



Geoheritage Merits of the Zaskar Range of the Kashmir Himalaya: a Field Geology Museum from Precambrian to Present

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Abstract

The Zaskar Range is unique in varied aspects and is always been an attraction to the geoscientists and tourists due to its geographic location. The most of the area and routes are not easily accessible but it is the place where the glaciers are accessible by road and hence the best place for the study on glacial geomorphology and geology. Geologically, it represents the northwestern extension of the Spiti Basin, and constitutes the southern part of the Ladakh Himalaya. This range lies between the Great Himalayan and Ladakh ranges from SW and NE. It exposes the Higher Himalayan Crystalline (HHC), Paleo-Mesozoic Tethyan Sequences, and Indus Suture Zone composed of Kargil Mollase, flysch, and ophiolitic mélange. It is an ideal field museum of young orogenic tectonic and lithological settings and faunal remains from Cambrian onwards. Sediments of the Zaskar Range show sub-vertically, tightly folded, and wedge type structures in the north and open to tight folds in the south. In the present study, we have revealed the geoheritage value of each of its exposures taking the field, areal-air, and Google traverses from Kargil to Zangla along the Suru, Shankoo, Doda, and Zaskar valleys and air traverse from Leh to Lesser Himalaya of Kashmir. It is also an ideal sequence of Quaternary glacial episodes, the natural laboratory, and the open practical school for earth scientists. Eleven geoheritage sites are proposed in the Zaskar region with several geotopes under each site, covering many potential sites of this region. In the coming days, the geopark of the Zaskar may be envisaged.

Keywords Zaskar Range · Geoheritage · Ladakh · Crystallines · Quaternary

Introduction

The term “Geological Heritage” can be applied to any naturally occurring location that is easily accessible and has important geological features, including structural, stratigraphic, paleontological, and geomorphic. Geological characteristics that provide information about the history of earth science or the evolution of Earth or that can be utilized for research, education, or reference on a scale ranging from

global to regional are included in the definition of geoheritage (Brocx and Semeniuk 2007). If a portion or outcrop is recognized as having geological heritage, it may have an occurrence of a fossil, mineral, or structure that can only be found in one spot, as well as any other aspect of the earth that is only found at its place of occurrence. The relevance of humanity’s history, culture, aesthetics, and religion are all intertwined with the concept of geoheritage (Brocx and Semeniuk 2007). The legal preservation and conservation of naturally given legacy, often known as geoheritage, is a synthesis of numerous international, national, and regional laws (Dauvin et al. 2004). UNESCO issued a resolution in 1972 to conserve the world’s cultural and natural heritage. UNESCO defines natural heritage as a diverse set of biological and geomorphological/geological characteristics of nature that are well-intentioned for preservation. In recent years, the appraisal and importance of Earth’s heritage and management have grown in the shape of geodiversity and biodiversity concepts (Brilha 2002, Zouros 2004, 2005, Staces and Larwood 2006, Carcavilla et al. 2007, Panizza

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2009, Zouros 2007, Zouros et al. 2009, Zouros et al. 2009). Conservation of geological sites and materials was rarely an issue for the developing science during the early history of geology and paleontology, as new places with “fresh” fossil assemblages were constantly uncovered (Page 2018).

In the latter decades of the nineteenth century, urbanization and industrialization began to degrade a number of well-known areas. Conventionally, by the middle of the twentieth century, a widespread awareness of the need for site conservation had emerged (Page and Wimbledon 2009). However, only in late twentieth century the majority of nations felt need for conservation and protection of heritage sites (Page et al. 1999; Page 1999). Geologically significant locations must be maintained because geological features and fossils are part of the natural heritage and can be used to study the science of several geological events (Page 2018). Besides this, preservation of geologically significant locations is also essential for educational and economic reasons (Page 2018). Geoheritage has attracted more attention in recent years, through the construction of geoparks and geotourism around the world. Dowling and Newsome (2006, 2010) define geotourism as sustainable tourism with a primary focus on geological features in a way that supports environmental and cultural appreciation, understanding, and conservation, and is locally beneficial. It is a type of tourism in which the features of the landscape and its evolution generate a tourist experience that is more than the sum of its parts, drawing people with a variety of interests (Dowling and Newsome 2010). Geotourism may have the ability to elevate the profile of the earth scientists, as well as funding research and provide employment possibilities (Kelley et al. 2019). Attempts have been made to preserve geomorphological features, and these efforts have focused on the identification and documentation of geosites (Panizza and Piacente 1993, Wimbledon et al. 1995, Wimbledon 1996, Panizza 2001, Reynard 2004, Carobene and Firpo 2005). The management of the environment and an assessment of the geoheritage’s long-term viability, potential hazards, and geodiversity are all included in the geoconservation of geoheritage. Geodiversity refers to the combined geological, geomorphological, pedological, and hydrological properties (Seth et al. 2017). In the same way, fauna and flora are natural treasures that need to be preserved along with the geological ones. On the other hand, in contrast to forests, wild life, and the environment, geological characteristics which record the history of the planet cannot be recreated. Such heritage monuments are natural value for the country where they occur and must be safeguarded. The notion of “Geopark” arose in order to save geoheritage. Over the last few years, there has been a substantial increase in interest in geoheritage conservation, geopark establishment, and geotourism research.

Geoparks are united geographical areas where sites and landscapes of international geological significance

are safeguarded and managed (UNESCO 2016). It blends geological preservation and local sustainability (Zouros 2004). “Geoparks” are great resources for teaching “Earth Sciences” (Kelley et al. 2019). They preserve geological history, improve public understanding of earth sciences, and promote regional economic growth (Patzak and Eder 1998, Eder 1999). There are many opportunities for teaching earth sciences in these locations, and instructors and researchers may count on support. Geoparks allow us to bring geosciences into culture, demonstrating that human culture is not independent of nature (Menegat 2009).

Several countries joined the European Geopark Network in 2000 and the UNESCO-supported Global Geopark Network in 2015–2016. A classified system for geoconservation, geo-education, and geo-tourism consists of a geosite at the lowest scale, geotope confines at greater scales, and a geopark at the biggest scale (Eder 2008; Ieleniz 2009; Joyce 2010; Moufti and Németh 2013, 2016). A geopark is a federally/legally protected region that preserves, educates, and develops geological heritage through geotourism (Dowling and Newsome 2010). Geoparks can boost the local economy through geotourism. In several nations, geological and geomorphological features are protected by identifying and documenting “geosites” (Panizza and Piacente 1993; Wimbledon et al. 1995; Wimbledon 1996; Panizza 2001; Reynard 2004; Carobene and Firpo 2005). India has great potential for geoparks and geoheritage sites. Some of the heritage stones (e.g., Deccan traps, Vindhyan sandstone, Jaisalmer Golden limestone, Jodhpur sandstone) (Kaur et al. 2019a, b, 2020a, b) and geoheritage locations, e.g., Slates from Chamba and Kangra, Elephanta Caves, Deccan traps, and Cenozoic successions of western Kachchh (Shekhar et al., 2019). Chauhan et al. (2023) identified Precambrian orogenic, collision tectonics, ophiolites, carbonatites, deep water to shallow shelf carbonates, miogeosynclines, ancient global oxidation events, and algal blooms that remarkably preserved in a small area around Udaipur in Rajasthan and have proposed 27 geological heritage sites. Joshi et al. (2022) proposed a field structural geology museum situated in an abandoned Shivrajpur-Bhat manganese mines, at Champaner Archaeological Park, a UNESCO World Heritage Site, in Gujarat. Chauhan et al. (2021) proposed the Kachchh Basin as a unique geoheritage and national geoparks potential. Bhoale et al. (2021) identified Jurassic fossil geotope sites in Wagad (E. Kachchh) with its cultural and historical significance. Terrestrial Martian analogues in Kachchh area also identified as potential geoheritage sites (Chavan et al. 2022). Thakkar et al. (2022) proposed the Harappan sites in Kachchh as potential locations for geoarchaeological tourism. We propose a national geopark of Zanskar Range of Kashmir Himalaya that could become a UNESCO geoheritage site.

The Himalaya is a classic example of an orogenic system created by continent–continent collision (Dewey and Bird 1970; Dewey and Burke 1973). Its youthfulness and spectacular exposure make it ideal for the study of diverse geologic processes related to collision and mountain building. As the continental mass cannot be subducted, so the continuous northward movement of the Indian plate resulted into the rise of the Himalayas. The pressure of the impinging plates could only be relieved by thrusting upward, contorting the collision zone, and forming the jagged Himalayan peaks. The northern boundary of the Himalayan range is the east-flowing Yarlung Tsangpo (Tsangpo–Brahmaputra River) and west-flowing Indus River. These two rivers flow mostly in the Tibetan Plateau and Ladakh Trans Himalaya. Stratigraphically, the major lithologic units in the Himalayan orogen consist of the Neogene Siwalik Group, the Proterozoic Lesser Himalayan Sequence (LHS), Himalayan Crystalline Complex (HHC), and the Proterozoic to Eocene Tethyan Sedimentary Sequence (TSS) (Le Fort 1996) (Fig. 1). Structurally, the HHC rocks constitute the basement for the Paleozoic and Mesozoic Tethyan sediments sequence (Le Fort 1975). The above lithostratigraphic units are separated by the major terrain boundary thrusts. For example, the Siwalik sediments are differentiated by the Main Boundary Thrust (MBT) from the LHS (metasedimentary rocks) whereas the Main Central Thrust (MCT) is a tectonic boundary between the LHS and the HHC. Similarly the South Tibetan Detachment System (STDS) differentiate the HHC from the TSS (Fig. 1).

The northwest tip of India first collided with the southern part of the Eurasian plate at ~55 million years (Ma) ago (Le Fort 1996). By ~40 Ma, the two continents appear to have met along the full length (~2500 km) suture zone (Dewey

et al. 1988). The palaeomagnetic data suggests that since collision, ~1000 km of Indian plate is consumed beneath the Eurasian plate, predominantly in the southern part of the Tibetan plate (Harrison et al. 1998). Knowing the timing and sequence of thrusting within the Himalaya and southern Tibet is pivotal to understanding the evolution of the Indo-Asian collision. It was suspected that thrusting within the Himalaya is relatively late stage response in the overall accommodation of India’s collision with Asia ~55 Ma ago (Burbank et al. 1996). Even today, it remains unclear why crustal-scale thrusting within the collision zone was delayed for perhaps 20–30 Ma following the onset of collision (Harrison et al. 1992). The early Miocene slip on the MCT is responsible for the production of High Himalayan leucogranites which are dated between 24 and 19 Ma (Coleman and Parrish 1995; Harrison et al. 1995). Activity on the MBT initiated at ~11 Ma and continued perhaps intermittently into the Pleistocene (Burbank et al. 1996). The structural and chronometric data indicate reactivation of the MCT during the late Miocene (11–5 Ma) which led to the formation of the underlying MCT zone and apparent Himalayan inverted metamorphic sequences. Melt generation and granite emplacement are mainly related to the exhumation stage of the Greater Himalayan Sequence (GHS) during the late Oligocene to early Miocene (Harris and Massey 1994; Hodges 2000; Searle 2013; Zeng and Gao 2017).

The Himalaya being the ideal place to study the orogenic processes and continent–continent collision in the world, the geologists from all over the world have studied extensively each sector of it and unfolded the gigantic geotectonic odyssey of this region through thousands of research articles. Not only the geology, the Himalaya used to be the place of research for ancient Vedic people for

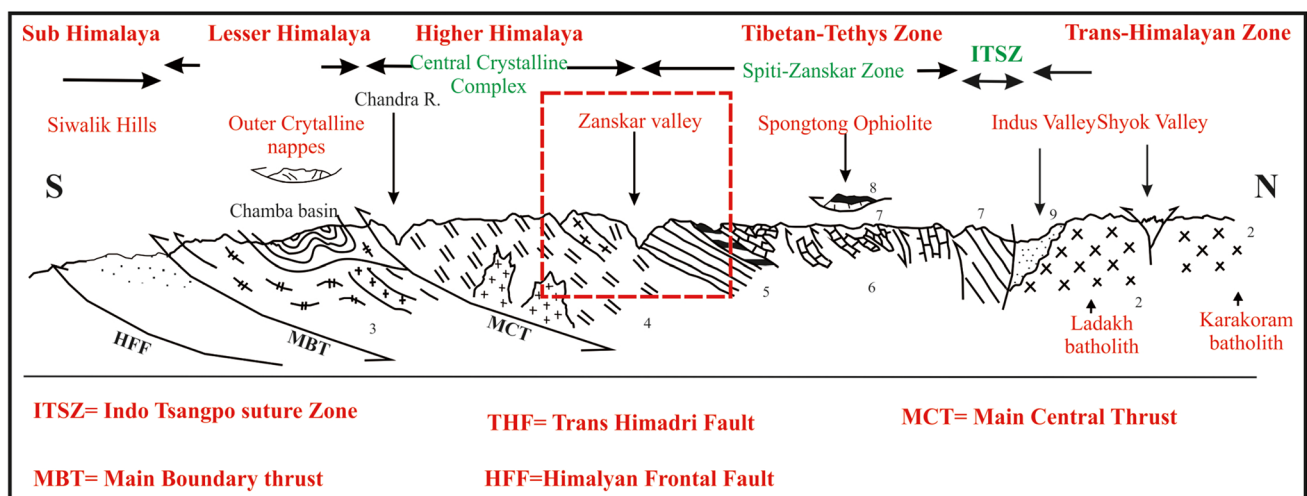


Fig. 1 Location of Zaskar valley in the Cross section from south to north profile. Note the valley is a junction between the Tethys sedimentaries and Central Crystalline which is known as STDS—South Tibetan Detachment System (modified after Gansser, 1964 and Valdiya, K.S. 1998)

the use and study of medicinal plants and minerals and it is also an abode of great deities of Hindus. The Rishis, the ancient scientists performed unending and severe penances for the quest of knowledge and the flora and fauna preserved in these loftiest mountains, snow cladding peaks, deep valleys, dense forests and cold deserts in the Himalayas. It is the home of almost 10000 glaciers and the world's 10 highest peaks. The objective of the present work is to focus on prolific geological features found in Zanskar Range of Kashmir Himalaya in the western end of Himalayan mountain belt (Fig. 2A, B). The Zanskar Range lies between the Great Himalayan and Ladakh Ranges from SW and NE sides respectively and exposes the Higher Himalayan Crystalline (HHC), Palaeozoic, and Mesozoic (Tethys) sequences and Indus basin constitutes the southern part of the Ladakh Himalaya and geologically it represents the northwestern extension of the Spiti Basin. Zanskar covers an area more than 7000 square kilometers. This part is extremely rich in terms of ideal geomorphology of collision tectonics, thrust related tectono-geomorphic features, glacial, fluvio-glacial, glacio-fluvial topography, youthful erosional and depositional features, and complete sequence of Precambrian to Holocene sediments. The Lower Palaeozoic, Mesozoic, and Cenozoic sequences

are the home of gigantic and varied folds and thrusts, and are useful for the students and researchers to understand the great geological processes occurred in last 50 Ma. In the present study, we have revealed the geoheritage value of each of its exposures taking the field, areal, and Google traverses from Kargil to Zangla along the Suru, Shankoo, Doda, Phuktul, Thaple, Kurgiakh, and Zanskar valleys and air traverse from Leh to Lesser Himalaya of Kashmir. We have identified such impeccable locations and exposures between Kargil and Zangla in Zanskar (Fig. 3A, B). They may be of importance for the new generation geoscientists as the area is considered as a field museum for structures, tectonics, stratigraphy and sedimentary rocks with varied fossil records and processes and the Quaternary glaciations.

