Jour. Geol. Soc. India (2022) 98:903-910
https://doi.org/10.1007/s12594-022-2093-z

ORIGINAL ARTICLE

Geologic, Geomorphologic, and Climatic Preparatory Conditions for the Evolution of the Dangkhar Landslide, Himachal Pradesh, India

Markus Kaspar* and D. Scott Kieffer
Institute of Applied Geosciences, Graz University of Technology, Rechbauerstraße 12, 8010 Graz, Austria
***E-mail:** *markus.kaspar@tugraz.at*

Received: 10 May 2021 / Revised form Accepted: 2 March 2022

ABSTRACT

With an estimated volume of approximately 15 to 20 km³, the Dangkhar landslide located in the Spiti valley, Himachal Pradesh, India, is one of the largest landslides on earth. Its initiation is geochronologically constrained to have occurred during the late Pleistocene and may be related to glacial retreat following local last glacial maximum, which, depending on the source, occurred around 80 to 30 ka years ago. There is significant value in understanding the causative factors contributing to such an enormous and rare event. On the basis of comprehensive field studies and laboratory investigations, it is concluded that erosional, structural, and depositional features within and surroundings of the Dangkhar landslide are critical for understanding landslide initiation and its long-term behavior.

The landslide developed as a block slide along a synformal flexure, and through-cutting lateral valleys fulfill the kinematic conditions for creating a massive removable block of earth. Deposits of weakly cemented and crudely bedded carbonate breccias in the landslide's toe region represent depositional activity during recession of the main valley glacier, and cross-cutting structural relationships involving ground ruptures (lineaments) and rock glaciers in the head region record long-term, ongoing landslide deformations subsequent to its initiation. Stable isotope signatures of samples indicate presence of freshwater associated with the formation of breccia deposits.

While many details concerning the timing and development of the Dangkhar landslide remain unknown, recent studies illuminate some very important aspects. The glacial history of the Spiti valley combined with structural kinematics are clearly important factors concerning landslide development. Also important are constraints concerning the minimum age of landslide initiation after recession of a valley glacier, and structural evidence documenting long-term ongoing slope deformations.

INTRODUCTION

Glacial activity, associated morphological terrain modifications and sediment transportation are controlling factors in landscape evolution. Glacial recession and glacio-fluvial actions constitute long-term, continuous processes modifying valleys in alpine, glaciated settings. Associated remnants from changing environmental conditions are changed valley morphologies, talus accumulations, moraine and landslide sediments or the combination of the two (Ballantyne, 2002). The recently studied Dangkhar Landslide (Kaspar and Kieffer, 2015; Kaspar, 2020) is located in the Himalayan high mountain region in the Spiti valley and unifies sedimentological and structural characteristics indicating environmental changes and preparatory circumstances for landslide evolution. The Dangkhar Landslide exhibits cross cutting relations with erosional and depositional glacial features, terrace and lake sediments, allowing conclusions regarding its formation setting and activity. This study highlights some of the most prominent geological and geomorphological and sedimentological and environmental characteristics of the area which aid in understanding the formation of the Dangkhar landslide at this location.

REGIONAL SETTING

Geomorphology and Geology of the Spiti Valley

The approximately 150 km long Spiti valley located in the northwestern Indian Himalaya is a rugged, high mountain region with elevations from ~2400 to 6750m (Ameta, 1979). Geomorphologically, the Spiti valley can be divided into upper and lower reaches, defined by a bend in the course of the Spiti river. The north to northwest trending upper Spiti valley has been sculpted by Quaternary fluvial, (para)-glacial and mass wasting processes (Bhargava, 1990). The area is characterized by a broad U-shaped valley profile, braided Spiti river pattern, talus mantled slopes and alluvial terraces (Srivastava et al., 2013) and locally lake sediments occur, formed due to river blocking by landslides and subsequent lake formation (Bookhagen et al., 2005; Anoop et al., 2012). The lower Spiti valley is characterized by a straight to meandering river channel, bound by steep slopes and tributaries with waterfalls (Phartiyal et al., 2009). The study area lies at the transition from the upper to lower Spiti valley between Lingti and the Manirang pass (Fig.1). Geologically, the region lies in the Tethys Himalaya comprising of sedimentary rocks dominated by limestones, dolomites, shales and sandstones (Bhargava, 2008).

