CHAPTER 2

Study Area and Modern climatic conditions

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2.1 Introduction

Since this study is aimed to understand changes in the ISM in NE and NW Himalaya, a detailed literature survey has been carried out from the previous published work which enabled me to identify the Wah Shikar and Mawmluh caves in Meghalaya, NE Himalaya and the Tso Moriri Lake in Ladakh, NW Himalaya for proxy studies. These caves lie in the region of maximum rainfall in the world. The cave deposits in this area are widely accepted and extensively analysed proxies to reconstruct precipitation changes in the NE Himalaya. Whereas, the Tso Moriri Lake lies in the monsoon marginal semi desertic region of Ladakh and hence is highly sensitive to any small climatic fluctuation in the NW Himalaya.

2.2 Shillong Plateau, NE Himalaya

The Wah Shikar cave (25° 21′ 25.42″ N, 92° 31′ 57.72″ E, 876 m, amsl) is located ~120 km SE of the Shillong city, Jaintia Hills district, Meghalaya. The Mawmluh Cave (25°15′32.27″ N, 91°42′45.37″ E altitude 1290 m, amsl) lies in West Khasi Hills district, Meghalaya, close to the city of Cherrapunji, ~3km south in south-west direction. Multi-level cave passages have been developed in both the caves, out of which the main passage encompasses a small rivulet. The cave acts as a water reservoir during non-monsoon months and the cave water has been used for domestic and agricultural purposes. Several active and inactive stalagmites can be seen at all the cave levels. The broken pieces of speleothems perhaps indicate some seismic activity in the region.

2.2.1 Geology and Geomorphology

Both the caves (Wah Shikar and Mawmluh cave) are located on the Shillong plateau which represents a remnant of ancient plateau of the Indian Peninsular shield (Sarma, 2005; Yin et al., 2010). The plateau consists of diversity of rock formations ranging from the Precambrian to Recent. General stratigraphic sequence of the Shillong Plateau district is given in Table 2.1. The major part is Jaintia series of Eocene period, Barail Formation of the Oligocene period and Shillong Group of rocks (Figure 2.1). The rocks of Precambrian Gneissic Complex are granite gneisses, biotite gneisses, carbonatite and amphibolite, and traversed by the sills and dykes of both acidic and basic nature (Anon, 1974; Singh and Singh, 2000; Sarma, 2005. Shillong Group of rocks overlies the Gneissic Complex and also intruded by the sills and dykes (Sarma, 2005). Tertiary Rocks are represented by formation of Langpur, Shella, Kopili, Barail, Surma and Dupitila (Figure 2.1, Table 2.1). The host rock of both the caves belongs to the Shella Formation (middle Eocene, Jaintia group) comprising alternations of sandstone and limestone (Frank and Becher, 1998; Singh and Singh, 2000; Kharpran Daly, 2006; Gebauer, 2008).This limestone is overlain by ~40 meters of sandstone, interbedded by the coal seams (Singh and Singh, 2000). The Quaternary sediments overlie the tertiary rocks and occur in patches in the form of pebbles with brown colored clay. Recent alluvium is encountered in the river valleys and adjoining regions.