Nomenclature of Zanskar comes from the local word "Zangskar" meaning white copper. Zanskar is basically a Buddhist area with a small Muslim population. It covers the area of ~7000 km² and is situated at an elevation between 3500 and 7000 masl. The climate is extremely severe and it remains cut off from the rest of the world from November to June when limited helicopter service is the only link with outside world or the frozen Zanskar River which is generally called as *Chadar* road that links Zanskar with Leh. The

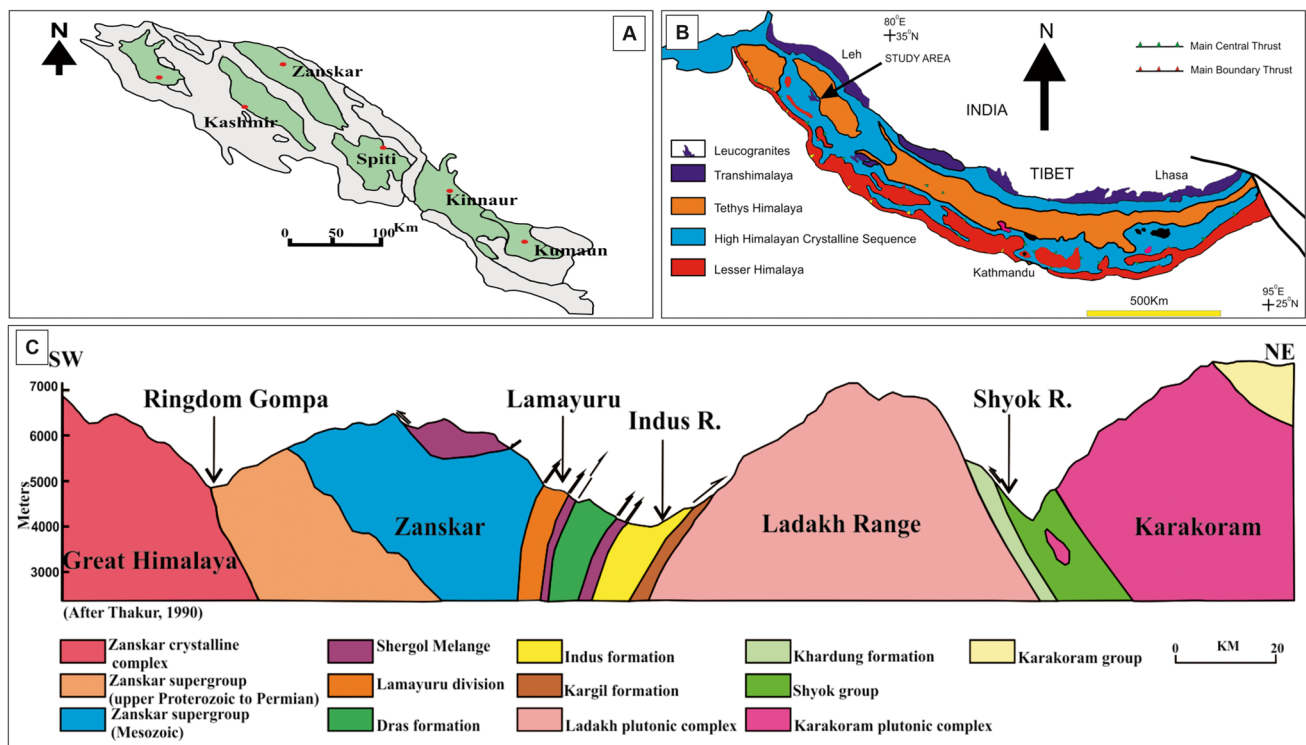
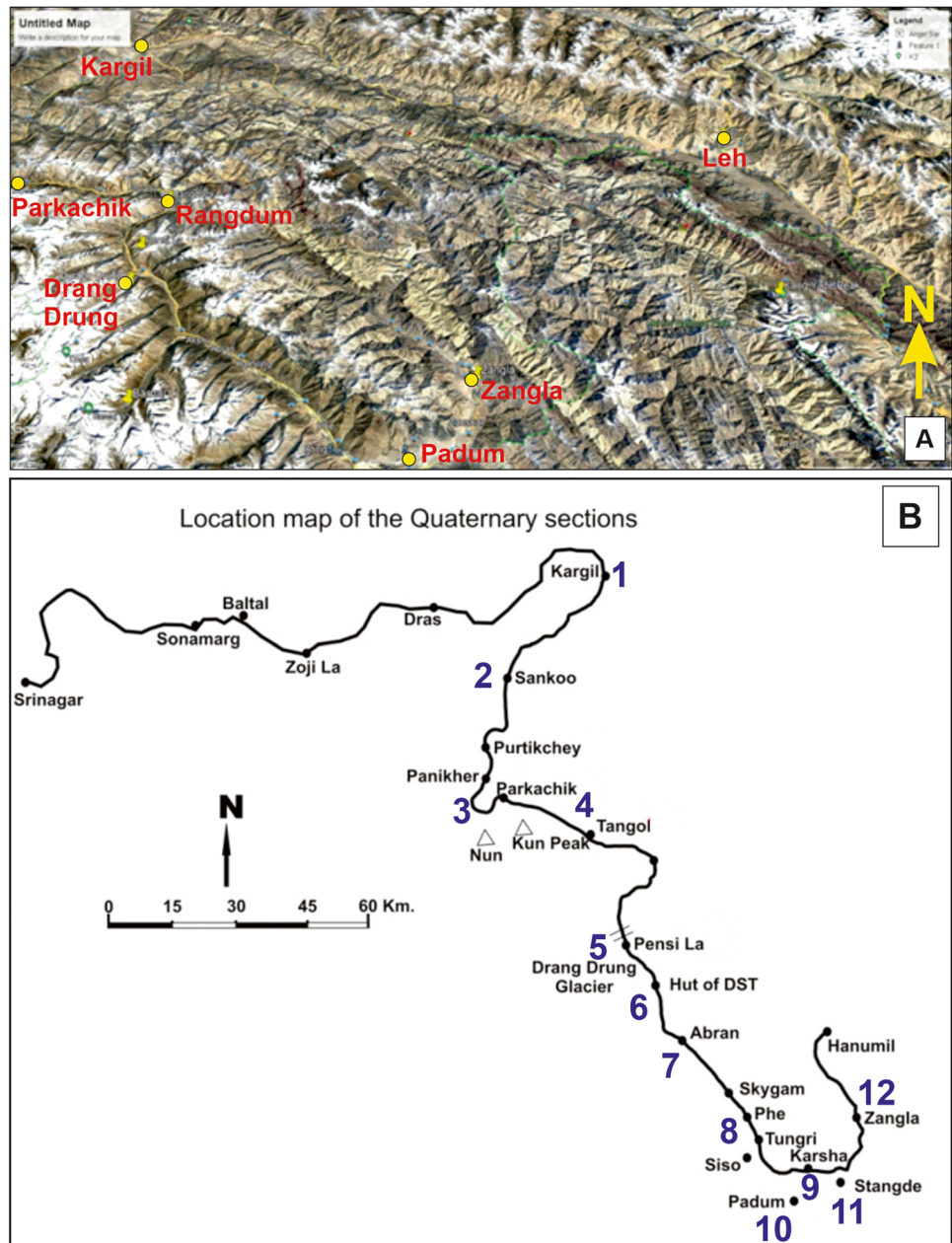


Fig. 2 **A** Map showing Tethyan sedimentary domains from Kumaon to Zanskar. They form a comprehensive sedimentary record of northern continental margin of Indian plate and sandwiched between the ITSZ and Crystallines (compiled from various sources). **B** Map

showing regional litho-stratigraphic units of Himalaya (Modified after Gansser, 1964, Valdiya, 1998). **C** SW-NE cross section covers Neo-Proterozoic to Permian and Mesozoic super groups in the Zanskar valley (modified after Thakur, 1981)

Fig. 3 **A** Google image showing the route from Kargil to Zangla in Suru, Doda, and Zaskar river valleys where the geoheritage features are marked and explained. **B** The line sketch showing the geoheritage locations explained (they include the Precambrian to Quaternary sites, from Kargil to Zangla).



region remains snow-covered during winters and movement of people comes to nearly standstill even within the region.

Geology and Tectonic Set Up of Zaskar Range

The Zaskar range runs parallel to the Great Himalayan Range, and is situated to its north (Fig. 2A, B, C) (Parcha et al. 2015; Parcha, 2021). The only access to the main inhabited valleys of Zaskar tehsil is through high passes situated in the Zaskar Range, the Great Himalayan Range, and their off-shoots. The most important passes of Zaskar

Range are Pensi La (4400m) leading to Kargil situated to the Northwest, Purfila (3950m), Namatsela (4350m), Charchala (5200m), and Shapodakla (5648m) leading to Leh in the Northeast. The Zaskar Range nearly separates Kargil district from Leh district (Fig.3A, B).

The Zaskar valley provides a rich repository of the pre- and post-collision history preserved in the sedimentary sequences spanning a period ranging from Proterozoic to Eocene (Fig. 4A, B). The stratigraphy of the Zaskar region of Ladakh Himalaya is compiled and summarized by Parcha (2021) in Table 1. The Haimanta Group is a thick succession of sedimentary rocks that overlies crystalline rocks of the Greater Himalaya and terminates at an unconformity that separates Cambrian rocks

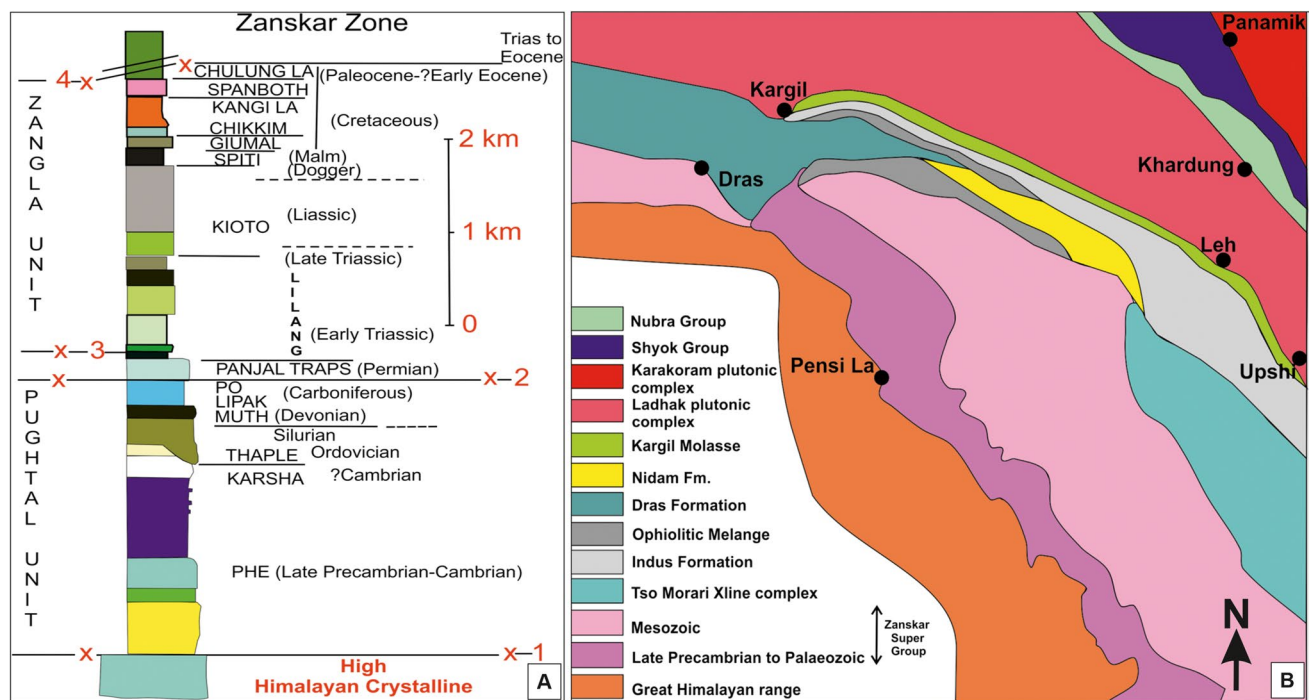


Fig. 4 **A** Generalized litho-units of Zaskar valley covering Higher Himalayan Crystalline to the Eocene (Baud et al., 1984). **B** Map showing major Geological formations from Great Himalayan Crystalline to Karakoram complex (modified after Thakur, 1981)

from Middle Ordovician and younger deposits. Nanda and Singh (1976) first established a stratigraphic nomenclature for the Cambrian of the Zaskar Valley and defined the siliciclastic Phe Formation and the carbonate-rich Karsha Formation (Fig. 4A, B). Garzanti et al. (1986) recognized the Kurgiak Formation as a siliciclastic unit conformably overlying the Karsha Formation and developed a series of members within each of the Phe, Karsha, and Kurgiak Formations (Fig. 4A, B). The Zaskar crystalline represents NW continuation of the Central Crystalline of Kumaun Himalaya. Along their northern margin, they are overlain by the Phanerozoic sequence of the Zaskar Tethys Himalaya with a tectonic contact and to the south exists the Kashmir and Chamba sequence which show Tethyan zone affinities (Thakur et al. 1990). Metamorphosed volcanics and carbonate beds presumed to be Permian and Lower Triassic in age, respectively. They occur as infolded syncline within the Zaskar Crystalline. The Permian–Triassic sequence together with the underlying Precambrian Zaskar Crystalline has been refolded by later generation folds. One such later generation fold extending for more than 20 km along its axial trace between Nun-Kun and Sankoo forms the Suru dome (Nun-Kun dome). The Suru dome is doubly plunging and NW-SE trending antiformal structure that has folded the regional schistosity as well the metamorphic isograds. Honegger et al. (1982) have mapped the following mineral zones: the chloritoid zone, garnet-biotite zone, staurolite-kyanite zone, sillimanite zone, and sillimanite-K Feldspar zone. The highest grade metamorphics

lie towards the core of Suru-dome, and the metamorphic grade progressively decreases outwards to the overlying rocks.

