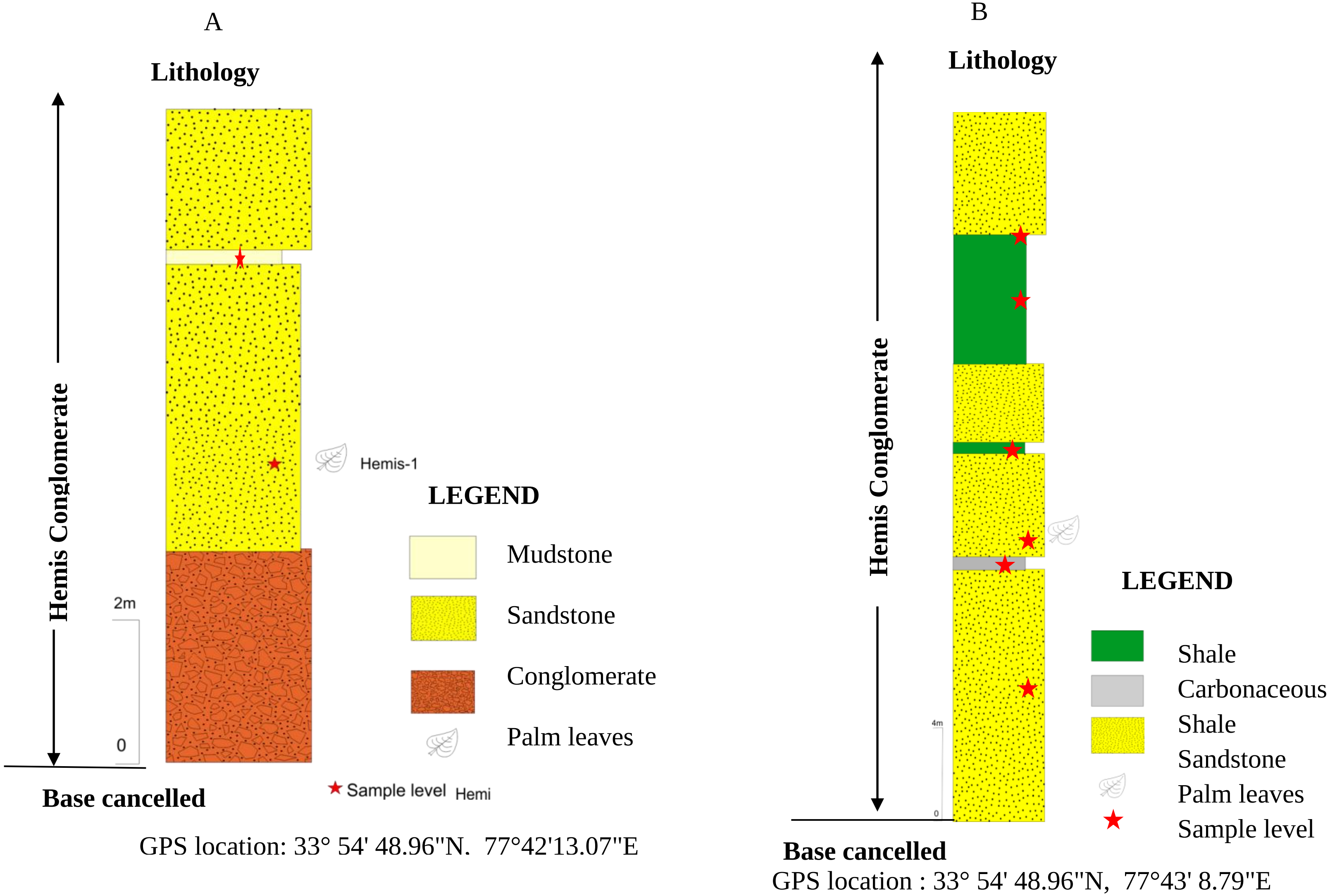


Fig. 2.10 Litholog of measured Hemis section-1 (A), and Hemis Gompa section-2 (B), near Hemis Gompa, Leh Ladakh.

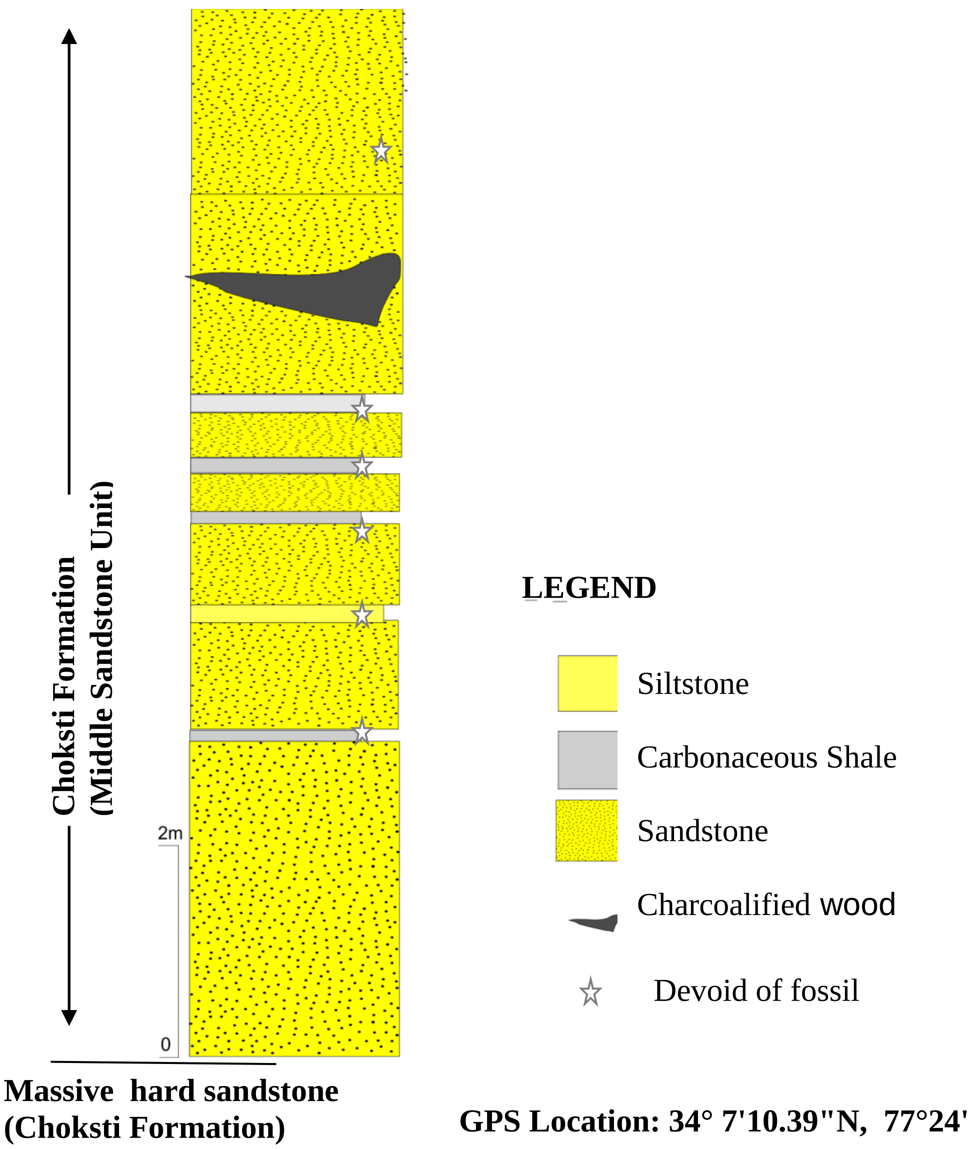


Fig. 2.11 Litholog of measured Trauche section-1 (a), and Trauche section-2 (b), between village Yangthang and Saspoche

2.5.2 Western Ladakh

The area exposed around Kargil is considered as Western Ladakh during present work. At Kargil, the molasse sequence consists of alternating red shales, grey sandstones, siltstone, grey shale and conglomerates etc. The conglomerate pebbles are of the composition of gabbro, basic rocks, red shales, chert, limestone, etc., and of variable sizes. In western Ladakh, two sections have been measured (Chapter-1, 1.6.5.1 and1.6.5.2 and Figs. 2.11, 2.12 and 2.13) and for these two sections, stratigraphy nomenclature of Bhandari et al., 1977 (Table 2.6) has been followed.

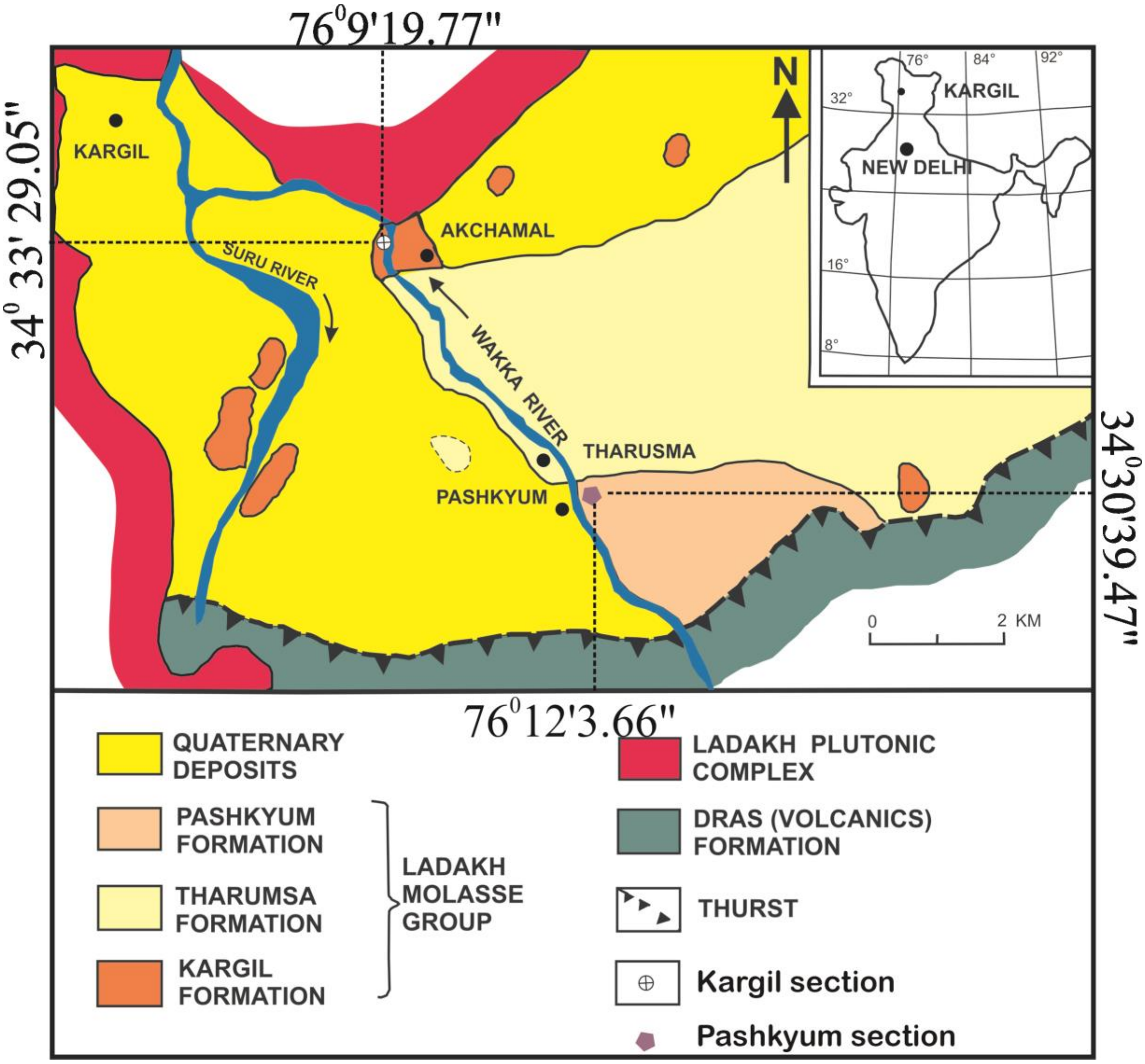


Figure 2.12 Geological map of western Ladakh, NW Himalaya (modified after Kumar et al. 1996). Showing Location of measured section at Kargil and Pashykyum village.

Table: 2.8 Litho-stratigrpahy of Ladakh Molasse Group (after Bhandari *et al.*, 1977)

Dras Volcanics		
--Thrust contact--		
Indus Molasse Group	Pashyam Formation (900m)	Purple mudstone and green, fine to coarse grain sandstone in the lower part and conglomerate interbedded with purple mudstone
	Tharumsa Formation (700m)	Thick ,multistoried grey sandstone and massive grey mudstone with subordinate amount of marl and conglomerate
	Kargi Formation (200m)	Conglomerate, greenish grey sandstone and purple mudstone with marl-.
-------------------------------------Unconformity---		
Ladakh granite		

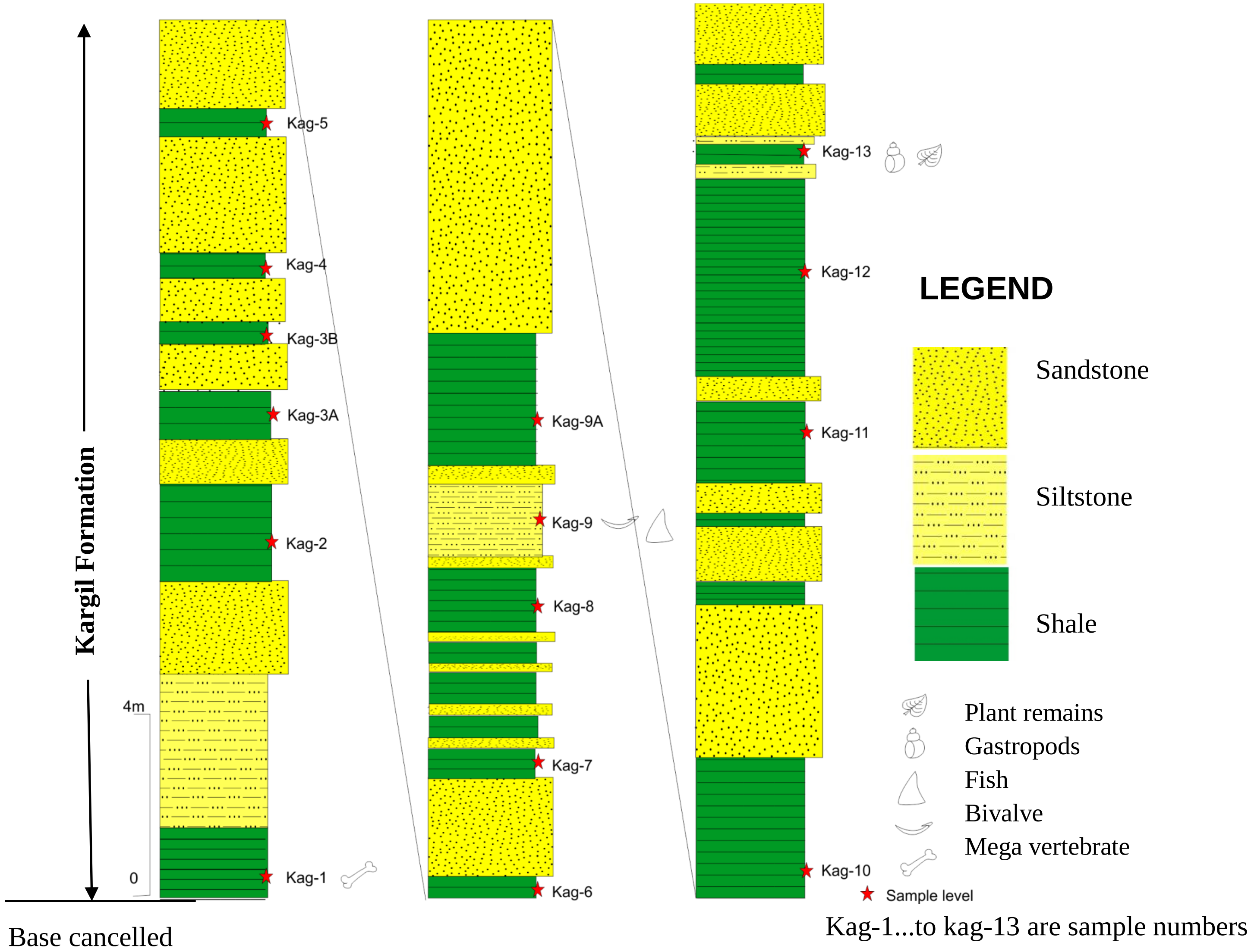


Fig. 2.13 Litholog of measured Kargil section-1, near Kargil town, western Ladakh.

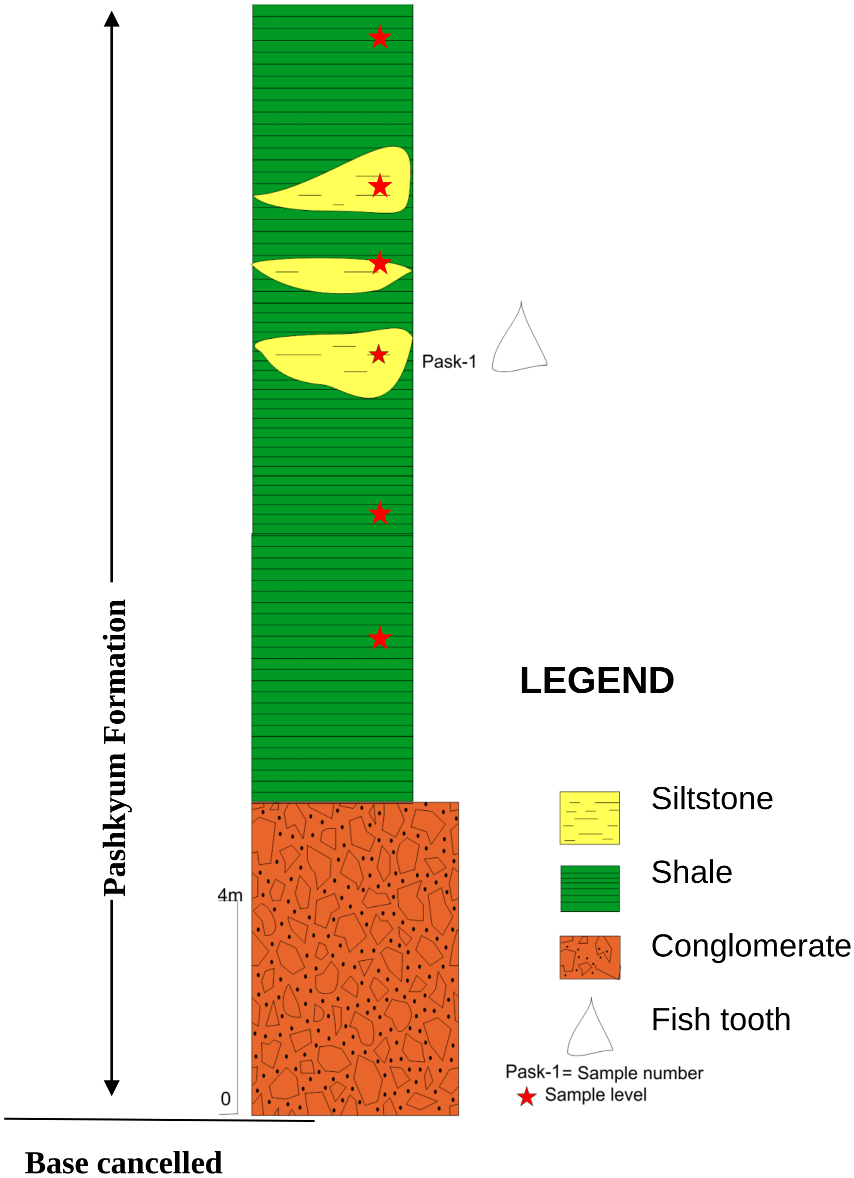


Fig. 2.14 Litholog of measured Pashykyum section-1, near Kargil town, western Ladakh.

2.5.3 Eastern Ladakh

Figs 2.15a and b shows the various stratigraphic units exposed and a juxtaposition of various lithological units in the Liyan – Nyoma area of eastern Ladakh. A number of sections have been measured in this sector of Ladakh around Nyoma and Liyan (chapter-1, Section-1.6.7, Fig 2.15). The Nyoma section overlies unconformably over Ladakh granitoids. The stratigraphic section exposed near Liyan, apart from the basal unconformable contacts, are tectonic in nature. The stratigraphic classification and nomenclature of Nanda and Sahni, (1990) has been followed for Liyan and Nyoma section

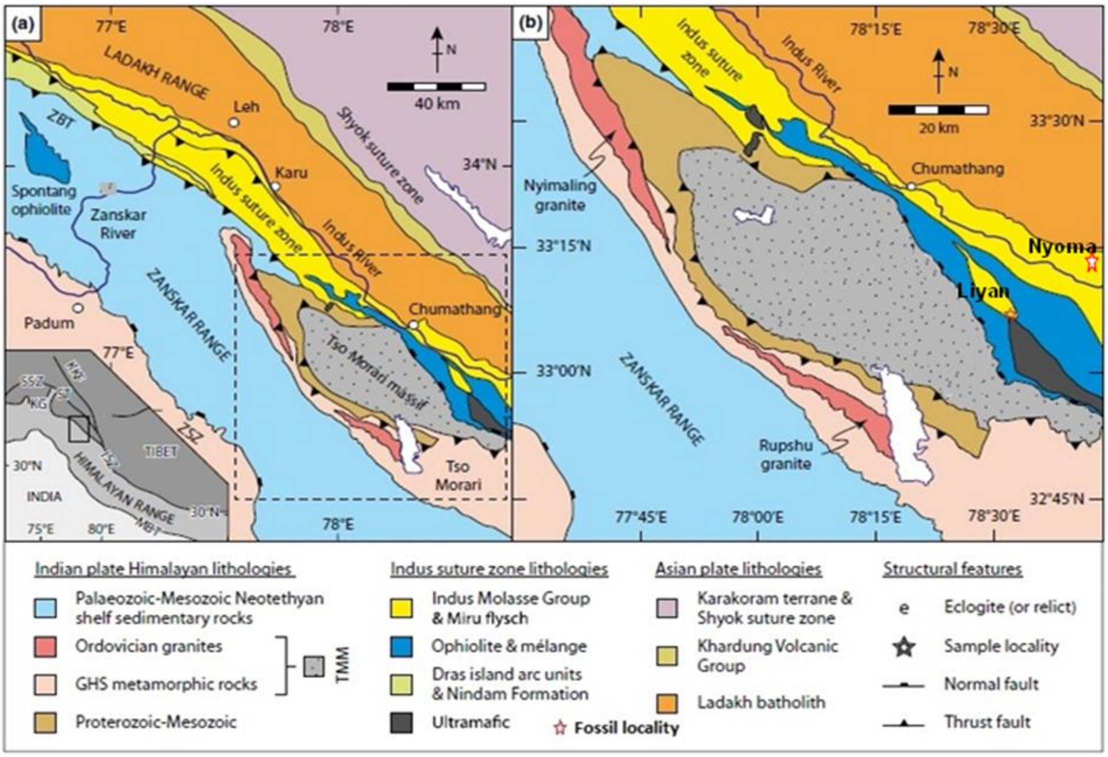
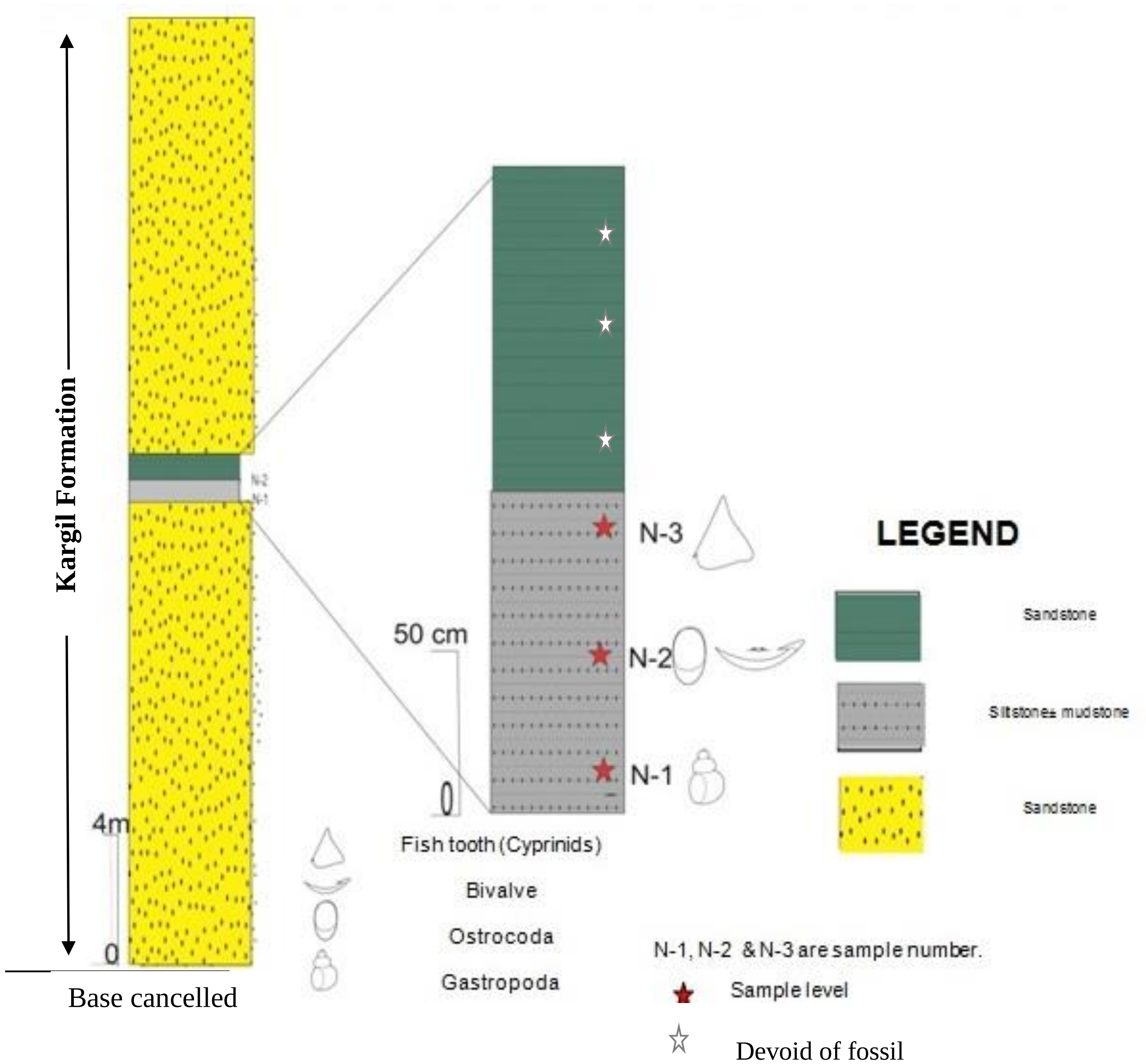
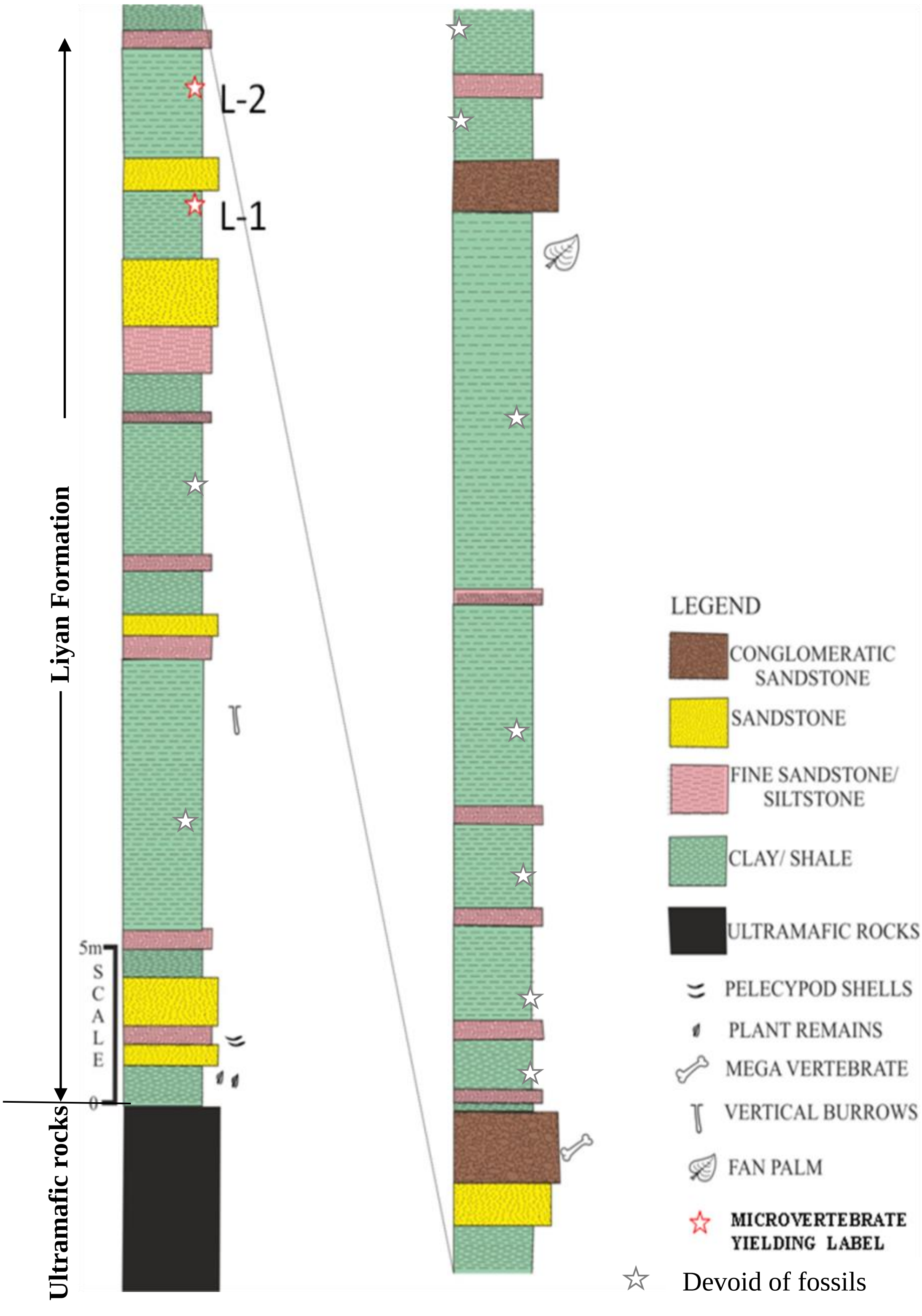


Figure 2.15. Geological map of eastern Ladakh, NW Himalaya(after Thakur, 1981; Thakur & Misra, 1984; Steck, 2003; Epard & Steck, 2008, Palin et al., 2014). a. Showing the main tectonostratigraphic units in the Indian plate, the Indus suture zone and the Asian plate. b. Location of measured section of Nyoma and Liyan Gompa.