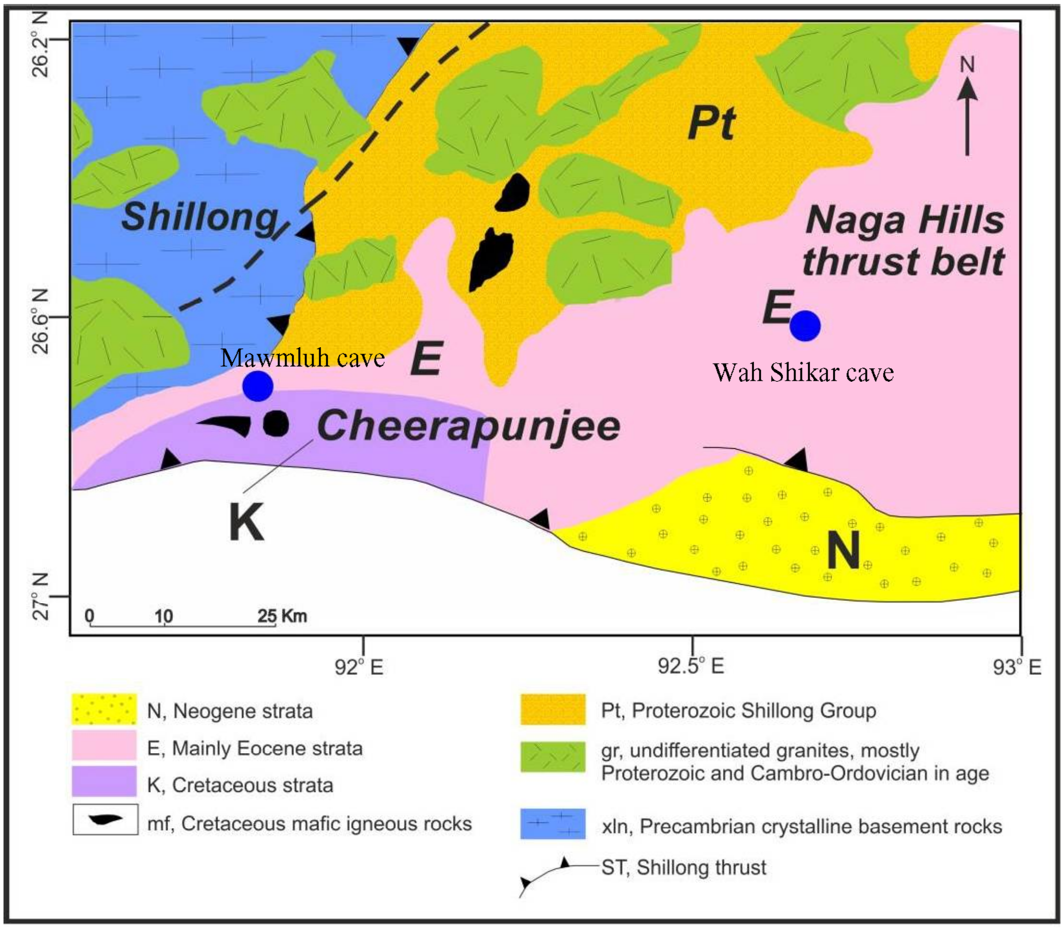

Figure 2.1 Geological map of the Shillong Plateau near the Wah Shikar and Mawmluh caves, Meghalaya, NE Himalaya (after Yin et al., 2010).

2.2.2 Modern climatic settings and vegetation

The Shillong Plateau experiences tropical monsoonal climate and shows a strong seasonality. Rainfall is very unevenly distributed (Murata et al., 2007; Breitenbach et al., 2010). The average annual temperature and precipitation is 23.3°C and 4000 mm, and 23.8°C and 3350 mm in Jaintia Hills district and West Khasi Hills district, respectively (Murata et al., 2007; 2008; http://www.indiawaterportal.org/met_data/). More than 85% of the total annual rainfall is received between May and October (Murata et al., 2007; 2008). In the non-monsoon season, there is a shortage of water on the Plateau. The use of caves as underground water reservoirs (Gebauer, 2008) is a visible expression of this problem. The natural vegetation in the district is characterized by sub-tropical dense forests (Chauhan and Singh, 1992). The major plant species are *Eupatorium adenophorum*, *Lantenacamara*, *Rubus sp*. *Paspalumorbiculare*, *Isachnehimalaica*, *Globba clarkia* etc. The primary forest cover has been declined rapidly in the last few decades due to unscientific mining and land use and the degraded sites are colonized by *Pinuskesiya* into secondary forests (Sarma, 2005).