The Quaternary of Zaskar Valley

Quaternary stratigraphy in the Zaskar valley is dominated by the glacio-fluvial sequences along with the discrete occurrences of lake deposits. The Drang-Drung Glacier, to the east of Pensi La (La=pass) (4400 m) is the second largest glacier in the NW Himalaya after Siachen Glacier and feeds the Doda River. The Pensi La is a topographic divide separating the Doda river basin in the east and Suru basin in the west (Fig. 5). The accumulation area of the glacier lies in the northern ranges of the Higher Himalayas. Around Pensi La, relict, and modern proglacial lakes are observed. The development of wide “U”-shaped valleys and preservation of discrete trails of moraines in Suru and Zaskar valley indicate that these glaciers descended a lower elevation compared to their present position (Fig. 5). In addition to this, there seems to be structural control on the limit of northern extent probably associated with the activity along the STDS running parallel to the Suru and Doda rivers (E-W).

Various studies (Mitchell et al., 1999; Taylor and Mitchell, 2000; Lee et al., 2014; Sharma et al., 2018; Sharma and Shukla, 2018) over the years have documented the landforms in detail to understand the landscape evolution in the

Table 1 Lithostratigraphy of the Tethyan succession of Zanskar Valley

Formation	Lithology	Age
Chulung La Formation	Red beds, fining upward sequence, fine grained sandstone followed by siltstone and on the top by red muds	Late Paleocene–Early Eocene
Spanboth Formation	Nodular mudstone, wackestones, dark marly clays interbedded with bioclastic packstones, brown weathered quartzarenites	Paleocene
Kangi La Formation	Dark marls, marly clays with phosphatic nodules, and calcareous arenites	Late Cretaceous
Fatu La Formation	Grey, red, and green colored marly limestones	Early Late Cretaceous
Chikkim Formation	Nodular limestone and mudstones	Middle Cretaceous
Disconformity		
Giurnal Sandstone	Dark grey sandstone, pelitic mudstone/siltstone interbeds with sandstone, quartzarenite, black glauconitic sandstone with ferriferous nodules	Lower to Middle Cretaceous
Spiti Shale	Dark shales, marls, calcareous quartzose siltstone and sandstones	Late Jurassic to Early Cretaceous
Unconformity		
Ferruginous Oolite Fm.	Yellowish-brown ferruginous carbonate and quartzarenites	Late Middle Jurassic
Unconformity		
Kioto Limestone	Planar to nodular packstones, wackestones intercalated with marls	Late Triassic
Quartzite Series	Limestones, quartzarenites, micaceous siltstones, and quartzites	Middle Late Triassic
Zozar Formation	Limestone and dolomite	Late Middle Triassic
Hansa Formation	Marls, shales nodular limestones, and dolomitic limestones	Middle to early Late Triassic
Tamba Kurkur Fm.	Nodular limestones, limestones, and shales	Lower to Middle Triassic
Kuling Formation	Shales, siltstones, phosphatic nodules microconglomerates, and bioclastic limestones	Late Permian
Phe Volcanic (Panjal Traps)	Bedded basaltic flows	Middle to early Late Permian
Chumik Formation	Calcareous shale and glauconite arenites	Late Early Permian
Unconformity		
Ganmachidam Fm.	Gritty conglomerate, sandstone, and shale	Early to late Middle Permian
Po Formation	Calcareous sandstone, quartzite, black shale layers, and siltstone	Middle Carboniferous
Lipak Formation	Dolomitic limestone, sandstone, black shale, and beds of gypsum	Early Carboniferous
Muth Formation	Compact massive white quartzite and friable sandstone	Middle to Late Devonian
Unconformity		
Takche Formation	Limestone, shale, sandstone siltstone and gritty dolomite	Late Ordovician to Middle Silurian
Thango Formation	Conglomerates, sandstone interbedded with shale and siltstone	Late early Ordovician
Unconformity		
Kunzum La Formation	Thinly to thickly bedded brown weathered dolomite, limestone, green shale and silt stone	Lower Cambrian to early Late Cambrian
Batal Formation	Micaceous quartzite, carbonaceous phyllites black carbonaceous slate, brown ferruginous sandstone, and grey and green siltstone	Neoproterozoic Early Cambrian
Zanskar Crystalline	Micaceous quartzites, phyllites, chlorite, mica schists, migmatite-associated granites, granite gneiss, migmatites, amphibolite, and calc-silicates	Precambrian

Compiled from Srikantia et al. (1978), Baud et al. (1984), Gaetani et al. (1986) and Garzanti et al. (1986, 1996), Parcha (2021)

Quaternary times. The features like bedrock erosion of the valley flanks by the glacial actions (trimlines) in the Nun-Kun Massif region (Sentik glacier; ~70 ka; Lee et al., 2014); the classical U-shaped valley morphology (Sharma et al., 2018; Sharma and Shukla, 2018) along with the silty-sandy lacustrine deposits in the Tsarp Chu valley (~80 ka; Mitchell et al., 1999; Taylor and Mitchell, 2000) have been inferred as the signatures of the oldest glacial advancement on the Zanskar

ranges. Climatically, the time of advancement corresponds to the cold and wet MIS-4—a period known for strengthened westerlies (Fontugne and Duplessy, 1986; Hughes et al., 2013) with lowered temperature and increased moisture (Taylor and Mitchell, 2000). This is the most extensive glacial stage reported without ambiguity across the NW Himalaya (Owen et al., 2006; Hedrick et al., 2011; Sharma et al., 2016; Ganju et al., 2018; Sharma and Shukla, 2018).

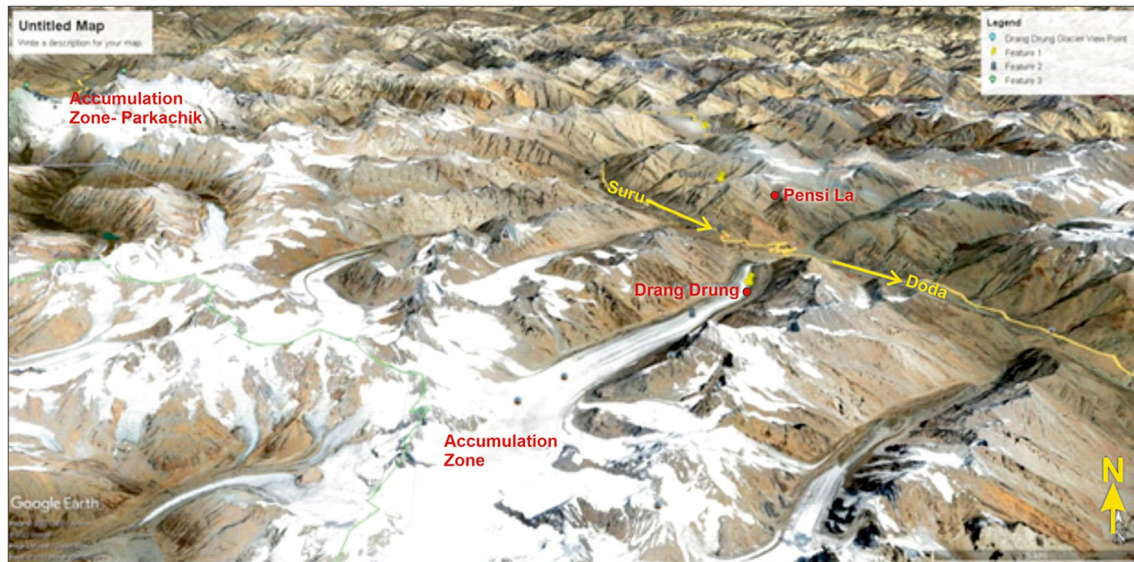


Fig. 5 The Google image of northern range of Higher Himalaya showing snow accumulation area of the glaciers. Note the longest glacier seen in the middle is Drang-Drung Glacier meets at Pensi-La,

a topographic divide separating the Doda river basin in the east and Suru basin in the west. To the east another accumulation zone is seen which generates Parkachik glacier

The Padam valley in the Zaskar ranges has preserved the multiple ridges of the second major glacier advance is dated between ~18 and 24 ka (Sharma et al., 2018; Sharma and Shukla, 2018) and corresponds to the Last Glacial Maxima (LGM) (Mix et al., 2001). The Indian Summer Monsoon (ISM) is known to be reduced considerably during the LGM (Duplessy, 1982; Prell and Kutzbach, 1992) while the westerlies shifted equator wards by storm tracks (Li et al., 2016 and references therein) and were implicated for driving the glacier advance (Taylor and Mitchell, 2000; Ali et al., 2013; Lee et al., 2014; Sharma et al., 2016; Sharma and Shukla, 2018). Globally, a decrease in temperature correlates well with the insolation minima in the northern hemisphere (Bond et al., 1999; Fleitmann et al., 2007). The younger set of moraines post-LGM advances (~15 ka) document the marginal advance of the glaciers probably in response to the cooler phases (Zhou et al., 2008) with strengthened westerlies (Li et al., 2016).

The Pensi La has also preserved multiple recessional moraines dated to the early to mid-Holocene in Southern Zaskar Range (Sharma and Shukla, 2018). Although most of the records are now obliterated as the road is widened in the valley. Besides, the Zaskar valley has extensive flat-topped outwash gravel terraces between ~13 and 6 ka formed due to widespread glacial retreat (Jonell et al., 2018; Sharma and Shukla, 2018) in response to largely increasing summer insolation and intensification of the ISM (Demske et al., 2009; Bhushan et al., 2018; Wünnemann et al., 2010). Major villages such as Padam have occupied outwash gravel surfaces both for infrastructure as well as agriculture. The alluvial fans and the associated relict lake sediments followed by

loess and paleosol formation deposited post the widespread valley aggradation indicate unstable (fluctuating) climatic conditions.

Geoheritage Sites on Kargil–Pensi La Route

The transect from Kargil to Pensi La has preserved the record of Higher Himalayan crystallines of Zaskar, oldest meta-sedimentaries like Phe formation of Precambrian and Cambrian age which largely comprises of grey siltstones and sandstones (Fig. 4B, 6A, B). There is a gap in the succession from Ordovician to Carboniferous. Thereafter, continuous records of sedimentation are preserved from Cambrian onwards. From Triassic, Jurassic, and Cretaceous, the sedimentary record is in the form of mostly limestone, sandstones, shales, and quartzite (Fig. 4B). Around Kargil (Kargil molasses), the fresh water deposits in the form of molasses are also observed.