GPS, Location: 33°10'55.44"N, 78°39'35.05"E

Fig. 2.16. Litholog of measured Nyoma section-1, near village Nyoma , earstern Ladakh.



GPS, Location: 33° 6'22.89"N, 78°32'47.31"E

Fig. 2.17. Measured Litholog of Liyan section, Nyoma Gompa , earstern Ladakh.

CHAPTER 3

SYSTAMATIC PALAEONTOLOGY

SYSTEMATIC PALEONTOLOGY

Order Foraminiferida Eichwald, 1830
Superfamily NUMMULITOIDEA de Blainville, 1827
Family Nummulitidae de Blainville, 1827
Genus *ASSILINA* d'Orbigny, 1839
Assilina dandotica Davies, 1937
(Pl. 1, figs. 1-5 and 7, Pl. 4and5)

Type species. 1937 *Assilina dandotica* Davies in Davies and Pinfold, p. 28, pl. 4, fig. 1-3 and 6-8.,

1981 Assilina dandotica Davies, 1937; Schaub, p. 206, pl. 84, figs. 1-6.
1995 Assilina dandotica Davies 1937; Racey, p. 70, pl. 9, figs 1-5.

Horizon and Locality: Sumdo Formation along the river Zanskar, Nimu -Chilling road, district Leh, Jammu and Kashmir.

Description: Test is almost small consist of granules in form of surface ornamentation and it extending from the centre of the shell to the periphery of the shell spiral growth is regular in equatorial section, and opening is tight, slowly. Chambers shape rectangular, higher than long, septa dense in initial whorls and become curved to incline in adult /outer whorls. In axial section, test is inflated, thick and lenticular. Meglaospheric form having diameter range 2210 -2676 µm while microspheric form shows 764- 834 µm diameter. Thickness (T) of figured microspheric form (Plate 1 figure 7) is measured as 374.646µm, diameter (D) 374.646, size of proloculus 79.039 µm, and T/D= 1: 2 .

Remarks: *A. dandotica* is differes *A.pustulosa* by its smaller size and quasi evolute test.

***Assilina laminosa* Gill, 1940**
(Plate. 1, fig.6, Plate.3, figs. 1-2)

Horizon and Locality: Sumdo Formation along the river Zanskar, Nimu -Chilling road, district Leh, Jammu and Kashmir.

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Description: Test is inflated, completely involute and periphery is sharp. Chambers are almost isometric and separated by straight septa. It shows in axial section, thick lateral laminae of spiral sheet, in which the lamina of each whrol can be followed by growth lines. It is non-granulated, smooth, and numerous pillars structures are common near the poles. Chambers are typically a narrow tapering of spiral sheet at the margins and resembling an arrow headed in shape (Plate 3; figure 1-2).

Remarks: This species is the microspheric form of *Assilina sublaminosa* Gill 1940.

***Assilina granulosa* d'Archaic**
(Plate. 14, fig. 2)

Horizon and Locality: Nummulitc Limestone Formation along the river Zanskar, Nimu - Chilling road, district Leh, Jammu and Kashmir.

Description: The test is large, flat, smooth and relatively thin in the centre with sharp margins. Granules are concentrated at the pole to form a bunch. Thickness to diameter (T/D) ratio of the test ranges in between 1: 5- 1:11 with an average value of 1: 7. Septa are curved forward up to 1/3-1/4 than becoming straight along the marginal cord height; Chambers are twice as high as long. In axial section spiral sheet envelops completely the inner whorls but it does not envelop completely the outer whorls.

Remarks: this species is the Form-B of Assilina leymer.

Assilina leymerie d, Archaic and Haime
Assilina leymeriei (d'Archiac and Haime) Cuvillier and Sacal, 1957,
(Plate. 9, fig. 8)

Horizon and Locality: Sumdo Formation along the river Zanskar, Nimu -Chilling road, district Leh, Jammu and Kashmir.

Description: Test is lenticular to flat and periphery is sub rounded. Granules are common in the central part of the test. Spire is regularly opening and loosely coiled. Septa are almost straight to inclined but sometimes curved back. Chambers are mostly isometric to rectangular and longer than height. The marginal cord is non uniform and thick. In axial section polar pillars are distributed almost uniformly both side of test but less prominent.

Remarks: this is the megalospheric form of *Assilina granulosa* d, Archaic.

***Assilina spinosa* Davies**
(Plate. 14 figs 3 and 5)

Horizon and Locality: Nummulitc Limestone Formation along the river Zanskar, Nimu - Chilling road, district Leh, Jammu and Kashmir.

Description: This is a small in size, stouter, heavily granulated, more tightly coiled form than the typical *Assilina granulosa*. It has a regularly opening spire (figure 3.8 A), large proloculus, septa curved back throughout the spire, chambers rectangular, higher than long, marginal cord is thick and uniform,1/4th of the chamber height (Plate 7; figure 14). In axial section a spiral sheet is totally enveloping the earlier whorls but never completely enveloping the later whorls. Thickness to diameter (T/D) ratio ranges from 1:6 to 1: 10 but averages 1: 5. The adult forms diameter is usually 5-7 mm.

Remarks: this is the microspheric Form B of *Assilina subspinosa* Davies.

Assilina subspinosa Davies
(Plate. 13, fig. 6)

Horizon and Locality: Limestone unit of Sumdo Formation along the river Zanskar, Nimu - Chilling road, district Leh, Jammu and Kashmir.

Description: Test is highly ornamented and granulated heavily in the centre. Granules stand out in test in form of spines. Chambers are mostly higher than long and septa are like those in Assilina spinosa.

Remarks: It differs from Assilina spinosa *having* relatively more concenterated spines in the middle part of the shell and *Assilina spinosa* there is no central depression in the middle part of the shell.

Genus NUMMULITES Lamarck, 1801

***Nummulites atacicus* Leymerie, 1846**

(Plate.7, figs. 6-8; Plate. 8, fig.5; Plate.10, figs. 1-7; Plate. 11, figs. 4-7)

1846 Nummulites atacicus Leymerie, p. 358, Plate. 13, figs 13a-e.
1995 Nummulites atacicus Leymerie 1846; Racey, p. 32, pl. 2, figs 18-20.
2016 Nummulites atacicus Leymerie 1846; Ahemd et al, p.l.3, figs. 11-14.

Horizon and Locality: Limestone unit of Sumdo Formation along the river Zanskar, Nimu - Chilling road, district Leh, Jammu and Kashmir.

Description: Test is lenticular to biconical, small in size with sharp margins sharp with regular, tight and thick, spire; chambers shape isometric subquadrate with regular, septa is slightly inclined and proloculus size is large. Test is lenticular to biconical with sharp/semi sharp edges. In equatorial section- in all whorls spire is thick and tight with regular growth.

Septa is regularly distributed and slightly inclined and arched. Chambers are isometric or subquadrate to subrhomboidal in shape. In axial section thin pillars radiate from the umbilical region toward periphery of test. Moderately uniform marginal cord.

Remarks: *Nummulites atacicus* is differs from *Nummulites praecursor* by its isometric and subrhomboidal to subquadrate shaped chambers and regular septa from *Nummulites globulus* Leymerie, having relatively straight septa, proloculus size large. It can be distinguished by from *Nummulites discorbinus* having less tightly coiled spir as well as sepata curved sepata.

Distribution: *Nummulites atacicus* occurs in the middle part of investigated Sumdo Formation section, associated with *Nummulites globulus, Discocyclina dispansa* and *Alveolina* sp., indicating the SBZ8 biozone

Nummulites globulus Leymerie, 1846
(Plate. 8 fig.7 and Plate. 13 fig.1)

1846 Nummulites globulus Leymerie, p. 359, Pl. 13, figs.14a-d.
1981 Nummulites globulus Leymerie, 1846; Schaub, p. 137, pl. 40, figs 1-80.
1995 Nummulites globulus Leymerie 1846; Racey, p. 48-49, pl. 5, figs 18, 22-23.

Horizon and Locality: Limestone unit of Sumdo Formation along the river Zanskar, Nimu - Chilling road, district Leh, Jammu and Kashmir.

Description: The test is biconical and small. Spire is tight and compact in early whorls, regularly opening in later whorls. Septa are gently curved in early whorls and in later whorls become inclined and/or sometimes curved back towards the periphery. Septal filaments are straight to radiating septal filaments are present. Chambers are rectangular to isometric in shape, higher than long in early whorls but in later whorls tending to become longer than high. The marginal cord is thick but it is non-uniform. In axial section it shows scattered pillars. there is a slightly deprression at centre of pole (Pl. 13, fig.1). Diameter of figured test is measured as 1709.788 mm.

Remarks: *Nummulites globulus* resembles *Nummulites* discorbinus but differentiated by relatively loose spire. It is distinguishable from Nummulites atacicus by its smaller proloculus size and thick polar pillars. Nummulites globulus Leymerie is the microspheric form of Nummulites mamilla Fichtel and Moll.

Distribution: *Nummulites globulus* occurs in association with Nummulites atacicus, *Discocyclina dispansa* and *Alveolina* sp. in the Sumdo Formation in the Sumdo section indicating a SBZ8 biozonal age.

Nummulites mamilla Fichtel and Moll
(Plate. 7, fig. 4; Plate.8, fig. 3; and Plate 11, fig. 5, 8 and 9)

1925, Nuttalli, p. 445, Pl. 17, fig.1-3.

Horizon and Locality: Limestone unit of Sumdo Formation along the river Zanskar, Nimu - Chilling road, district Leh, Jammu and Kashmir.

Description: Test is small radiate, megalospheric form and characterized by a apical mamelon. The diameter of test varies from1.4 to 3.0 mm and thickness of test varies from .95 mm to 1.75 m. This species is characterized by a opening spire very rapidly. Septa are straight to inclined and sometimes curved back. Chambers are mostly rectangular to isometric in shape and longer than higher . Septal filaments are S shaped. The marginal cord is thick and equals 3/4th of the chamber height. The size of proloculus in the figured test (Pl.7 fig.4) is.548mm. In axial section it sshows subrounded alar prolongation and thick polar pillars as well as a large proloculus are present (Plate.11; fig. 5 and 8-9).

Remarks: *Nummulites mamilla* Fichtel and Moll is considered by Doville to be variety of *N. guettttardi* (Nuttalli, 1925)**.**

Distribution:: *Nummulites mamilla* occurs in association with *Nummulites atacicus*, *Nummulites globulus*, *Discocyclina dispansa* and *Alveolina* sp. in the Sumdo Formation in the Sumdo section indicating a SBZ8 biozonal age.

Nummulite Wadiai, Davies,1927
(Plate 3; figs 6-8,10, 11 and 13; Plate-7, fig.2)

Horizon and Locality: Limestone unit of Sumdo Formation along the river Zanskar, Nimu - Chilling road section, district Leh, Jammu and Kashmir.

Description: Test is lenticular and margin is sharp projecting. The average diameter is 2.389 mm and average thickness is 1.114 mm. There is radiainting slightly faliciform septal fillaments. The protoconch is large and circular and average diameter is .145 mm .

Remarks: It is recorded by Davies (1927) from Ranikot Formation in Pakistan.

***Nummulite* sp. A**
(Plate.7 fig. 5; Plate 8 fig. 1; Plate.9 figs1-4 and 7, Plate 13 fig.2)

Horizon and Locality: Limestone unit of Sumdo Formation along the river Zanskar, Nimu - Chilling road, district Leh, Jammu and Kashmir.

Description: Test compressed with moderate. Septal fillaments are radial and curved as periphery. Proloculus size is large and measured as 285 µm of figured test (Plate. 9 fig-3) as 285 µm. Suture are curved and chamber size increase towards periphery, is about twice as high .

Remarks : It co-occur with *Nummulites atacicus* an *Nummulites globulus* and suggest and SBZ-8 age range. It is probably new form (?) as proloculus size is very large. It has been kept for open nomenclature.

Nummulites cf planulatus Lamarck
(Plate.2 fig. 6)

Horizon and Locality: Limestone unit of Sumdo Formation along the river Zanskar, Nimu - Chilling road, district Leh, Jammu and Kashmir.

Description: Test is medium to large in size and lenticulars to subglobulars in shape, the diameter varies from to form. Septa is straight in early whorl and slightly curved in later whorl, chamber are almost recatangular.

Remarks: Present form is very poorly preserved and closely resemble with ***Nummulites planulatus*** of Ghafurand Qadir (2008, Plate.2 fig.8) early Eocene of Iraq.

Family DISCOCYCLINIDAE Galloway, 1928
Genus DISCOCYCLINA Gümbel, 1870
Discocyclina dispansa (Sowerby, 1840)
(Plate.4, fig. 1-4, 7 and Plate.5 fig. 1-2, 5-6)

1840 Lycophris dispansa Sowerby, p. 327, pl. 24, figs 16a-b.
1963 Discocyclina (Discocyclina) dispansa (Sowerby); Gupta, p. 39-40, pl. 1, figs.1-9; pl. 2, figs 1, 3-9.
1965 Discocyclina dispansa (Sowerby); Samanta, p. 422, pl. 1, figs 1-3, 5.

Type material. Type form has been not designate by Sowerby (1840, pl. 24, figs 16a-b) from original material, Kutch basin, India. Sowerby's (1840), repository is unknown. Gupta (1963, pl. 1, figs 1-9; pl. 2, figs 1, 3-9) recollected specimens of *Discocyclina dispansa* from the type locality, Middle Eocene Kutch, India and designated neotype, now housed in the Indian Institute of Technology (Kharagpur), India (specimen number is unknown).

Horizon and Locality: calc shale and limestone litho unit of the Sumdo Formation along Zanskar river, District Leh , Jammu and Kashmir.

Description: Evenly lenticular test with archiaci-type adauxiliary chamberlets; embryo semi-nephro- to trybiololepidine, subspherical protoconch, spherical dueteroconch; equatorial chamberlets small, elongated in shape; thick pillars; moderate size embryonic chambers.

Descriptions: In megalospheric form (Plate. 1 fig-3) test small-medium size, lenticular and there is marked umbo in some specimens. Embryo trybiololepidine to semi-nephro. Chambers are archiaci type adauxiliary chamberlets. Protoconch subspherical in shape and has outer diameter of 101µm-134µm. Deuteroconch shape is spherical and having outer diameter of 179µm-239µm. Equatorial chamberlets are elongated. Annular chamber walls of equatorial chamberlets mostly show regular concentric arrangement. Lateral chamberlets are 121µm-250µm in width and 42µm-82µm in height, rarely show overlapping, moderately layered,. In microspheric form test large, lenticular in shape. The lateral chamberlets are mostly regularly layered. Pillars are thicker more than megalospheric forms. Lateral chamberlets are 121µm-1556µm wide and 30µm-44µm high.

Remarks *Discocyclina dispansa* differs from *Discocyclina sowerbyi* in having moderate sized embryonic chambers and smaller dimensions of equatorial chamberlets. It is distinguishable from *Discocyclina seunesi* by having semi-nephro- to trybiololepidine embryo and archiaci type adauxiliary chamberlets and from *Discocyclina ranikotensis* by its larger lenticular test and greater number of thicker pillars.

Discocyclina sella (d' Archiac, 1850)
(Plate. 5, fig. 4)

1850 Orbitolites sella d' Archiac, p. 405, pl. 8, figs 16-16a.
1965 Discocyclina sella (d' Archiac); Samanta, p. 426, pl. 2, figs 1-7; pl. 4. Fig. 11.

Horizon and Locality: Limestone litho unit of the Sumdo Formation along Zanskar river, District Leh , Jammu and Kashmir.

Description: Test is in medium size, strongly compressed, lenticular to flattened with thin sharp edges. Lateral chamberlets are elongated rectangular in shape. Pillars are thick and strong in peripheral region, become thinner toward the centre of the test. In axial section, lateral chambers are 14µm-26µm high and 26µm-41 µm wide.

Remarks. *D. sella* distinguished from *D. ranikotensis* Davies, 1927 by its low lateral chamberlets and its larger test, and from *D. seunesi* Douville, 1922 and *D. dispansa*

(Sowerby, 1840) by its compressed flattened to lenticular to test. It is recorded in the upper Sumdo Formation in the Nimu- chilling section associated with *Assilina dandotica, Ranikothalia nuttalli, D. dispansa, Nummulites atacicus* and *N. globulus* which indicate a SBZ5/6-SBZ8 biozonal range for D. sella within the Indus Suture Zone.

Genus **DISCOCYCLINA** Gümbel, 1870

Type species. Orbitolites prattii Michelin, 1846, from the Late Eocene of Biarritz, France.

Discocyclina ranikotensis Davies, 1927
(Plate. 4, figs. 5-6 and Plate. 6 figs. 4-5)

1927 Discocyclina ranikotensis sp. nov. Davies, p. 281-282, pl. XXII, figs 10-12.
1937 Discocyclina ranikotensis Davies; Davies and Pinfold, p. 55, pl. III, fig. 22.
1959 Discocyclina ranikotensis (Davies); Nagappa, p. 180, pl. 8, figs 2-3.
1991 Discocyclina ranikotensis Davies; Butt, p. 82, pl. 3, fig. g.
1999 Discocyclina ranikotensis Davies; Akhtar and Butt, p. 140, pl.2, figs 1-2.

Horizon and Locality: Calc shale litho unit of the Sumdo Formation, along Zanskar river, District Leh , Jammu and Kashmir.

Description: Test is thin, small, unribbed and strongly compressed to flattened, with low umbo and crowded pillars. In axial section, lateral chamberlets are rectangular in shape or faintly hexagonal to elongate.

Remarks: All specimens are microspheric in present work. D. ranikotensis is distinguishable from other unribbed Late Paleocene-Early Eocene forms such as D. dispansa (Sowerby, 1840) and D. seunesi Douville, 1922 by its small flattened test with very low umbo.

Superfamily ORBITOIDOIDEA Schwager, 1876
Family LEPIDORBITOIDIDAE Vaughan, 1933
Orbitosiphon punjabensis Davies, 1937
(Plate.4, fig.10, Plate.5, fig. 9 and Plate.6, 7-8)

Type specimen: Davies in Davies and Pinfold (1937, pl. VII, figs 1-2), Geological Survey of India, Kolkata Type no. 15887

1937 *Lepidocyclina (Polylepidina) punjabensis* Davies, p. 53, pl. VII, figs 1-8, 14, 16.
1944 *Orbitosiphon tibetica* (Douville, 1916); Rao, p. 95-99, fig. 3.
2002 *Orbitosiphon punjabensis* (Davies) 1937 emend.; Ferrandez-Canadell, p. 5-6, pl. 1, figs 1-26.

Horizon and Locality: calc shale litho unit of the Sumdo Formation exposed at Sumdo village along Zanskar River, District Leh, Jammu and Kashmir.

Description. Test is discoidal and concave-convex shaped embryo bilocular with a rounded deuteroconch and subspherical protoconch. Protoconch size slightly larger than deuteroconch, followed by single auxiliary chamber on one side of the embryo. Later chambers show growth orbitoidal type, forming annulus. Equatorial chamberlets are of ogival in shape and spiral arrangement, connected by crosswise-tilted stolons. In axial section it shows lateral chamberlets with piles are well-developed on both sides of meridian layer.

Remarks. All form in present investigation are microspheric and very poorly preserved. *O. punjabensis* is distinguished from the species of *Setia* by possessing an embryo with a single auxiliary chamber.

Discocyclina chudeaui Schlumberger, 1903
(Plate.6, figs. 3 and 6)

1903. Orthophragmina chudeaui Schlumberger; Schlumberger p. 282, PI. 9, fig.18-20; fig. E.
1963. DiscocycUna chudeaui Schlumberger; Bieda, pp. 118, 205, PI. 18, figs 2-4
1973. DiscocycUna chudeaui Schlumberger; Olempska, P. Pl. 4 fig 2a.-2b.

Horizon and Locality: calc shale litho unit of the Sumdo Formation exposed at Sumdo da village along Zanskar river, District Leh , Jammu and Kashmir.

Description: Test is lenticular. Central umbo is almost invisible. Papillae are irregular in size and not very conspicuous. Large papillae are interspaced by small and occur in the central part of test, while in the periphery they are small. Five to six large lateral chambers, and shaped is like rhomboid of irregular polygons, occur in rosettes. Equatorial section. - Embryonic apparatus of the trybliolepidine type. Protoconch slightly elliptical, surrounded by a subspherical deuteroconch. Embryonic chambers considerably larger (0.1 mm high) and wider than the next equatorial chambers. Main auxiliary larger than the lateral auxiliary chambers while periauxiliary chambers slightly larger than next equatorial chambers. Iin axial section. - near embryonic chamber, equatorial chambers are in subsquare shape, their lengthas well as height increasing towards periphery. Lateral chambers very large, about and variable in length and size of chambers increases towards the periphery.

Remarks: Specimens of *D. chudeaui* is very much similar to described by Olempska (1973) but it is marked by a somewhat smaller diameter of test those described by Neumann (1958) and Bieda (1963). Present material is very poorly preserved so proper biometric parameter could not be possible to measure.

***Discocyclina* sp.**

(Plate.6, figs. 1 and 2)

Horizon and Locality: calc shale litho unit of the Sumdo Formation along Zanskar river, District Leh , Jammu and Kashmir.

Description: Description: Test is simple with rounded umbo, measured in figured test (Plate.6, fig. 20) 43.130 µm. Pillars are few and concentrated in the umbonal area. Lateral chamberlets are rectangular in shape.

Remarks: Due to paucity of well preserved sections and less abundance in present material comparison or specific identification was not possible.

Alveolina oblonga *D'Orbigny*
(Plate. 12, figs. 9-10)

1960 Alveolina oblonga D'Orbigny, Hottinger, p.141, pl. 9, figs. 4-16.

Horizon and Locality: Limestone unit of Sumdo Formation along the river Zanskar, Nimu - Chilling road, district Leh, Jammu and Kashmir.

Description: Test is subcylindrical to elliptical and ends are broadly rounded. Test is medium in size with porcellaneous and imperforate wall. The chamberlets are in single layer.

Remarks: The present specimens are closely related to *A. oblonga* D'Orbigny

Distribution: *A. oblonga* is originally reported from Paris basin of Lower Eocene interval. It is also reported from the lower Eocene of Europe. Al-Hashimi (1975) recorded this species from the lower Eocene of Iraq. In the present studies, *A. oblonga* is rare in the Middle Eocene of the studied section.

Alveolina ellipsoidalis Schwager 1883
(Plate. 12, fig. 1)

Description: Test is small and oval in shape. Axial diameter of test ranging from 1.29 to 1.34 mm. The axial section is elongated in one direction. Proloculus is followed by one or two whorls of milioline chambers and by six or nine whorls of adult chambers and chamberlets. In present work test is microspheric and microsphere is followed by early streptospiral coiled chambers and later following chambers are planispirally coiled. The basal layer is thin. Chamberlets are spherical in shape in the inner whorls and ovoid or rectangular in the outer whorls.

Alveolina schwageri Checchia-Rispoli, 1905

Horizon and Locality: Limestone unit of Nummulitic Limestone Formation along the river Zanskar, Nimu -Chilling road, district Leh, Jammu and Kashmir.

(Plate-12, fig.7)

1905 *Alveolina schwageri* Checchia-Rispoli, 1905, pl. 12, Figs. 11–14.
2010 *Alveolina schwageri* Checchia-Rispoli, Matsumaru and Sarma, p. 559, pl.4 fig.6.

Description: Test is fusiform and small. Spherical in early whorls. The equatorial diameter varies between 2.52 and 2.67 mm, axial diameter measures from 4.1 to 4.5 mm. Index of elongation between 1.6 and 1.7. The proloculus is spherical with a diameter of 330 m. The initial two whorl whorls are spherical and encircled by 4 elongated along axial zone. In this stage the test is fusiform in shape.

Phylum: Crustacea
Class: Ostracoda
Order: Podocopid
Suborder: Podocopida
Superfamily: Cypridaea
Family: Candonidae
Subfamily: Candoninae
Genus *Candona* Baird, 1845
Candona himalaica Bajpai, Whatley, Prasad and Whittaker, 2004
(Plate. 15 figs.1-3 and 7-8)

Horizon and Locality: Mudstones of the Kargil formation exposed at village Nyoma, District Leh, Jammu and Kashmir.

Description: The carapaces are medium to large in size, strongly sexually dimorphic with males show relatively less angular poster-dorsally and posteriorly while the adult female carapaces are strongly bevelled posterodorsally and strongly umbonate dorsally at two-thirds the length from the anterior margin. The greatest height is in the posterior third, the dorsal margin is slightly convex and not umbonate, in male carapaces. The male carapaces are gently convex posterodorsally. In both male and female carapaces, the anterior margin is narrowly rounded with the apex a little below mid-height in females and sub-ventral in males. The ventral margin is shallowly concave medianly. The surface of the carapaces is smooth. The juveniles have equally rounded anterior and posterior margins and have different shapes from adults.

Remarks: Present form is very much similar to *Candona himalaica* Bajpai, Whatley, Prasad and Whittaker, 2004, described from central Ladakh molassic sequences at Trauche.C. himalaica differs from Candona *shandongensis* known from the Late Oligocene of China in its less triangular in shape.

***Candonidae* Gen et. sp.**
(Plate. 15 figs. 4 and 6)

Horizon and Locality: Sandstone of the Kargil formation exposed at village Nyoma, District Leh, Jammu and Kashmir.

Description: The carapaces are medium in size and elongated in lateral view. Both the anterior and posterior margin broadly rounded both ventral and dorsal margin are straight. Carapaces surface is smooth.

Remarks: Due to limited carapaces and poor preservation it is open for nomenclature. Better preserved specimens are required to know their specific generic as well as species level affinity.

Cypridopsis sp.
(Plate. 15 fig. 5)

Horizon and Locality: Sandstone of the Kargil formation exposed at village Nyoma, District Leh, Jammu and kashmir.

Description: The carapaces are thin shelled, sub-circular to eliptical in outline, surface smooth right valve slightly larger than left valve. Dorsal margin comprising undulating hinge that has shallow saddle behind the highest point which is the anteriorly place on the dorsal margin. Maximum height in the middle of surface.

Class : Osteichthyes Huxley, 1880
Subclass : Actinopterygii Klein, 1885
Division : Teleostei Müller, 1846
Superorder : Ostariophysi Sagemehl, 1885
Order : Cypriniformes Bleeker, 1859
Family : Cyprinidae Cuvier, 1817
Genus: Barbus Cuvier and Cloquet, 181

***Barbus* sp.**
(Plate.16. fig.1, 4,6, 7-8 and10 and in Plate. 7. fig. 1-2, 6, 8,10 and 11-12)

Horizon and Locality : Claystone of the Liyan formation, exposed north of Liyan Gompa and mud stone of Kargil Formation near village Nyoma in Leh district, Jammu and Kashmir.

Description: The teeth are conical in shape and a well developed hook is present at the tip of the tooth. The teeth are broader towards the root and much narrower towards the apex. The enameloid is relatively thick. The teeth bear close similarity to the genus *Barbus*. The teeth are heterodont in nature and are described under three morphotypes

Morphotype-1: In this morphotype, the anterior teeth (Pl.16., fig.1, 4,6, 7-8 and10 and in Plate.17, fig. 1-2) are conical in shape, terminate distally in a short conical hook and strongly bulged at the base. A small, slightly depressed masticatory area occurs below the terminal hook with a narrow longitudinal groove in the middle bounded on the margins by less marked crests. In one of the teeth (Plate.3 fig.1) the groove is almost triangular and more prominent. Below the hook the masticatory area is also broad and elongated, delimited laterally by two moderately marked crests. In one tooth two small blunt cusps occur on the lateral margins of tooth just below the terminal hook(Plate.2, fig.7). Fish tooth vary in size from .5mm to 1mm.

Morphotype-2: The anterior teeth of this morphotype (Plate.16, Fig. 2-3,5 Plate.17, Fig. 5, 7, 9) are cylindrical to conical in outline with a short terminal hook relatively long (Plate 3 fig.5) below, which occur a small masticatory area with corrugated surface. Anteroposteriorly teeth are compressed and terminate distally in a relatively shorter hook (Plate-2 fig-9). Under the hook the masticatory area is very elongated bounded on either side by well-defined crests enclosing a deep groove and is extending down the height of the tooth. Some tooth having very pointed hook (Plate-2 fig 2).

Morphotype-3: In this morphotype teeth are triangular, terminate distally in a short pointed(Plate-17: fig 6), curved (Plate.-17: fig-10) pointed (Plate.-17: fig-12) (or blunt hook(Plate.-3: fig-11) and thicker towards base. In one toothh a small, slightly depressed masticatory area occurs below the curved hook with a depressed longitudinal groove in the middle bounded on the margins by less marked crests. In one of the teeth (Plate.-17 fig.1) the groove is almost triangular and more prominent. Below the hook the masticatory area is also broad and elongated, delimited laterally by two moderately marked crests. In one tooth two small blunt cusps occur on the lateral margins of tooth just below the terminal hook(Plate.2, fig-7). Fish tooth vary in size from .5mm to 1mm. \

Genus: **Schizothorax, Heckel, 1838**
***Schizothorax* sp.**
(Plate. 17, Fig. 3and15)

Horizon and Locality: Claystone of the Liyan formation, exposed north of Liyan Gompa in Leh district, Jammu and Kashmir.