Climate and Glaciation

Largely shielded from the summer monsoon precipitation by the High Himalaya (Pir Panjal range), the Spiti area is often referred to as the cold desert (Bhargava and Bassi, 1998). According to the Köppen-Geiger climate classification (Kottek et al., 2006), the study area is

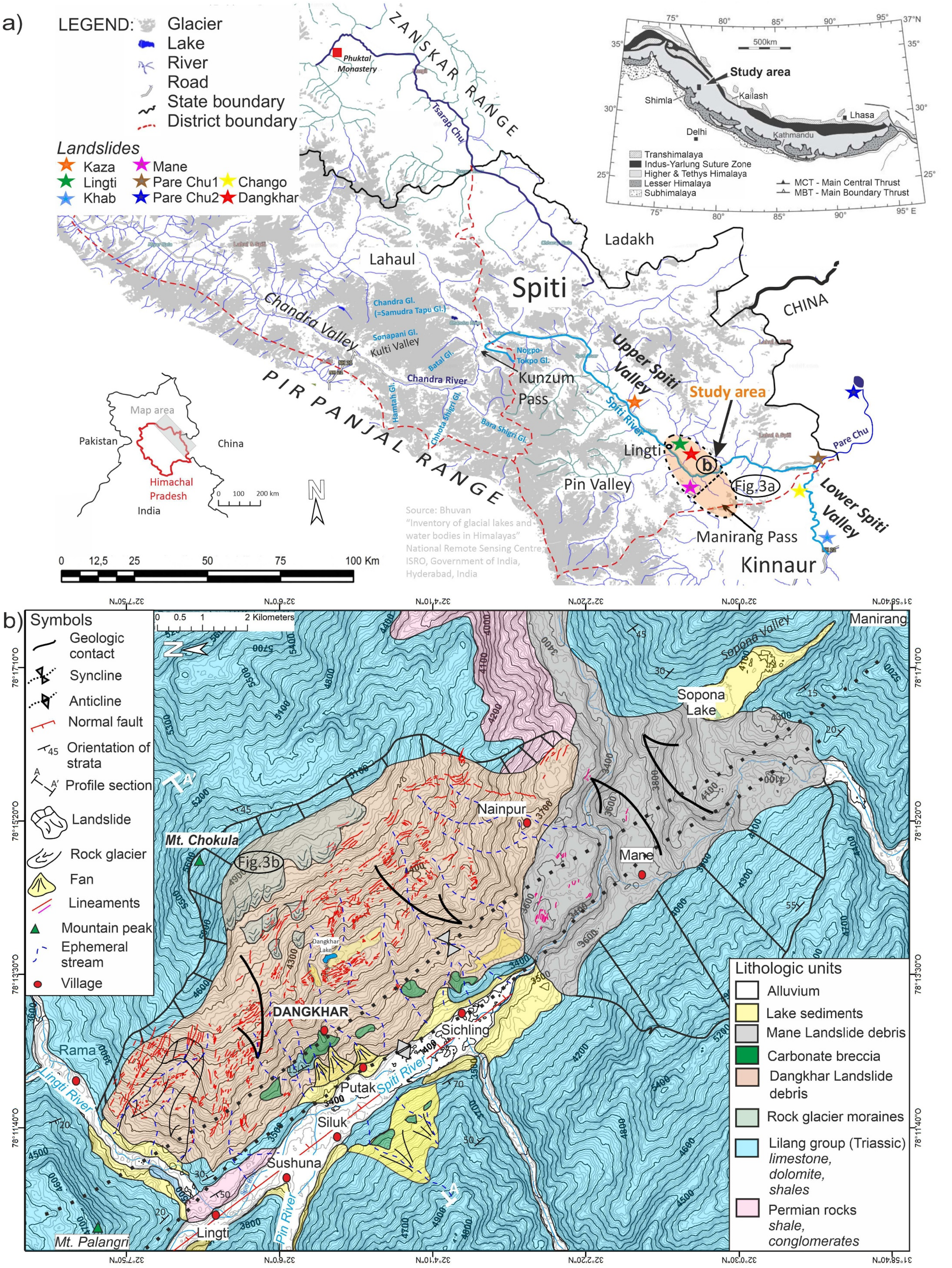

Fig. 1. Setting of the study area. a) Location and physical setting of the study area within Himachal Pradesh. Top right insert (Neumayer et al. 2004) illustrates geologic framework of the Himalaya. b) Generalized geologic map of the study area; A-A‘ denotes location of cross section shown in Figure 2.