Zaskar GHS-1: Kargil Molasse Near Kargil Town

Molasses are defined as terrestrial and shallow marine deposits formed nearest the rising mountain front. It consists of various interbedded rock types including conglomerates, sandstones, and shales. The Kargil formation, exposed at its type locality at Kargil, shows its maximum thickness ~1000 m (Fig. 7A). It extends in isolated outcrops along the Indus valley, overlying the southern margin of the Ladakh plutonic complex. In Kargil basin, the Kargil molasses overlies the Ladakh granitoids,

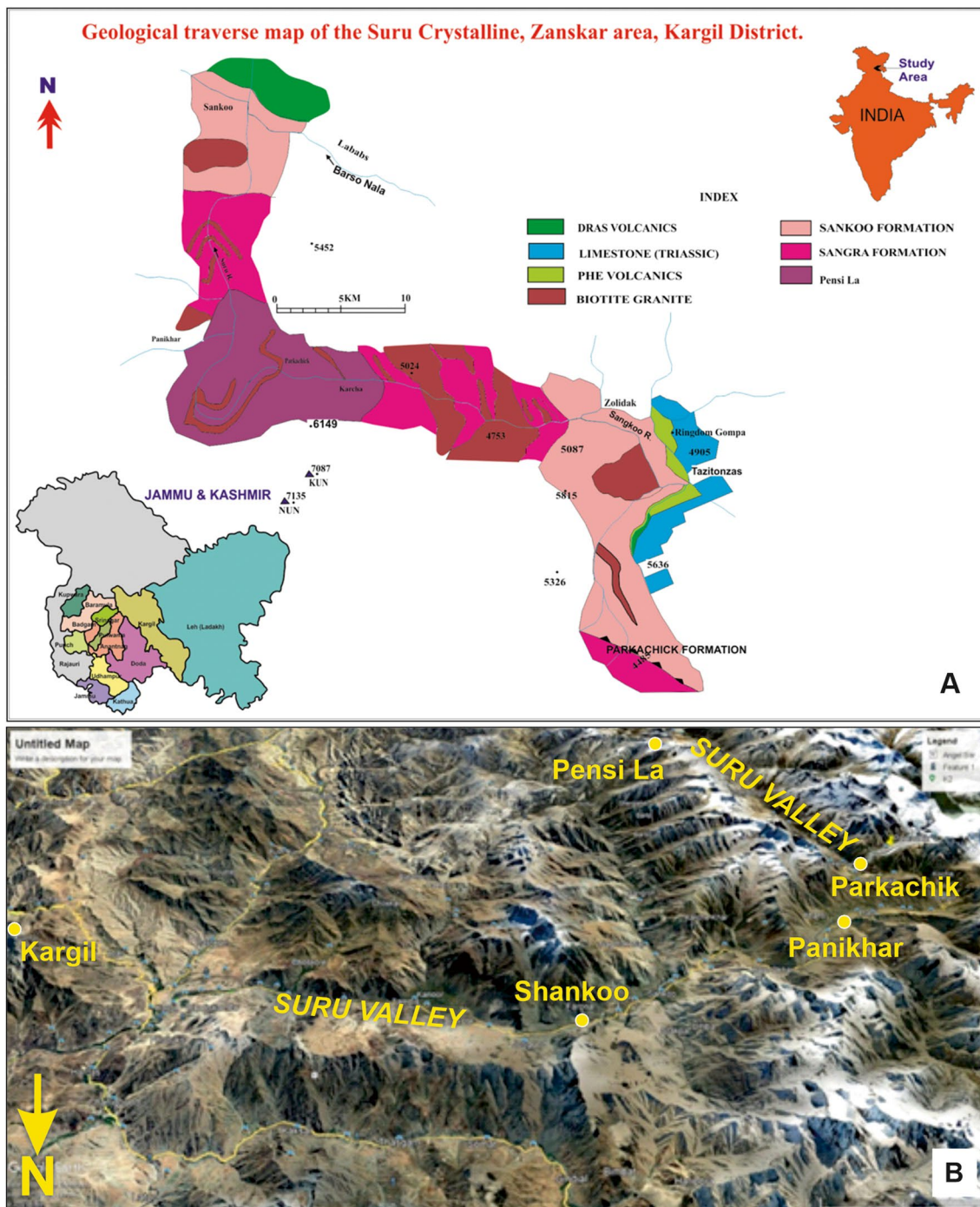


Fig. 6 **A** Geological map of the field traverse from Sankoo to Pensi-La. It starts with the Dras volcanic near the Dras and Kargil and cut across several Precambrian sequences resting over the Higher Himalayan Crystalline with gneisses and schists of Suru, Sangra and

Parkachik formations. They are traversed by the younger leucogranites. Note the Tethyan sequences of Triassic are exposed to the higher reaches (compiled from various sources). **B** The Google view of the entire route from Kargil to Pensi-La

Dras Formation, and ophiolitic mélangé (Fig. 4B). This was reported by Sahni and Bhatnagar (1956) and Tewari (1964) and is considered the type area for the vertebrate fossils in the Trans-Himalayan Zone. It is also called as the Wakka Chu molasses, represents fluvial sedimentation

in an intermontane basin (Brookfield and Andrew-Speed 1984). Based on rich faunal assemblage collected from Wakha river section in Kargil, Late Miocene to Pliocene age was assigned to the formation (Mathur 1983). Ctenodactyloid rodent assemblage described from the Kargil

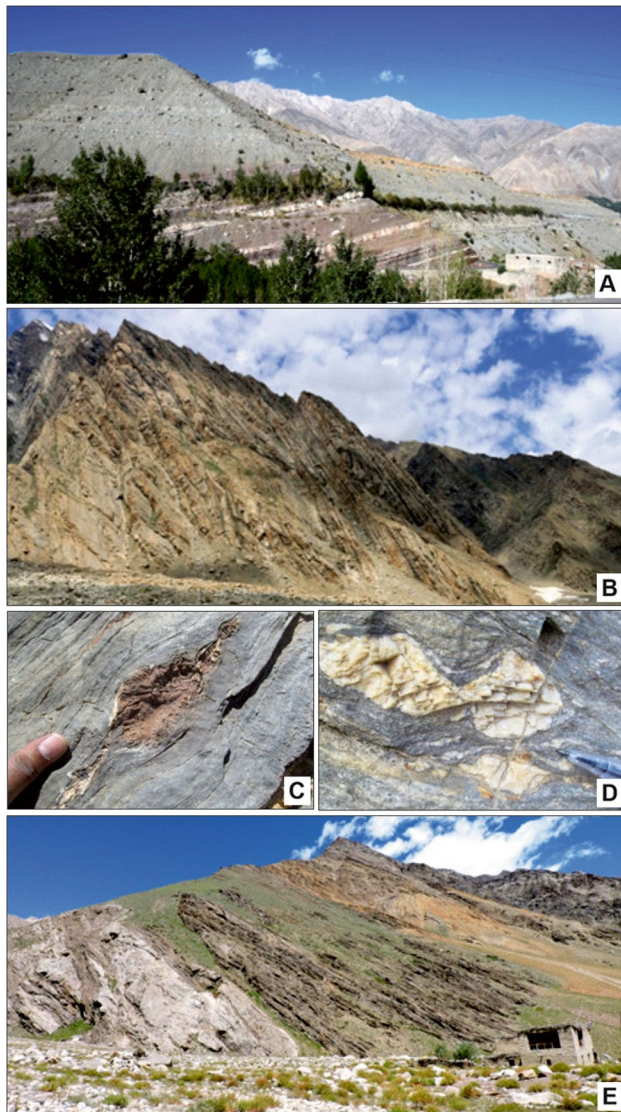


Fig. 7 **A** The photograph of a typical molasses deposits of Kargil near Kargil town. It shows sandstones, conglomerates, and shales that deposited in the deep trough like basin formed during the initial phase of Himalayan rise. The distant hills are Dras volcanics. **B** A view of HCC exposed along the Suru river valley near the Suru river bridge. They are the parts of Suru crystallines. It is overlain by the Precambrian metasedimentaries composed of biotite schists, amphibolites schist. **C**, **D** The augens of oriented orthoclase grains within the crystallines and metasedimentaries. **E** The distant view of the crystallines that are overlain by the Precambrian metasedimentaries composed of biotite schists, amphibolites schists

formation at Kargil locality suggests upper Oligocene to Middle Miocene age (Nanda and Sahni 1998). The Geosite-1 (ZGHS-1) selected south of Kargil town merits all the characteristics of the typical molasses deposits viz. sandstones, conglomerates and shales that deposited in the deep trough like basin formed during the initial phase of Himalayan rise (Yin 2006) (Fig. 7A).

Zaskar GHS-2 Higher Himalayan Crystallines (HHC) at Suru Valley

The Higher Himalayan Crystalline rocks are exposed in the Suru Valley and were earlier grouped under the Suru crystalline group. Based on the degree of the metamorphism and mineral assemblages, the Zaskar crystallines are further classified into three formations, Parkachik, Sangra, and Sankoo respectively. It is exposed all along the Suru River valley and well exposed near the Suru river bridge with bending and oriented orthoclase grains (Fig. 7B–D). It is overlain by the Precambrian metasedimentaries composed of biotite schists, amphibolite schist (Fig. 7E). ZGHS-2 is selected at the bridge near Shankoo village where all the formations are well exposed. Rocks of blueschist facies, related to subduction zone, are exposed near Sapi La and Mulbekh at the northern termination of Suru Crystalline where it abuts against the ophiolitic mélange.

Parkachik Formation

The upper amphibolite facies rock of the Parkachik Formation is composed of kyanite-sillimanite schists and gneisses with concordant sheet of foliated mica granite and intrusive bodies of leucogranites (Fig. 8A). The Parkachik Formation is well exposed between Panikhar and Zolidiak and near the snout of Drang-Drung Glacier. Around Panikhar village, it is overlain by the Sangra Formation which passes upward into the low grade rock of the Sankoo Formation. To the south of Anti village, the Parkachik Formation is directly overlain by the Permian–Triassic volcanic of Tethyan zone (Panjal Traps).

Sangra Formation

The middle amphibolite facies rocks of the Sangra formation consists of garnet and garnet staurolite schists with concordant sheet of mica granite and thick bands of amphibolites (Fig. 8B). Granite occurs as a sheet-type body concordant to regional foliation. It is foliated along its margins and massive in the central part. The Sangra Formation is well exposed between Chechesna and Yoljuk Mehta village and between Rungafarka Glacier and Hamjul Nala.

Sankoo Formation

It constitutes the uppermost part of the Suru crystalline group, made of low grade metasedimentaries and granite bodies (Fig. 7E). It consists of chlorite-biotite schist with thinly interbedded limestone, quartzite, amphibolites, and carbonaceous phyllite. Granite body containing

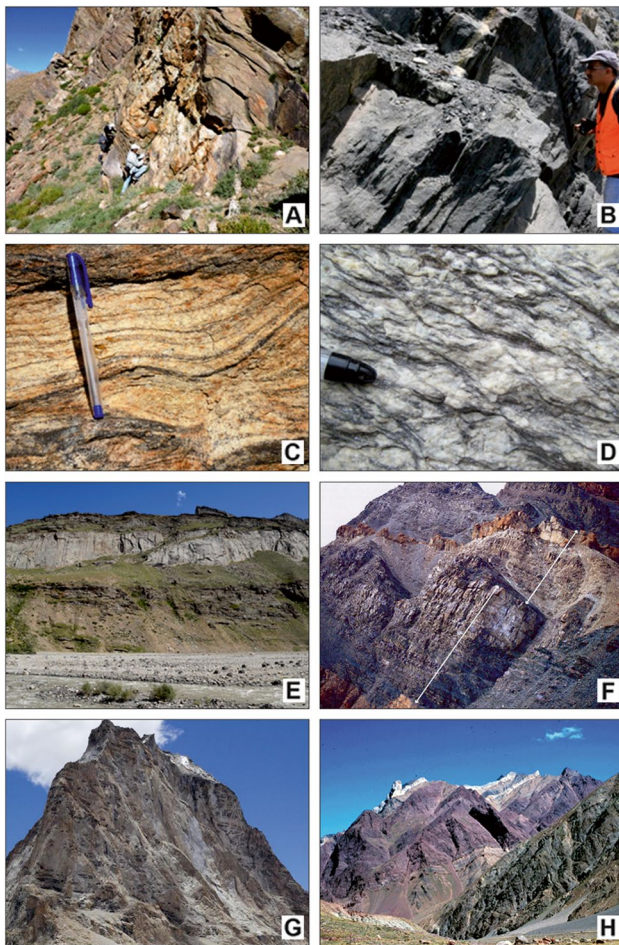


Fig. 8 **A** Leucogranite intrusive body within the amphibolites of the Parkachik Formation mostly composed of kyanite-sillimanite schists and gneisses. **B** Garnet staurolite schists of the middle amphibolite facies rocks of the Sangra Formation. **C** A close view of paragneiss of Suru Formation, the oldest crystalline of the Zaskar area. Note the foliation planes are discernible and the dark minerals are pyroxenes and biotites. **D** The gneiss of the same formation (Suru Crystalline) where augens are fully developed made up of orthoclase. **E** The sandstone layers in Phe Formation are in contact with thick grey micaceous siltstone and grey-green siltstone exposed along the Suru River. **F** Thinly to thickly-bedded brown weathered dolomite, limestone with thick green shale and siltstone of Kunzum La Formation is exposed in Zaskar valley. **G** Spectacular view of Gumbok Ranjan granite massif exposed between Kurgiakh Chu and Rile Nadi in the SE Zaskar. **H** A view of bedded purple quartzite, with red-brown sandstones of Thango Formation exposed at Kurgiakh

biotite and muscovite occurs as a large lens concordant to regional foliation. The Sankoo Formation is well exposed around the Sankoo village along Barso Nala, Umba Nala, and around Zolidiak village between Hamjul Nala and Pensi La. In Sankoo area, it underlies the Dras volcanics of the Indus Suture Zone along a thrust contact. At Zolidiak and Pensi La area, it is tectonically overlain by the Phe Volcanics and Zolidiak limestone of the Zaskar Tethyan sequence.

Zaskar GHS-3 Suru Formation: the Crystalline

The Suru Formation is the oldest formation of the Zaskar area and corresponds in age to the Vaikrata System. It consists of rocks ranging from metapellites, metapsammites, calcareous metasediments, and gneisses to granites. Biotite-quartz-sillimanite schist, quartz-kyanite-garnet schists, graphite schist, paragneiss, amphibolite, calc-silicate granite gneiss, porphyritic, garnetiferous and augen varieties, migmatites, garnetiferous mica schists, quartz chlorite hornblende schists, quartz schist, quartzite and marble, purple micaceous quartzite, phyllites, chlorite, mica-schists, and associated granites form the Suru crystalline group from almost beginning of the Suru Valley to Rangdum village (Fig. 8C, D).

Zaskar GHS-4 (PC and Metasedimentary of Palaeozoic)

The Lower Palaeozoic rocks in Zaskar region overlie the metamorphic rock of the HHC (Lydekker 1883). Nanda et al. (1969) named this as Phe Formation. Parcha (2021) had compiled and summarized the stratigraphy of the Zaskar valley.

Batal Formation (Phe Formation)

A monotonous succession of grey–greenish sandstone with preserved wave ripples extends from Rangdum Gompa to Kurgiakh (Fig. 8E). The age of the formation ranges from Precambrian to Lower Cambrian. The name of Phe Formation was introduced by Nanda and Singh (1976) to define the basal sedimentary sequence of Zaskar overlying the rocks of the Higher Himalayan Crystallines as an equivalent of the Haimantas (Griesbach 1891; Hayden 1904; Fuchs & Linner 1995). Srikantia et al. (1977) mapped the Spiti and Zaskar areas and Srikantia (1977) and Srikantia and Razdan (1981) designated the Haimanta System as the Haimanta Group and divided it into three regional formations, viz., Batal, Kunzum La, and Thango which are continuous from Spiti and Kinnaur to Zaskar. The stratigraphic nomenclature used in the present paper is mostly after Srikantia (1977) and Srikantia and Bhargava (2018). Lithologically it is composed of grey green phyllites, grey quartzites, siltstones, fine grained sandstones, and slates. The Batal Formation at Rangdum Gompa gets totally covered by Phe Volcanics and appears again near Sankoo in the Suru Valley. Due to the lack of any diagnostic fauna except some infrequent trace fossils, the age of this formation is only roughly assigned between Neoproterozoic and Early Cambrian (Parcha 1998).