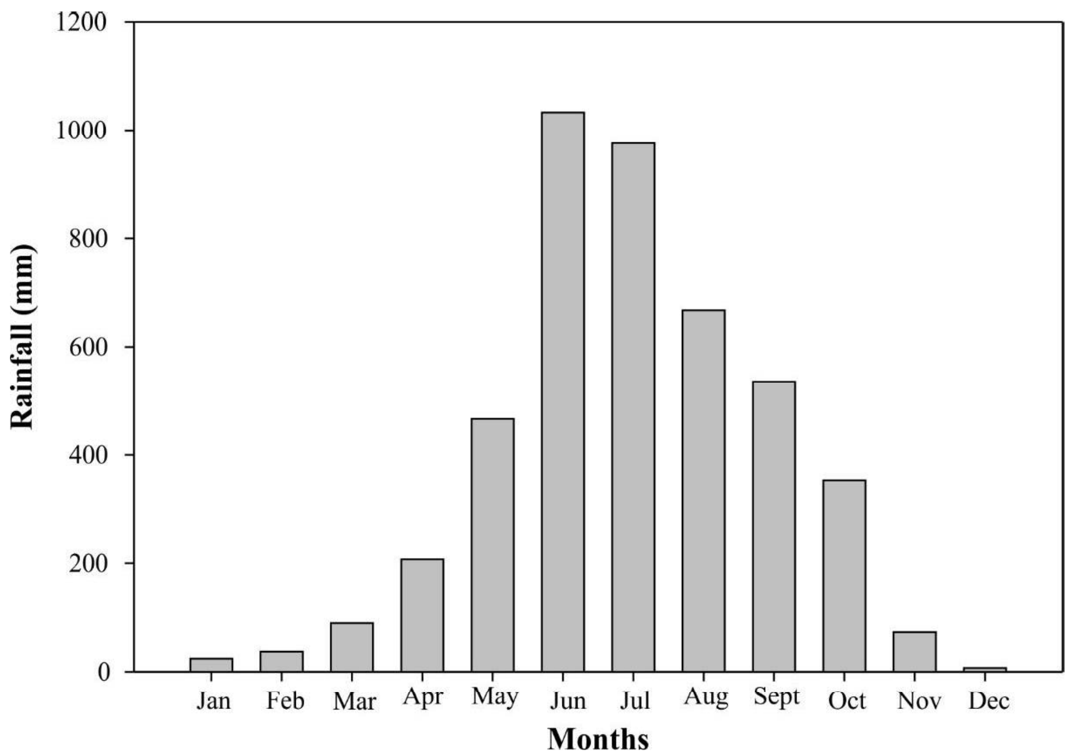

Figure 2.2 Average monthly rainfall in Jaintia Hills district, Meghalaya, NE Himalaya during 1901 to 2000 (http://www.indiawaterportal.org/met_data/).

Table 2.1 Lithostratigraphic succession of study area near the Wah Shikar and Mawmluh caves, Shillong Plateau, NE Himalaya (after Yin et al., 2010).

Age	Group	Formation	Rock Type
Recent	Newer alluvium	Unclassified	Sand, sily and clay
Pleistocene	Older Alluvium	Unclassified	Sand, clay, pebble, gravel and boulder deposits
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~Unconformity~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			
Mio-Pliocene	Dupitila		Mottled clay, felspathic sandstone and conglomerate
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Oligo-Miocene	Surma		Sandstone, siltstone, shale, mudstone
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~Unconformity~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			
Oligocene	Barail		Hard compact, fine grained grey sandstone, shale, siltstone
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~Unconformity~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			
Eocene	Jaintia	Kopili	Shale, sandstone, marl
		Shella	Alteration of sandstone-limestone
		Langpur	Calcareous shale, sandstone, limestone
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~Unconformity~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			
Proterozoic	Intrusives		Porphyrytic and coarse grained granite, dolerites
	Shillong		Quartzites, phyllites and mica
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~Unconformity~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			
Precambrian	Gneissic Complex		Boititegneiss, granitic gneiss, migmatite, mica schist, amphibolite

2.3 Tso Moriri Lake, NW Himalaya

The Tso Moriri Lake (32° 54' 36"N, 78° 19' 12" E, 4515 m a.s.l.) is a brackish water, oligotrophic lake, currently open and located ~150 km southeast of Leh city, in the Rupshu area of eastern Ladakh (Figure 2.3). It covers a surface area of ~147 km^2 and the catchment area of ~2263 km^2 (Leipe et al., 2014). Lake water is slightly alkaline with an average pH of ~8.0 (Singh et al., 2008). The lake receives water either from precipitation or snowmelt through three major perennial streams; Kyagar Nugma in the north, Phirse Chu in the south and Korzok Chu in the west direction. The Lake remains in frozen conditions from December to February months (personal communication with local residents). The Lake undergoes around 1-3 m variation in water level in a year, high stands during the summers.