Description: The teeth are conical in shape and a well pointed crown is present at the tip of the tooth. The teeth are broader towards the root and very gently narrower towards the apex. The enameloid is relatively thick. The teeth bear close similarity to the genus *Schizothorax.* One slity narrow depression is present just below the apex at middle of tooth crown (Plate17 :fig15)

Genus: **Cyprinus, Linnaeus 1758,**
***Cyprinus* sp.**
(Plate. 17, Fig.13-14)

Description: The teeth are conical in shape and a well pointed elongated crown is present at the tip of the tooth and slightly curved. The teeth are gently broader towards the root. The enameloid is relatively thick. The teeth bear close similarity to the genus *Schizothorax*). The outline of tooth is smooth

Genus: ***Squalius***, Linnaeus 1758,
(Plate. 17, Fig 4)

Horizon and Locality: Claystone of the Liyan formation, exposed north of Liyan Gompa.

Description: The Pharyngeal tooth looks similar to genus *Barbus* but the grinding surface is distinct and well defined. Tooth is elongated cylindrical in shape and ending in a hook having serrated one side edge and a medial longitudinal depression is present just below the pointed hook.

Fish scale and Vertebra
(Plate. 16 fig.11, Plate-17 fig.16)

Horizon and Locality: Claystone of the Liyan formation, exposed north of Liyan Gompa.

Remarks: The fish teeth recovered from the Liyan Formation bears strong resemblance to those of the family ***Cyprinidae***, a bony fish taxon belonging to Ostariophysi which is the second largest teleost superorder of fish. Similar cyprinid teeth have been recorded from the Kargil Formation, western Ladakh at Nyoma (Sahni et al 1984), Upper Oligocene-Lower Miocene Upper Dharmasala Formation, Kangra Valley, Himachal Pradesh (Tiwari *et al*. 1991), Middle Miocene Ramnagar Member of the Mansar Formation, Lower Siwalik Subgroup, Jammu (Parmar and Prasad 2012), Plio-Pleistocene Karewa Group (Kotlia, 1989), as well as from the early Miocene of Kutch (Prof. S. Bajpai, Pers. Comm..). Cyprinid scales has been also recorded from the Eocene intertrappean beds of Deothan and Kheri in Central India (Hora, 1938). Though oldest record is known from China (Lin, 1933; Cheng, 1962; Stycherskaya, 1986; Taki, 1975) . However, the

Fossil cyprinid pharyngeal teeth have been reported from many Miocene and Pliocene deposits of Europe. The most important reports come from the Upper Oligocene- Lower Miocene molasse deposits of Switzerland and Hautesavoie, France (Gaudant *et al.*, 2002), Middle Miocene of Sansan (Gers), France (Gaudant, 2000), Middle Miocene of Steinheim am Albuch (Wurtemberg), Germany (Gaudant, 1989), Middle Miocene of Willershausen am Harz (Basse Saxe), Germany (Gaudant, 1997), Middle Miocene of Fohnsdarf basin (Styria) Austria (Gaudant, 2010), and from the Upper Miocene of Gotzendorf ander Leitha, Vienna Basin, Austria (Gaudant, 1994), Middle Miocene of Foh

This superorder Ostariophysi containing nearly 8000 species today has a global distribution except Antarctica, Greenland and New Zealand. Ostariophysi are useful for determining historical continental relationship and are divided into Anotophysi and Otophysi. Otophysi consists of four distinct orders , namely Cypriniformes (Minnows and Carps), Siluriforms (Cat fishes) Characiforms (Characins) and Gymnotiforms (knife fishes) (Briggs, 2005). In these Cypriniformes (Minnows and Carps) are typical freshwater fishes in which the upper jaw is usually protractile; mouth is always toothless; adipose fin is absent; head almost always scaleless and the fishes have weberian ossicles (4 small bones and their ligaments connecting the swim bladder to the inner ear for sound transmission. And the most important in the present context is the 5^{th} ceratobranchial is enlarged as the pharyngeal bone with teeth ankylosed (joined) to it. Cyprinids and non-Cyprinids are the two recognized groups of the fishes comprising Order Cypriniformes. For Cyprinids pharyngeal teeth are in one to three rows and there are maximum of 8 number of teeth in each row whereas in non-cyprinid pharyngeal teeth are greater in number but only in one row. Cyprinidae itself is the largest freshwater fish family with about 210 genera and about 2010 species and 1270 species are native to Eurasia and greatest number in China and South East Asia.

While isolated pharyngeal Cyprinids being rather molariform are easier to identify, the extant cyprinids are not always easy to distinguish from other fishes. Basic cyprinid characteristics include no teeth on the jaws, a single dorsal fin, pelvic fins in the abdominal position, pectoral fins low on the side, and no adipose fin. The scales are cycloid and the lateral line system is typically well developed. The head typically has no scales.

Cyprinids do not have jaw teeth; instead they use pharyngeal apparatus to process food. This process consists of modified thick pharyngeal arch that bars teeth and chewing pad that is located in the roof of the pharynx. The size and shape of the arch and teeth are closely tied to the diet of the species. The lips are usually thin, but in some cyprinids they are enlarged and suckerlike or even lobed. Most Cyprinids lack barbels on the lips but they are present in a few genera. A swim bladder is always present and is usually two chambered. Cyprinids and several related groups have a Weberian apparatus comprised of modified anterior vertebrae that connect the inner ear to the swim bladder. The Weberian apparatus transmits sound vibrations to auditory receptors in the brain and is thought to give Cyprinids a keen sense of hearing. Most Cyprinids have a typical minnow shaped body form, but some are elongated, some compressed and others robust. Many Cyprinids are sexually dimorphic (Etnier and Starnes, 1993; Jenkins and Burkhead, 1994; Nico *et al*., 2005).

The pharyngeal teeth of *Barbus* sp. Morphotype I, teeth described here exhibit some morphological similarities with *Rutilus*, *Palaeocarassius*, and *Barbus* known from the Oligo-Miocene molasse deposits of Europe, in view of the absence of complete pharyngeal bones bearing all the tooth series in the present collection and wide geographic separation from the two areas, their referral to these European taxa is deferred until more well preserved specimens are obtained. *Barbus* sp. morphotype-1 specimens is also similar to extant forms of ***Barbus putitora*** and *Hypselobarbus* which is confined in India only. While *Barbus* sp. morphotype-2 and 3 shows similarity in morphology with the middle miocene *Barbus* sp. reported by (Gaudant, 2010; fig 8 and9) . In present collection genus *Schizothorax* and *Cyprinus shows* similarity in morphology with isolated teeth described by (Plate-3 , fig. 8a and8b) while *Cyprinus* shows similirty with (Kotlia, 1989, Plate.2 , Fig- 1a and1b).

Order? Rodentia

(Plate. 18 figs. 1-11 and Plate. 19 figs. 1-7)

Description: The present material consists of a number of tooth fragments that are being tentatively assigned to rodents. The thickness of the enamel in these fragments varies between .06 mm and .07 mm. They are being assigned to rodents for following two main reasons are

a. The enamel is present only on one side (i.e. outer) of the fragments, which is characteristic of rodents. b. Limited observations of the enamel utrastructure seen under SEM reveal a banded appearance (Plate.4 fig. 1and5 and Plate.5 figs. 1 and 3) which is reminiscent of uniserial prismatic pattern found in rodents.

Remarks: Similar incisor fragments have been reported from the Kargil Formation of western Ladakh (Nanda and Sahni, 1998). For enamel ultrastructural comparisons, the works of Wahlert (1968) and Martin (1992) are useful.

Class: Reptilia

Subclass: Diapsida
Infraclass: Archosauromorpha
Superorder: Archosauria
Order: Crocodylia
Family: Incertae sedis.
(Plate. 20, Fig.6)

Horizon and Locality: Carbonaceous shales and siltstones of Kargil Molasse exposed right side of Kargil -Batalik road in 4 ESE direction from Kargil town

Description: A single tooth recovered during the course of present work from the sediments of Ladakh Molasse at Kargil is incomplete with a broken tip. From the preserved portion, it appears to be conical in shape and its basal part bears longitudinal flutings. In basal cross section, the tooth has an elliptical outline and longitudinal depression is present on crown surface which is broder towards root and narrower towards apex.

Remarks: In its gross morphology, this tooth possibly represents the anterior series of the dentition. As similar morphology occurs in several groups of crocodiles and the tooth is incomplete, it is difficult to offer any comments on its familial status.

Division: Charophyta
Class: Charophyceae
Order: Charales
Family: Characeae L. Cl. Richard, 1815
Genus: Chara Vaillant, 1719
***Grambastichara* cf. *tornat*a** (Reid and Groves, 1921) Horn af Rantzien, 1959
(Plate. 19, fig.8)

Horizon and Locality: Mudstones and siltstones of Ladakh Molasse exposed near Nyoma Gompa sections.

Description: Large Gyrogonites, prolate, elliptical, apically rounded, basally conically extended, spiral cells sinistrally coiled, flat to convex, distinct intercellular sutures, 9-10 spiral convolutions, apical pole rounded to slightly protruding, apical rosette low, basal pole rounded, swollen towards basal centre, basal pore pentagonal in shape.

Remarks: The specimens under study are nearly similar to those referred to Grambastichara cf. cylindrica except for the basal tapering and size differences. In the latter character, they are comparable to Grambastichara cf. tornata documented from Kargil molasse of Wakka Chu River section, Kargil (Tewari and Sharma, 1972).

Phylum: Mollusca
Class: Bivalvia

Subclass: Palaeohetrodonta
Order: Unionoida
Superfamily: Unionacea
Family: Unionidae Fleming, 1828
Genus: *Unio* Lamarck, 1819
Unio kohlii Sahni and Bhatnagar, 1958
(Plate. 20, figs.1-5)

Horizon and Locality: Grey, fine-grained shale of Kargil section and grey sandstones of Nyoma Gompa section.

Description: In the present collection shells are poorly to moderately preserved and shape is sub-quadrate to oval. The length of the shells is greater than their height. The posterior and anterior d ends of the shells are round, the anterior one being more regularly than the posterior one. The dorsal margin of shell is almost straight and ventral margin is moderately curved. The conspicuous umbones are located near the anterior end. The shells are ornamented with anterior-posterior running concentric striations.

Remarks: The present specimens described here in this work exhibit similar morphology morphology of Unio kohlii recorded from Kargil (Sahni and Bhatnagar, 1958). Sahni and Bhatnagar (1958) compared the unionid shells from Kargil Molasse with the Unio species from the Deccan intertrappean beds, Siwalik deposits and oil measures of Burma. According to them, Unio kohlii differs from Unio hunteri and U. carteri in the absence of an umbonal ridge and prominent curved furrows radiating from the umbonal apex present in the intertrappean forms; from Lamellidens vredenburgi in the absence of a narrow posterior wing and almost centrally located umbones of the latter; from L. jammuensis by its smaller dimensions; from Indonaia in the absence of an umbonal ridge; from Lamellidens quadratus in which the shells are much more inflated, considerably larger and proportionately higher than long.

Class: Gastropoda
Subclass: Pulmonata
Order: Basommatophora
Family: Melaniidae (Lamarck) Gray
Genus: *Melania* Lamarck
cf. *Melania kargilensis* Sahni and Bhatnagar, 1958
(Plate. 24, figs.1-11)

Horizon and Locality: Carbonaceous shales and siltstones of Kargil Molasse exposed right side of Kargil -Batalik road in 4 ESE direction from Kargil town.

Description: **In present work** shells are medium in size, turreted and elongated spire with 6 - 7 whorls that regularly increase in size and convex in outline. The aperture is oblique ovate in outline and shell is ornamented with prominent spiral lines. The sutures between the whorls are impressed.

Remarks: Recovered shells are exhibit remarkably similarity to *Melania kargilensis* of Sahni and Bhatnagar (1958). However, vertical ornamentationthat included lines as well as ribs in addition to spiral lines on the whorls noticed by Sahni and Bhatnagar (1958) has not been seen in the specimens described here.

Family: Planorbidae Gray, 1840
Genus: *Indoplanorbis* Annandale and Prashad, 1921
***Indoplanorbis* sp.**
(Plate 22 figs.7-8 and Plate 23 figs.9-12)

Horizon and Locality: Mudstones and siltstones of Ladakh Molasse exposed near Nyoma Gompa sections.

Description: The shells are very small in size and discoidal in outline. There are two or three whorls which rapidly increase in size and the whorls have rounded convex margins. The body whorl overlaps all the whorls which are not visible from the basal side. The sutures between the whorls are impressed. All the recovered specimens are preserved as casts and generally have a smooth surface.

Remarks: This molluscan genus is present in most of the investigated sections but the specimens are poorly preserved. In general morphology, these specimens appear to resemble closely those of *Indoplanorbis* Annandale and Prashad, 1921. Better preserved specimens are required to know their species level affinity.

Genus: *Paludina*
***Paludina* sp.**
(Plate 21 fig.5-6 and 9, Plate. 22, figs. 4-5 and 9)

Horizon and Locality: Mudstones of the Kargil formation exposed at village Nyoma, District Leh , Jammu and Kashmir.

Description: Shell thick, ovate-conical, spire short and acute, three to fourpreserved whorls, whorls convex, sutures impressed, aperture small and subspherical, smooth surface.

Remarks: The fragmentary nature of the shells does not permit any taxonomic assignment at species level. However, these specimens exhibit features characteristic of the genus *Paludina*. Particularly, the present specimens closely resemble *P. takliensis* described by Hislop (1860) from the Deccan intertrappean beds.

Genus Bellamya

***Bellamya* sp.**

(Plate. 21, fig 4, 7, 8, Plate.23 fig. 2, 4-5)

Horizon and Locality: Mudstones of the Kargil formation exposed at village Nyoma, District Leh , Jammu and Kashmir.

Description: Shell elongated turbinate in shape, moderately solid, spire elevated, long, equal or slightly larger than the body whorl. Shell consisting of 3-4 whorls, gradually and regularly increase in size. The whorls are rounded and separated by impressed suture. Aperture partially preserved, body whorl not greatly enlarged in size. Shell surface marked with coarse and fine striate or growth lines. Aperture broadly ovate, small, thinly lipped, inner lip is thicker than the outer lip.

Remarks: The specimens under present study exhibit similar morphology with *Bellamya celsipiralis* described by (Gurung24) from the Churia (Siwalik) Group of Tinau (Nepal) and (Nath 2013) from Upper Siwalik of Jammu, Jammu and Kashmir, India.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.11 LADAKH FLYSCH/TAR GROUP, JAMMU AND KASHMIR DISTRICTS NW HIMALAYA

In the present work, a detailed and a systematic studies resulted in the recovery of a number of early Eocene Foraminifera from upper Sumdo Formation (Calc Shale-Limestones units) and from Nummulitic limestone (limestone units). This fauna documents the earliest Eocene and middle Eocene transgression within the Indus Suture Zone and probably related to the regional tectonic phases. The total number of foraminifers and their generic diversity has been considered for purposes of biochronology and biostratigraphic correlation. For age determination of fossil bearing units, the shallow larger benthic foraminifera biostratigraphic Zonation (SBZ) scheme of Serra-Kiel et al. (1998) with amendments for the placement of the different biozonation boundary at the boundary between biozones, updated larger benthic foraminifera (LBF) zonation of Paazzoni et al. (2017), has been adopted. This SBZ scheme is based on the earlier LBF biostratigraphic studies of Hottinger (1960), Hottinger et al. (1964), Schaub (1981) and Hottinger & Drobne (1988), and recent Indo-Pakistan-Tibatean LBF biostratigraphic studies of (Afzal et al., 2010, BouDagher-Fadel, 2008 and 2015; Zhang et al., 2013, etc.) and is applicable to the Tethyan shallow marine realm as far south as Somalia and southeast to the Indian subcontinent (Hottinger 1971; Pignatti 1994; Jauhri 1998; Scheibner & Speijer 2008a). A list of larger benthic foraminifers recovered from the Sumdo and Nummulitic Formation in the present work is given in the tables 4.1 and 4.2, respectively.

4.1.1 AGE OF THE LADAKH FLYSCH

Absence of well preserved fossil assemblages has seriously hampered the age estimates of Lower Cenozoic sedimentary sequences of Indus Suture zone. Early Eocene LBF biozones SBZ/6–SBZ9 has been recognised from Sumdo Formation. These biozones are identified on the basis of one or more key markers and their first and last occurrences (Fig. 4.1). A short summary of age diagonstic LBFs that delineate these biozones in investigated sections is given below and list of species occurrences are shown in Fig. 4.1 .SBZ scheme of Serra-Kiel et al. (1998), suggests that *Assilina dandotica* is restricted to the SBZ-5 Biozone in the Tethyan realm. However, Tosquella et al. (1998) demonstrated that *Assilina dandotica* extends to the SBZ6 Biozone. Ozcan et al., 2015 discussed *Discocyclina ranikotensis* has a wide stratigraphic range based on its occurrence in Dhak Pass beds (Hangu Formation), Khairabad Limestone (Lockhart Limestone) Patala and Nammal Formations in Pakistan and provisionally proposed to cover OZ 2 and (Orthophragminids Zonation of western Tethys, Less). Before (Ozcan et al 2015), *Discocyclina ranikotensis* has been reported from various stratigraphic levels ranging in age from late Paleocene to early middle Eocene in Pakistan, Iran, Italy and Slovakia. It was reported from late Paleocene (Afzal, Khan, Khan, Alam, & Jalal, 2005; Ahmad, 2010; Ahmad et al., 2014; Baruah & Das, 2007; Imraz, 2013; Latif, 1976; Sameeni, İmtiaz, Saleem, Haneef, & Naz, 2014; Sameeni, Nazir, Abdul-Karim, & Naz, 2009; Sigal et al., 1971; Yaseen, Rajpar, Munir, Roohi, & Rehman, 2011), late Paleocene to early Eocene (Afzal, 2010; Afzal et al., 2010; Butt, 1991; Hanif et al., 2013; Nagappa, 1959; Sameeni et al., 2014; Shafique, 2001; Weiss, 1993), early Eocene (Babazadeh, 2008, 2011; Schweighauzer, 1953), from late Ypresian- early Lutetian (Mirza, Sameeni, Munir, & Yasin, 2005). *Alveolina ellipsoidalis*, in the Western Tethys, appear in early SBZ6, P5a (BouDagher-Fadel, 2013) but later work BouDagher-Fadel (2015) carried out standard for LBF biozonation in Tibet area and observed that *Alveolina ellipsoidalis* do not appear before latest by SBZ6 in the Tethyan Himalaya. So it can be inferred that presence of *Alveolina ellipsoidalis* in association of *Assilina laminosa and* Assilina dandotica in lower part of fossiliferous Sumdo Formation indicate an SBZ-6 biozone. *D. archiaci*, has been consider as a key taxon for early Eocene orthophragminid zonation in western Tethys, it has been also recorded from Pakistan NW Himalayas (Ozcan et al., 2015). It occurs in Sumdo Formation with last appearance of *A.dandotica. Miscellanea miscella* has been reported from Afghanistan (Kaever 1970), northeastern Turkey (Sirel 1997b), Iran (Rahaghi 1983) and India (e.g. Jauhri 1998; Jauhri & Agarwal 2001; Jauhri et al. 2006) from horizons equivalent to the SBZ5 Biozone. In parts of the Lower Indus Basin of Pakistan (e.g. in the Sind and Balochistan provinces),M. miscella occurs in association with LBFs characteristic of the SBZ5 Biozone (e.g. Hottinger 1971; Hottinger et al. 1998; Akhtar & Butt, 2000).

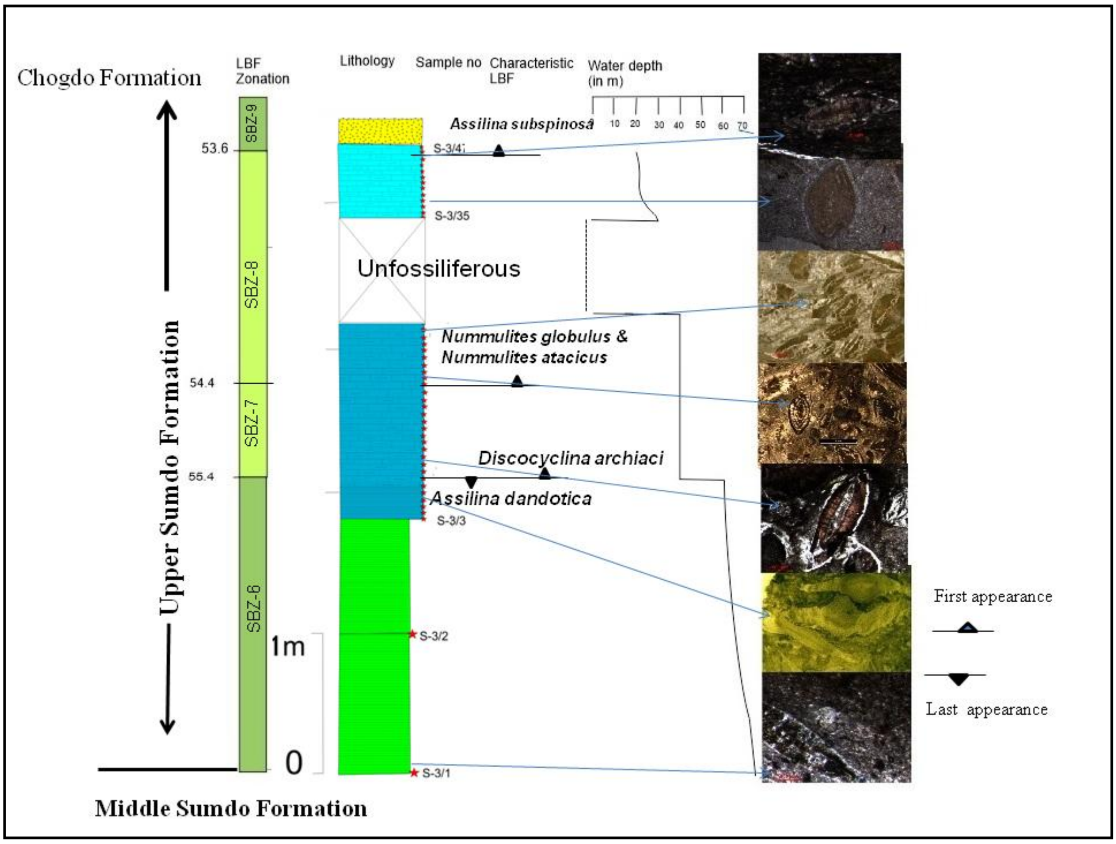

Figure. 4.1: LBF biozonatiion and inferred paleobathemerty during the deposition of Sumdo Formation (based on Ahamad et al., 2016; Fadel, 2008, 2013 and 2015; Zang et al 2013; Serra Paazzoni et al., 2017; Kiel et al., 1998; Ozcan et. al. 2015 etc).

Miscellanea miscella has been reported from Afghanistan (Kaever, 1970), northeastern Turkey (Sirel, 1997b), Iran (Rahaghi, 1983) and India (e.g. Jauhri, 1998; Jauhri & Agarwal, 2001; Jauhri et al., 2006) from horizons equivalent to the SBZ5 Biozone. In parts of the Lower Indus Basin of Pakistan (e.g. in the Sind and Balochistan provinces), *M. miscella* occurs in association with LBFs characteristic of the SBZ5 Biozone (e.g. Hottinger 1971; Hottinger et al. 1998; Akhtar & Butt, 2000). However, in India, *M. miscella* has been reported to range up to the SBZ6 Biozone (e.g. Mathur et al. 2009; Tewari et al. 2010). In the Hanna Lake and Zranda sections, the disappearance of *M. miscella*, together with *Assilina dandotica* and *Ranikothalia nuttalli*, suggests that its upper biostratigraphic limit is within the SBZ6 biozone. LBF studies of various workers (Bellen et al., 1959; Karim and Bazainy, 2007), from Kurdistan in northeast Iraq, suggest that *N. globulus* was found in the early Eocene shoal facies and its also known from the early Eocene (Middle Illedian 2) of northern Spain and Southern France (Middle Illedian 2) (Höttinger, 1960; Tambareau and Villate, 1977; Robador et al.,1991; Schaub

1981). However, in India, it has been recorded from the early Eocene (Middle Illerdian 2~SBZ8) and middle Eocene (Middle Lutetian 2~SBZ15) (Jauhri,1996 and Jauhri et al., 2006; Jauhri and Agarwal, 2001). *N. globules,* with *N. atacicus,* occurs synchronously in Europe (Schaub, 1981). Therefore, the synchronous first occurrence of these two species i.e *N. atacicus,* and *N. globules,* can be considered to be excellent bio event and used in this work to demarcate the boundary between SBZ 7 and SBZ 8 (early Eocene:Middle Illerdian 1-Middle Illerdian). At the base of SBZ 8 biozone apart from two species first occurrence of *N. mamillita* is also noticed in this work while end of SBZ 8 base of SBZ-9. Recently Zhang et al. (2012) has established LBF biozonation of Tethyan Himalaya of Tibet and observed the first occurrence of *Assiina subspinosa* at SBZ 9 . Thus, recovered Larger benthic foraminifers during the course of this work, suggests an age of SBZ5/6 to SBZ 9 (i.e., 55.80 - 53.6 Ma, planktonic foraminiferal zone P5 to lower P6b, Papazzoni et al., 2017) of upper Sumdo Formation (Fig. 4.1). *D. sella* has been recorded in the present work from Sumdo formation, also known from Pakistan in association with *Assilina dandotica*, *Ranikothalia nuttalli*, *D. dispansa*, *Nummulites atacicus* and *N. globulus*. These occurrences indicate SBZ5 - SBZ8 biozonal range for *D. sella* in the Indus Basin. D. sella has also been reported from the Eocene of France, Spain, India, Italy and Japan (Samanta,1969; Matsumaru and Kimora, 1989; Afzal et al.). LBFs from the Nummulitic Limestone Formation, are represented by wall preserved fossil *Assilina granulosa*, *Assilina spinosa*, *Assilina subspinosa*, *Alveolina* sp. *Nummulites* sp. etc and few poorly preserved form, of *Nummulites escheri*, and *Cuvillierina vanbellini*. The presence of *Assilina spinosa*, *Assilina subspinosa*, *Nummulites escheri*, and *Cuvillierina vanbellini* points the age ofNummulitic Formation to be equivalent to SBZ11 (Baudagar-Fadel, 2008), i.e., an age range of 50.4 to 49. Ma, based on the Geological Time Scale 2012. Beside the LBF the micro gastropoda genus *Turritella*, Coral: *Coleilonus elongates*, single isolated fish tooth and broken bivalve shell were also observed from Nummulitic Limestone Formation .

Isotopic dating of detrital zircons also support, the biostratigraphic all data from the Indus Basin sediments. Detrital zircons from the Tar Group (Jurutze and Chogdo Formations) yielded $^{206}Pb/^{238}U$ ages ranging between 100 - 50 Ma (Middle Cretaceous-early Cenozoic) with the youngest analyzed zircon in the Jurutze Formation providing an age of 53.4± 1.4 Ma

(Henderson et al., 2010a) and 60 – 49 Ma (Wu et al., 2007). Similarly, the youngest detrital zircon ages from the Chogdo Formation indicate 50.8±1.0 Ma (Henderson et al., 2010). The zircon ages from the Nummulitic Limestone fall in two dominant age groups, 85- 110 Ma and 150-160 Ma, with only three ages falling within the range of late Cretaceous to early Cenozoic of, which, the youngest age is 52.5± 0.7 Ma.

4.1.2 ENVIRONMENT OF DEPOSITION OF LADAKH FLYSCH/TAR GROUP

LBF preferred to live in symbiotic relationship with unicellular algae. In tropical shoal as well as in carbonate reef environments, LBF house various algae including diatoms, chlorophyceans , rhodophyceans. and dinophyceans. This symbiosis provides nutrients from photosynthesis, which facilitate life in different water depth and it is also favour maximum carbonate production by intake of carbon dioxide (Flügel, 2004). Stable, nutrient deficient, oligotrophic, conditions are highly advantageous but when nutrient resources become plentiful, they cannot respond competitively (Hallock, 1985). LBF may gain all or only part of their nutritional requirements from their endosymbionts (McEnery and Lee, 1981). Availability of nutrient is almost linked to salinity and temperature ; Upwelling adds nutrients whilst reducing temperature, runoff adds nutrients whilst reducing salinity, and evaporation concentrates nutrients whilst raising salinity (Hallock and Schlager, 1986). It is very important to note that at extreme values, the temperature as well as salinity are limiting factors for all LBF, while at intermediate values they have a negligible selective effect and short lived extreme values, as observed in tidal pools and mostly produce contorted tests (Höttinger, 1983). The quantity of available nutrients depends on the substrate (Gerlach, 1972),while Substrate comprises of organic particles (e.g. faecal pellets , plant material, faecal pellets and detritus) and inorganic particles (e.g. shell debris) plus interstitial water and air. Silty and muddy substrates are often rich in organic debris and the small pore spaces may contain bacterial blooms, which can support large populations of foraminifera. Many of these foraminiferal species are delicate, often elongate forms. Foraminifera from the coarser substrates may be thick shelled, heavily ornamented and of biconvex or fusiform shape (Brasier, 1980). Different wall structures reflect differences in light attenuation through the water column and of water energy (Haynes, 1965). These include small spaces within the test walls that harbour algae (Hansen and Dalberg, 1979), and pits on the interior of the chamber walls in which the algal cells reside (Hansen and Reiss, 1972; McEnery and Lee, 1981). Many studies have documented systematic morphology changes with variation in habitat depth in living, symbiont bearing species (e.g., Haynes, 1965; Höttinger and Dreher, 1974; Larsen, 1976; Hansen and Buchardt, 1977; Höttinger, 1977a; Larsen and Drooger, 1977). Although living distribution patterns of the symbiont-bearing LBF are confined to tropical and subtropical shallow marine environments, their distribution is determined by a complex set of inter-related parameters such as temperature, nutrient levels and light (Renema, 2002). The paleoecological analysis of the recent LBF can be utilized to deduce the paleoenviromental reconstruction of their habitat. In the study area abundant LBF are *Discocyclina, Assilina Nummulites* and *Alveolina.* Their paleoecology and depth distribution are briefly discussed as follows.