Kunzam La Formation

In the Zanskar, the Kunzam La Formation is characterized by the appearance of thick dolomitic beds, thinly to thickly bedded brown weathered dolomite, limestone, green shale, and siltstone (Fig. 8F). In this formation, stromatolites are very common. The formation is well exposed in the Marling Nala section of Kurgiakh, Karsha, Purni, Kuru, Tanze, and in the Tsarap Chu areas. The formation is richly fossiliferous; it contains ichnofossils, trilobites, and brachiopods (Peng et al. 2009, Pandey and Parcha, 2018). Srikantia and Bhargava (2018) argued that the Karsha Formation of Nanda and Singh (1976) and Kurgiakh Formation of Garzanti et al. (1986) are mappable only in small part of the Zanskar. It has been assigned the age from Lower to early Late Cambrian (Parcha 2004, 2008). The Kunzam La Formation is intruded by dolerite dykes and Gumbok Ranjan granites at places in the Zanskar Valley. (Fig. 8G)

Thango Formation

Nanda and Singh (1976) used the term Thaple for the rocks resting above the “Ordovician Karsha Formation” and below the “Kenlung Formation” (Muth Formation) in Zanskar, but it lacks details and did not include conglomerate which is characteristic of the sequence. Hence, the name Thango Formation was suggested by Srikantia and Bhargava (2018) which is adopted in the present classification. It is a regionally mappable formation present in Spiti, Kinnaur, and Zanskar. Lithologically, it is composed of red-brown sandstones alternating with conglomerates, bedded purple quartzite (Fig. 8H). The Thango Formation has not yielded any significant fossils in Zanskar except poorly preserved fragments of brachiopods and crinoids (Parcha 2021). The Volcanics is not associated with this formation. Parcha (2021) has compiled and revised the stratigraphy of the Zanskar region (Table 1).

Gumbok Ranjan Granite

It is exposed in the Gumboranj massif between the Kurgiakh Chu and the Rile Nadi in the southeastern part of Zanskar. The granite is intrusive into the Batal and the Kunzam La formations. It is a leucogranite and represents a significant Lower Palaeozoic granite intrusion in the Tethyan belt of the Higher Himalaya (Parcha 2021 (Fig. 8G).

Takche Formation

It is nicely exposed in the upper Lingti Valley in Zanskar. Lithologically, it comprises of brown weathered ferruginous calcarenite. This formation crops out intermittently as has been observed near Chumik Marpo in the Upper Lingti

Valley where it is represented by brown weathered ferruginous calcarenite with corals, crinoids, and fragmentary brachiopods. It has been assigned Late Ordovician to Early Silurian age (Parcha, 2021).

Muth Quartzite

The Muth Formation is a noticeable lithostratigraphic unit which occurs between the Takche Formation and the Lipak Formation. Lithologically, it comprises of pure white quartzarenite with thin layers of sandstone (Parcha, 2021). The Muth Quartzite in Zanskar area has not yielded any fossils. The best section in the Zanskar is the Tangze-Kogma where it is well exposed.

Lilang Group

The Lilang Group comprises of a uniform succession of limestone, dolomite, and shale that are characteristic of Triassic of the northwestern Himalaya. It has been divided into four formations, viz., the Tamba Kurkur Formation, the Hanse Formation, the Zozar Formation, and the Quartzites Series

Kioto Limestone

This formation is exposed from Rangdom Gompa to the Tanze area. Lithologically, it consists of packstones and wackestones intercalated with marls. The top of this formation is characterized by minor dolomitization and small borings.

Ferruginous Oolite Formation

The contact with the underlying Kioto Limestone is sharp and unconformable. The formation is exposed from Rangdom Gompa to Tantak. It comprises of yellowish-brown ferruginous carbonate sediments. The Ferruginous Formation is overlain with sharp contact by the Spiti Shale. Based on the ammonite, crinoid, and gastropod fauna, late Middle Jurassic age was suggested to this formation.

Spiti Shale Formation

This formation is exposed in the Rangdom Gompa and in Zangla area of Zanskar. Lithostratigraphically this formation comprises of intercalated marls and calcareous quartzose siltstone. Sandstones rich in belemnites are recorded. In Zangla area, the boundary with the Giumal Sandstone Formation is transitional but well exposed.

Giurnal Sandstone Formation

This formation is exposed in Dibbling, Zangla, and in Rangdom Gompa to Tantak area of Zaskar basin. Besides this, the other formational units present in this region are Chikim, Fatu La, Kangi La, Spanboth, and Chulung La Formation (Parcha, 2021), (Table.1).

Zaskar GHS-5 Moraines at Tangol Village–Suru Valley

From the village Panikhar to the upstream side, two generations of lateral moraines on the southern flank (HHC) are well preserved. The older moraine which are covered with shrubs and grasses laterally extend down to the Suru River and are incised by a glacially fed stream (Fig.9A). The younger moraines have a sharp crested ridge and are barren in terms of vegetation and with fresh appearance and terminates ~1000 m above the older moraine with a crudely developed curvilinear ridge (latero-frontal moraine) (Fig. 9A). Presently, the accumulation area of the glacier is very small and is backed by a sharp headwall. The ablation zone of the glacier is riddled with crevasses (Parcha et al., 2015).

Zaskar GHS-6 Parkachik Glacier–Suru Valley

Near Parkachik village, a glacier descends down from the north facing slope into the Suru River (Fig. 9B, C). This is the only place in entire western Himalaya where one can reach to the glacier snout by road (Fig.9C). The catchment area of the glacier is located in Nun Kun massif. The over steepened ablation zone of the glacier is covered with transverse and linear crevasses. The glacier is confined by two sharp eastern and western ridges, through which the glacier is squeezed and it expands as it is unconfined in the lower reaches (towards the Suru River). The snout of the glaciers is followed by few lakes which are dammed by the recent lateral moraine suggesting that the glacier receded in recent times (Fig. 9B, C) (Parcha et al. 2015).

Three generations of lateral moraines are observed flanking the present day glacier. The oldest lateral moraine is named as Parkachik Glacial Stage-I (PGS-I) and is preserved only on the right flank (towards the west) and has subrounded crest, covered with grasses (Fig. 9B, C) (Sharma S. et al. 2018). The second glacial stage (PGS-II) is represented by ~300 m long, ~50 m thick, paired, sharp crested lateral moraine ridges separated by ~400m wide ablation zone of the glacier. The moraines are relatively fresh and devoid of appreciable vegetation (Fig. 9B, C). PGS-III is proximal to the modern glacier which probably represents the neoglacial stage (Parcha et al. 2015).

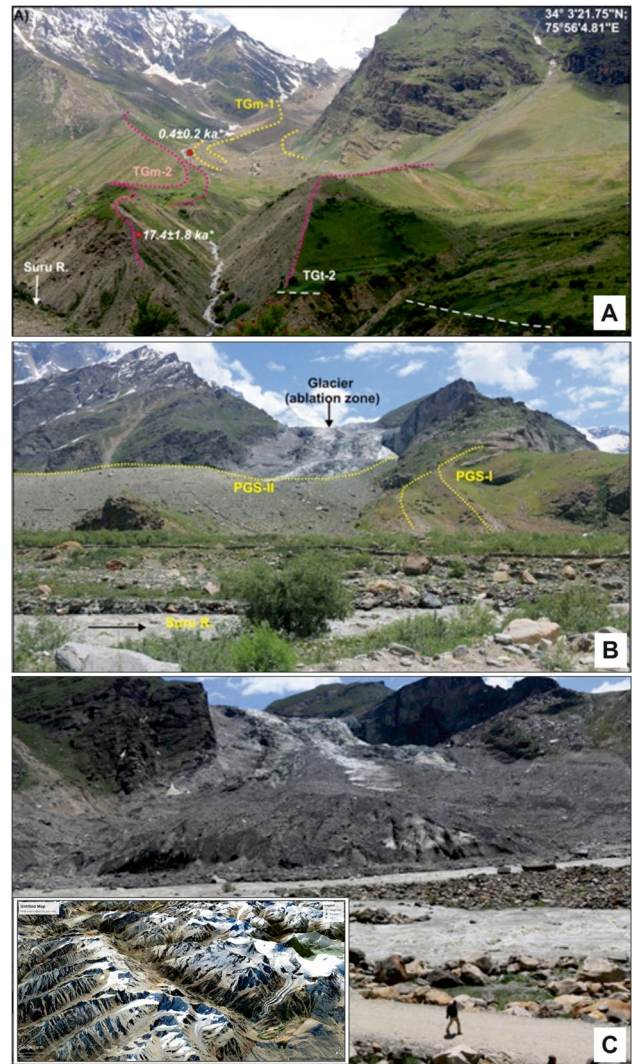


Fig. 9 **A** A view of two generations of lateral moraines on the southern flank (HHC). The older moraine is covered with shrubs and grasses and laterally extends down to the Suru River where they are incised by a glacially fed stream. Note the younger moraine has a sharp crested ridge and is barren with more fresh appearance while the older moraine has crudely developed curvilinear ridge. **B** A view of Parkachik Glacier with three generations of lateral moraines indicating three glacial stages (PGS-I, PSG-II, and PSG-III). Note the older one is vegetated and the younger one is barren and sharp. The PGS-III is proximal to the modern glacier which probably represents the Neoglacial stage. **C** The snout of Parkachik Glacier is seen very close to the road. Notice the frontal moraines near the snout. The inset Google view shows the accumulation zone of the same glacier (see arrow); also note the Shankoo valley in which the glacier enters. This is the most approachable glacier in entire Himalayan range

Zaskar GHS-7 Rangdum

Rangdum geosite is a significant location for the geological and geomorphological studies in Zaskar Himalaya because it is where one can see the contact between the HHC (Sankoo and Sangra Formations) and Panjal Traps;

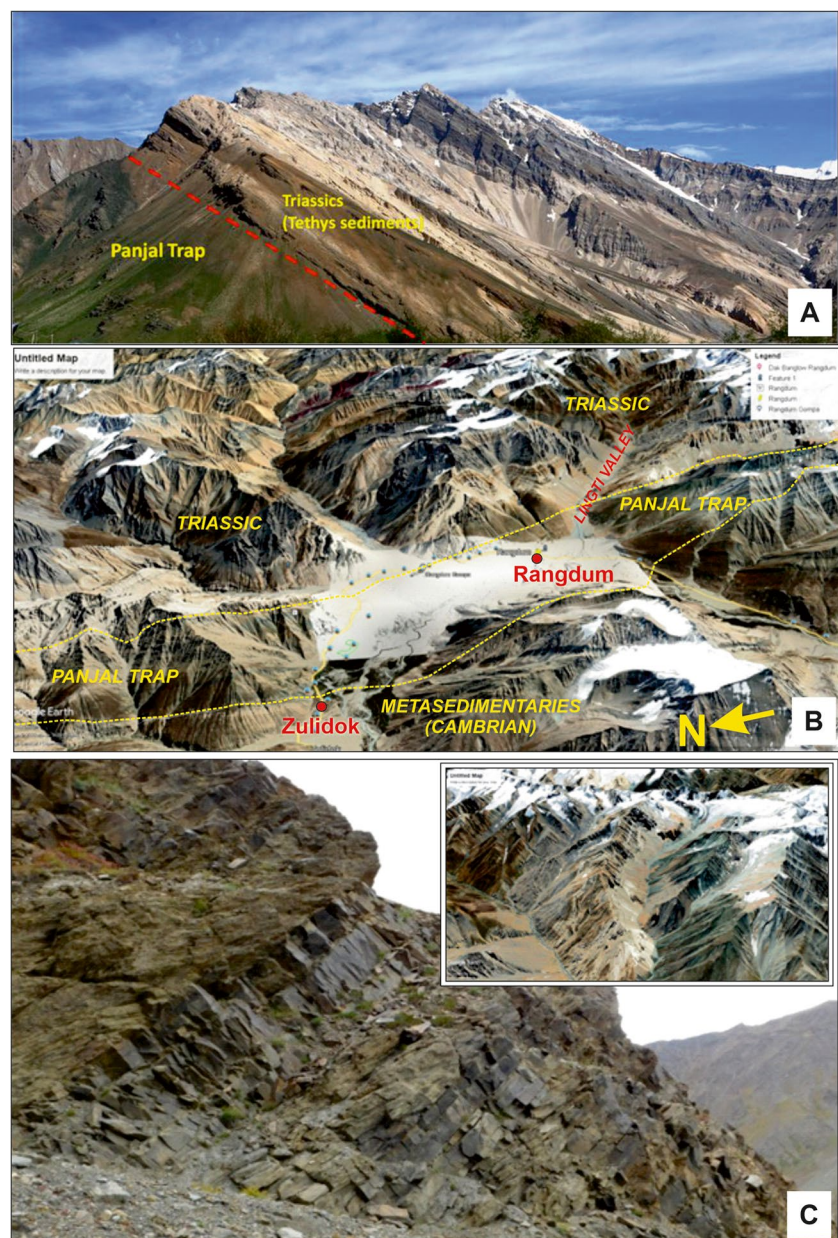
furthermore, the trap is overlain by the Tethys Triassic sequence. The spectacular contact is seen from the distance facing the large “U”-shaped Valley of Sankoo River having discernible records of the last glaciation epoch (discussed later). The N-S valley of Zolidiak from Rangdum village (and Rangdum Gompa) exposes innumerable varieties of gems preserved in the crystalline rocks of HCC. Each site at Rangdum is explained as a separate geotope.