2.3.1 Geology and Geomorphology of the Tso Moriri Lake region

The Tso Moriri Lake is situated in the Tso Moriri crystalline complex, in a north-south extended valley which is surrounded by the mountain peaks of Zanskar and Ladakh ranges exceeding 6000 m, amsl (Steck et al., 1998; Hedrick et al., 2011; Wünnemann et al., 2010). The Tso Moriri crystalline complex is bounded by Zildat ophiolitic mélange of the Indus-Tsangpo suture zone in the north and Trans Himalayan rocks to the South. The northern boundary of the Tso Moriri Lake catchment is characterized by the Puga gneisses (early Paleozoic to late Precambrian) comprising of augen gneiss and boudins of eclogites. (Figure 2.3; Thakur and Misra, 1984; Steck et al., 1998; Table 2.2). Haimanta Group (lower Protozoic to Cambrian) sediments with dominant carbonate lithology are exposed in the southern boundary of the catchment. Haimanta Group has been intruded by coarse grained, unfoliated Rupshu granite in the south of Korzok village (Thakur and Misra, 1984; Fuchs and Linner, 1996).

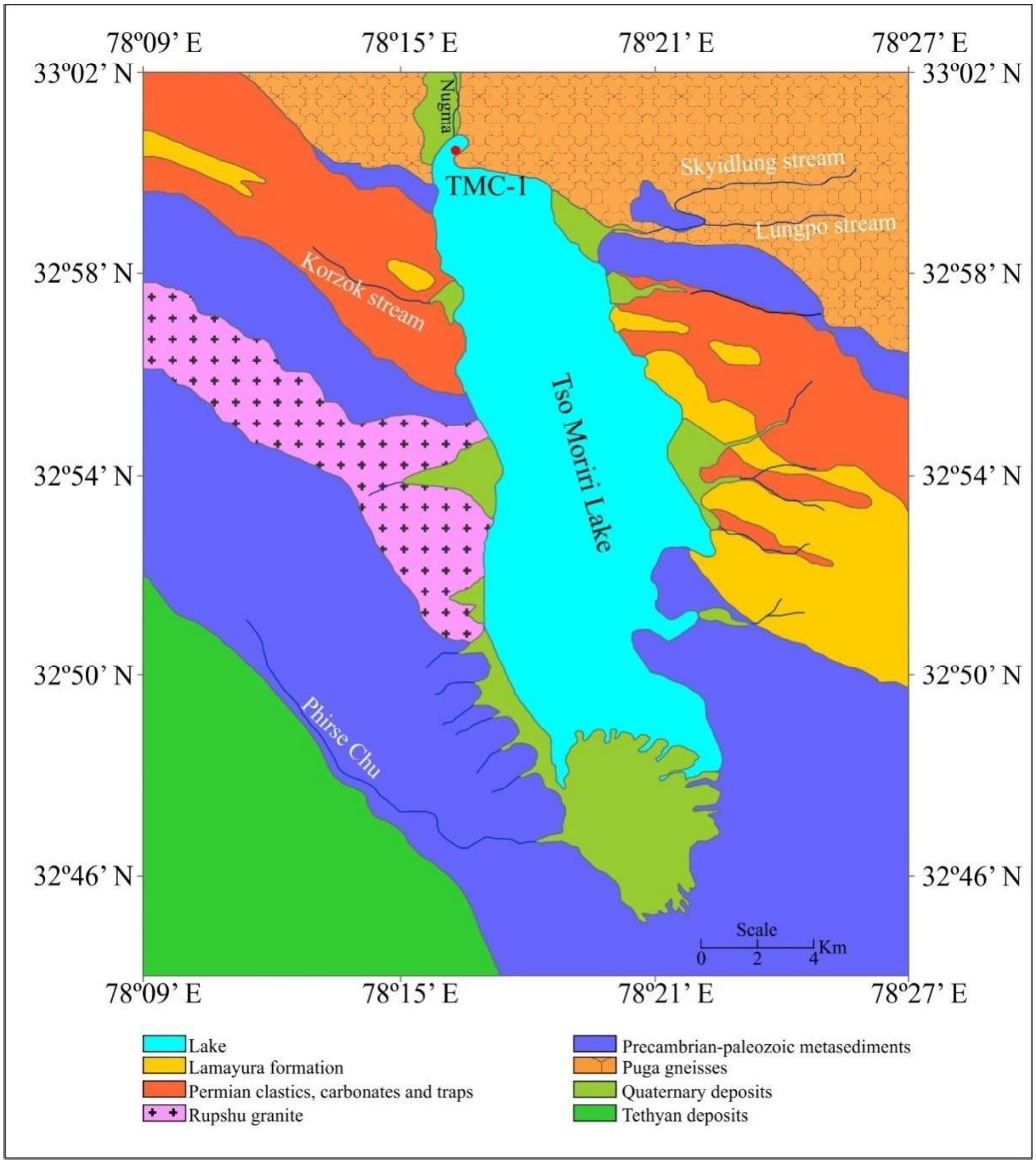

Figure 2.3 Geological map of the Tso Moriri Lake, Ladakh, NW Himalaya (after Mishra et al., 2014).

The northeastern part of the lake is dominated by Lamayuru Formation (Triassic-Jurassic) consisting of limestone, shale and marls. The geomorphology of the Tso Moriri catchment region indicates dominance of glacial and fluvial deposits. The Quaternary deposits are represented by the fluvial fills, alluvial fans, sand ramps, debris flows, palaeo-lake deposits and glacial moraine deposits.