Nummulites/ Paleonummulites venosus species is found in the depth range of 15-85 m, in quiet back- and forereef areas on a sandy substrate below fair weather wave base (Hohenegger, 2000), on coarser sand (Langer and Hottinger, 2000), and it is also found at the reef base (Renema and Troelstra, 2001). Fossil *Nummulites* is reported from the El Garia Formation in Tunisia (Racey, 2001), the Jdeir Formation offshore Libya (Anketell and Mriheel, 2000), the Seeb Formation in Oman (Racey, 1994), representing a mid ramp environment. These are also reported from Eocene inner shoal ramps of the French Alps (Sinclair et al., 1998). Sandy near shore deposits of southern Tethys have Nummulites perforatus (Herbs, 1988), which is also reported from the inner shoal to mid ramp rocks in the Pyrenean Basin (Gilham and Bistrow, 1998). N. perforatus associated with *Assilina* and *Spiroclypeus* representing middle to upper ramp settings in northern Italy (Bassi, 1998). Nummulites are found associated with red algae and Discocyclina representing allochthonous shelf edge banks in northern Italy (Arni and Lanterno, 1972).

Assilina is reported from the Pyrenean Basin in association with Discocyclina representing the outer ramp environment (Luterbacher, 1998), of Helvic Nappes Switzerland (Herb, 1988) and Oman (Racey, 1994). Ghose (1977) reported *Assilina* from turbid water fore- and backreef facies from the Paleogene of northern India.

Alveolina Species of Alveolinella quoyi represents 3-5 m depth of very shallow protected waters where it is located on algal covered rubbles as an epibiont, and also lives in the range of 20-30 m water depth, on stable substrates with inorganic detritus in Papua New Guinea (Serverin and Lipps, 1989). It is also reported from the shallow shelf between 5-75 m water depth range in the Sesoko Island, Japan (Hohenegger et al., 1999) and within the 3-50 m depth range from the reef base on hard substrate in the SW Sulawesi, Indonesia (Renema and Troelstra, 2001). *Alveolinella* sp. is another example which is recorded from the 10-80 m water depth range in fore- and backreef of tropical seas (Reichel, 1964; Hottinger, 1973). It is reported from the Great Barrier Reef on a sandy substrate laterally adjacent to seagrass (Maxwell et al., 1961), from a less than 30m (< 30m) deep lagoon (Newell, 1956), from the back reef shoals where no clastic input occurs (Henson, 1950) in Raroia Atoll. In the fossil record, *Alveolina* is found in association with *Orbitolites* from the Eocene Jdeir Formation in the offshore Libya, representing a back ramp environment (Anketell and Mirheel, 2000). It is also reported to be associated with milliolids and Orbitolites from the shallow protected lagoon in inner ramp settings of the Pyrenean Basin (Gilham and Bristow, 1998; Luterbacher 1998). In the Southern Tethys, the early Eocene–middle Eocene record indicates inner shallow platform margin settings (Sartorio and Venturini, 1988). Alveolina was found leeward of the backbank facies in the Sirite Basin Libya (Arni, 1965).

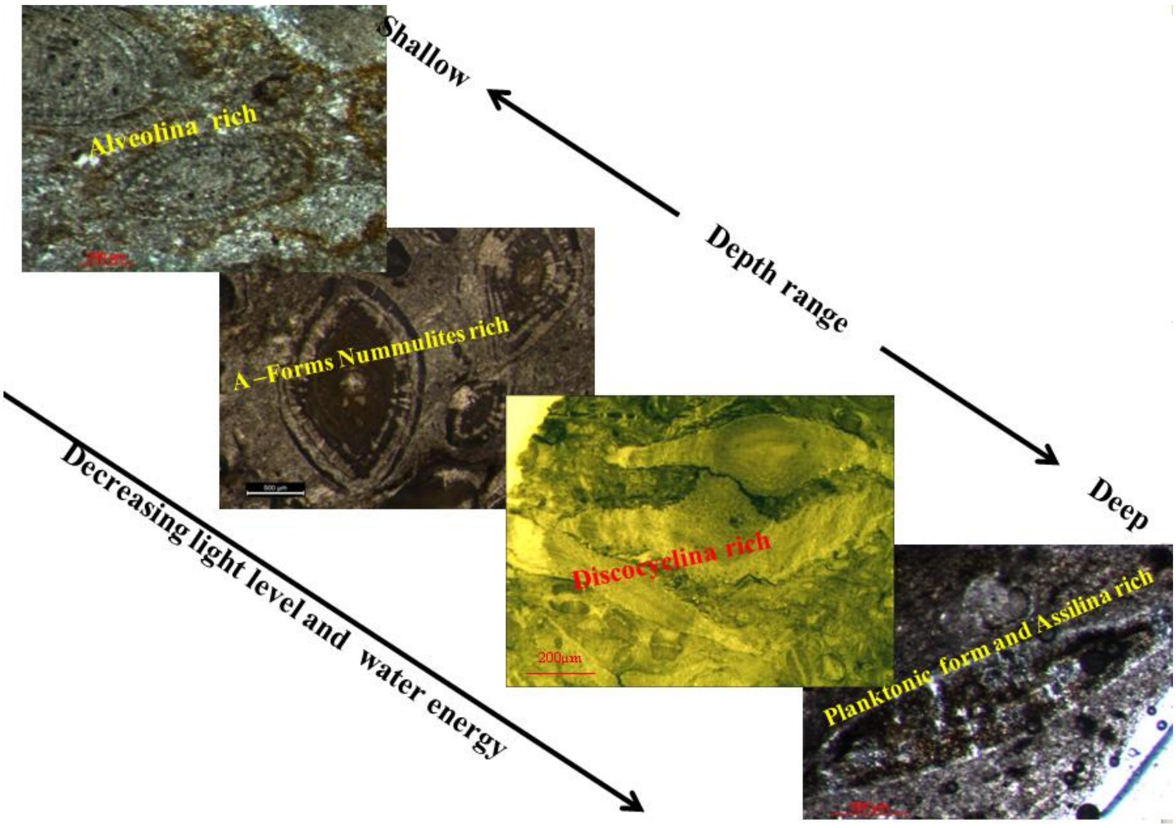

Figure 4.2: The depositional environments of Sumdo Formation, which prevailed during the early Eocene within the Indus Suture Zone, Ladakh Himalaya. Planktic foraminifera and *Assilina* shows deeper enviornments outer ramp, while *Alveolina* shows inner ramp platform carbonate setting (after Racey, 1994 and Fadel, 2008).

Discocyclina sp. represent normal marine conditions below FWWB, found slightly deeper than *Assilina* sp. but shallower than *Operculina* sp. When it is found in association with

Alveolina sp. and *milliolids*, Discocyclina sp. represent the backreef environment (Geel, 2000). Broken Discocyclina sp. tests associated with *Nummulites* sp. and *Assilina* sp. are recorded from the Eocene Jdeir Formation in offshore Libya, representing a forebank environment (Anketell and Mirheel, 2000). The ovate forms found in the inner ramp above FWWB and flattened forms occur in the mid to outer ramp settings in the El Garia Formation, Tunisia (Loucks et al., 1998). Robust forms are recorded from fore shoals above FWWB, flattened form from back shoal lagoons (5-20m) below FWWB in the French Alps (Sinclair et al., 1998). Largest forms have been recorded from the Late Eocene, inner-mid ramp deposits in the northern Italy (Bassi, 1998). Discocyclina is recorded from the outer ramp deposits of Oman (Racey, 1994) and from the Pyrenean Basin (Gilham and Bristow, 1998). It represents middle to outer bank, reef core and forereef areas (large and stout form) in the Paleogene rocks of India (Ghose, 1977). In studied section of Sumdo Formation the lowermost fossiliferous unit comprising *Assilina* and planktonic foraminifera suggests a deeper marine condition,which followed by an assemblage dominated by Discocylina-Asiilina suggeting an outer ramp setting of platform and other one dominating by Nummulites and Discocyclina. Middle part of sumdo formaton, comparising *Nummulites- Assilina* and Uppermost limestone unit dominating by mainly *Alveolina*, suggest a shallowing upward facies trend in an overall inner shallow platform environment (Fig.4.1 &4.2). Absence of coral and dominance of Discocyclina -Assilina-Nummulites suggest an warm climatic condition during deposItion of Sumdo Formation. In Nummulitc Limestone Formation the assemblage is dominated by Assilina -Nummulites and associated with coral and gastropods which suggest an back reef -lagoonal environment of deposition.

4.2. LADAKH MOLASSE/INDUS GROUP, JAMMU AND KASHMIR DISTRICTS NW HIMALAYA

4.2.1 AGE OF THE LADAKH MOLASSE

Younger Ladakh molasse/Indus Group hampered with age diagnostic microfossils data in comparison to the older Ladakh Flysch/Tar Group. During the present course of study ostrocod fauna *Candona himalaica* was recorded from Kargil Formation, Eastern Ladakh, (Nyoma section) suggests an age of Late Oligocene. Before the present work it was only known from Basgo Formation, central Ladakh near Trauche village, recorded by Bajpai et al. (2004), in association with *Dongyingia*. Late Oligocene age of ostrocods level of Basgo

Formation, central Ladakh has been favoured by (Bajpai et al. 2004) on the basis of *Dongyingia* as all known species of *Dongyingia* (earlier to Bajpai et al 2004) are reported from the Upper Oligocene Dongying Formation of China. Before this work, *Candona Himalaica* was known only from central Ladakh. Micro vertebrates and associated fossils recovered from Liyan Formation during this work are long ranging and hence not reliable to determine the precise age of sequences. An attempt has made to date basal molasse unit of Liyan formation, eastern Ladakh, tentatively, and late Eocene age of microvertebrates fossil level of Liyan Formation has been inferred by Verma & Maurya (in press) in view of recovered Juxia, reported by Tiwari, (2003), at 9.2 m above of micro vertebrates level. As the skull morphology of *Juxia*, rhinoceratid is closely comparable with *Juxia sharamurense* (Chow & Chiu, 1964), is known from the Shara Murun Formation, of Middle Eocene of Mongolia but slightly more evolved than the Mongolian species in terms of dental characters, hence a late Eocene age for the Liyan Formation was suggested by Tewari (2003). Recovered gastropoda: *Melania kargilensis*, from Kargil Formation, Kargil area also points Eocene age (Sahni and Bhatnagar 1958) of fossiliferous level. Thus fossils recovered from about 10m above base level of Ladakh molasse, conform that the lower most unit of ladakh molasse must be after than late Eocene-oligocene . Due to limited fossil availability and poor age constrain potential age of the molasse deposits of study area has been debated since long time. Late Cretaceous (Maastrichtian) age of Basgo Formation, central Ladakh was suggested by Van Haver (1984) on the basis of ostracods *Bythoceratina* sp. and *Platycythereis* sp. Van Haver (1984) also inferred Palaeocene-Early Eocene age of overlying Temesgam Formation. Thus, Van Haver (1984) suggested an age of Late Cretaceous and Palaeocene-Early Eocene for the Basgo and the Temesgam formations. But finding of Late Oligocene Ostrocoods fauna from Basgo Formation by Bajapi et al.,(2004) confirms much younger age of Molasse deposits. Searle et al. (1990) also raised the doubt and considered the ostracod taxa reported by van Haver (1984) as reworked fossils, which means that the these taxa do not indicate the true depositional age of the Basgo Formation and it was derived from somewhere else. The age of the molasse deposits has been debated for long and the assigned ages varied from Eocene, Oligo-Miocene , Miocene-Pliocene etc (see table no. 2.1, chapter-2). Eocene age has been favoured by Sahni and Bhatnagar (1958) for molassic sequences exposed near Kargil (Kargil Molasse/Wakka-Chu Molasse/ Kargil Formation) on the basis of fossil assemblages such as gastropods *Melania kargilensis*, *Viviparus* sp., *Planorbis* sp. and palm leaf impressions of *Sabal* or *Tachycarpus*. Tewari (1964), correctly identified the post- Eocene sedimentary deposits of Kargil basin as molasse instead of flysch (Lydekker, 1883; De Terra, 1935) and suggested Miocene-Pliocene age for these sequences by comparing them, with similar molasse deposits of Trans-Himalayan region at Hundes in Tibet and Kailas Conglomerate. Dixit et al. (1971), while documenting a mammalian tooth belonging to *Hyoboops* of Miocene of Africa from the Kargil Molasse, assigned a Miocene-Pliocene age for the fossiliferous horizon, as suggested by Tewari (1964). Tewari & Dixit, (1971), suggested a Post- Middle Eocene to pre-Pleistocene age for these sequences based on the occurrence of foraminifer *Nummulites* and algae *Corallina* of Lower Eocene age in the clast of conglomerate at the top of Kargil Molasse. Tewari and Sharma (1972) inferred Oligocene-Miocene age for the Kargil Molassic sequences at Kargil area based on charophytes assemblage *Grambastichara* cf. *tornata*, Horn af Rantzien, Grambastichara cf. cylindrica, Horn af Rantzien, and Harrisichara cf. vasiformis, Grambast. Dixit et al. (1971) re examined the *Hyoboops* (a mammalian tooth) described earlier from the Kargil Formation / Kargil Molasse, near Baroo colony, Kargil western Ladakh, and came with a conclusion that *Hyoboops* has close affinity to *Brachiodus* known from the Lower Miocene Bugti Beds, Baluchistan and *Ancodus* (Hypopotamus) *bovines*, known from the Oligocene Isle of Wight, Hempstead. Thus, on the basis on age range of charophytes and taxonomic affinities of Hyoboops, Tewari and Sharma (1972) favoured an Oligocene-Miocene age for the Kargil Molasse. Savage et al. (1977) restudied the mammalian tooth Hyoboops, and assigned a taxonomic name *Hyoboops palaeindicus* to it. Based on occurrences of *Hyoboops palaeindicus*, which is known from the Lower Miocene Dera Bugti bone bed, Baluchistan (now in southern Pakistan), Savage et al. (1977) suggested same age for the Kargil Formation. Stratigraphic classification has been provided by Bhandari et al. (1977) on the basis of palynofossils which included some reworked taxa as well and divided the molassic sequences of Kargil area into Kargil, Tarumsa, and Pashkyum formations and suggested ?Palaeocene-Eocene, Eocene-Miocene, and Miocene ages for these formation respectively. Late Oligocene age for Kargil molassic sequences was suggested by Nanda and Sahni (1990) based on the mammals, artiodactyl taxa including *Lophiomeryx kargilensis* and *Cryptomeryx savage*, which shows close affinity to Oligocene *Cryptomeryx* and *Lophiomeryx* of Europe (Nanda & Sahni, 1990). However, in later work Kumar et al. (1996) raised a question and were of the opinion that *Cryptomeryx* is a junior synonym of *Iberomeryx* from Oligocene-Miocene of Asia and supported this view in light of the recorded *Ctenodactylidae* rodent fauna : *Fallomus razae* (Flynn et al., 1986), *F. ladakhensis* (Nanda and Sahni,1998), *Wakkamys* *hartenbergeri* (Kumar et al., 1996), (Ctenodactylidae rodent fauna) and *Zindapiria (*Flynn and Cheema, 1994) from the Kargil Molasse is remarkably similar to that of Bugti Member of Chitarwata Formation, Pakistan, so there is no compelling evidence for Oligocene age of the Kargil Molasse. In fact, Kumar et al. (1996) felt that the Kargil Molasse ctenodactylid rodent fauna is slightly derived from that of Bugti Beds of Bugti Member (Chitarwata Formation), Pakistan and rather more closer to that of Lower Miocene age assemblage of Zinda PirDome, Pakistan. Based on this observation, Kumar et al. (1996) suggested an Early Miocene age for the Kargil Formatio/Kargil Molasse. Prasad et al. (2005) documented a fragmentary cricetid rodent molar representing *Democricetodon* sp. from the Basgo Formation same locality of Bajpai et al,(2004), and suggested an early Miocene for Basgo Formation on the basis of fact that no species of Democricetodon has been recorded from rocks older than Lower Miocene. Thus ,these fossil evidence, represented by Late Oligocene ostracods and Early Miocene cricetid rodents from the basal part of central Ladakh Molasse, places the older Basgo and younger Temesgam Formations as equivalent of Nurla, Choksti and Nimu formations of the (Henderson et al 2010)) rather than with the Jurutze, Sumdo, Chogdo and Nummulitic Limestone formations of the southern Tar Group. Furthermore present work also points that Kargil Formation at Nyoma area eastern Ladakh may be ? correlatives of Basgo Formation and it may be correlatives of Liyan Formation at Liyan Gompa area/ Kargil Formation/ Kargil Molasse or Wakka-Chu Molasse of the western Ladakh Himalaya. It is evident from above discussion that though Ladakh molasse/ Indus group comprises limited fossil data but occurrence of fossil assemblages (freshwater gastropods, bivalves, ostracods, charophytes, cyprinid fishes, and mammals) more or less from molasse deposits of Eastern, Central and Western Ladakh along the Indus Suture Zone shows close similarity with stratigraphic arrangement and fossil content of basal unit of molasse those deposited in the central part of the Indus Suture Zone near Basgo, Taruche and Saspochey villages in Leh district and in the western part of the suture zone near Kargil town in the Kargil district. The thickness of molasse sequences in these three sector varied may be due to configuration of basin and sediment supply but basal molasse sequences are started to deposited in similar time in the Eastern, central and western sectors of Indus basin (Ladakh range). Radiometric dating of detrital zircon ages for the molassic sequences , Indus Group, central Ladakh are dominated by middle Cretaceous to Middle Eocene ages except for two grains which give age mid-Jurassic (171.0± 4.5, 173.3±3.8 Ma) grains from the Nurla Formation (Henderson et al., 2010a). On the basis of U-Pb isotopic ages of detrital zircon indicate that the Choksti Formation was deposited later than 45-41 Ma but before 35 Ma. The detrital zircons from the Upper Nimu Formation suggest ages of 41.3±.0 Ma (Henderson et al., 2010a) and 41.0± 0.3 Ma (Wu et al., 2007).This was considered as the maximum age for the upper Indus Group. In the absence of any isotopic data from the molasse north of the modern Indus river and as fossils are not known from Nurla, Choksti and Nimu formations, the exact stratigraphic relationship between these formations and the northern molasse are not clear.

4.2.1 PALEOENVIRONMENTS AND BIOGEOGRAPHIC AFFINITIES OF THE BIOTA FROM LADAKH MOLASSE

The ostracod fauna recovered from the studied sections is represented by mainly *Candona himalacia*, and *Eucypris* sp. *Candona* and *Eucypris* are widely distributed taxa (Bhatia, 1968; Bojie, 1978; Hou et al., 1988) known from freshwater habitats. Fishes belonging to the family Cyprinidae are known from the freshwater deposits of Africa, Europe, Asia and North America (Otero, 2001). Ladakh Cyprinids fishes during present study comprise mainly genus *Barbus, Schizothorax, Cyprinus, Squalius* and associated with Charophytes. The occurrence of fish taxa, *Schizothorax, Cyprinus* indicates the presence slow-moving or still waters, whereas Barbus indicates faster moving waters that suggest the presence of nearby streams or rivers (Gaudant *et al.*, 2002). Among the molluscs of the present collection the recovered gastropods show very close affinities with the Paludina bugtica (Blandford, 1883) and Vivipara atavia (Annadale, 1921) known from the Oligocene-Miocene beds of Gaj stage, Bugti hills, Baluchistan (Pakistan) and to *Vivipara gregoriana* and *V. dubiosa* (Annadale, 1924) known from the Pliocene Dawna Hills of Burma. These gastropods are long age ranging and they found in present day modern stream and prefer muddy substrate and low energy condition (Fig. 4.3). However other known fossil from Ladakh molasse such as vertebrates fossil fish: cyprinid, silurid or channid fishes, (Dixit *et al.*, 1971; Savage *et al.*, 1977; Sahni *et al.*, 1984; Nanda & Sahni, 1990, 1998; Kumar *et al.*, 1996, Tiwari, 2003, Prasad et al., 2005., Parmar et al., 2013), Invertebrates: Molluscs- gastropods*: Subzebrinus gudei* , *Melania kargilensis*, *Viviparus* sp. indet., *Planorbis* sp. indet.; bivalves: *Unio kohlii* . (Stoliczka, 1874; Lydekker, 1883; De Terra, 1935; Sahni & Bhatnagar, 1962; Tewari & Dixit, 1971; Mathur, 1983; Garzanti & Van Haver, 1988). Ostracods : *Dongyingia sannionis*, (Bajpai et al. 2004), Charophytes: *Grambastichara* cf. *tornata*, *G.* cf. *cylindrica*, *Harrisichara* cf.*vasiformis* (Tewari &Sharma, 1972) are suggests an fresh water habitat during the depostion of Ladakh molasse. Beside it Palm leaf fossill *Tachycarpus* belongs to Plant *Prunus* which suggest an a warm temperate climatic condition (Guleria et al., 1983

4.4 STRATIGRAPHIC EVOLUTION OF LOWER CENOZOIC SEDIMENTARY SEQUENCES OF LADAKH HIMALAYA

Marine to continental sedimentation is one of the important criteria used to date the timing of the India-Asia collision, which resulted in the uplift of the Himalayas (Najman et al. 2010). Occurrence of continental sedimentary sequences provide an evidence for the timing of the disappearance of the Tethys sea. After Collision of Dras- Kohistan Ladakh arc with Eurasia an arc bounded basin has been formed and known as Indus Basin (Henderson et al., 2010)

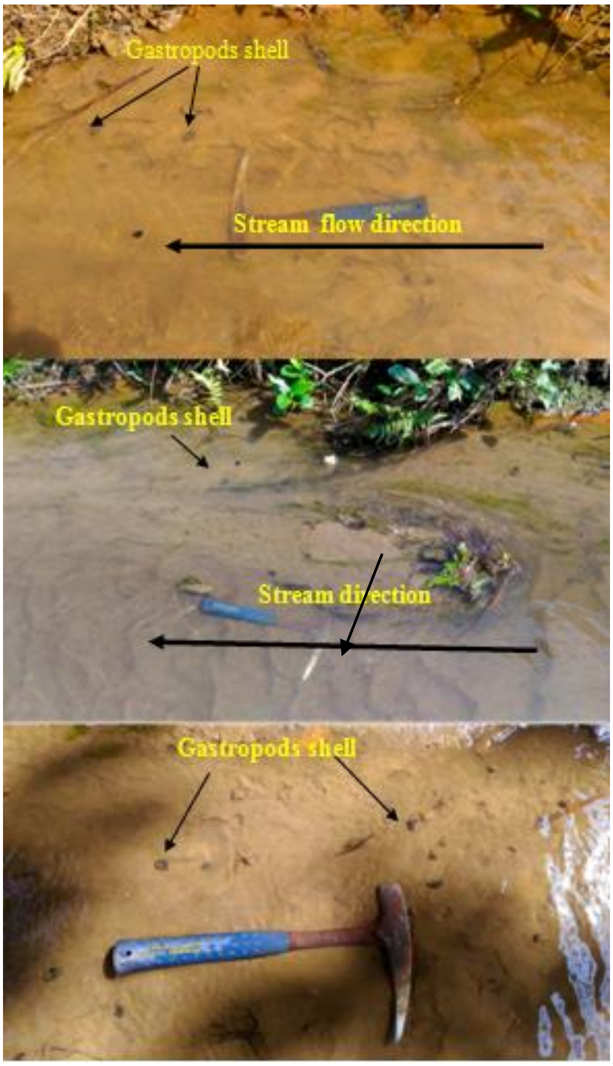

Figure. 4.3 Showing depositional environment of extant form of Liyan Gastropods

Within Indus Basin sedimentation started took place with the deposition of Jurtze and Sumda Formations (Henderson et al. 2010).

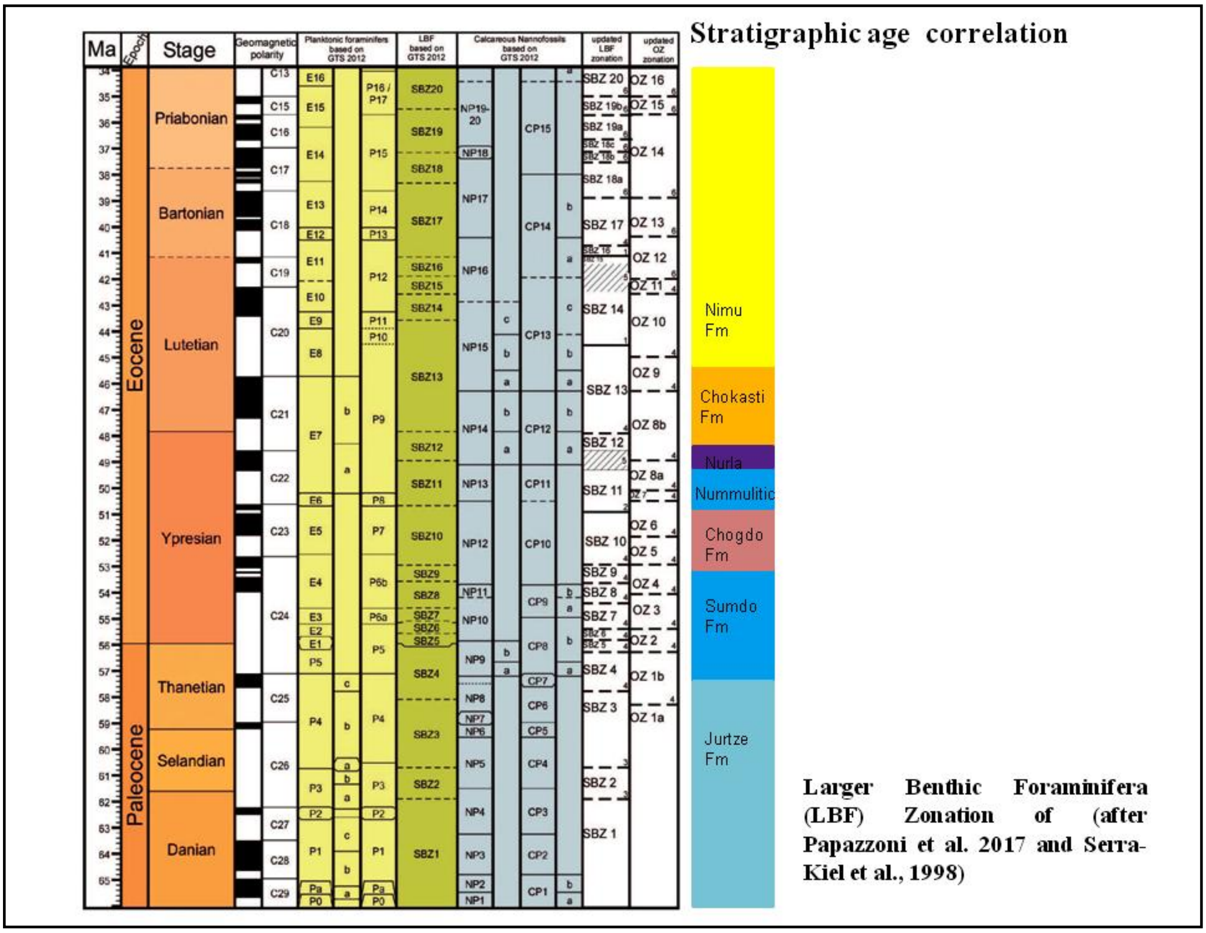

Figure. 4.4 Correlation of different Lower Cenozoic stratigraphic unit of Ladakh Himalaya with standard shallow benthic foraminiferal bio-zonation.

Within Indus Basin sedimentation started taking place with the deposition of Jurtze and Sumda Formations (Henderson et al. 2010). Jurtze formation was dominated by shale and Sumdo by shale and Limestone. So age of uppermost Sumdo Formation suggest, timing of first session of marine deposition within Indus Basin Ladakh. LBF biozonation suggests that last deposition of Sumdo Formation took place at SBZ8/SBZ-(9~ 53.6 Ma.) and similarly upper age of Nummulitic Limestone suggests end of second session of marine deposition i.e. SBZ-11(~49Ma). This time is recorded as global sea level fall by Haq et al. (1987), but with in suture zone, it points marine incursion, so it may happen probably due to Himalayan collision related tectonics.