Rangdum Geotope–7a: Panjal Trap

The Panjal Trap/Phe Volcanics appear continuously from the Gurloke Nala of the Lingti Valley in the southeast to Zolidiak (Zulidok) in Rangdum Gompa area to the northwest

(Fig. 10A, B, C). The flows of volcanics appear without much time lag, as the top of the individual flow surface are without any sign of erosion. The Panjal Trap constitutes a noticeable lithological unit laterally throughout the southern escarpment face of the Zanskar Mountains flanking northern part of Lingti, the Phise, the Kurgiakh, the Doda, and the upper reaches of Suru River (Fig. 4B). However, from Karsha and Padam to Tanze, they lie upon the Karsha Formation. It has been observed by various workers that from Zanskar to Lahaul, the Panjal Traps are overlain by the Kuling Formation (Dèzes 1999; Gaetani et al. 1990). On the basis of their stratigraphical position between the Chumik and Kuling formations, Gaetani et al. (1990) assign them to Early Permian age.

Fig. 10 **A** A view of a conspicuous P/T (Permian–Triassic) boundary seen ~3 km from Rangdum village; notice the dark colored Panjal Volcanics are overlain by buff colored Triassic limestones and quartzites. **B** Google view of Rangdum, Zulidok, and to the SE of it the Gurloke Nala and Lingti valley where dark green colored Panjal Volcanics are exposed while light colored Triassic are overlaying it. Between two yellow lines are the traps. **C** Close view of Panjal Traps which is overlain by the Triassic. See the inset Google view where two formations are very clear



Around Rangdum Gompa, the Panjal Trap is overlain by alternating greenish grey schistose limestone, schist, and black phyllites exhibiting brown weathering (Fuchs, 1979). Fuchs (1982) noticed that in the Rangdum Gompa, the light to dark green schistose trap shows sporadic amygdaloids and greenish chloritic phyllites alternate with the trap (Fig. 10C). Honegger (1983) stated that the Panjal Traps are mainly silica-saturated or nepheline normative basalts belonging to the tholeiitic and alkaline series. They show extensive growth of secondary minerals and widespread overprinting by metamorphic paragenesis, with south eastward decreasing grade, from medium low grade green schist facies in Rangdum Gompa area.

Rangdum Geotope–7b: Permian–Triassic Boundary

Three kilometers from Rangdum village a distinct contact between dark colored Panjal volcanics and buff colored Triassic limestones and quartzites are seen from the distance (Fig. 10A). This exposed contact runs for several kilometers in Zanskar range; it extends till Zanskar valley near Stongde Gompa and traceable up to Zanskar Valley. The site is a dear destination for stratigraphers and those studying the Mesozoic biostratigraphy of Himalaya.

Rangdum Geotope–7c: Mineral-Rich Crystalline

The crystallines exposed near Rangdum and also near the Dolma point at Pensi La are the homes of numerous precious to semi-precious stones/ minerals. Communicating with the locals, we come to know that rubies, emeralds, and other precious gem minerals are found deep into the valleys. The HHC and the Precambrian are also traversed by the leucogranites which are the best formations of such precious minerals.

Geoheritage Sites on Pensi La to Zangla Route

Going from Pensi La to Padam, we are driving through the Doda valley where we come across some isolated villages with meager population; they are, viz., Akshu, Abran, Hamling, Remla Kaisam, Phey, Ating, Tungri, and Su (Fig. 11A). The rocks exposed are crystallines and metasedimentaries all along the valley. The SW side is the Great Himalayan Range composed mainly of the gneisses and schists of the HHC (Fig. 11B); the snow clad peaks are the origins of numbers of glaciers including Drang-Drung (Drung Drang) and Barnaj Li (clearly visible from the air traverse). The distant hills to the NE side of the Doda valley is garlanded by the sharp peaks containing highly contorted and folded limestones and quartzites of Tethys Himalaya mostly Mesozoic,

which are further exposed from Padam to Zangla route in Zanskar valley.

Zanskar GHS–8 Dolma Point—Precambrian to Quaternary Events

The Dolma point (from the name of a local women, found here staying in an ugly, stinking rock dwelling “Dogcha”) or the base of Drang-Drung Glacier is an important location as far as the Precambrian stratigraphy, regional tectonics, and Quaternary glaciations history are concerned (Parcha et al. 2015).

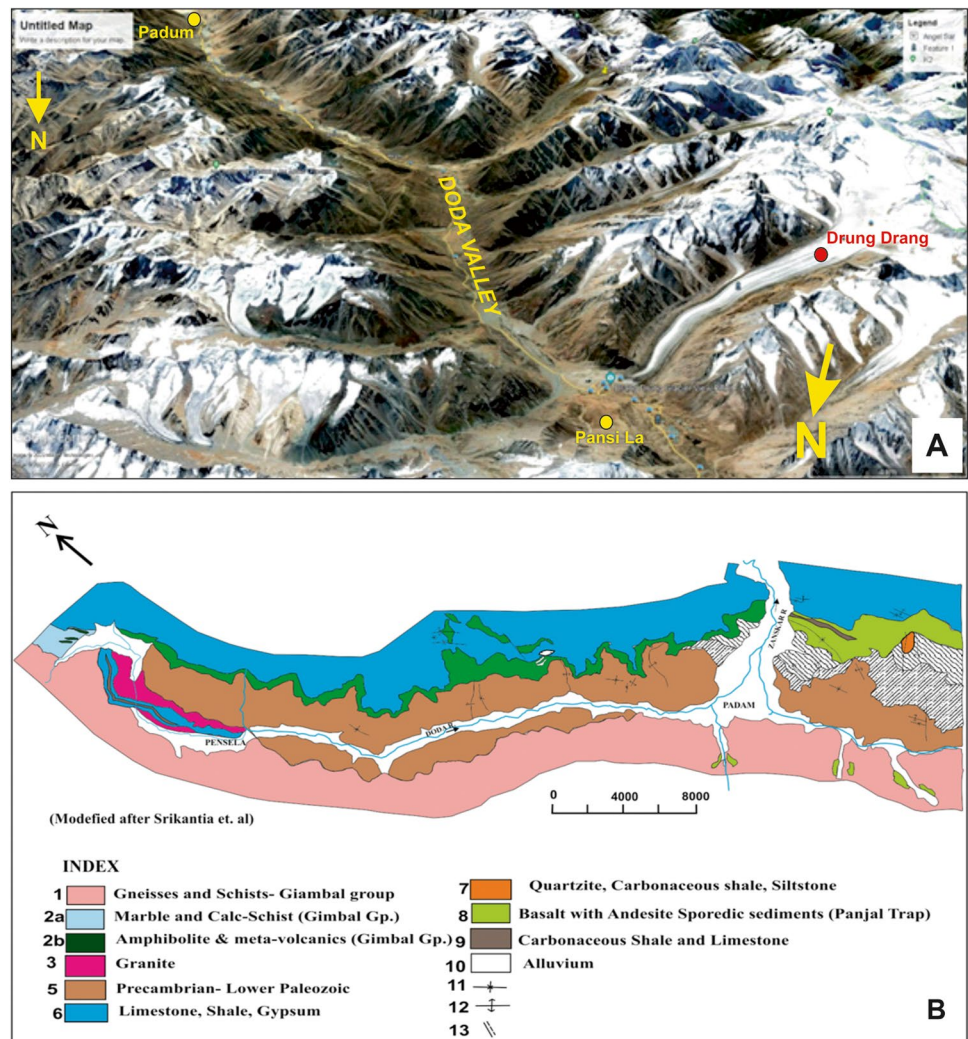
Dolma Geotope–8a Crystallines, Leucogranites, and Volcanics

Sangra Formation of HHC is exposed here with numerous inclusions and crisscrossing veins equivalent to the leucogranite. There are bands of amphibolites with concordant sheets of mica granite exposed south of the STDS. Near Pensi-La the Sankoo crystallines are tectonically overlain by the Phe Volcanics and Zolidiak limestone of the Zanskar Tethyan sequence. The crystallines here are identified by the pygmatic folding, highly sheared and folded gneisses with two major deformation episodes (D_1 and D_2). The metamorphic episode here is post- D_1 and pre- D_2 tectonic deformation. Leucogranite bodies are emplaced during post D_1 and pre- D_2 time. At many places, biotite flakes are aligned along the crenulation cleavage that is syn- D_2 and rotated garnet porphyroblasts are also of syn- D_2 . Appearance of chlorite and muscovite indicates retrograde metamorphism which is interpreted to have taken place during D_3 deformation.

Dolma Geotope–8b Drang-Drung Glacier–Pensi La

A trail of hummocky moraines around Pensi La (highest pass: ~14000 feet) can be seen in the Google image (Fig. 12A). The STDS passes through the Pensi La. A patch of degraded relict lake deposit dominated by varves and rythmites preserved at the highest elevation. In addition to this, few active lakes (kettle holes) are nested between the moraine depressions pointed by the yellow arrows in Fig. 12A. North trending Drang-Drung Glacier is the major glacier which terminates immediately below the Pensi La. This glacier has catchment in the southern Higher Himalaya (Fig. 12A, D). The ablation zone is riddled with linear and transverse crevasses with few small proglacial lakes in front of the snout (Fig. 12A). Contemporaneous lateral moraine probably emanates from the equilibrium line altitude (ELA) and runs parallel to the glacier which is dissected by the debris avalanche. Morphology of the glacier suggests that the accumulation area is fed by east and west valleys, meeting at the center of east-west trending ridge, following which

Fig. 11 **A** The Google 3D view of the route between Pensi-La to Padam showing Doda valley where the longest valley glacier of Zanskar, Drang Drung joins to Doda at Pensi-La; the zone of accumulation is seen in the Higher Himalayan range. **B** A Geological map from Pensi-La to Padam route. Note the water divide at Pensi-La where Doda River originates and flows down to Zanskar River at Padam. The river cuts the Precambrian and Cambrian rock units on the way (Modified after Srikantia et al. 1980)



the glacier flow towards the north. After some distance, it takes slightly westward turn in the middle, whereas in the vicinity of the snout, the flow direction is towards the north-east (Fig. 12A).

Dolma Geotope–8c Drang-Drung Glacier Landforms

This is probably the most ideal place for glacial landform study in entire Himalayan region. Five generations of lateral moraines can be discerned here below the snout of the glacier (Fig. 13A). The oldest moraine at ~4000 m occurs as multiple hummocky mounds located preferentially on the western side towards Suru Valley (near Pensi La). The remaining four lateral moraine ridges are preserved in the eastern side below Pensi La in the Ahram River (Doda River). Present day flow of the glacial melt is towards the east. Presence of moraines on Pensi La top suggests that Drang-Drung Glacier once flowed towards the west into the Suru Valley. Following this, there seems to be rapid recession of the glacier (vertical thinning

exceeded the lateral shrinking) due to which the melt water streams during the recessional phase were unable to cut through the oldest moraine. The moraine in fact acted as a barrier and thus, forced the glacier to deflect eastward into the Abran river valley. The presence of outwash terraces with that of the deglaciations can be inferred that the valley witnessed at least four events of glaciation with decreasing magnitude. The alluvial fans and scree aprons are the youngest events which postdate the valley-fill deposits (Fig. 13A).

Zanskar GHS–9 Akshu

Contrary to the earlier place (Drang Drung), the active glacier snout is ~8 km away from the Doda valley near Akshu. Some remnants of the lateral moraines are overprinted by the glacial outwash or younger fluvial terraces, and hill slope scree deposits near the confluence and a few km inside the tributary valley (Fig. 13B, C). The valley further upstream ends at the “Barnaj Li” and



Fig. 12 **A** A Google view of Drang-Drung Glacier to show its present day trend towards the Doda valley, while the older moraines are preserved opposite side of Pensi-La where numerous relict lakes are seen within the moraines (see arrow). **B** A view of relict lake within the older moraines to the north of Pensi-La—see the arrow in upper figure. **C** A view of ablation zone with linear and transverse crevasses; the older moraines are in the foreground. **D** A spectacular view of Drang-Drung Glacier. Note the proglacial lakes in front of the snout

“Hagshu” massifs that generate four large valley glaciers making significant glacier field depicted in the Google images as well as the pictures taken from the flight over it (Fig. 13B, C).

Zanskar GHS–10 Karsha Gompa–PC and Cambrian Stromatolites (Padum)

Conspicuous exposures of dolomites containing trace fossils of trilobites occur at Karsha village near Padum (=Padam) town of Zanskar valley (Fig. 14A). The Karsha Formation overlies the Phe Formation and is dominated by sandstone, siltstone, and dolomite (Fig. 4A). Planar/



Fig. 13 **A** A view of five generations of lateral moraines below the snout of the Drang-Drung Glacier. The oldest moraine at ~4000 m occurs as multiple hummocky mounds located on the western side towards Suru Valley. The remaining 4 lateral moraine ridges are seen towards the Doda River. **B** The Google view of another glacier where the snout is ~8 km away from the Doda valley. Note the massif of “Barnaj Li” and “Hagshu” generates four large valley glaciers making significant glacier field. **C** A view of some remnants of the lateral moraines overprinted by the glacial outwash or younger fluvial terraces, and hill slope scree deposits near the confluence of a tributary valley and Doda River.

hemispheroidal stromatolites are commonly found near the Karsha Gompa. The Karsha Formation divided into two members, namely the Mauling Member and the Thidisi Member (Nanda and Singh, 1977). At the bottom and top of this member, large stromatolites are present suggesting prevalence of sub-tidal environment with low terrigenous influx during the deposition of Thidisi Member. On the basis of the occurrence of trilobites, the age is assigned as Middle Cambrian to the Karsha Formation.