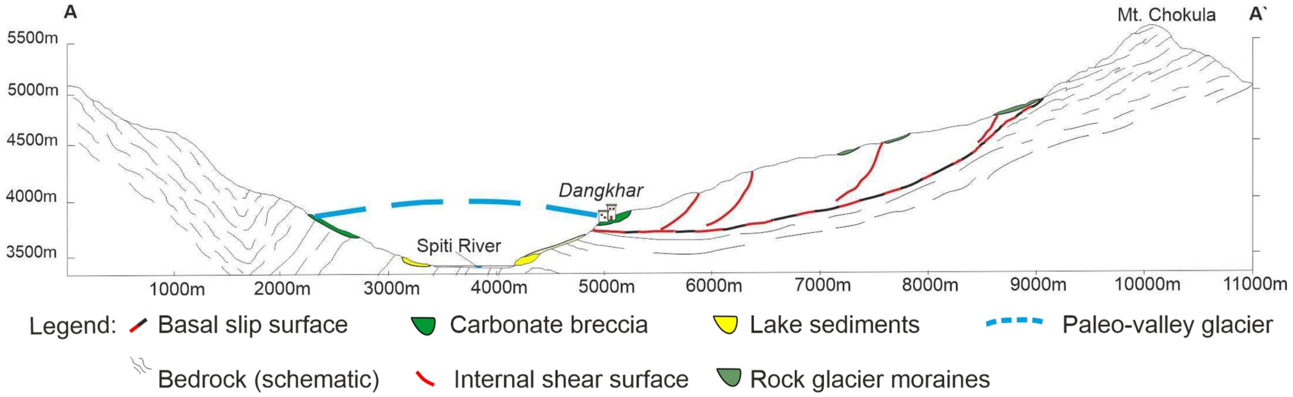

Fig. 2. Cross section of the Dangkhar Landslide sowing major elements discussed in the text.

situated in the ET climatic zone, indicating polar (E) tundra (T) conditions. Summer monsoon precipitation usually results in <50 mm of rainfall, while continental winter westerly disturbances (Rawat et al. 2015) are responsible for the snow dominated winters with <200 cm of snow. Temperatures throughout the year vary from – 25 C° in winters to + 30 C° in summer time (Srivastava et al., 2013; Phartiyal et al., 2009).

Based on the enormous accumulations of debris and the U-shaped valley geometry, an extensive glaciation covering the entire upper Spiti valley during the Pleistocene is suggested (Ameta, 1979; Bhargava and Bassi, 1998). This last high stand is referred to as Chandra glacial stage and is the least well known stage in the region (Saha et al., 2016). Hughes et al. (2013) in their synopsis on global glacial maxima point out, that in the Himalaya, the extensive late Pleistocene glaciations occurred during Marine Isotope Stage MIS 3 and earlier, approximately between 80 – 30 ka. However, there is a strong variability and asynchronous timing of glacial advances in the Indian Himalaya which makes the correlation of glacial stages across basins difficult (Owen and England, 2005).

Striated rock surfaces indicate glacial movement in the upper Spiti Valley (Bhargava and Bassi, 1998) when glaciers descended down from Kunzum pass, attaining a thickness of 300m to 600m (Saha et al., 2016; Eugster et al., 2016). Exposure dates suggest that a rapid recession occurred between 23 – 19 ka ago (Eugster et al., 2016) and pollen records confirm this pattern about 26 ka ago, when the region attained its desert character (Bhattacharyya et al., 2006). For the study area, located at the transition to the lower Spiti valley, the currently available dates imply, that the maximum glacial extent occurred in a time frame that is older than the known ages from the upper Spiti valley. A regional Holocene glacial advance occurred between 7.6 – 6.8 ka (Anoop et al., 2013), and a glacial advance is recorded by pollen analysis from about 2.3 – 1.5 ka ago (Chauhan et al., 2000; Bhattacharyya et al., 2006). From the past 0.7 ka onwards, colder climatic conditions prevailed (Bhattacharyya et al., 2006) until the Little Ice Age (LIA) peaking around the end of the 19th century (Rawat et al., 2015). Characteristic remnants from the LIA are rock glaciers exhibiting steep, unvegetated frontal slopes and surficial lobes and ridges and formed due to reduced precipitation during the LIA (Owen, 1999). They reflect the ongoing retreat of glacial ice since the late Holocene (Owen and England, 1998).