2.3.2 Modern climatic conditions and vegetation

The area around the Tso Moriri Lake has high alpine desertic environment with average annual temperature around -4° C and average annual precipitation ~250 mm (Leipe et al., 2014). This region lies on the northernmost margin of ITCZ and lakes of the region are very sensitive to reflect the modest change in the precipitation. This region is influenced by the ISM as well as the MLW. The contribution of ISM precipitation decreases as we move northward and westward. The ISM is the chief source of precipitation near the Tso Moriri Lake and contributes about 70% of regional annual precipitation between June and September (Fontes et al., 1996; Tian et al., 2007; Leipe et al., 2014). TRMM precipitation data of the Tso Moriri region from 2009 to 2014 also suggests around 65% of precipitation contribution by the ISM. Rest of the precipitation is supplied by the MLW during winter months and local convection. The precipitation occurs generally in the form of snowfall but drizzles also occur twice/thrice in the summer monsoon season. Earlier investigations have suggested high variations in the lake level in the past (Leipe et al. 2014; Mishra et al., 2015). The modern regional vegetation is of desert-steppe and high alpine plant communities commonly comprising *Chenopodiaceae*, *Artemisia*, *Polygonum*, *Poaceae*, *Oxytropis*, *Cyperaceae* (Hutchinson, 1937; Chandan et al., 2008; Leipe et al., 2014).