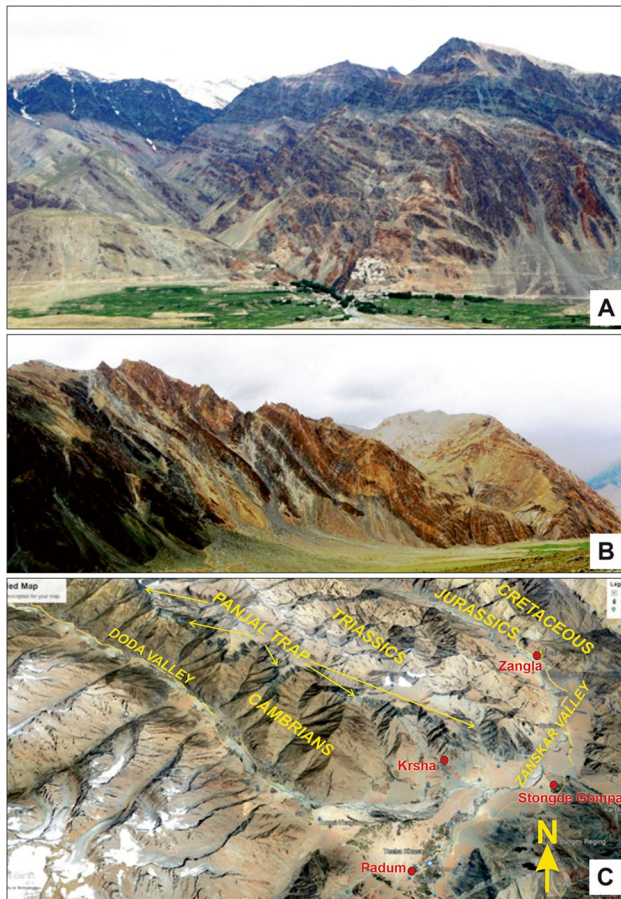


Fig. 14 **A** Sedimentary successions of Phe and Karsha Formations exposed near Karsha village along the Zangkar River. The Phe is Neoproterozoic to Cambrian, while the Karsha is Cambrian forming the basement of the Tethys Geosyncline. **B** The Panjal traps are seen to be overlain by the Triassic limestones with overturn, isoclinal recumbent, box, and chevron folds near the village Stongdey. **C** A Google view showing the route from Stongde Gomba (Padam) to Zangla along the River Zangkar, Cambrian, Permian, Triassic, Jurassic, and Cretaceous sequences is exposed with numerous folds in Mesozoic.

Zangkar GHS–11 Stongde Gomba–Zangla (The Triassic Field Museum of Structures)

In a traverse from Stongde Gomba (Padum) to Zangla along the River Zangkar, near the village Stongdey, the Panjal Traps are seen to be overlain by the Triassic limestones with overturn, isoclinal recumbent, box, and chevron folds (Fig. 14B). The Zangla sequence spans from Permian to Eocene (?). The sequence overlies the Panjal Traps conformably, followed by Late Permian Kuling Formation to the Cretaceous in eastern Zangkar.

Zangkar Geotope–11a Phe Volcanics/ Panjal Trap

The belt of basic volcanic rocks in Zangkar valley has been designated as the Phe Volcanics after the name of the

stream which flows across this belt. The term Panjal Trap is used to designate this thick sequence of basaltic rock within the Tethyan sediments. The volcanic rocks are also observed at Rangdum and Stongdey Gompas (Fig. 14B, C).

Zangkar Geotope–11b Structural Field Museum of Triassic

Thick sequences of intensely folded limestone of Triassic age are exposed both the sides of the Zangla valley (Fig. 15A). Late Permian Kuling formation is found near Stongde Gomba in this valley. In this section, we can see huge limestone sequence of Tamba Kurkur Formation which represents the basal formation of the Lilang Group; it can be divided into three members (Srikantia et al. 1980). The lower member is composed of thinly bedded, slightly nodular limestone followed by intercalations of shales. Joshi and Arora (1976) reported ammonites, bivalves, and conodonts. Among these *Otoceras*, *Ophiceras*, *Meekoceras* are most important. Based on conodonts, Lower Triassic age has been assigned to this member. A few kilometers further downstream in the Zangkar valley, the second member exposes as massive thickly bedded nodular limestone. The Lower and Middle Triassic boundary can be marked within this member without any marked lithological changes. The upper member of the Tamba Kurkur is characterized by bedded limestone which is grey, greyish black, and greyish blue in color with upward increasing shaly intercalations. According to Gaetani et al. (1986) and Vannay (1993), this formation represents marine pelagic sedimentation in outer shelf with low sedimentation rates. The younger Triassic quartzites are seen exposed significantly here between Stongde and Zangla (Fig. 15B). The name Quartzite Series was first defined by Hayden (1904) for distinct white and brown quartzites intercalated with limestone and shales. Baud (1984) and Gaetani et al. (1986) has used this name in Zangkar to designate the whole succession of sediments between Zozar and Kioto Formation. The unit is continuous throughout western Zangkar. This sequence contains white to green, mostly fine and very fine grained, very well to moderately sorted, sub-angular to sub-rounded, and immature to super mature sandstones; they are mostly subarkose, cemented by either quartz, chlorite, alkali-feldspars, or calcite making the base of Kioto Limestone. In the topmost part, beds are very rich in belemnites crop out at the Zangla fortress (Parcha et al., 2015).

Zangkar Geotope–11c Jurassic and Cretaceous of Zangla

As we advance in the valley, near Zangla village, the folded sequence of limestone and quartzite of Triassic age are found

Fig. 15 **A** A view of intensely folded Triassic limestone sequence overlying the Panjal Traps at Stongdey Gonpa on way to Zangla from Padam in the Zaskar valley. **B** The younger Triassic Quartzites are seen exposed significantly between Stongde and Zangla. **C** A view of massive gray to black Jurassic Kioto limestone having small ammonites and belemnites found near Zangla village. **D** A spectacular view of Cretaceous Giumal Sandstone overlying the Kioto at Zangla. The erosion makes spectacular gorges and conical hills. **E** A view of Phugtal Monastery/Gompa. Note that it is actually made in a rock cut cave: Here “Phugtal” means “cave” in the local language



to be overlain by thick grey limestone (Fig. 15C). The Spiti Shale also crops out at Zangla area and is traced till the Rangdom Gompa (Stoliczka, 1866). It consists of splintery shales with nodules and arenaceous intercalations. Here the lower beds are full of belemnites. The depositional environment of the Spiti Shale was pelagic with anoxic conditions at the bottom. Baud et al. (1984) have assigned earliest Cretaceous age to the unit.

Zaskar Geotope–11d Phugtal Gompa (Padum-Phuktul Crystallines and Panjal Traps)

The name Phugtal means cave in the local language. Phugtal Monastery/Gompa is located in the remote Lungnak Valley in south-eastern Zaskar, and is amongst the top attractions in Zaskar. The Gompa has a remarkable rock cover with rock-cut caves (Fig. 15E). The monastery is made up of mud and wood. To reach Phugtal monastery, it is a 1-day trek from the village of Cha or Khangsaar

in Zaskar. The view from the monastery is also something to relish; one can enjoy the panoramic views of the meandering Lungnak River and the entire valley. The major attraction of Phugtal Gompa is its caves which are believed to have been visited by many sages and scholars. The people believe that these caves existed for more than 2550 years. The Phe Volcanics (Panjal Traps) belt constitutes a very noticeable lithological unit here in Zaskar valley too (Fig. 14C). As these rocks are unfossiliferous, it is their stratigraphical position between the Chumik and Kuling formations which led Gaetani et al. (1990) to assign them to (Upper Sakmarian to Djulfian) Early Permian age.

In the Zangla section, a conspicuous exposure of the sandstone, stratigraphically found resting over the Kioto known as Giumal Sandstone forming spectacular gorges and conical hills due to peculiar weathering (Fig. 15D). It extends till Rangdom Gompa area and consists of grey to green, often burrowed, locally cross or graded-bedded,

very fine to fine grained, moderately to well-sorted, sub-angular to sub-rounded sandstones, and intercalated layers of black shales. They are followed by the Chikkim Limestone with a very sharp boundary. The formation is bracketed between two pelagic, bathyal units. Gaetani et al. (1983) studied the Zangla Unit and suggested Upper Cretaceous and Paleocene/Eocene age to this unit.

Air Traverse from Leh to the Foothill of Lesser Himalaya

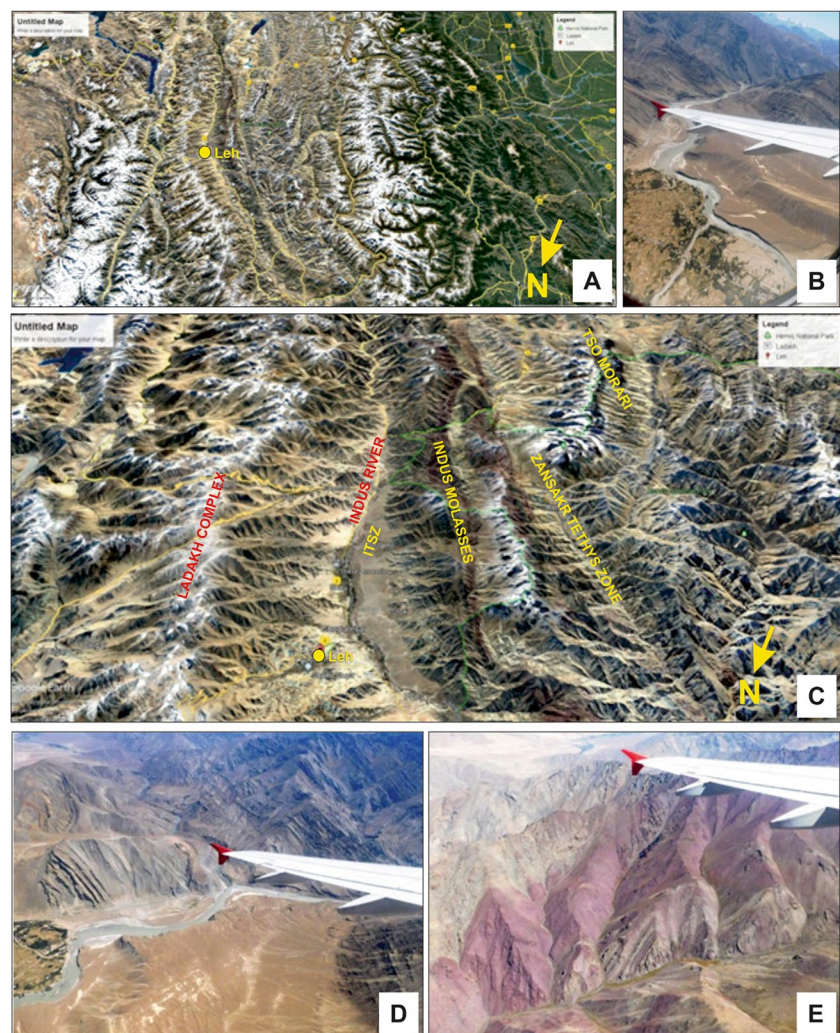
Flying over the Himalayan terrain certainly is a charm for the Earth scientists especially in the areas of cold desert like Ladakh and Zaskar where there is hardly any vegetation; hence, the rock units are bare, exposed in their fullest with characteristic structures of each rock unit. We have made a tour using Google earth as well as flew (in aircraft) over the Leh town and proceed towards south across the Ladakh complex, Indus suture zone, Tethys Himalaya, Tso Morari Complex, Great Himalayan Range, and Kishtwar range of southern Kashmir Himalaya (Fig. 16A). We identified the regional units with their very characteristics (geomorphological and geological) seen as bird eye view from the sky taking into account regional geology of the great collision zone of the world. It is found that some of the ideal regional features which cannot be identified and envisaged on the ground are apparent and discernible from the 2–5 km of height. The glaciers of the Zaskar Range and the Great Himalayan range are incredibly palpable and can be an intensive tool for the study on glacial topography and its formation in Himalaya.

Tethys Himalaya, Tso Morari Complex, Great Himalayan Range, and Kishtwar range of southern Kashmir Himalaya (Fig. 16A). We identified the regional units with their very characteristics (geomorphological and geological) seen as bird eye view from the sky taking into account regional geology of the great collision zone of the world. It is found that some of the ideal regional features which cannot be identified and envisaged on the ground are apparent and discernible from the 2–5 km of height. The glaciers of the Zaskar Range and the Great Himalayan range are incredibly palpable and can be an intensive tool for the study on glacial topography and its formation in Himalaya.

Aerial Geoheritage View: 12–ITSZ and ZTZ

The Google image given in Figure 16A, C exposes Indus Tsangpo suture zone (ITSZ) along the Indus River with Ladakh granites at one side and Nindam, Indus, and Hemis Formations of the Tertiary age as molasses and

Fig. 16 **A** A Google view of Leh town and surrounding areas—Indus suture clearly divides the Ladakh complex to the NE with the Tethys Himalaya, Tso Morari Complex, Great Himalayan Range to the SW. See the Kishtwar range of southern Kashmir Himalaya so the SW (right side of the view). **B** A view from the flight window shows the Indus River with Quaternary terrace in the foreground while Indus molasses to the SW side of the river and Ladakh crystallines to the other side. **C** A close Google view distinctly separates 20-km-thick Indus molasses and flysch deposits having dark red and maroon color while the Tethys sequence of Mesozoic (Zaskar) are seen to the SW with distinct dip of the strata. The Tso Morari complex is also discernible as wedge shaped exposure to the upper part of the snap. **D, E** The photos taken from the airplane shows the Indus River with two distinct formations (Ladakh igneous complex and Indus molasses) and young terraces. Pink color in **E** is shale and mudstones belong to Indus molasses



flysch deposits at other side (Fig. 4B). They are flanked by the Zaskar Tethys sediments (ZTZ) (Mesozoic) and Tso Morari Crystallines to the southwest side (Fig. 16A; Fig. 4B). The flight view over the Indus River shows two distinct formations and young terraces (Fig. 16D) while the other view, (Fig. 16E) a few km away (SW) from it facing pink colored shales, mudstones and sandstones belong to Indus molasses. Northward drift of India led to the subduction of its oceanic crust under the Asian Plate in the beginning of the Late Cretaceous. It resulted in formation of several volcanic and volcano–sedimentary domains including the Nindam forearc basin in the ITSZ in which the Late Cretaceous–Early Eocene Nindam Formation was deposited. The subduction also resulted in formation of a shallow linear basin (Indus Basin) in which the flyschoid Indus Formation (?Paleocene–Early Eocene) and the overlying molassic Hemis Formation (Middle–Late Eocene) were deposited (Mathur et al., 2009; Thakur and Mishra, 1984, Thakur, 1983).