Table 1. Major landslides in the Spiti Valley (compiled from Srivastava, 1988; Bookhagen et al., 2005; Gupta and Sah, 2008; Kaspar, 2020).

Name	Volume (km^3)	Landslide type (blocked river)	Age
Dangkhar	15-20	Rock slide	Pleistocene/Holocene
Mane	1.4	Rock slide (Spiti River)	Holocene
Chango	1	Rock slide (Spiti River)	Late Pleistocene
Khab	0.8	? (Spiti River)	Late Pleistocene
Kaza	0.5	Rock avalanche (Spiti River)	Holocene
Lingti	0.3	Rotational earth slide (Lingti River)	Holocene
Pare Chu 1	?	Rock slide,	1975 A.D.
Pare Chu 2	?	Rock fall (Pare Chu)	2000 & 2003 A.D.

Landsliding

During abnormal monsoon years precipitation in the Spiti valley is up to two times greater compared to the decadal mean, leading to increased sheet erosion, debris flows and landslides (Bookhagen et al., 2005; Srivastava et al., 2013). The Spiti Valley hosts several large landslides with volumes from 0.3 to 20 km^3, including paleo and recent landslides (Table 1; Fig.1a).

Debuttressing and increased precipitation are considered the controlling factors in the majority of the Spiti valley landslides, since their timing falls into phases of deglaciation and enhanced monsoon activity (Srivastava et al., 2013). Moreover, seismic events play an important role in triggering contemporary and paleo-landslides in the Spiti region, due to their occurrence in the proximity of active fault zones (Anoop et al., 2012). The Kinnaur earthquake ($M_S = 6.8$) in 1975 triggered landslides along the flanks of the Pare Chu (Singh et al., 1975; Srivastava, 1988), locally blocking the river course (Table 1). Recent catastrophic events include the Pare Chu landslides in 2000 and 2003 A.D. when a meltwater lake emptied quickly in a landslide lake outburst flood (LLOF) after the landslide induced dam breached, causing 156 fatalities (Gupta and Sah, 2008).

METHODS

Detailed remote and field mapping from macro to micro scale of landform features was performed in order to assess the characteristics of erosional, depositional and structural features in the study area. High resolution satellite images (Google Earth | GeoEye) were utilized for photointerpretive mapping extent and distribution of large-scale glacial, sedimentological, and landslide structures. ASTER GDEM derived topographic basemaps created in ArcGIS (Version 10.2) and profiles were used to illustrate the mapped features on a scale of 1:15,000. Stratigraphy of glacial deposits is based on the morphology, position/elevation, weathering and vegetation characteristics proposed by Sharma et al. (2018).'M' denotes moraine, with subscripts 'D' and 'S', indicating the location Dangkhar and Sopona, respectively. Numbers refer to the morphostratigraphic age of the moraine where '1' indicates the youngest (morphostratigraphically) deposit. Field reconnaissance combined with review of published data and reports of the past 200 years were used to refine the mapped results and morphostratigraphy.