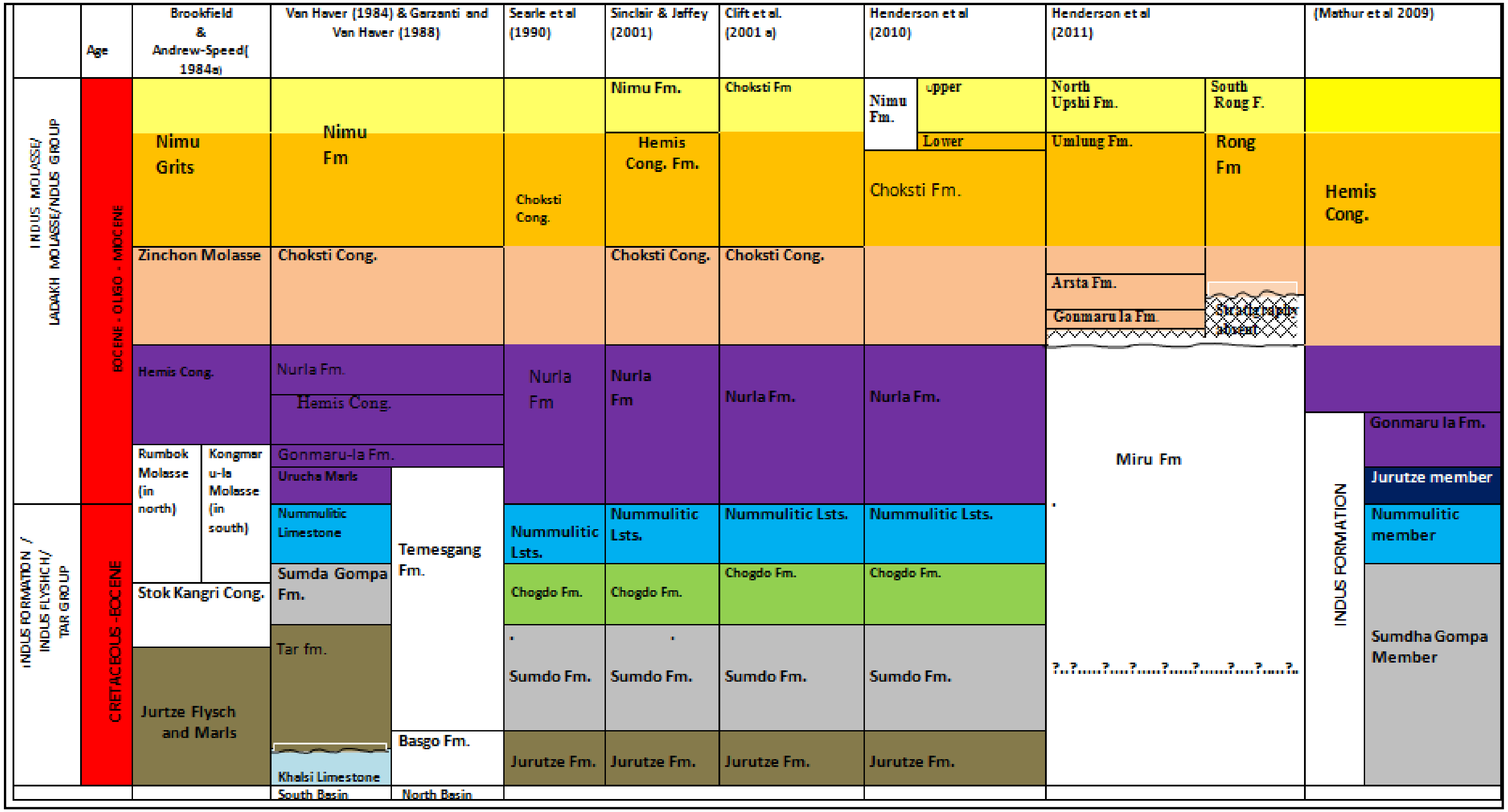

Fig: 4.5. Correlation of different stratigraphic unit within the indus suture Zone Ladakh (Modified after Henderson et al., 2011).

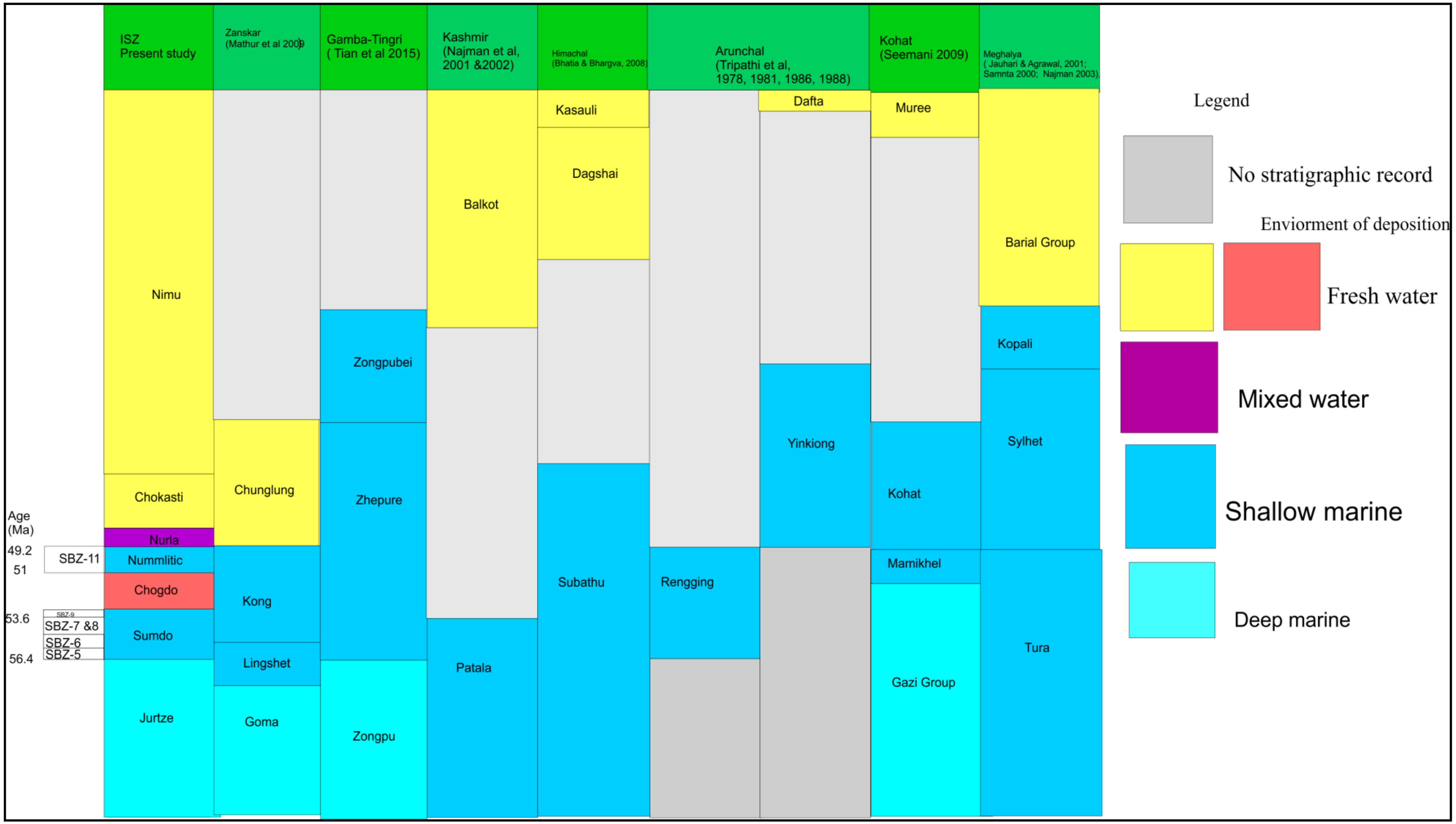

Fig: 4.6. Regional correlation of different stratigraphic correlation Lower Cenozoic strata of ISZ throughout the Himalaya

Though no fossil has been recovered from chogdo Formation during present work, but to its stratigraphic position between Sumdo and Nummulitc Limestone Formation, it may be deposited probabably around SBZ-9 to SBZ-10 (**Fig. 4.4**). In present work no fossil has been recovered from Nurla Formation but Mathur et al., (2009) recorded *Turritella subathooensis*, *Seila stracheyi*, *Diplodonta subathooensis* and *Pitar subelongata*, suggesting lower part of middle Cuisian age from shale –siltstone bed, south of Jhingchan and shallow marine to brackish water enviornment of deposition. After deposition of Nurla Formation, complete fresh water condition was established with the suture zone, and Choksti and Nimu and their correlatives deposited in different sector of Indus basin (Fig.4.5). Different stratigraphic unit of ISZ has been correlated with other sector of Himalaya (Fig. 4.6) which suggest that Sumdo Formation is equivalent to upper part of Patala Formation and disappareance of Neo-tethys has been first took place in Kashmir Himalya and Ladakh Himalaya .

CHAPTER 5

SUMMARY AND CONCLUSIONS

In the present work, a detailed and a systematic paleontological studies has been led the recovery of early Eocene LBF from upper Sumdo Formation and Nummulitic Limestone Formation of Tar Group. Early Eocene LBF biozones SBZ6–SBZ9 range has been recognized from Sumdo Formation and LBF assemblage is represented by various species of genera *Assilina, Nummulites, Discocyclina* and *Alveolina.* The key biomarker species from Sumdo Formation has been identified as *Assilina dandotica*, *Nummulites atacicus*, *N. globulus* and *A. subspinosa*. The last last occurrence of *A. dandotica* in the ISZ is demarcate the upper boundary of the SBZ6 biozones and Lower boundary of SBZ-7. The base of SBZ-8 biozone is defined by the first appearance of *N atacicus*, *N.* globulus while first appearance of *A. subspinosa* marks the base of SBZ-9 and end of SBZ-8. Thus recovered Larger benthic foraminifers during course of this work suggests an age of SBZ6 to SBZ 9 ie 55.80 - 53.6 Ma age range based on the Geological time scale (GTS) 2012, equivalent to planktonic foraminifera zone P5 to lower P6b of Upper Sumdo Formation. LBF from the Nummulitic Limestone Formation suggest Nummulitic Formation age of SBZ-11 i.e. an age range of 50.4 to 49. Ma, based on the GTS 2012. Beside the LBF the micro gastropoda genus *Turritella,* Coral: *Coleilonus elongatus* and single isolated fish tooth broken bivalve shell were also observed from Nummulitic Limestone Formation. This stratigraphic unit is last completely marine deposition in Ladakh Himalaya. The investigated Sumdo section can be correlated with the Upper part of Ranikot Formation of Pakistan, middle part of Dibling Limestone Formation of Zanskar, Indian Passive margin, upper part of Patala Formation of Kashmir Himalaya, while Nummulitic Limestone Formation can be correlated with Upper part of Kong Formation of Zanskar Basin, Renging Formation, Arunachal Pradesh, Umladoah Formation Meghalaya, India; Middle part of Zehpure Formation of Tingri-Gampa, Tibet, Mama Khel Formation, Kohat basin Pakistan.

Based on stratigraphic position of Chogdo Formation between Sumdo and Nummulitic Limestone Formation age of Chogdo Formation can be inferred ~SBZ-10 which demarcate the first fluvial depostion within the ISZ probably correspond to the one continent-continental collision event within the ISZ. Over all faunal assemblage (Nummulite- Assilina dominant and coral absences) of Sumdo Formation suggest an warmer climatic condition and deposition has taken place outer to inner platform setting. However Nummulitic Limestone deposited in inner marine platform (back reef) environmental condition. Basal Molasse deposits of Ladakh/Indus Molasse Group/ Ladaakh Molasse Group yielded assemblages includes- Vetertebrates: fish teeth, fish scale and Vertebra representing: Cyprinidae: *Barbus* sp., *Schizothorax* sp., *Cyprinus* sp., *Squalius* sp., Rodents:? Rodentia Gen et. Sp., Crocadaliyan tooth: Incertae sedis Gen et. Sp.., Invertebrates: Mollusca: Gastropoda- *Melania kargilensis* Sahni & Bhatnagar, Indoplanorbis sp., *Paludina* sp., *Bellamya* sp. Bivalves: *Unio kohlii* Sahni & Bhatnagar, Ostracods: *Candona himalaica* Bajpai, Whatley, Prasad & Whittaker, Candonidae Gen et. Sp., *Cypridopsis* sp., Charophytes: *Grambastichara* cf. *Tornat*a Reid & Groves.

The occurrence of fish taxa, *Schizothorax*, *Cyprinus* indicates the presence slow-moving or still waters, whereas *Barbus* indicates faster moving waters that suggest the presence of nearby streams or rivers fluvial system was also supported by: gastropoda- *Melania kargilensis Indoplanorbis* sp., *Paludina* sp. , *Bellamya* sp. Bivalves: *Unio kohlii,* Ostracods: *Candona himalaica*. So microvertebrates fossil and their association suggests a typical fresh water ie. Lacustrine to fluvial environments of deposition for basal molasses horizons which militates changes in landscape from marine to freshwater regimes and completes disappearance of neo-Tethys which occurred due to the Himalayan tectonics and final suturing between Indian and Asian plates. The occurrence of these fresh water fossil assemblage from basal molassic stratigraphic unit in eastern (Nyoma and Liyan areas), central (Taruche, Saspochey and Basgo areas) and western (Kargil area) Ladakh, along the Indus Suture Zone also shows close similarity with stratigraphic arrangement and fossil assemblage suggest fossiliferous molasse deposits of these areas are either homotaxial in nature and these faunal assemblages suggests Late Eocene to early Miocene age of deposition in view of the occurrence of freshwater gastropods *Melania kargilensis*, *Planorbis* sp., Ostrocods: *Candona himalaica, Cypridopsis* sp., *Dongyingia sannioni* and *Eucypris alpina (*Bajpai et al 2004), and *Eucypris alpina*, leaf impressions of rhinoceratoid skull: *Juxia sharamurense (Tewari, 2003).*

The affinities of Liyan and Nyoma assemblages in realtion to (?) contemporaneous assemblage from Kutch (Gujarat), Kasauli Himachal Pradesh has subareial connection. Sedimentary deposits in Ladakh, Kasauli and Kutch were derived ultimately from the rising Himalayan mountain chain via rivers draining in northwestwards and southwards from Northern India into the Arabian Sea. These rivers were populated by fish, molluscs and their banks were the habitat of mammals and plants, providing biological continuity between the mountains on the one hand and the coast on the other. The shallowing in marine to continental sedimentation as well as presence of Asian origin land mammals, freshwater fishes, gastropods, plant remains on the Indian sub-continent evidence points towards continental -continental Collision between Indian with Asian plate probably occurred earliest by after deposition of Sumdo Formation ie 53.6 Ma and latest by after deposition of Nummulitic Limestone i.e 49 ma. It has been also observed that the *Disscosyclina*, *Assilina* are more diverse in early Eocene while Alveolina are rare Possibly India-Asia collision created local oceanographic condition and created biogeographic obstacles between east and west Tethys, preventing migration of texa between these two region .

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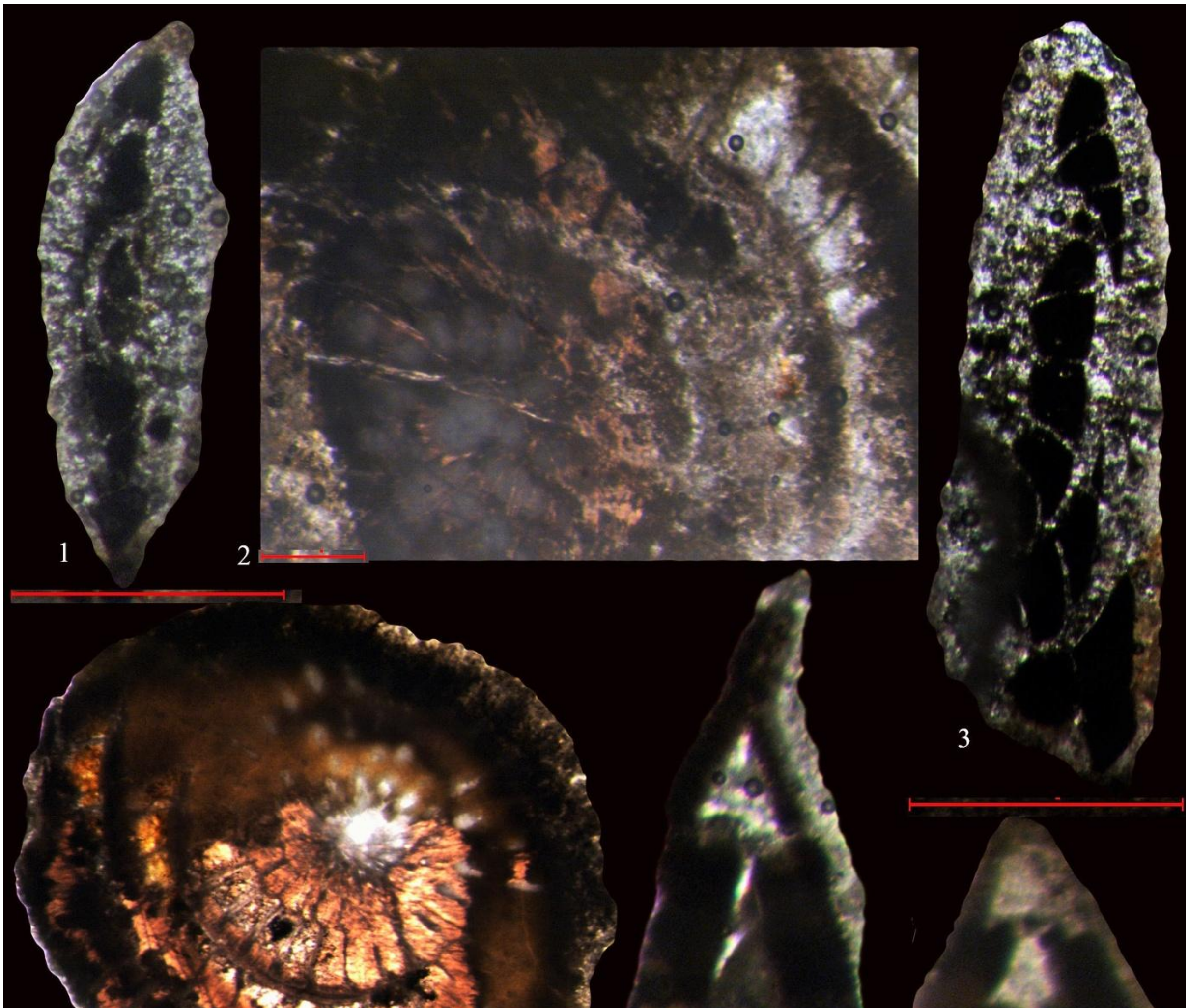

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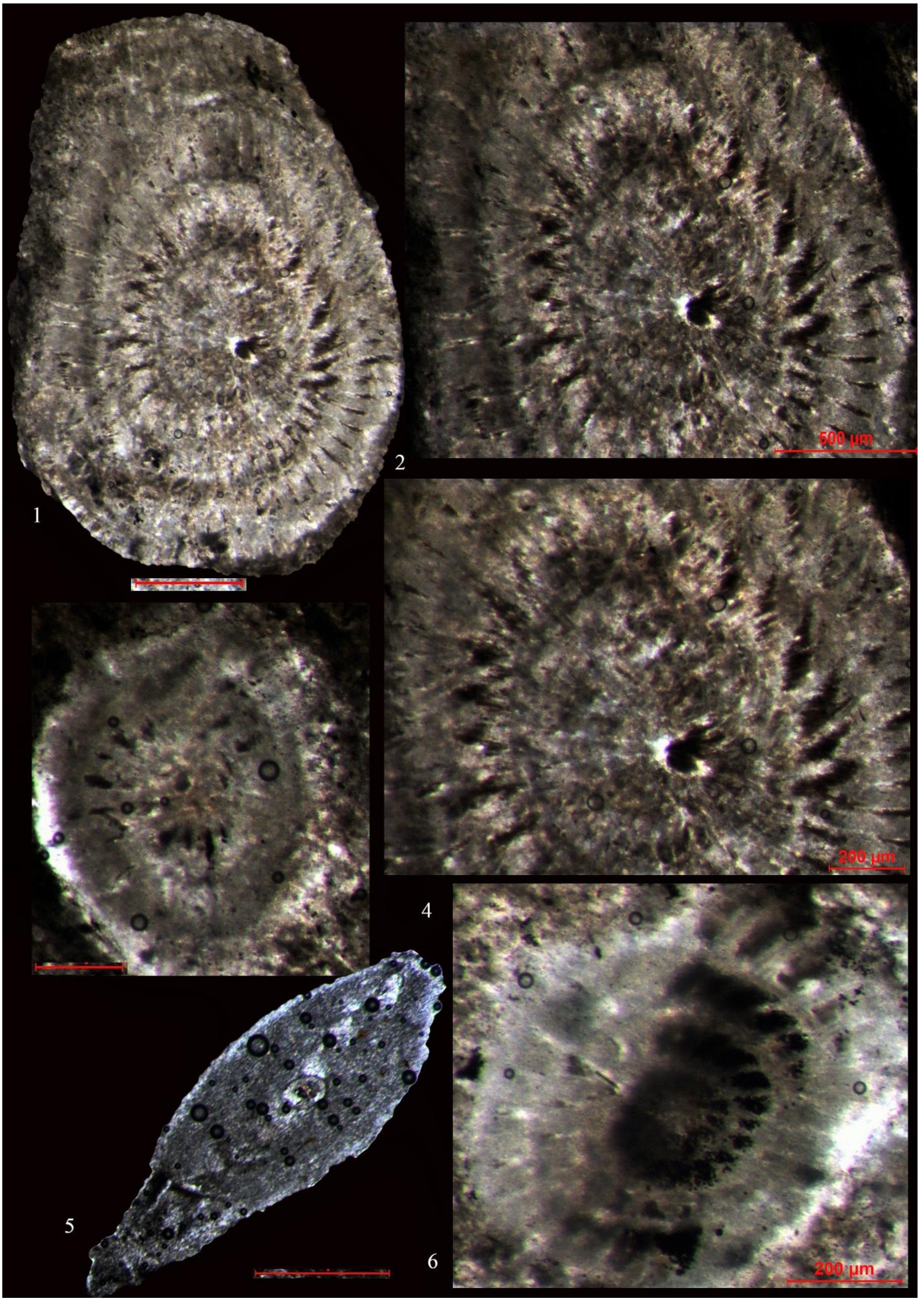

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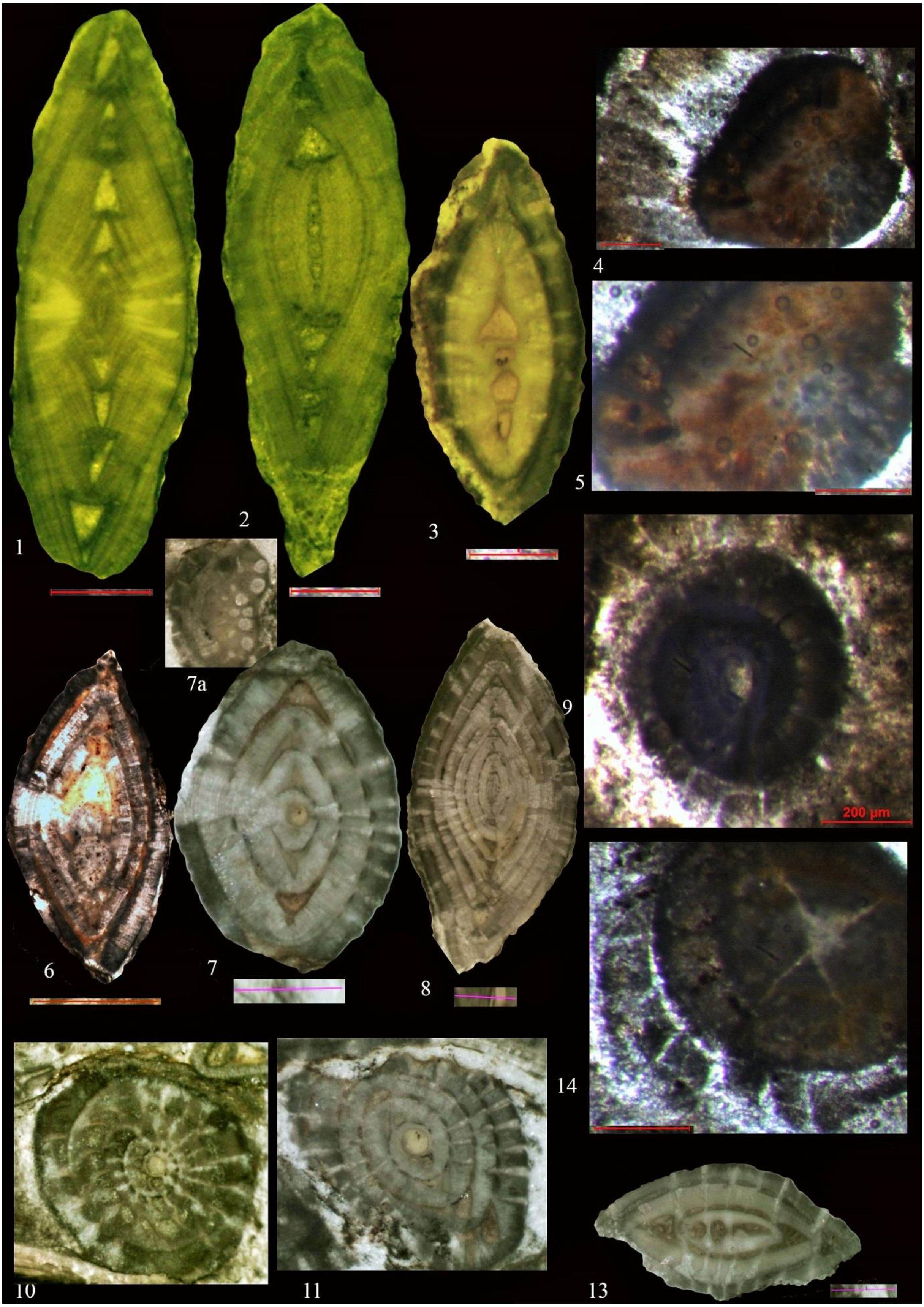

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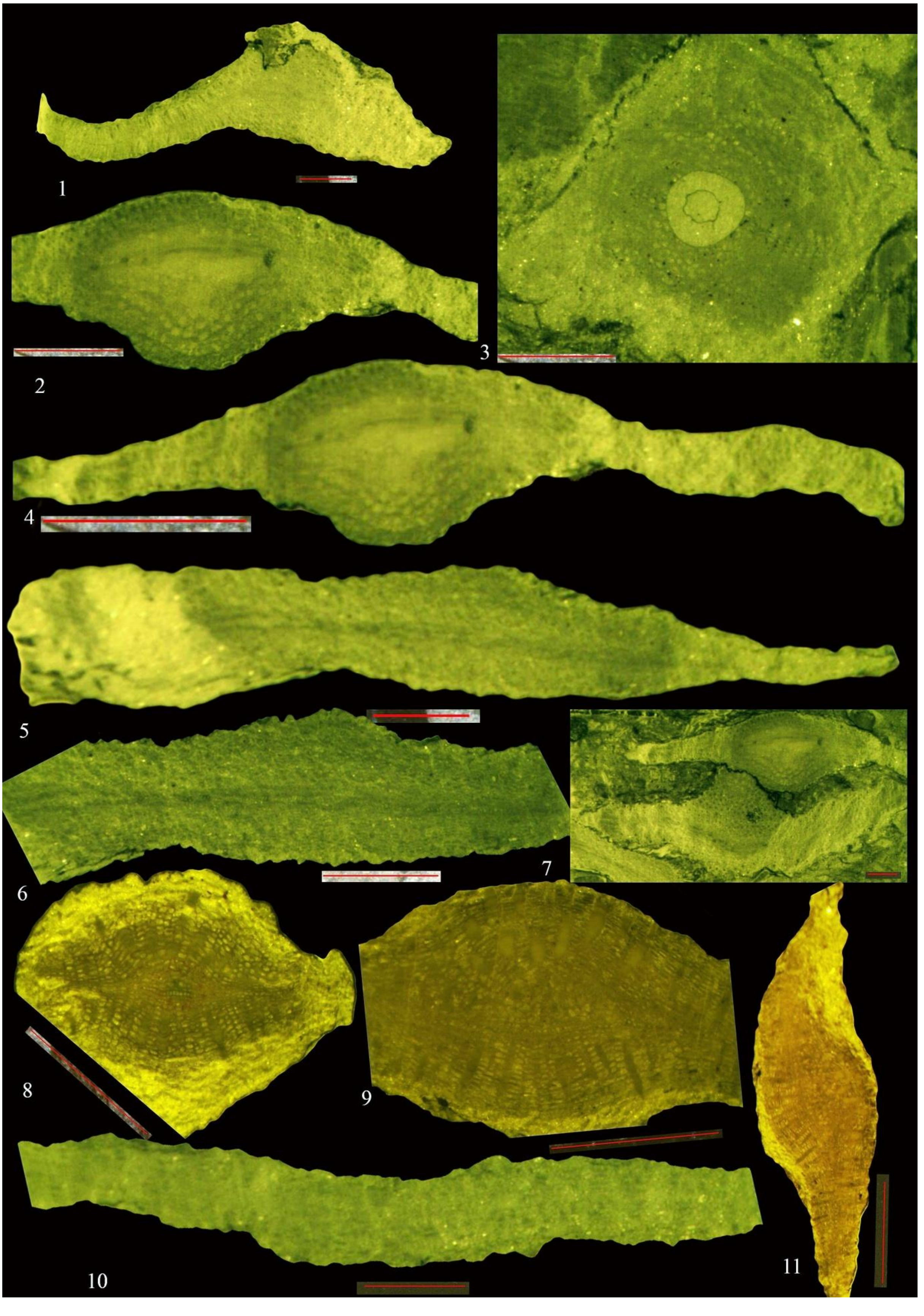

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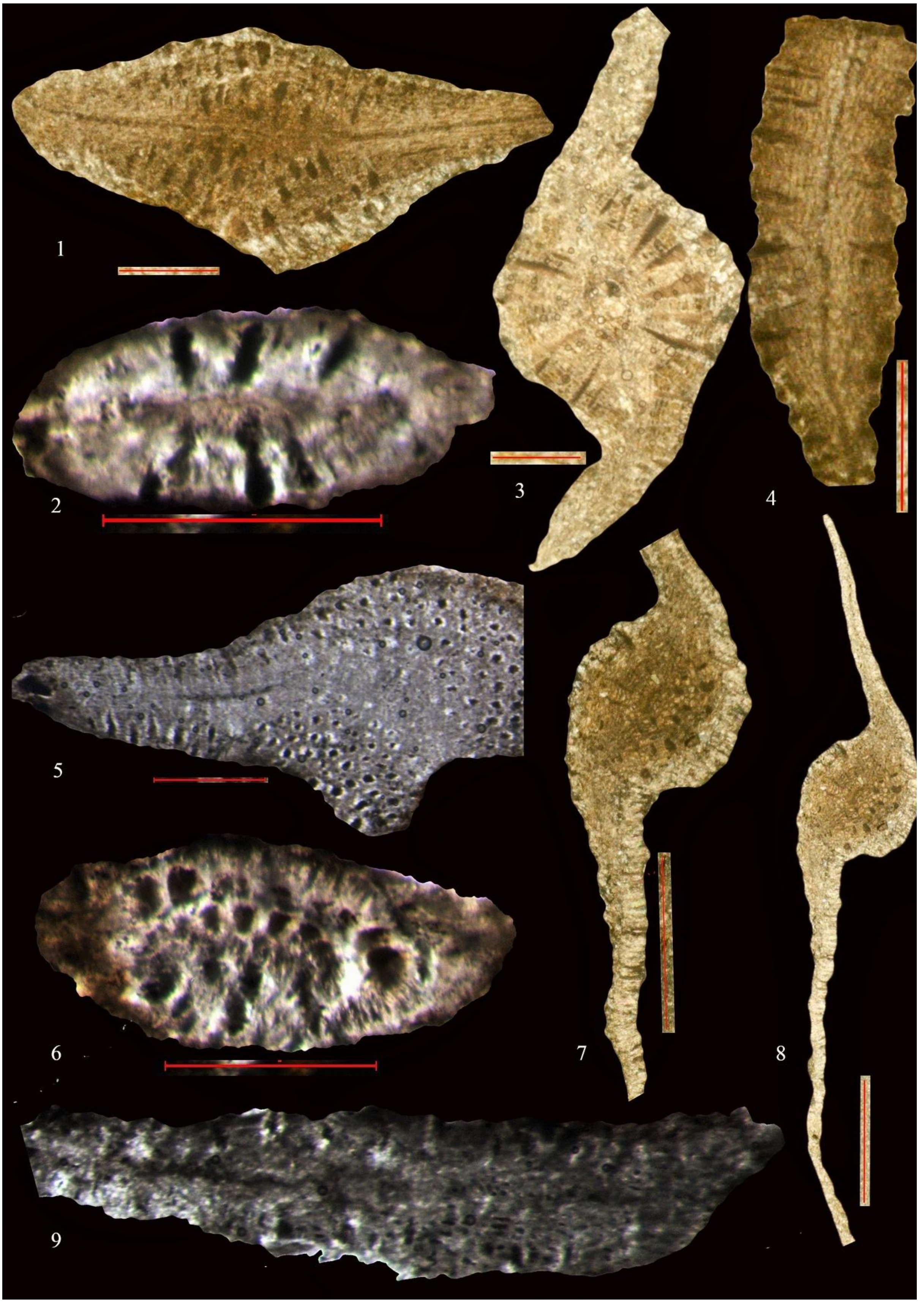