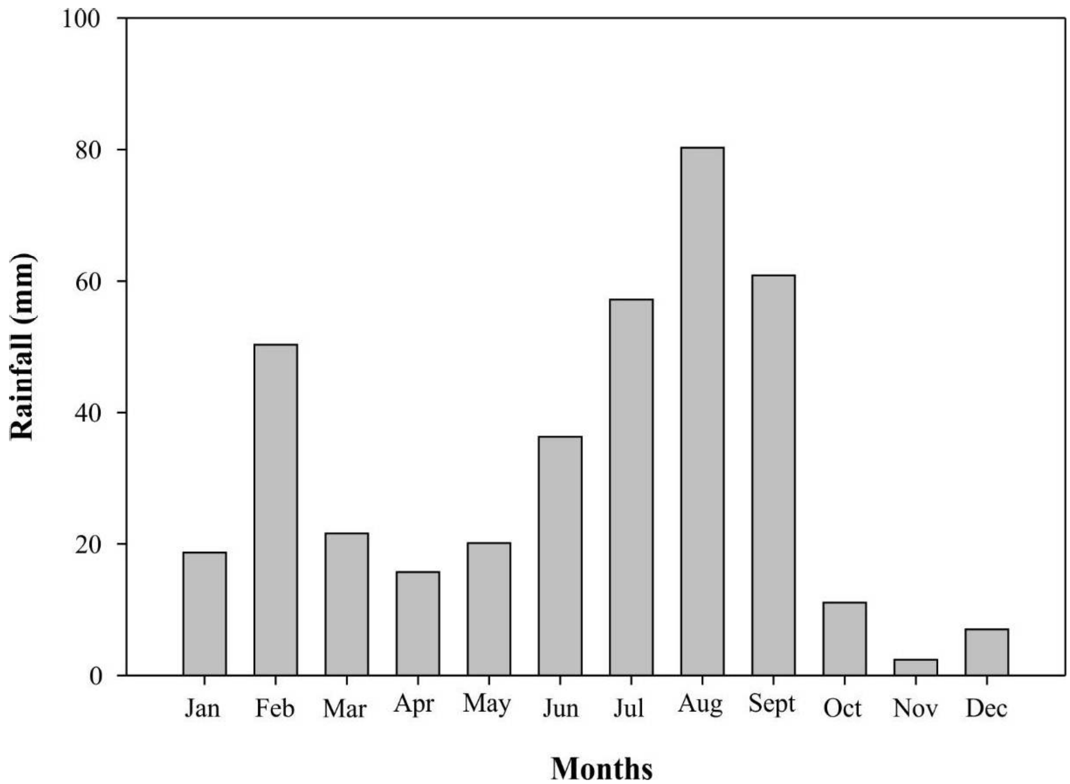

Figure 2.4 Average monthly precipitation around the Tso Moriri Lake, Ladakh, NW Himalaya from 2010 to 2014 based on Tropical Rainfall Measuring Mission precipitation data http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=TRMM B42_Daily).

The Korzok village, situated along the northwestern shore of the lake is the highest region in the world where agriculture is practised (Hutchinson, 1937). The main cultivated crops are Wheat (*Triticum*), Barley (*Hordeum*), millet (*Pancium*) and buckwheat (*Fagopyrum*) (Bhattacharya, 1991; Leipe et al., 2014). Chandan et al. (2008) have documented the presence of aquatic plants (*Potamogeton pectinatus*, *Potamogeton perfoiatus* and *Ranunculus natans*) on the lake bottom down to 10 m depth.

Table 2.2 Tectono-Stratigraphy of the Tso Moriri Crystalline zone in eastern Ladakh, NW Himalaya (after Thakur and Misra, 1984)

Tectonic zone	**Tectono-stratigraphic unit**	**Lithostratigraphic characters**	**Age**
Indus Suture Zone	Khardung formation	Acid volcanics-enclaves and dykes	Oligocene
	Ladakh plutonic complex	Tonalite, hornblende granite, granodiorite, biotite muscovite granite, pegmatite and aplite	Early Tertiary with 15-20 Ma plutons
	Kargil formation	Sandstone, grit, conglomerate, shale	Miocene
	Indus formation	Conglomerate, shale, sandstone and limestone	Cretaceous to lower Eocene
	Nidarophilite	Ultramafics, gabbro, pillow lava volcanic, chert and jasper	Jurassic-Cretaceous
	Zildat ophiolitic melange	Basic volcanic, chlorite schist, glucophane schist, limestone, serpentine	Cretaceous
Zanskar Zone (Tso Moriri Crystallines)	Rupshu and Polokong granite	Muscovite, biotite, hornblende, granite	Eocene-Oligocene
	Tanglang la formation	Chlorite, muscovite, biotite, garne, schist, amphibolite, marble	Carboniferos-Permian
	Puga formation	Muscovite, biotite, garnet, kyanite gneiss	Lower Palaeozoic to Late Precambrian
	Mesozoic of tethyn Himalaya	Dolomite, limestone, shale	Triassic-Jurassic