Aerial Geoheritage View: 13–Glacier Field of Zaskar

Further 30 to 50 km SW, a Google view (Fig. 17A) and an aerial view (Fig. 17B) of Zaskar glacier field are discernible with numbers of valley glaciers having variable lengths. Figure 17A shows the glaciers on the Tso Morari complex with the series of peaks (~6000m) known as Kang Yisay. A few km further to the SW direction flying almost parallel to the Doda valley, an exceptionally large glacial field is visible with ideal view of four valley glaciers with their terminal moraines meet to form a large valley and made medial and terminal/marginal moraines (Fig. 17C, D). These glaciers are originating from the massifs of “Barnaj Li” and “Hangsu” and going further down to meet Doda valley near Akshu village (Fig. 13B, C). Further to the south, seen is the panorama of lesser Himalaya of Kishtwar/ Kashmir with immensely dense vegetation and humidity as fluffy clouds over it (Fig. 17E). The obvious change of climate in a flight of just 30 min is unequivocally impressive way of practical study while traveling through such routes.

Fig. 17 **A** Google view of Zaskar glacier field with numbers of valley glaciers on the Tso Morari complex with the series of peaks (~6000m Kang Yisay). **B** A picture taken from the flight similar to that in “A—Google view.” **C** Flight view from a few km further to the SW direction over the Doda valley, an exceptionally large glacial field is visible with ideal view of four valley glaciers originating from the massifs of “Barnaj Li” and “Hagshu” (see Fig. 13B). **D** The flight view of these glaciers showing lateral moraines meet to form a large valley and made medial and terminal/marginal moraines. This finally joins to Doda valley at Akshu. **E** A flight picture further southwest showing highly vegetated mountains of lesser Himalaya of Kishtwar/Kashmir with fluffy clouds over it



The Life Through Zanskar

Tiger Hill and Kargil War Memorial

The beginning of the Zanskar Range from Zoji-La Pass not only geologically but strategically also is an interesting location for its strenuous terrain running parallel to the Line of Control (LOC), the border between India and POK—Pakistan Occupied Kashmir. In the winter of 1998–1999, the Pakistani Army crossed the LOC and occupied numerous heights in Indian Territory. They dominated the National Highway from Kargil to Srinagar and to Leh. The Indian Army launched Operation Vijay (“Victory”) in May 1999 to retake the territory, leading to fierce battles (the Kargil War) in the harsh terrain. The operation continued for over 2 months, leading to a crushing defeat for Pakistan army. In the memory of those soldiers (> 800) lost their lives, every year 26 July is observed as Kargil Victory Day and the Indian PM pays tribute to them at Amar Jawan Jyoti at Delhi. The memorial in its present form at Dras was constructed by the Indian Army in November 2014. The Tololing Heights, Tiger Hill, and Point 4875 (Batra Top) are visible from here where fighting took place during the conflict (Fig. 18).

Apricot

Apricot, locally known as “chulli” in Ladakhi and “Khurmani” or “Khubani” in Kargil and Kashmir, was introduced to the arid region of Ladakh over a century ago by Chinese traders passing through the area via the Silk Route. Now, in the twenty-first century, the fruit has become an integral part of Ladakh’s culture, heritage, and economy (Fig. 19A). The uniquely tolerant and highly stable plant of apricot has embraced the sandy soil of the cold desert and made it one of the largest producers of apricot in India. There are four



Fig. 18 The memorial of Victory of Kargil war of 1999. The Tololing Heights, Tiger Hill, and Point 4875 (Batra Top) is visible where fighting took place during the conflict

main varieties of apricot that grow in Ladakh: Halman, Safaida, Lakste-karpo, and Khanteh. Evidence of the apricot’s essentiality to the Ladakhi culture can be found in its prevalence everywhere in their cuisine. Locals use fresh and dry apricot as a delicacy and offer it during religious ceremonies. It is used to add flavor to mutton dishes, and during winter when resources are scarce, dried apricot serves as an energy source for the enduring people (source: Wikipedia).

Marmot

A typical Ladakhi long tailed mouse known as Himalayan marmot (*Marmota himalayana*) is a large, sturdy rodent weighing up to 9 kg with 15 to 31 inch length inhabits alpine grasslands throughout Himalayas and the Tibetan Plateau (Fig. 19B). The

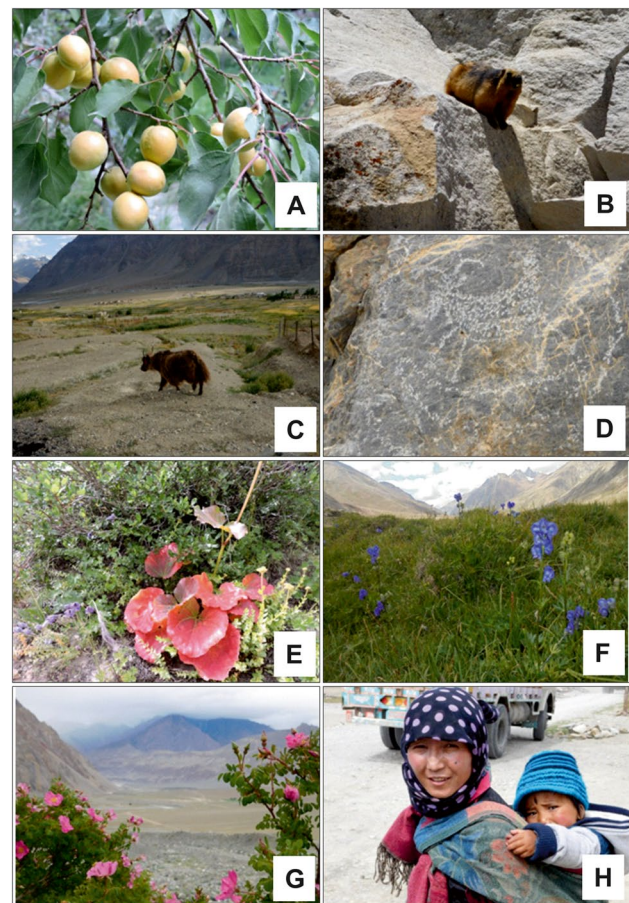


Fig. 19 **A** Apricot, locally known as “chulli” in Ladakhi, “Khurmani” in Kargil and Kashmir. It is an integral part of Ladakh’s culture, heritage, and economy. **B** A typical Ladakhi long tailed mouse known as Himalayan marmot. **C** Yak is “Tartary ox,” a species of long haired domesticated cattle found throughout Himalayan high altitude regions. **D** An interesting probably archaeological site near Zangla village where Kioto limestone is etched by the ancient people (?) depicting the local animals—mountain goat or ibis. **E, F, G** Typical flowers of Zanskar. **G** Atypical tribal people of Zanskar valley

golden-colored marmot found here are restricted to high altitude areas of higher Himalayan regions in China, Tibet, Pakistan, India, Afghanistan, and beyond the Pamir.

Yaks and Goats of Zanskar and Ladakh

Also known as the Tartary ox is a species of long-haired domesticated cattle found throughout Himalayan high altitude regions (Fig. 19C). *Bos grunniens* is the scientific name of this species. It is the backbone of the local village economy in Ladakh and Zanskar as it is used as a beast of burden to carry loads and to plough fields. The local people drink its milk and eat its meat. The Yak's thick hair is used to weave blankets and ropes while the dung provides fuel in the treeless areas of Zanskar, Ladakh, and Tibetan plateau (Wikipedia). Pashmina goats are the most important livestock of Ladakh. Wild goats, horses, and domestic sheep and goats are also found here.

Rock Painting/Etching

Near Zangla village along the Zanskar River, the Jurassic–Kioto limestone is found to be etched by the ancient people (?) depicting the local animals—mountain goat or ibis. Many such interesting figures are etched on these limestones showing the land was inhabited by the humans since ages (Fig. 19D).

Flora and Ethnology of Zanskar

The Zanskar and Ladakh Himalaya come under alpine and high alpine zones and are dominated by annual and perennial herbs, followed by few stunted shrubs and bushes. The vegetative growth starts at the commencement of summer when the melting snow provides abundant moisture. The flora is in full bloom in the month of August but starts disappearing by the end of September. The mountain slopes, meadows, and alpine pasturelands give a spectacular display of flowers of cold desert barren mountains. The region has been known for its rich medicinal plants since time immemorial and it has been a source for medicinal plants for most of the Asian traditional medical systems. The most commonly practiced traditional medicine of Trans-Himalayan regions of Indian cold desert is “Amchi system of medicine” (Tibetan Medicine) and the practitioners of this medicine are called Amchis (Superior of all).

The prolonged and freezing winter prevailing in cold arid zones forced local inhabitants to search for edible wild plants. Over the years of experience, perhaps by hit and trial methods, inhabitants of the area identified certain wild flora which are good enough to be used as vegetables. Generally tender shoots, leaves, stems, and underground parts of these plants are being used fresh or in dehydrated form. Besides, some of the wild edible plants are subjected to solar dehydration and stored as emergency vegetables for prolonged

winter. Flowers also symbolize purity, beauty, love, passion, and tranquility such as rose for love, pansy for thoughts, carnation (white) for women's love, French marigold for jealousy/sorrow, African marigold for vulgar mind, Narcissus for self-esteem, daffodil for regard, amaryllis for pride, iris for message, snapdragon for presumption, Jasmine for amiability, lily for purity, stock for luxury, and sweet pea for departure. Most of the cold desert flora of Ladakh Himalayas has been known for their attractive colors and aesthetic value. High alpine plant species like *Aquilegia* sp., *Delphinium* sp., *Juniperus* sp., *Meconopsis* sp., *Rosa* sp. (wild rose), and *Saussurea* sp. have tremendous importance in the religious places, gompas, and are used for various purposes on several occasions (Fig. 19E, F, G). In Ladakh, many tribal groups are present (Fig. 19H). These tribal groups are majorly represented by Boto (Buddhist), Dards, Balti, Brokpa, and Changpa which have attracted the attention of historians, anthropologists, sociologists, and ethnobotanists.

Conclusion

The geoheritage concept is not new to the world. As the developed countries exploited their geological resources or have preserved them for the future perspectives, they encouraged the low income group countries to explore and exploit more and more natural resources resulted into emptying of natural geological heritage of most countries excepting the front runners who made extensive geoparks, national parks, reserved ecological zones by imposing strict rules for their use, instead made the policies for importing from other countries. India being the exploding economy with the most populated country in the world, needs revenues for sustenance hence rarely thinks for sustainable mining as well as huge investments in making geoparks for the indirect and long term revenues. However, geologically and ecologically rich areas can be preserved for future generations and also for the world travelers to explore the untouched landscapes. The professional approach to the concept of geoparks, geoheritage sites, and geotopes is yet to cultivate in India.

As India owns all sorts of ideal geological formations in the peninsular part and within the 2500 km long youngest orogenic mountain chain, the features found here are undoubtedly the distinctive in the globe. The Tethys sediments started rising in early Paleogene concurrently with the deposition in the trench basin. The crystalline complexes of the Indian plate could not be subducted further at the original subduction boundary, instead the slabs thrust over the advancing Indian plate making several thrust zones and sheets. At the same time, the trench created at the suture zone squeezed to form Indus molasses and flysch deposits. All such ideal tectonic and lithological units of young displacements are seen all along the

Himalayan range. Most places like Kumaon, Garhwal, Nepal, and Sikkim become highly populated while the Zaskar Range of Kashmir Himalaya is relatively less disturbed by anthropological activities like urbanization, industrialization, etc. Reaching the valley itself is a challenge for the geologists because of the remoteness, not much logistics available, and extreme climates, therefore ideal for the geoscientists to study the features in its natural state. Looking to its uniqueness, our field and areal studies extracted the following points for the readers of the world.

1. Zaskar Range of Himalaya is an ideal and most natural, untouched (anthropological) geological site in entire Himalaya.
2. The molasses sequence of Kargil merits a text book sequence of shallow water and shallow shelf environments.
3. The crystallines of Suru and Shankoo valley are showing three major deformation episodes with the ideal sections of young/Tertiary Leucogranites. Innumerable gem variety minerals here make the site economically most important.
4. Rangdum Geoheritage site contains unique exposures of crystallines, metasedimentaries, Panjal Traps, and True Tethys sequence of Triassic and Jurassic folded rocks. It is also a home of the ideal preservation of erosional and depositional features of at least three glacial episodes including the LGM.
5. Parkachik glacier in Suru Valley merits one of the best places for the study of the moraines of various generations of glaciations and is close to the memorable road. Drang-Drung Glacier at Dolma point or at Pensi-La the highest pass in the region is the most conspicuous glacier seen near the road. It is an ideal place to study present day glacial features and past glaciations reflected by the stabilized moraines. Common and curious tourists always stop at this point for its beauty, but the common geological understandings at the site must be printed or distributed widely.
6. The new concept of airborne geoheritage study is introduced here especially for the Zaskar valley because the bare mountains are quite discernible with their full characteristics from the distance. The geomorphic study of the glaciers, climate change, receding of the glaciers etc. can be suggested out of this study.
7. Triassic fold museum at Stongde Gompa and Zangla is the most significant for the structural geologists and Geoscience students as they show almost all types of folds with the distance of almost 3 to 5 km.
8. The flora, fauna, ancient culture, ethnic variation, folk culture, and customs are still preserved in fullest, but with the proposed declaration of the Zaskar Geopark, all these features must be incorporated in a large umbrella.

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Author Contribution All the authors have participated in the field, generated data regarding the manuscript, and prepared all the figures and drafted the manuscript.

Declarations

Conflict of Interest There authors declare no competing interests.

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