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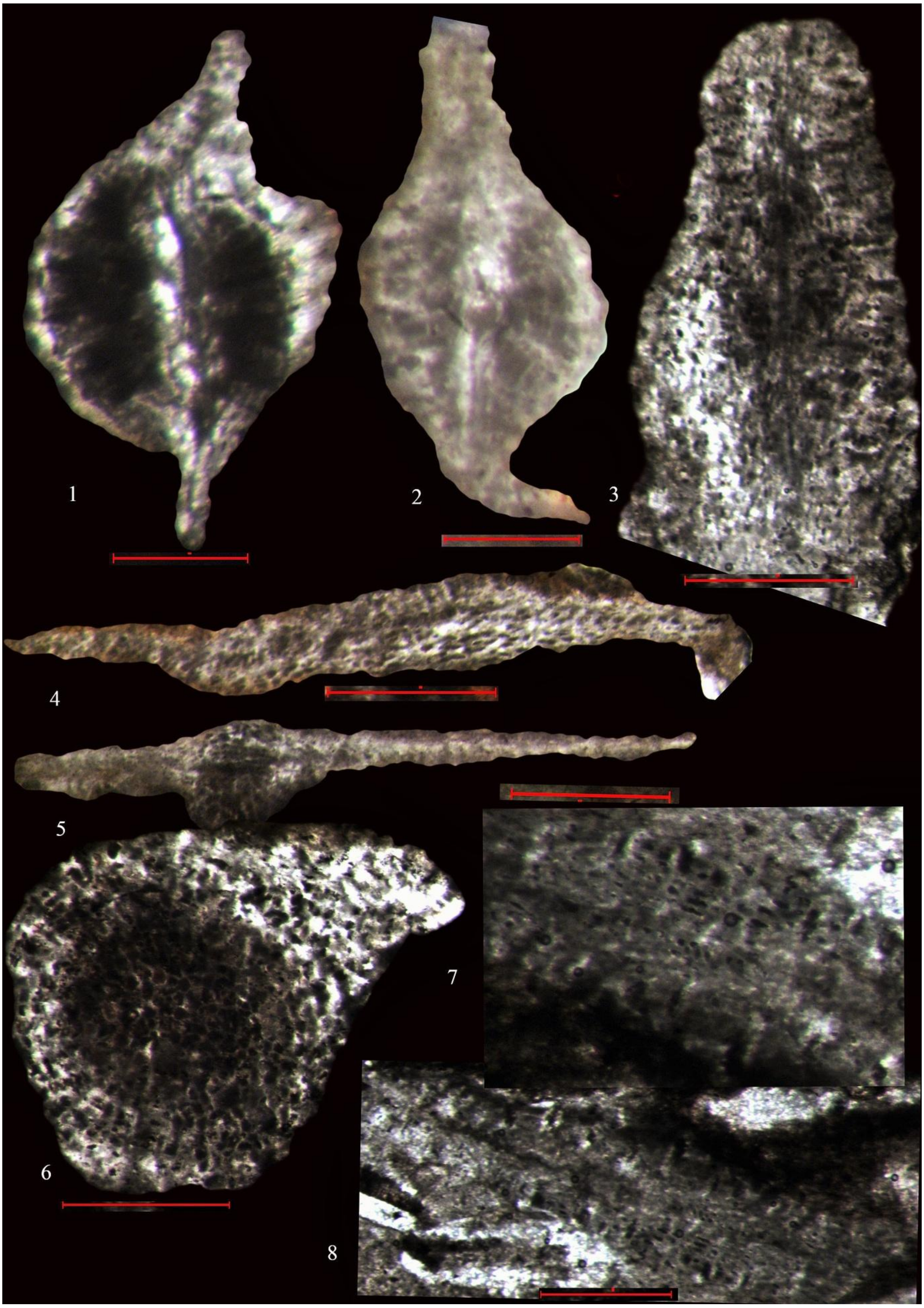

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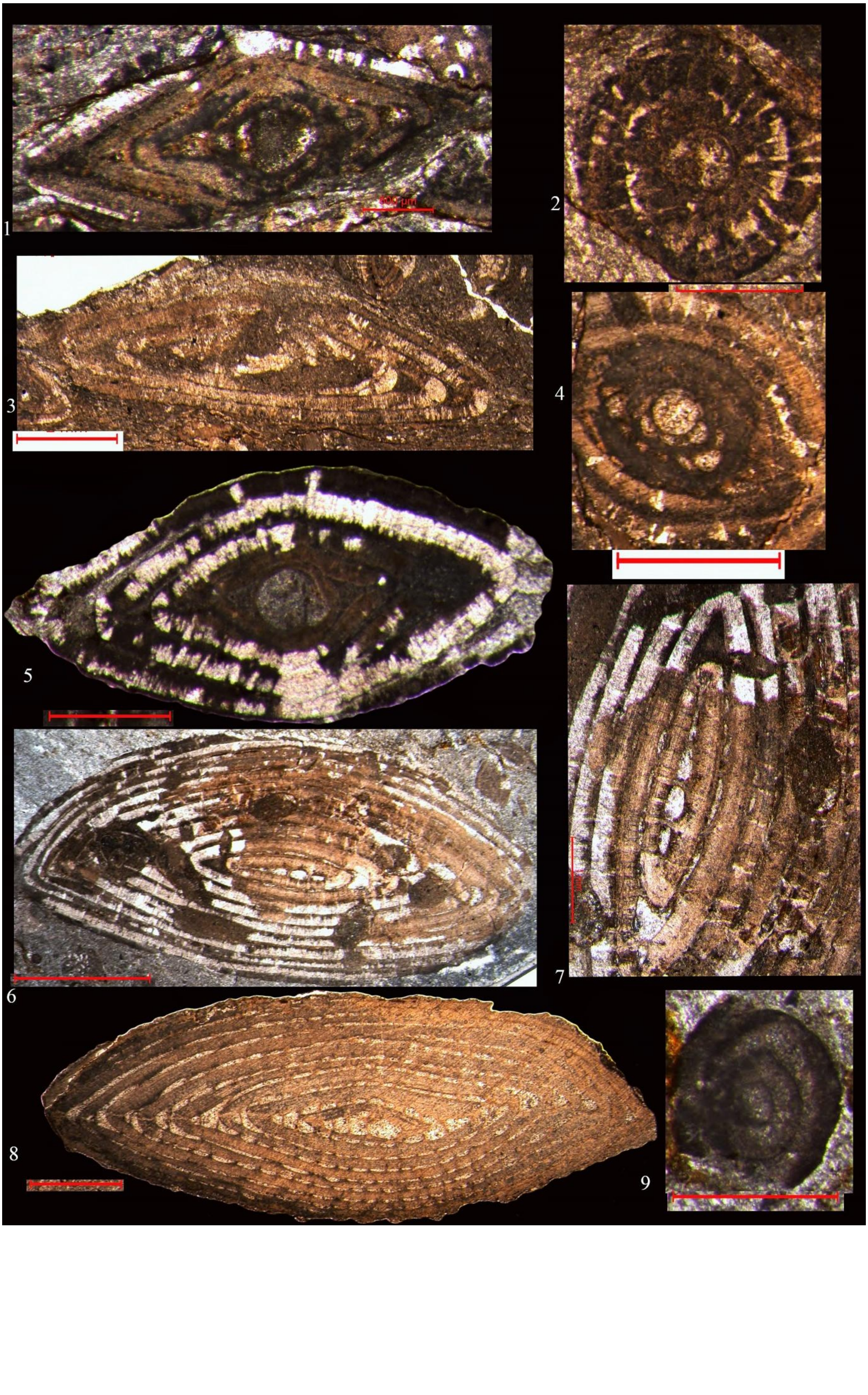

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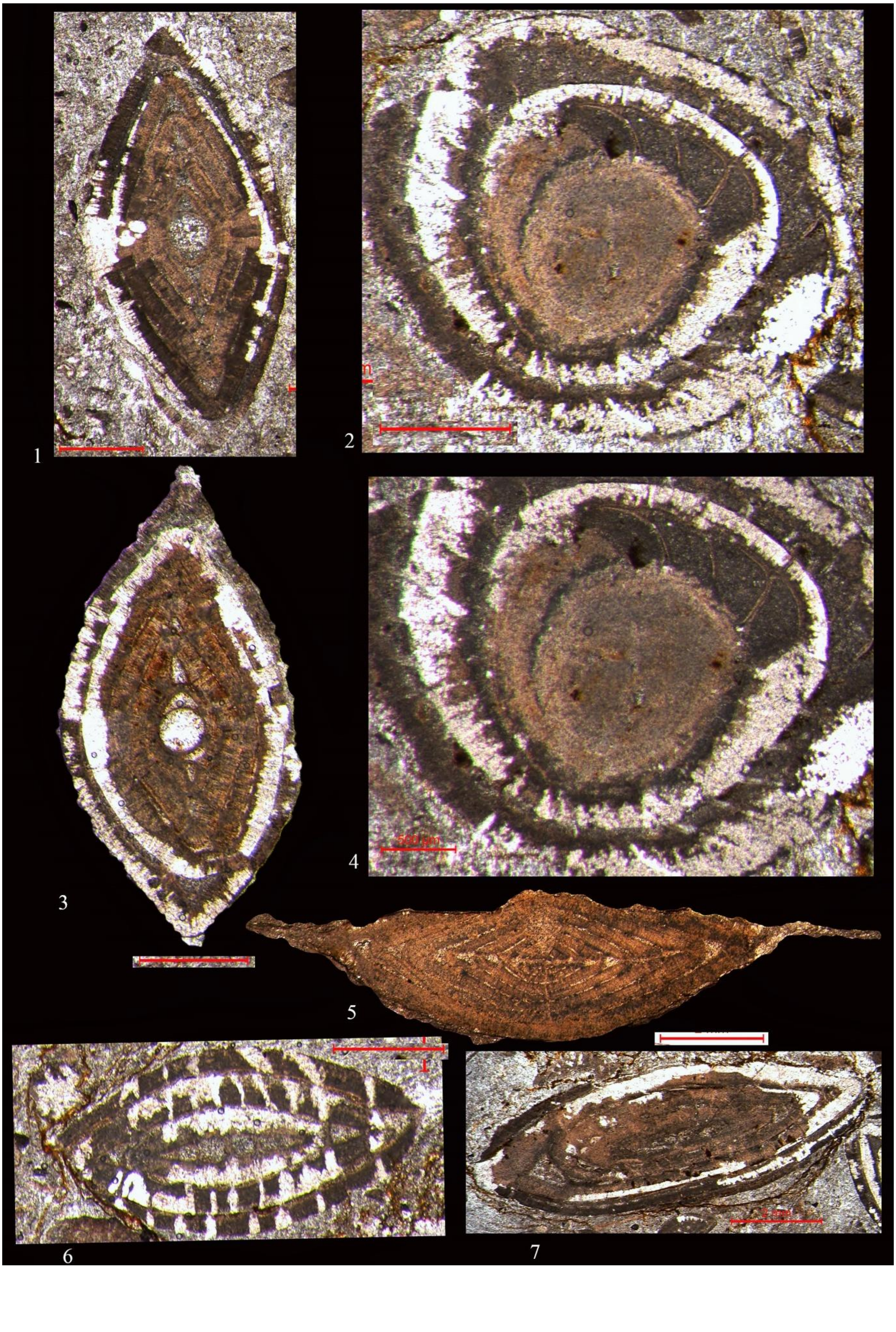

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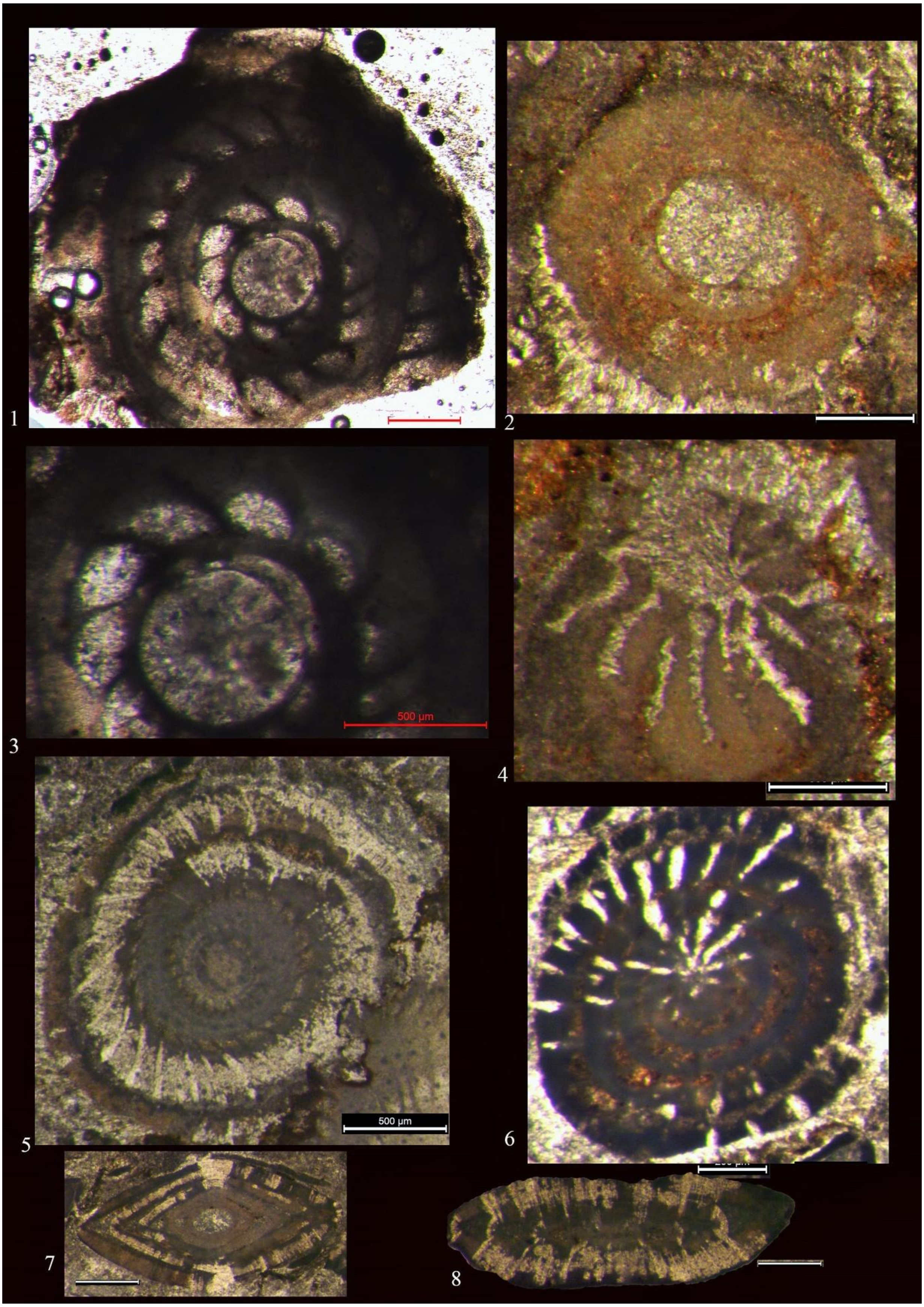

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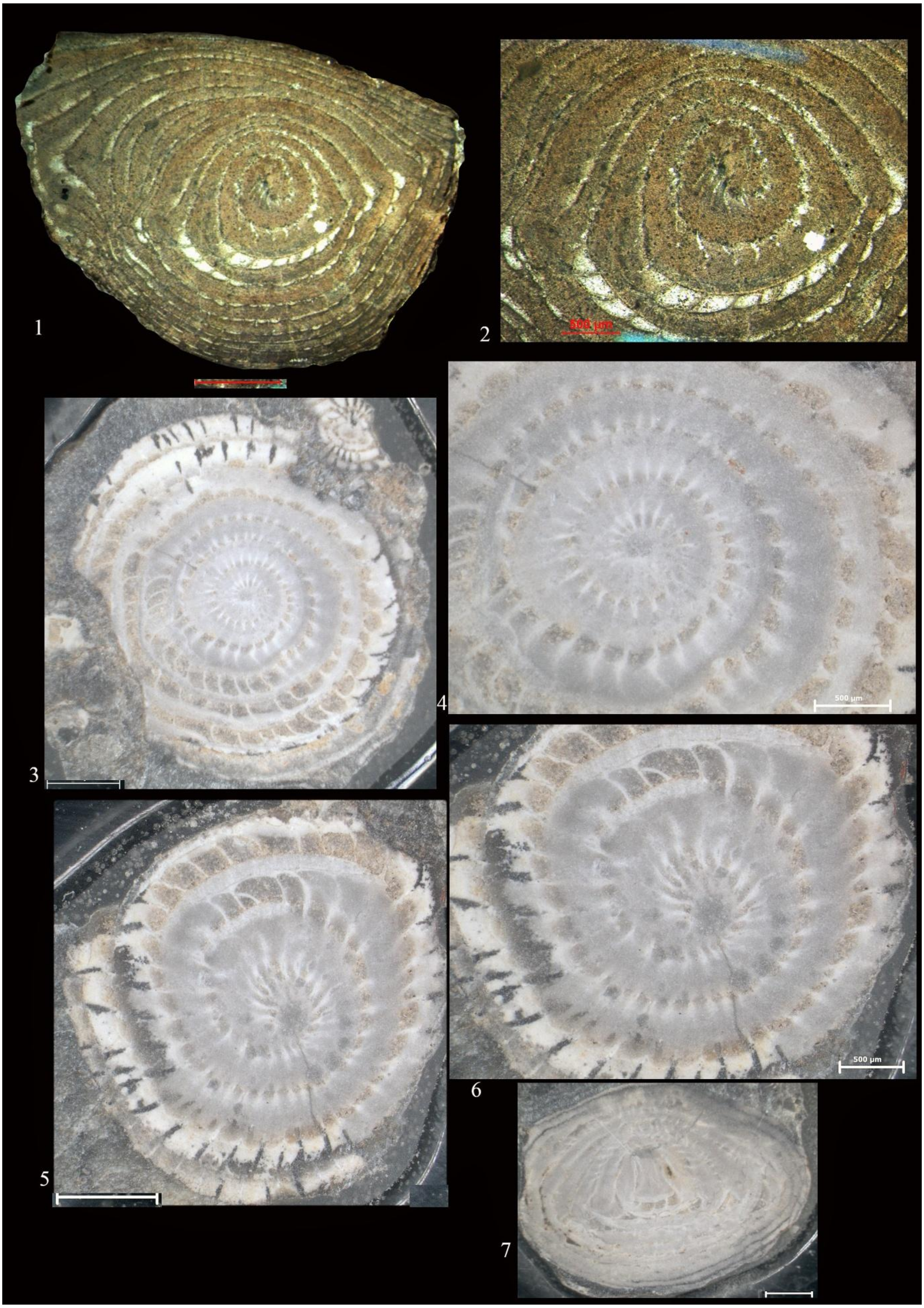

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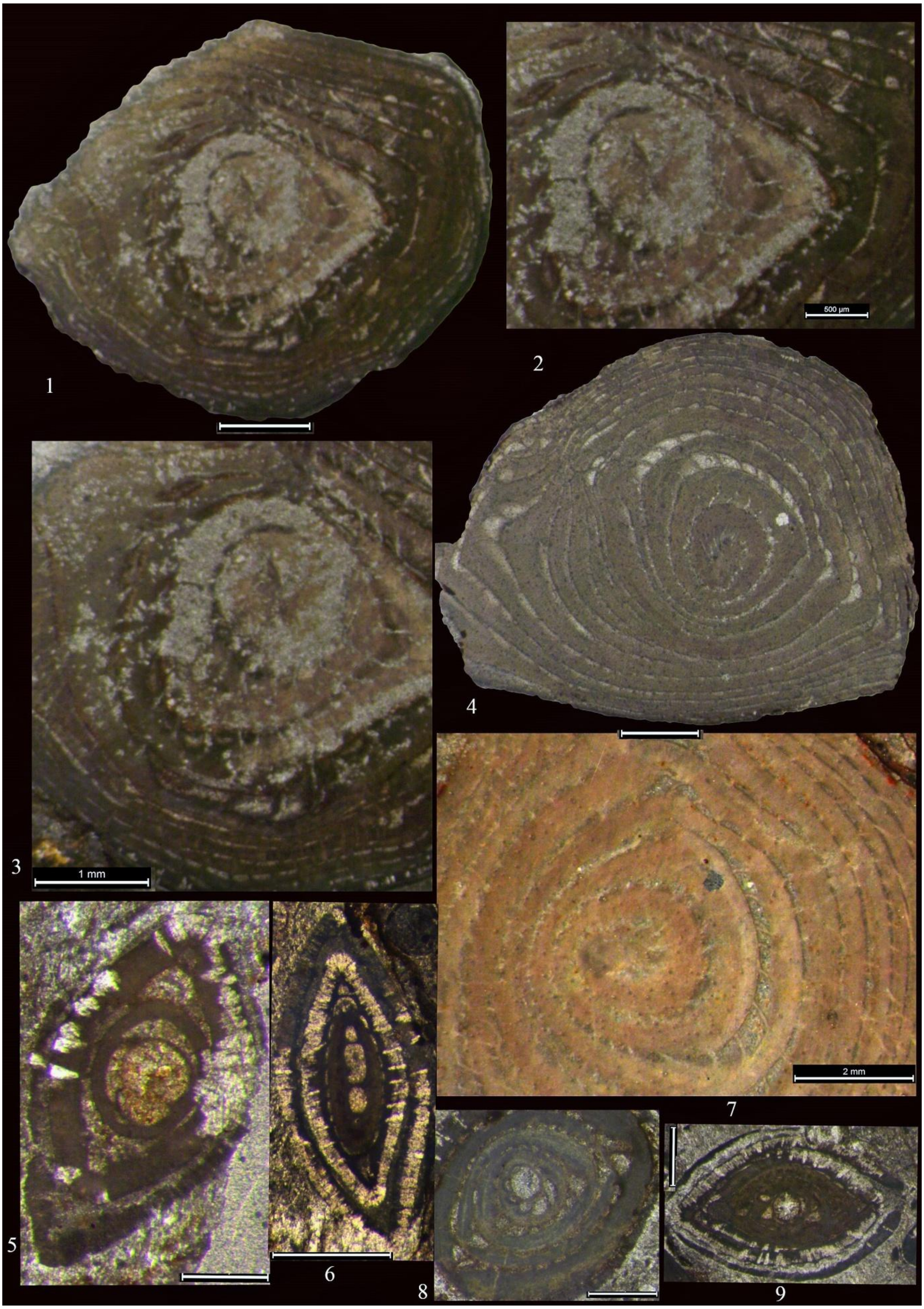

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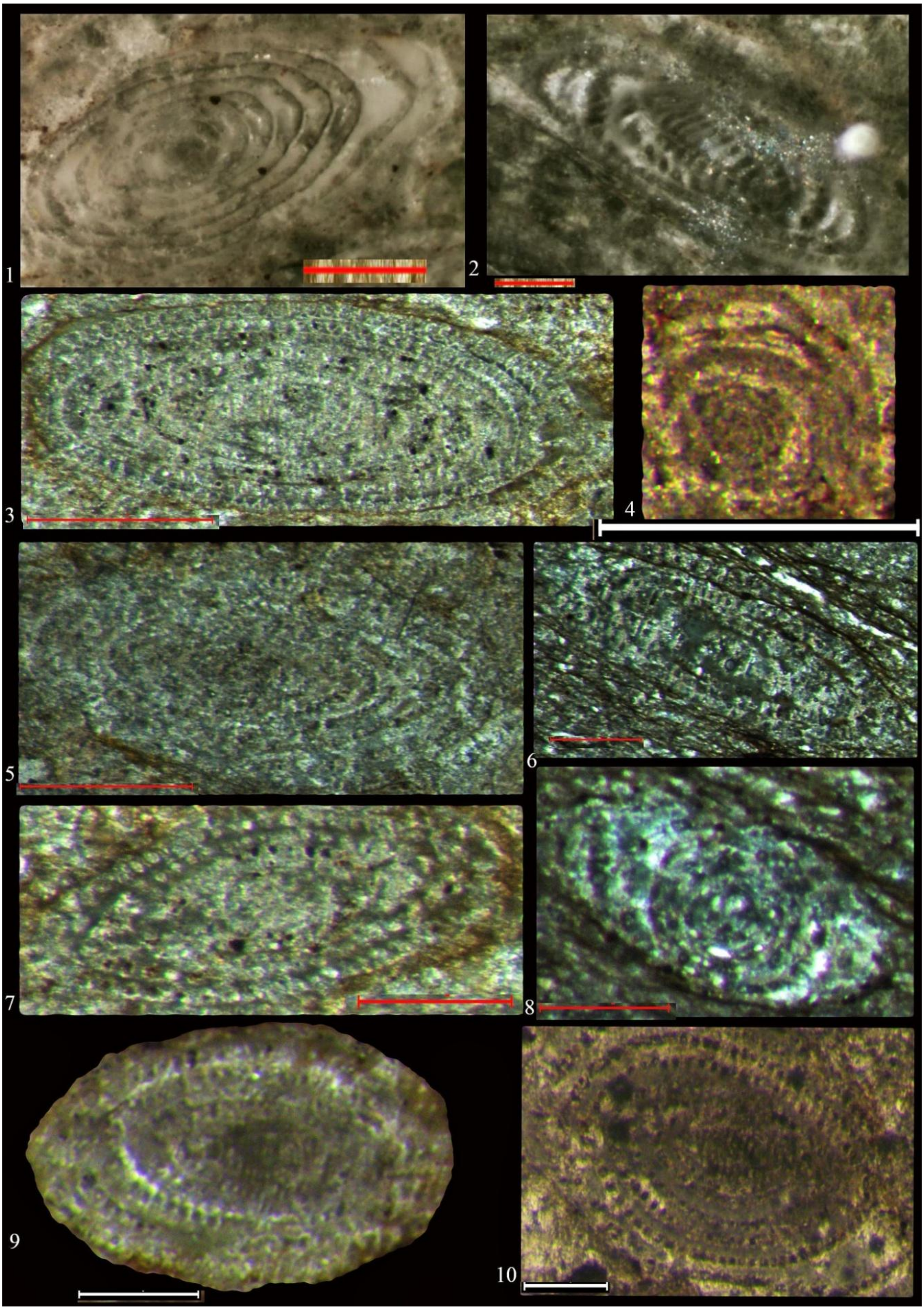

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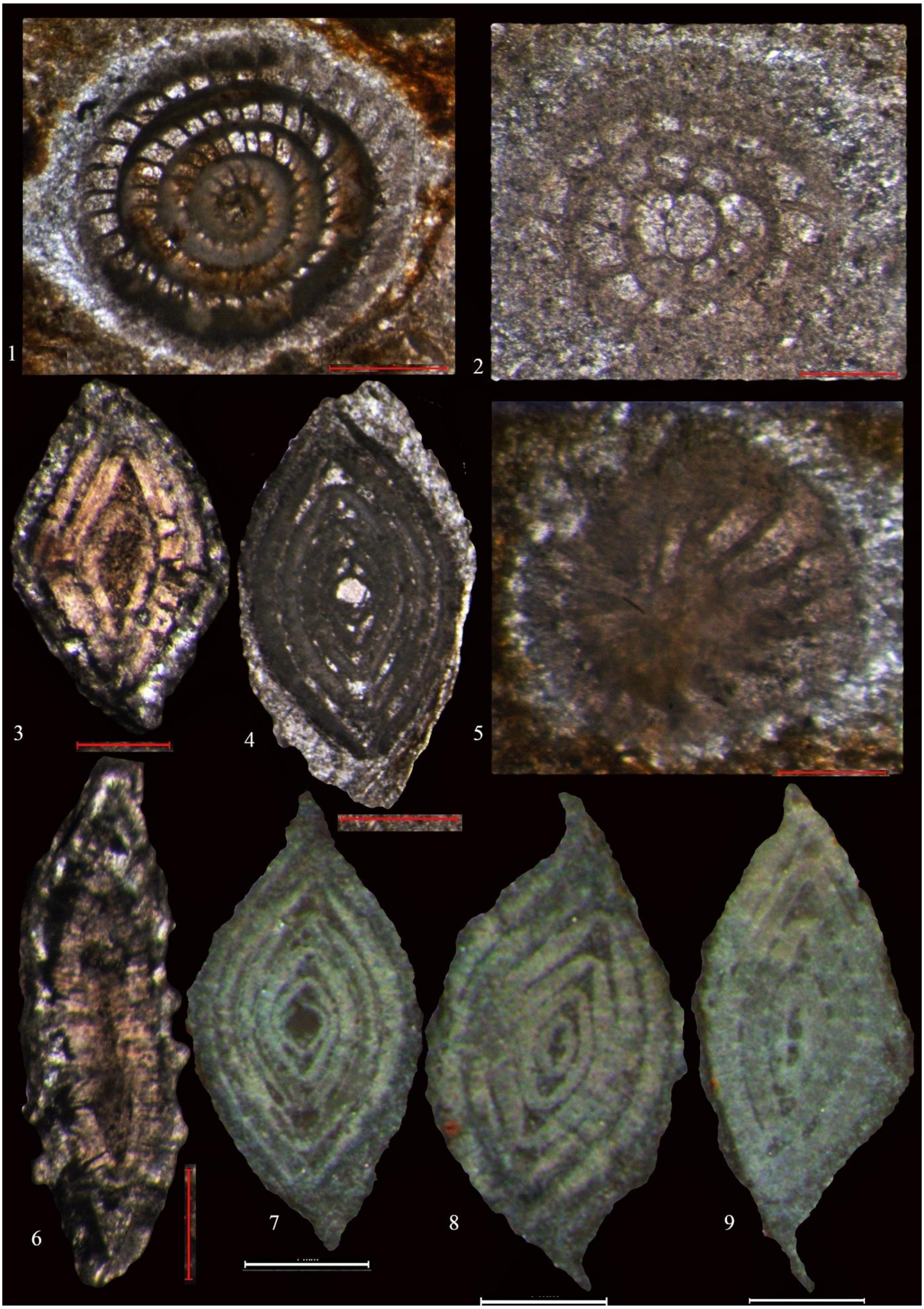

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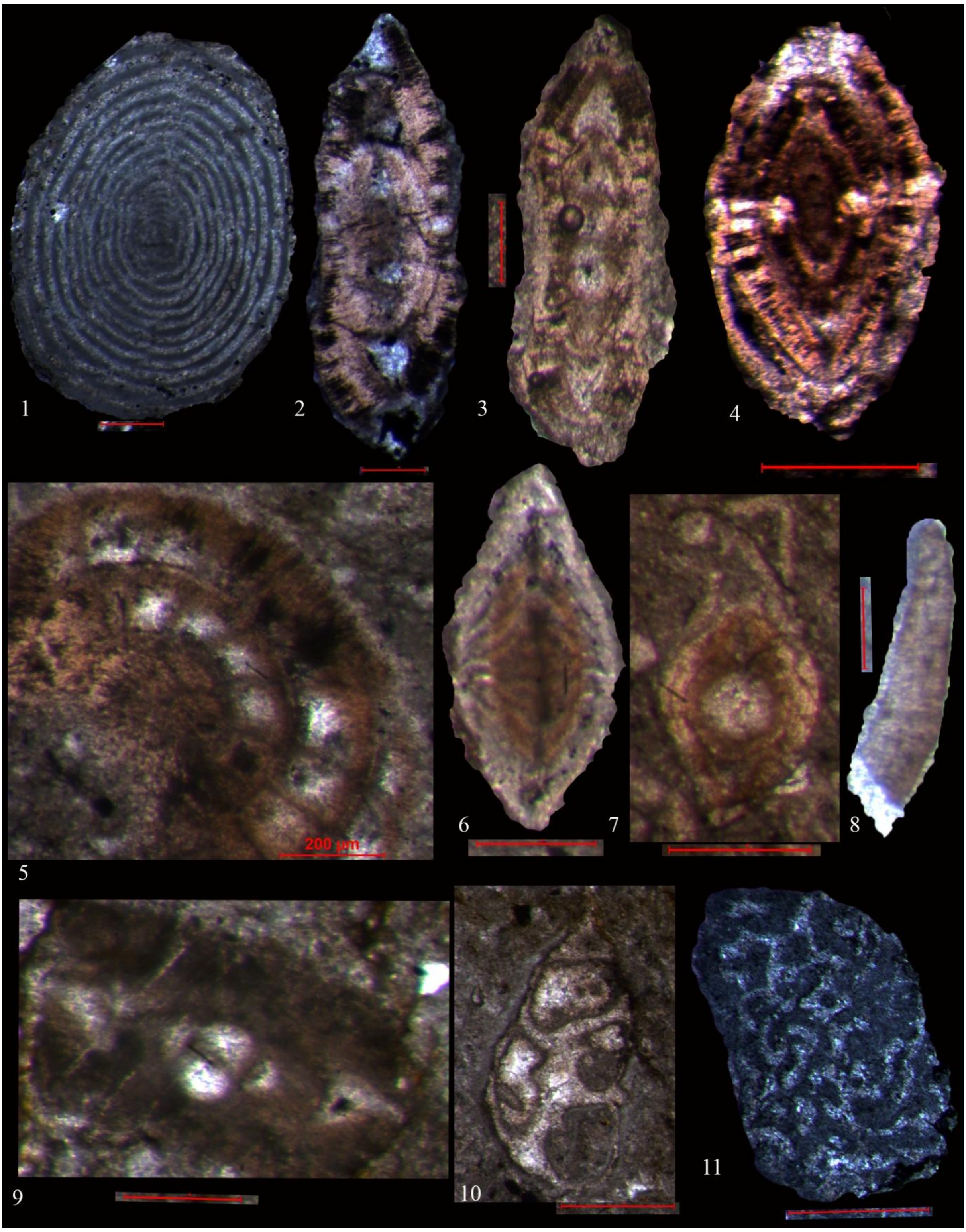

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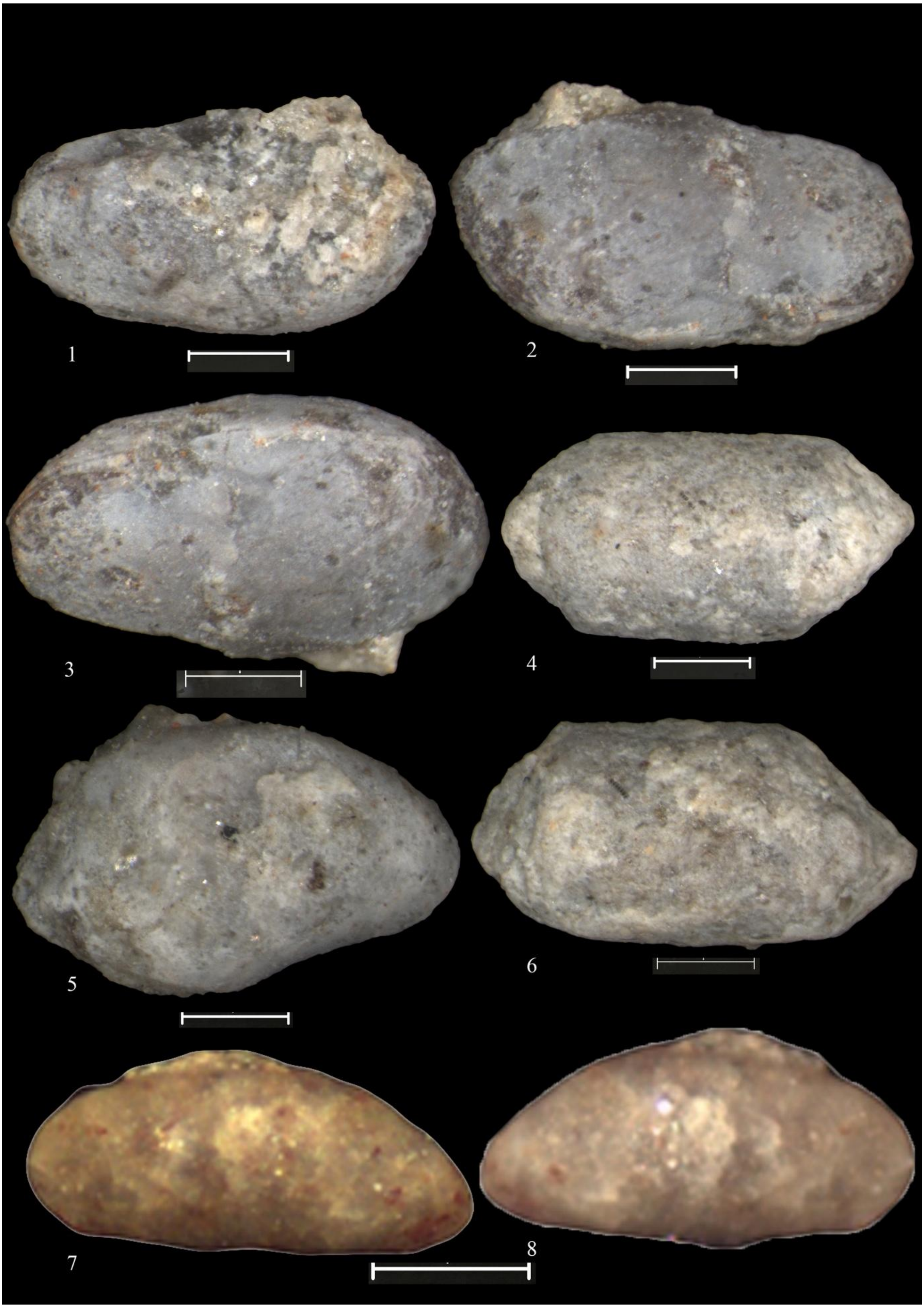

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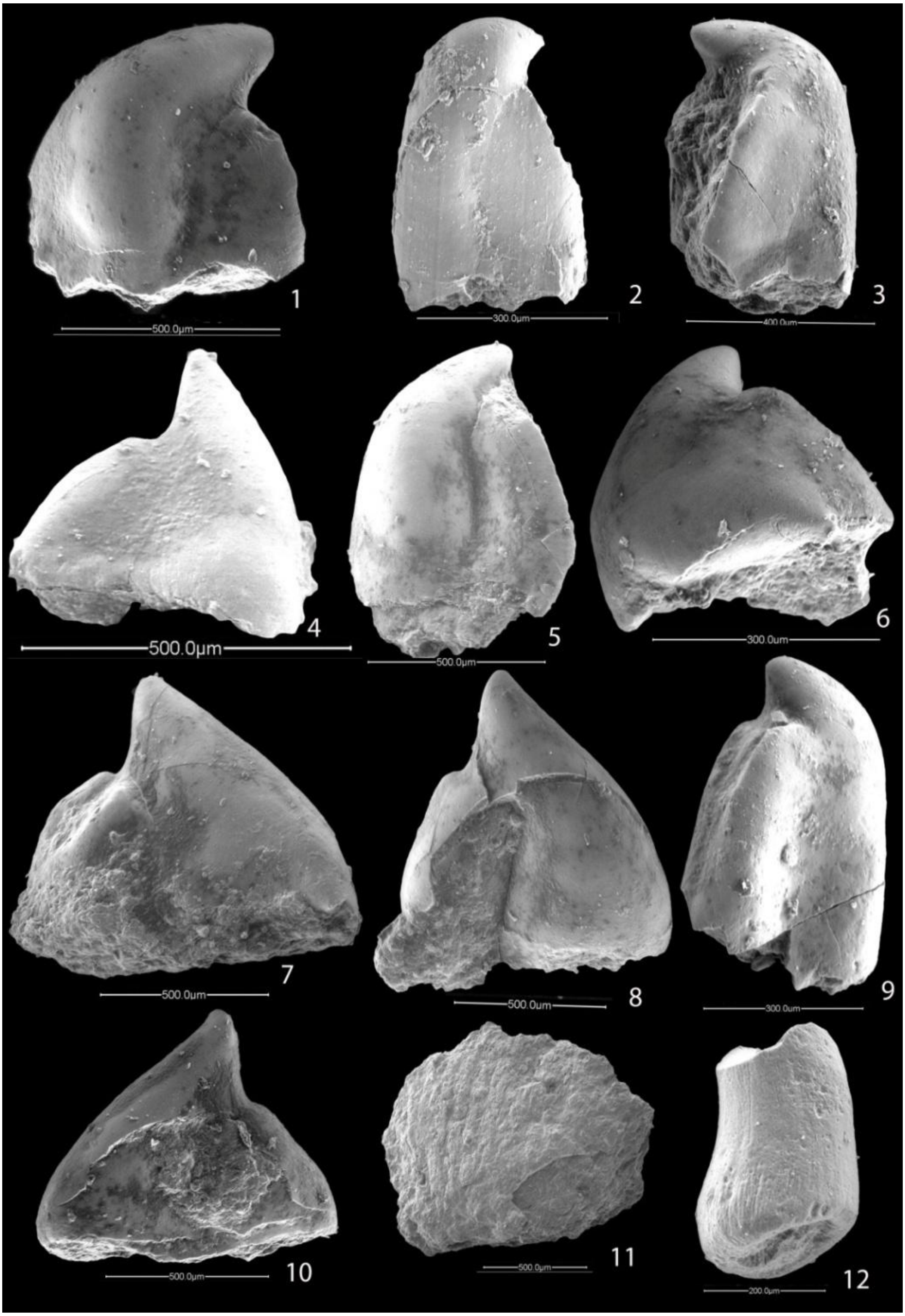
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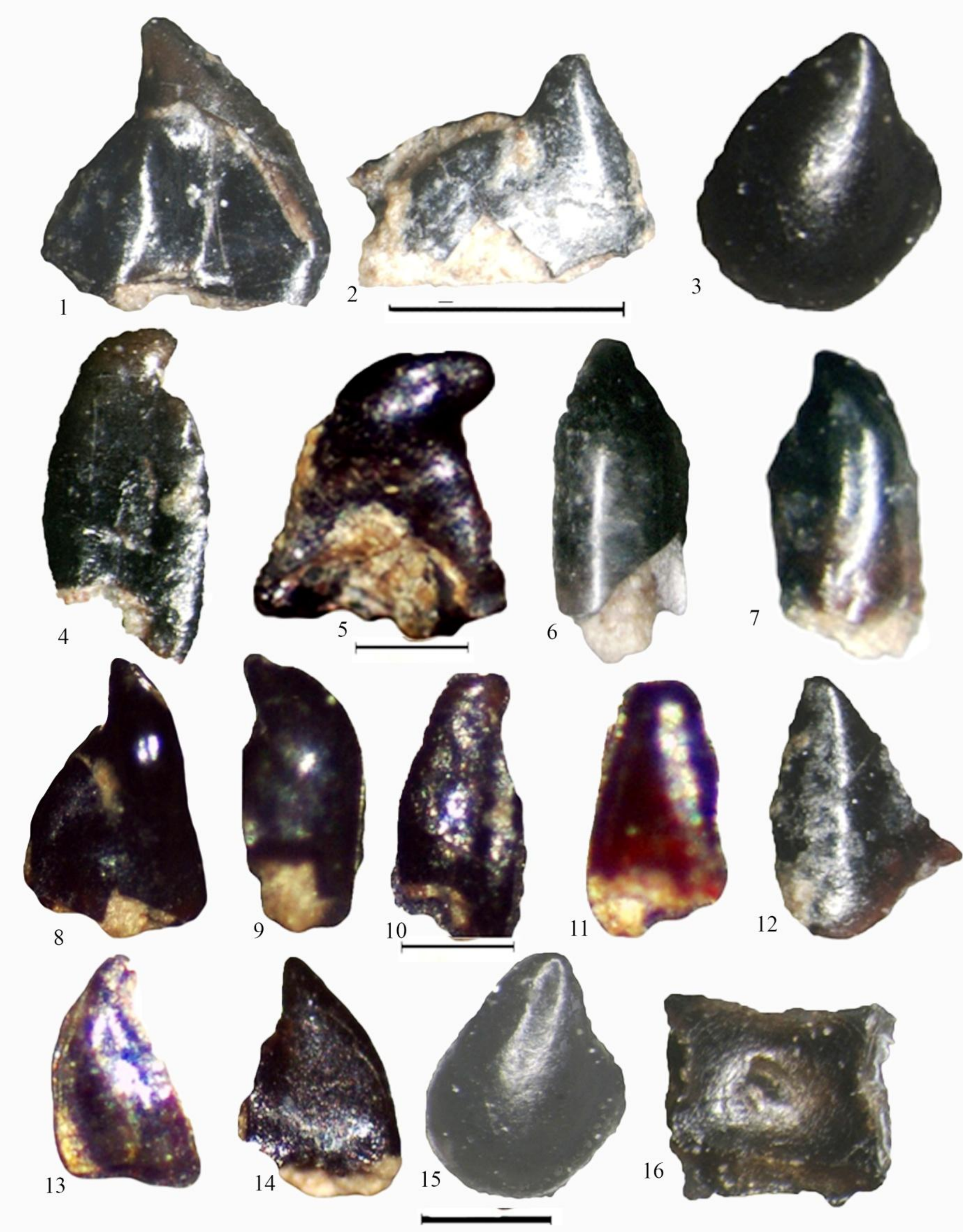

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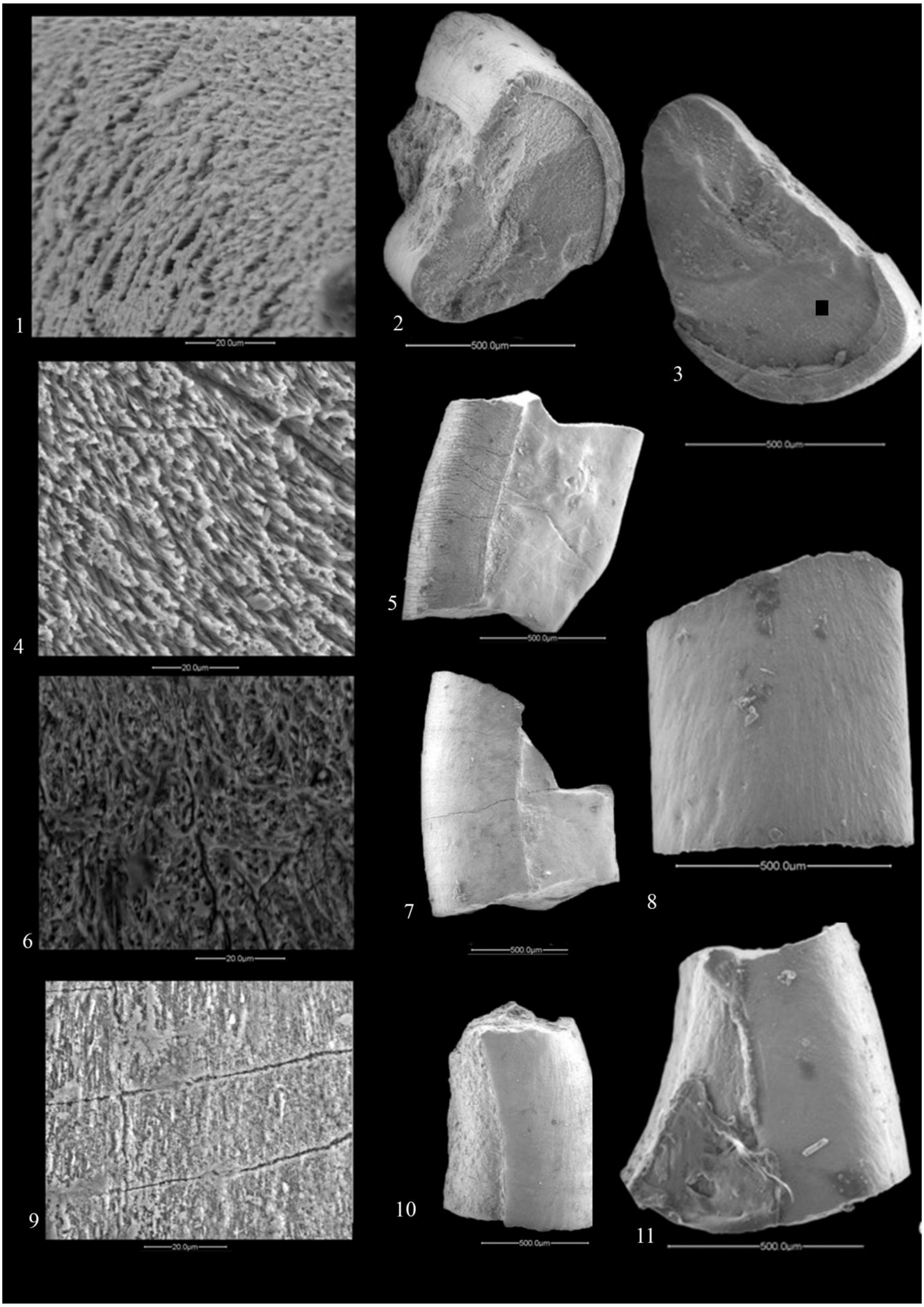
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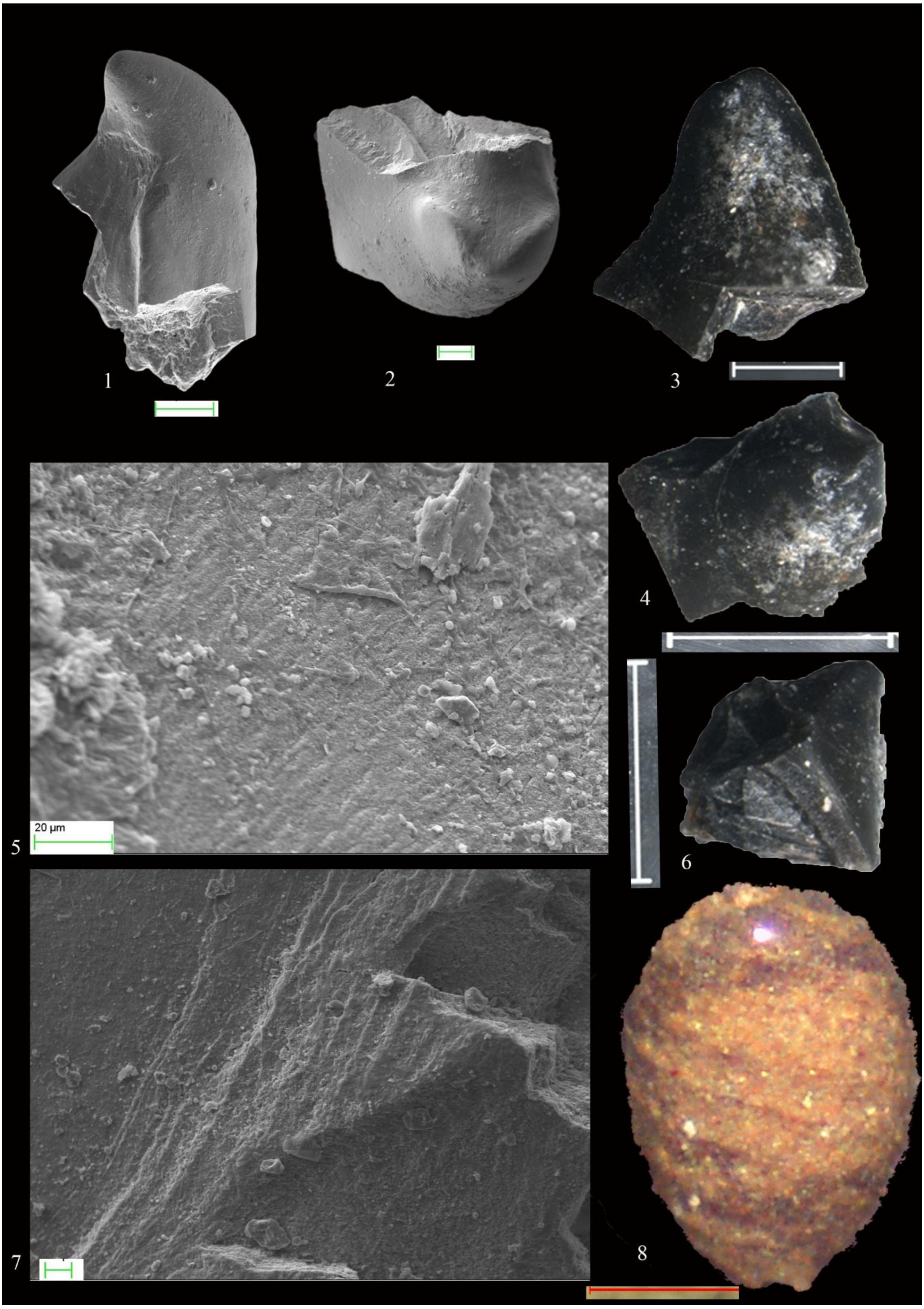

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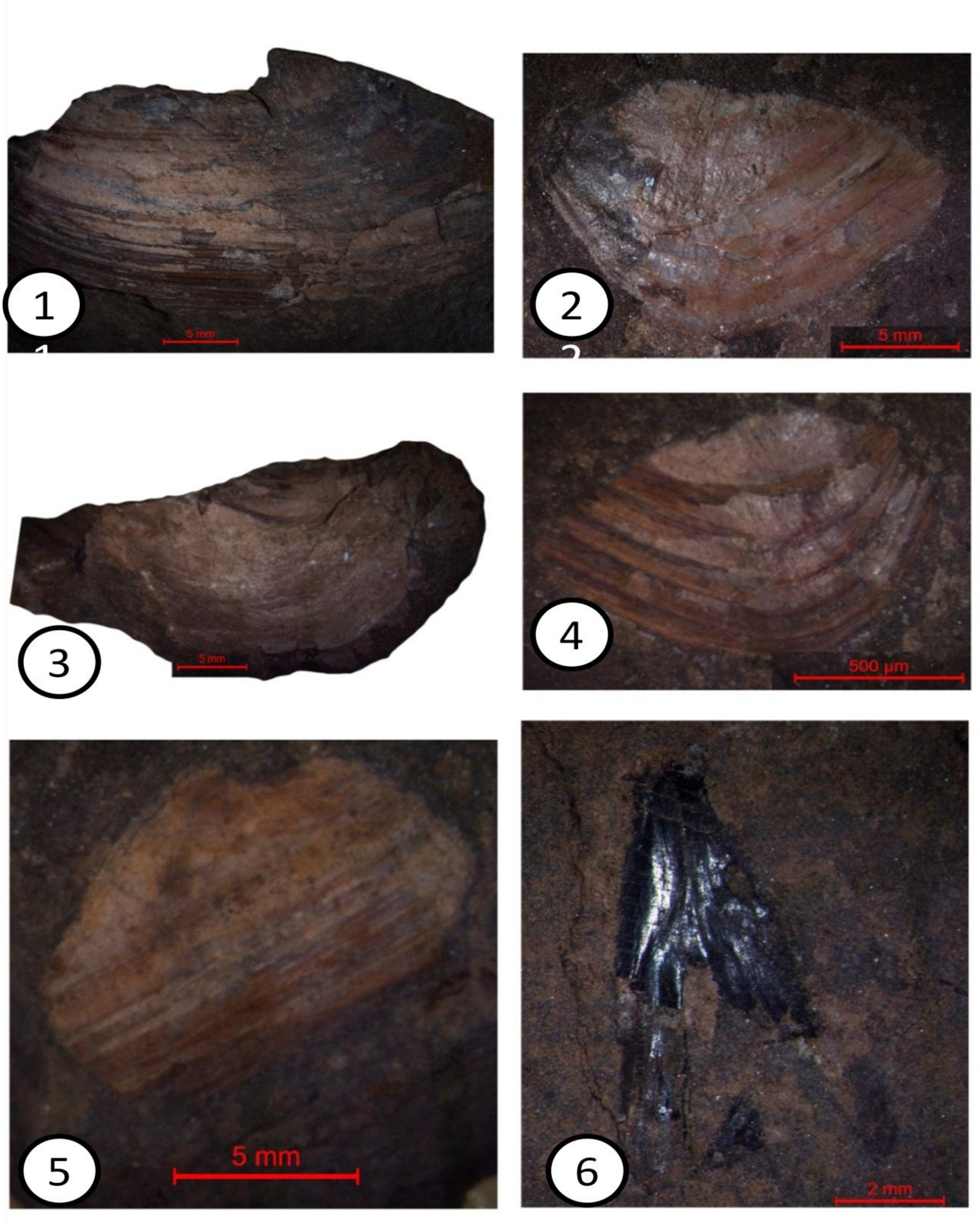

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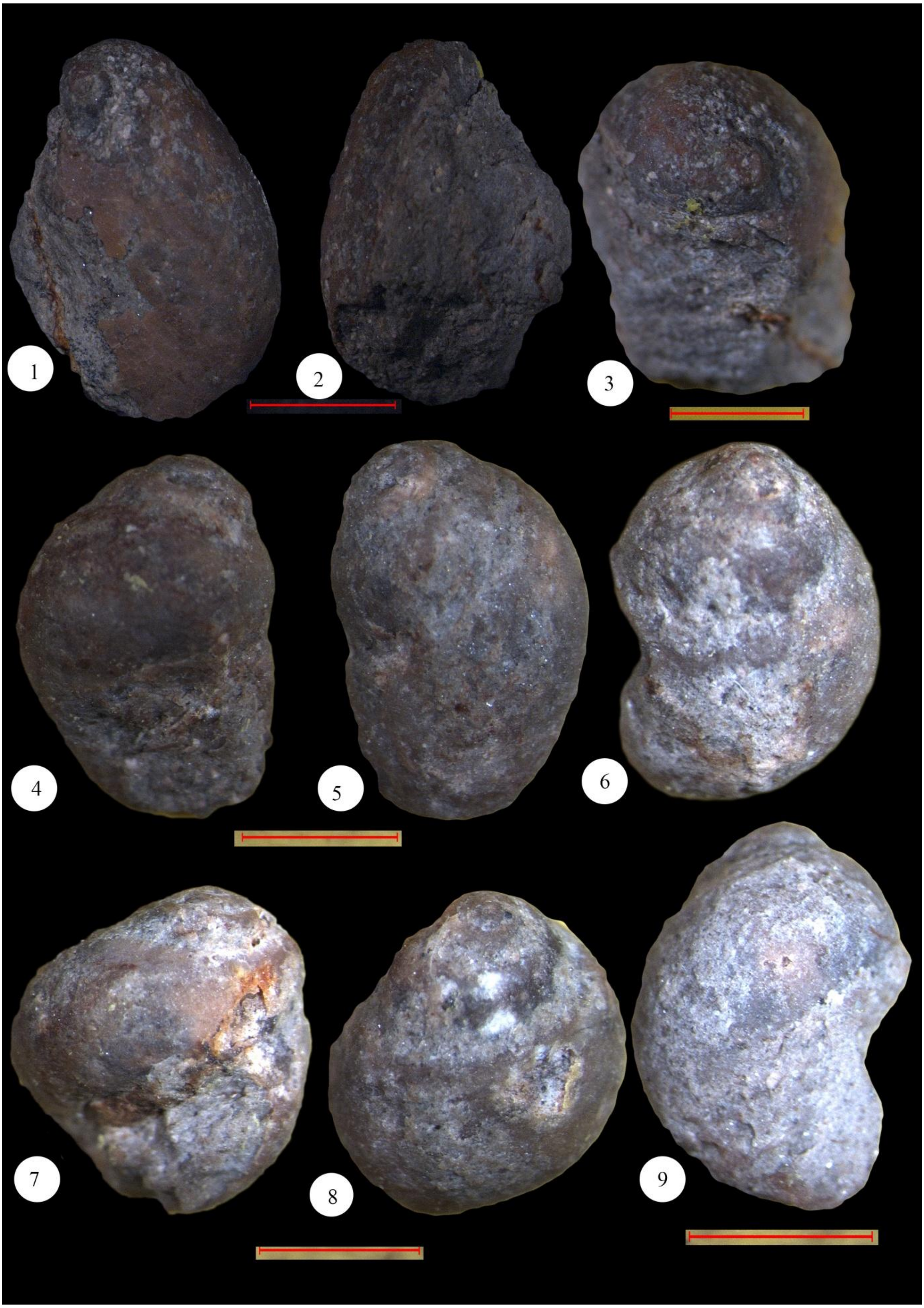

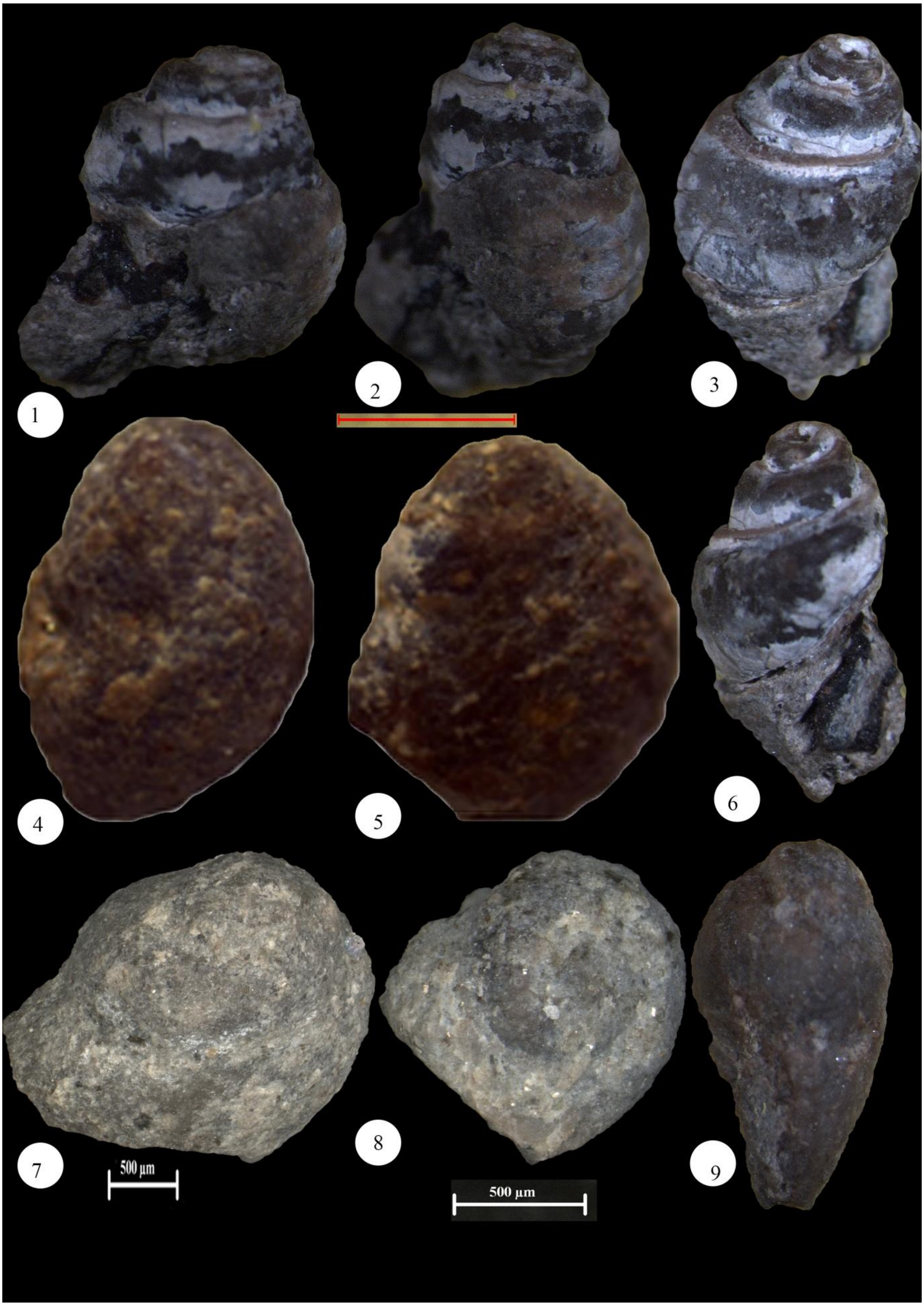
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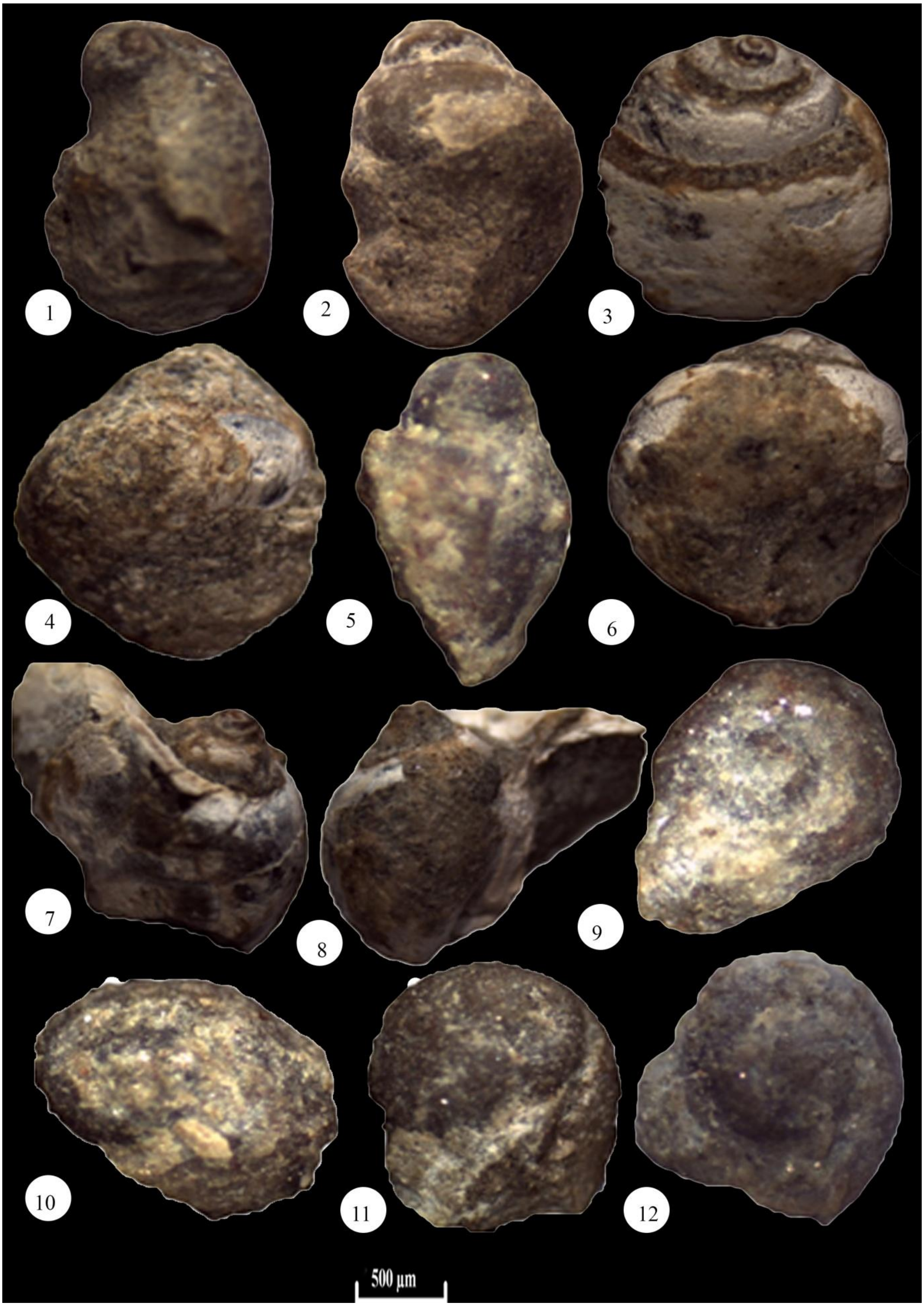

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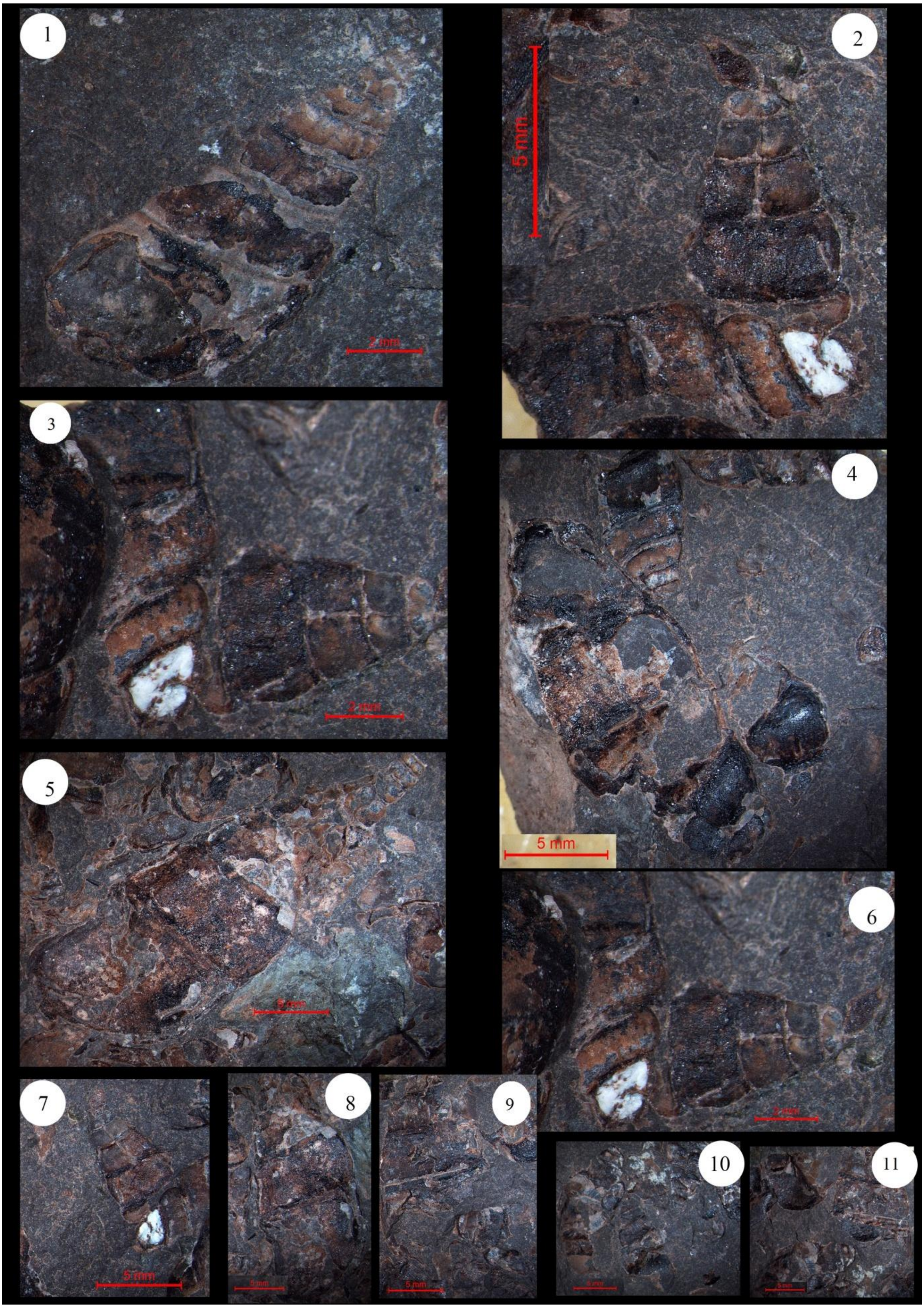

EXPLANATION OF PLATE 1

***Assilina dandotica* Davies 1937**

1: Axial section megalospheric form, sample no. S- 3/2. Scale bar = 500 µm.

2 : High resolution equatorial section showing surface granules. Scale bar = 200 µm.

3: Nearly axial section megalospheric form Sumdo section, sample no. S- 3/2. Scale bar = 500 µm.

4: Nearly equatorial section megalospheric form, sample no. S- 3/16. Scale bar = 500 µm.

5: Equatorial section showing chamber shapes and concentration of granules on pole. Scale bar = 500 µm.

7: Axial section microspheric form, sample no. S- 3/4. Scale bar = 500 µm. Scale = µm.

***Assilina laminosa* Gill 1953**

6: Axial section megalospheric form, sample no. S- 3/2. Scale bar = 500 µm.

***Assilina* sp.**

Planktic Foraminifera. Gen sp. indet

8: Axial section microspheric form, sample no. S- 3/1. Scale bar = 500 µm. .

EXPLANATION OF PLATE 2

***Nummulites* sp.1**

1: Nearly equatorial section microspheric form, sample no. S- 3/3. Scale bar = 500 µm.

2&3: High resolution equatorial section showing. Scale bar = 200 µm.

4: Nearly equatorial section microspheric form, sample no. S- 3/3. Scale bar = 500 µm.

***Ranikothalia cf. nuttalli* Davies**

5. Nearly axial section, sample no. S- 3/4. Scale bar = 500 µm.

***Nummulites* cf *planulatus*.**

6: Nearly equatorial section microspheric form, sample no. S- 3/3. Scale bar = 500 µm.

EXPLANATION OF PLATE 3

Assilina laminosa **Gill 1953**

1: Axial section microspheric form, sample no. S- 3/7. Scale bar = 500 µm.

2: : Axial section microspheric form, sample no. S- 3/7. Scale bar = 500 µm.

9: surfacial view microspheric form, sample no. S- 3/4. Scale bar = Scale bar = 200 µm.

Ranikothalia **sp.**

3: Axial section microspheric form, sample no S-3/5 Scale bar = 500 µm**,** Scale bar = 200 µm.

Assilina dandotica **Davies 1937**

4: polar surfacial view microspheric

5: high resolution polar view microspheric form, sample no. S- 3/4, Scale bar = 200 µm..

Nummulites wadiai **Davies 1927**

6: nearly tangential section megalospheric form, sample no - S-3/5 scale bar = 200 µm.

7: Axial section megalospheric form, sample no - S-3/5 scale bar = 200 µm.

8: nearly axial section microspheric form, sample no - S-3/5 scale bar =200 µm.

10: equatorial section microspheric form, sample no - S-3/5 scale bar = 200 µm.

11: equatorial section microspheric form, sample no - S-3/5 scale bar = 200 µm.

13: nearly tangential section microspheric form, sample no - S-3/5 scale bar = 200 µm.

EXPLANATION OF PLATE 4

***Discocyclina dispansa* Sowerby 1840**

1: axial section microscopic form, sample no. 3/6, Scale bar = 500 µm.

2: axial section microscopic form, sample no. 3/6, Scale bar = 500 µm.

3: axial section microscopic form, sample no. 3/6, Scale bar = 500 µm.

4: axial section microscopic form showing arrangment of equatorial chamberlets

7: axial section microscopic form,   sample no. 3/6, Scale bar = 200 µm.

***Discocyclina ranikotensis* Davies 1927**

5: axial section microscopic form, sample no. 3/6

6: axial section microscopic form showing arrangement of equatorial chamberlets form, sample no. 3/6, Scale bar =200 µm.

Discocyclina archiaci (*Schlumberger) *bakhchisaraiensis Less

8: axial section megalospheric form showing lateral chamberlets, sample no. S-3/7

9: axial section microscopic form, sample no. S-3/7. Scale bar = 200µm.

11: axial section microscopic form, sample no. S-3/7

***Orbitosiphon punjabensis* Davies 1937**

10: Axial section showing lateral chamberlets on both side of equatorial plane, sample no. , scale bar = 200µm.

EXPLANATION OF PLATE 5

***Discocyclina dispansa* Sowerby, 1840**

1: Axial section microspheric form**,** Sample no- S-3/38 Scale bar = 500 µm.

2: Axial section microspheric form, Sample no- S-3/16 Scale bar = 500 µm.

5: Axial section microspheric form,   Sample no- S-3/20 Scale bar = 500 µm.

6: Nearly tangential section microspheric form, Sample no- S-3/16 Scale bar = 500 µm.

***Discocyclina archiaci (Schlumberger) bakhchisaraiensis* Less**

3:Axial section meglospheric form**,** Sample no- S-3/38 Scale bar = 500 µm.

7: Axial section microspheric form**,** Sample no- S-3/7 Scale bar = 500 µm.

8: Axial section microspheric form**,** Sample no- S-3/7 Scale bar = 500 µm.

***Discocyclina sella* D'archaiae 1850 .**

4: Axial section showing lateral chamberlets,Sample no- S-3/31 Scale bar = 500 µm.

***Orbitosiphon punjabensis* Davies 1937**

9: Axial section showing lateral chamberlets on both side of equatorial plane, Sample no- S-3/7. Scale bar = 500 µm.

EXPLANATION OF PLATE 6

***Discocyclina* sp.**

1-2 : nearly axial section microspheric form sample no. S-3/17 Scale bar 1-2= 200 µm.

***Discocyclina chudeaui* Schlumberger, 1903**

3: axial section equatorial section, sample no- S-3/18 Scale bar = 500 µm.

6: equatorial section, sample no- S-3/18 Scale bar = 200 µm.

***Discocyclina ranikotensis* Davies 1927**

4: axial section microscopic form, sample no. 3/6

5: axial section microscopic form, sample no. 3/6.

***Orbitosiphon punjabensis* Davies 1937**.

7: Axial section showing lateral chamberlets on both side of equatorial plane, Sample no- S-3/18 Scale bar = 200 µm.

8: High resolution showing lateral chamberlets on both side of equatorial plane, Sample no- S-3/18 Scale bar = 200 µm.

EXPLANATION OF PLATE 7

Ranikothalia sahni

1: Axial section megalospheric form sapmle no. 3/6.

***Nummulites wadiai* Davies 1927**

2:axial section microscopic form, sample no. 3/6.

***Nummulites mamilla* Fichtel and Moll**

4: axial section microscopic form, sample no. 3/6.

***Nummulites* sp.2**

3: axial section microscopic form, sample no. 3/25

***Nummulites* sp.A**

5: axial section microscopic form, sample no. 3/25.

Nummulites atacicus

6:axial section microscopic form, sample no. 3/24.

7: axial section microscopic form, sample no. 3/24.

8: axial section microscopic form, sample no. 3/24.

***Spiriolina* sp.**

9: axial section microscopic form, sample no. 3/24.

EXPLANATION OF PLATE 8

***Nummulites* sp.A**

1: Nearly section, form sample no -S-3/27scale bar=200 µm.

*?**Nummulites cf pinfoldi***

2: Nearly equatorial section, form sample no --3/26scale bar=200 µm.

4: high resolution view showing chamber arrangement,

5: almost tangential axial section, form sample no -S-3/29scale bar=200 µm.

***Nummulites mamilla* Fichtel and Moll**

3: Nearly section, form sample no -S-3/26 scale bar=200 µm.

Nummulities atacticus

5: almost tangential axial section, form sample no -S-3/29 scale bar=200 µm.

6: almost axial section, form sample no -S-3/.... scale bar=

***Nummulites globulus* Leymarie**. vari Indicus Davies 1927..

7: almost tangential axial section, form sample no -S-3/31scale bar=200 µm.

EXPLANATION OF PLATE 9

***Nummulites* sp. A**

1: equatorial section megalospheric form sample no S-3/25. scale bar=200 µm.

2: equatorial section megalospheric form sample no S-3/24. scale bar=200 µm.

3: high resolution showing umbonal area form sample no S-3/25 scale bar=200 µm.

4: showing radial septal fillaments form sample no S-3/24. scale bar=200 µm.

7: axial section form sample no S-3/24. scale bar=200 µm.

***Nummulites* sp.3**

5: equatorial section megalospheric form sample no S-3/28. scale bar=200 µm

6: equatorial section microspheric form sample no S-3/28. scale bar=200 µm

Assilina leymeriei d'Archiac & Haime

8: nearly axial section from sample no S-3/28. scale bar=200 µm

EXPLANATION OF PLATE 10

Nummulites atacicus Leymerie.

1:Tangential section microspheric form, sample no - S-3/24 Scale bar = 200 µm.

2: High resolution showing chamber arrangement sample no S-3/45, scale bar= 200 µm.

3: Equatorial section microspheric form, sample no S-3/25, scale bar= 200 µm.

4: Equatorial section microspheric form, sample no S-3/24, scale bar= 200 µm.

5: Equatorial section microspheric form, sample no S-3/24, scale bar= 200 µm.

7: Equatorial section microspheric form, sample no S-3/24, scale bar= 200 µm.

EXPLANATION OF PLATE 11

***Nummulites* sp-4**

1: nearly tangential section, microspheric form, sample S-3/45 , scale bar = 200 um

2: high resolution tangential view, microspheric form, sample S-3/45 , scale bar = 200 um

3: nearly tangential section, microspheric form, sample S-3/45 , scale bar = 200 um

Nummulities atacticus

4: tangential section sample no S-345, scale bar=

6: nearly axial section, form, sample S-3/29 , scale bar = 200 um

7: high resolution showing chamber arrangement and septa.

***Nummulites mamilla* Fichtel and Moll**

5: nearly axial section, microspheric form, sample S-3/38 , scale bar = 200 um

8: nearly tangential section, microspheric form, sample S-3/45 , scale bar = 200 um

9: nearly axiall section, microspheric form, sample S-3/42 , scale bar = 200 um

EXPLANATION OF PLATE 12

***Alveolina ellipsoidalis* Schwager**

1: axial section, microspheric form, sample S-3/5 scale bar = 200 um

Alveolina sp. 1

2: axial section, microspheric form, sample S-3/7 , scale bar = 200 um

Alveolina sp.2

3: axial section, microspheric form, sample S-3/24, scale bar = 200 um

Alveolina sp.3

4: axial section, microspheric form, sample S-3/34 scale bar = 200 um

Alveolina sp. 4

5: axial section, microspheric form, sample S-3/46, scale bar = 200 um

***Alveolina rotundata* Hottinger**

6: axial section, microspheric form, sample S-3/46, scale bar = 200 um

***Alveolina schwageri* Chechia rispoli**

7: axial section, microspheric form, sample S-3/46, scale bar = 200 um

Alveolina sp5

8: axial section, microspheric form, sample S-3/47, scale bar = 200 um

Alveolina oblonga

9: axial section, microspheric form, sample S-3/45 scale bar = 200 um

10: axial section, microspheric form, sample S-3/45, scale bar = 200 um

EXPLANATION OF PLATE 13

Nummulites globulus* Leymerie var. *Indicus

1: nearly equatorial section, microspheric form, sample S-3/44. scale bar = 200 um.

4: nearl axial section megalospheric form from sample no. S-3/27. Scale bar = 200 um.

8: nearl axial section microspheric form from sample no. S-3/27. Scale bar = 200 um.

7: nearl axial section megalospheric form from sample no. S-3/27. Scale bar = 200 um.

***Nummulites* sp-A**

2: axial section, microspheric form, sample S-3/45, scale bar = 200 um

Miscellanea miscella

3: axial section, microspheric form, sample S-3/12, specimen a.

***Nummulites atacicus* Leymerie, 1846**

9 axial section, microspheric form, sample S-3/29, scale bar = 200 um.

***Assilina* sp.**

5: axial section, microspheric form, sample no S-3/34, scale bar = 200 um.

Assilina subspinosa

6: axial section, microspheric form, sample S-3/47, scale bar = 200 um

EXPLANATION OF PLATE 14

Alveolina cumcumiformis

1: Unflosculinized specimen, from sample no. Num- 2/6. Scale bar = 200 µm.

Assilina granulosa d Archaic

2 : Nearly axial section megalospheric, form sample no. Num- 2/6. Scale bar = 200 µm. Scale bar = 200 µm.

***Assilina spinosa* Schaub 1981**

3: Nearly axial section megalospheric form, sample no Num- 2/14. Scale bar = 200 µm.

5: Nearly equatorial section megalospheric form, Num- 2/14. Scale bar = 200 µm.

***Nummulites* sp-5**

4: Nearly axial section, from sample no. Num- 2/14 Scale bar = 200 µm.

***?Cuvillierina vanbelleni* Grimsdale**

6: tangential section microspheric, sample no. Num- 2/14. Scale bar = 200 µm.

***Nummulites* sp.6**

7: axial section megalospheric form, sample no Num- 2/3 Scale bar = 200 µm.

Fish tooth : *Indent*

8: Lateral view, from sample no. Num. 2/17- 3/2. Scale bar = 100 µm.

***Assilina* sp.**

9: Nearly axial section megalospheric form, sample no Num- 2/14. Scale bar = 200 µm.

Gastropoda: *Turritella* sp.

10. Lateral view , from sample no. Num- 2/20 Scale bar = 200 µm

Coral *: Coleilonus elongatus*

11: Tangential section, sample no. Num. 2/16. Scale bar = 100 µm.

EXPLANATION OF PLATE 15

1- 3 & 7-8 *Candona himalaica*, 1-3: male carapace, 1 (right) & 2 (left) lateral view of carapace, 3. carapace in ventral view ; 7-8 female juvenile carapace, 7 (right) & 8 (left) lateral view, 10. female carapace, lateral view. Scale bar = 200 µm.

4 & 6 Candonidae Gen et. sp.,: 4 (right) & 5 (left) lateral view of carapace. Scale bar = 200 µm.

5. *Cypridopsis* sp.. lateral view of carapace, Scale = 200 µm.

EXPLANATION OF PLATE 16

1, 4,6, 7-8 &10 *Barbus* sp., Morphotype-1 lateral view. Scale bar = 500 µm except 6=500 µm.

2-3, 5& 9 *Barbus* sp. Morphotype-2 lateral view. Scale bar 2&9= 300 µm, 3=400 µm, 5=500 µm.

11 Fish scale impresion . Scale bar= 500 µm

12 Rodentia, lateral view. Scale bar= 200 µm

EXPLANATION OF PLATE 17

1-2 *Barbus* sp., Morphotype-1 lateral view. Scale bar = 200 µm.

3&15 *Schizothorax* sp.lateral view. Scale bar = 200 µm.

4 *Squalius* sp.lateral view. Scale bar = 200 µm.

5, 7& 9 *Barbus* sp. Morphotype-2 lateral view. Scale bar = 200 µm.

6, 10&11-12 *Barbus* sp. Morphotype-3 lateral view. Scale bar = 200 µm.

13-14 *Cyprinus* sp. lateral view. Scale bar = 200 µm.

16 Fish vertebra, occlusal view. Scale bar = 200 µm.

EXPLANATION OF PLATE 18

1, 3 &5 Rodentia, Enamel ultrastructure . Scale bar = 20 μm.

2, 4&6 Incisor fragments . Scale bar = 500 μm.

EXPLANATION OF PLATE 19

1-2, 3-4&6 Rodentia, teeth, lateral (1,3-4,6) & vertical view Scale bar 1-2= 20 µm.3-4&6=200 µm.

5&7 Rodentia, Enamel ultrastructure Conical teeth, lateral. Scale bar = 20 µm.

8. *Lychnothamnus* cf. *breviovatus* Lu & Luo, 1990, 7. Lateral view. Scale bar = 200 µm.

EXPLANATION OF PLATE 20

1-5 *Unio kohlii* Sahni & Bhatnagar, 1958, lateral view of valve. Scale bar = 5mm except 4= 500 µm.

6 Incertae sedis. Gen et sp. Scale bar = 2mm.

EXPLANATION OF PLATE 21

1-3 Gastropoda indet, 1.spiral view , 2. apertural view, 3. umbonal view. Scale bar1-2= 2mm, 3 = 1mm.

4, 7-8 *Bellamya* sp. 4,7. apertural view, 8. spiral view. Scale bar = 1mm.

5-6& 9 *Paludina* sp. 5-6 spiral view, 9.apertural view. Scale bar = 1mm.

EXPLANATION OF PLATE 22

1-3, 6&9 Gastropoda indet, 1-3,6.apertural view. Scale bar1-2= 2mm, 3 = 1mm.

4-5&9 *Paludina* sp. 4-5 spiral view, 9 lateral view. Scale bar = 1mm.

7-8 *Indoplanorbis* sp. spiral view. Scale bar = 500 µm.

EXPLANATION OF PLATE 23

1,3, 6-8 Gastropoda indet, 1.Lateral view, 3&7. Spiral view, 6&8 apertural view . Scale bar = 500 µm.

2, 4-5 *Bellamya* sp. 2&4 apertural view, 5 side view. Scale bar = 500 µm.

9-12 *Indoplanorbis* sp. spiral view. Scale bar = 500 µm.

EXPLANATION OF PLATE 24

1-11, *Melania kargilensis* Sahni & Bhatnagar, 1958, 1,4-5, 8-11 lateral view, 2-3,6-7 apertural view . Scale bar = 5mm.