Outcrop studies were conducted to know local sedimentary structures and for sampling of material. Outcrop facies codes of deposits follow the nomenclature of Eyles et al. (1983). Details of inaccessible outcrop areas were inspected using gigapixel panoramas, acquired with a GigaPan Epic pro system and a Panasonic Lumix DMC FZ200 camera (accessible via: http://www.gigapan.com/galleries/13306). The samples were analyzed for their mineralogical composition and fabric by x-ray powder diffraction and thin section analysis, respectively. Stable oxygen, carbon and hydrogen isotope analyses were conducted on rock and water samples, respectively. Mineral compositions were analyzed at the laboratory of the institute of applied geosciences, Graz University of Technology, Austria, using a Panalytical Xpert Pro diffractometer. Cathodoluminescence (CL) imaging was performed using a Lumic HC5-LM microscope. Isotope analyses were conducted at the laboratories of JR-AquaConSol GmbH in Graz using a fully automated peripheral continuous-flow gas preparation device (Gasbench II) connected to a Finnigan DELTA plus XP Mass Spectrometer. Isotope ratios are reported against the Vienna Pee Dee Belemnite (VPDB) standard. Rigorous kinematic removability of the Dangkhar landslide was assessed by block theory (Goodman and Shi, 1985).

FINDINGS

Local Geologic Conditions and Structure

The Dangkhar landslide occupies the left bank of the Spiti valley between Lingti and Nainpur, covering an area of about 50 km². The local bedrock geology is characterized by limestones, dolomites, shales and sandstones of the Triassic Lilang Group (Fig.1b). The ground structure is dominated by an asymmetric syncline running beneath the Dangkhar landslide (Fig.2). The inferred basal slip surface follows this shape, daylighting approximately 200m above the valley floor. The Holocene active Spiti valley normal fault running along the valley floor, represents the most prominent tectonic feature in the area. The Spiti and Lingti rivers limit the Dangkhar landslide on three sides. Around the headscarp area of the Dangkhar landslide near Mt. Chokula, three pulses of glacial advances are recorded by rock glacier deposits. In the central part on a mid-slope bench, lake sediments occur around the Dangkhar lake and in a dry lake bed. Ephemeral stream channels cut into the landslide debris in a straight to dendritic pattern. Springs cluster near the toe region and locally in the upper area near rock glacier deposits. In the toe area, lithified deposits of carbonate breccia have formed, which, to a less extensive extent, are also present on the opposite valley side. Spiti valley parallel lineaments up to 500m in length occur throughout the Dangkhar landslide, representing surface expressions of internal shears. The Lingti landslide is part of the larger Dangkhar landslide and is facing the Lingti valley.

To the south, the Dangkhar landslide has an unconformable contact with the 8,700 years old Mane landslide. The Mane landslide blocked the Spiti river for about 2,500 years and a temporary lake formed (Bookhagen et al. 2005; Anoop et al., 2012). Lake sediments from that period stretch for about 10 km upstream from Sichling along the toe of the Dangkhar landslide. Locally the lake sediments are overlain by fan deposits. In the adjacent Sopona valley, a second lake (Sopona lake) formed due to blockage by the Mane landslide.

Glacial Signatures – Moraines and Geomorphic Expressions

Glacially carved valley sides, paleo-lake sediments, talus fans, terraces, and vast accumulations of debris were already recognized by the earliest expeditions from the 1820s to 1890s A.D. as evidence for alternating erosional and depositional conditions in the past (McMahon, 1897; Oldham, 1888). Falling in the timeframe of the LIA, these historic documents provide photographic evidence and descriptions of glacier termini in the Sopona valley and Manirang area (Fig.3). Theobald (1862) and Griesbach (1891) mention the lower end of the Sopona lake and Sopona camp to be approximately 8 and 5 km away from the glacier terminus, respectively. This refers to a location where presently fresh, unvegetated terminal moraine deposits (M_{S1}) are visible on satellite images. The present day snout of the Manirang glacier lies about 1.2 kilometer up the valley from the fresh moraine deposits, inferring an average recession rate of about 9.6 m/yr since the end of the LIA. Older, vegetated moraine ridges (M_{S2} and M_{S3}) exist near the Sopona camp (Fig.3a). Trimlines on higher levels along the valley flanks point to a former glacial highstand of the Manirang glacier when it reached down into the Spiti Valley. The LIA extent of the Manirang glacier (Fig.4a) is also featured in the 1866 expedition of Bourne (1870) and document the overall recession since then (Fig.4b).

In the upper region around the headscarp area of the Dangkhar landslide, lobate shaped, deposits progressively getting more subdue downhill (Fig.3b) represent rock glaciers of three glacial advances (M_{D1} to M_{D3}). The uppermost rock glaciers are located in the contemporary permafrost zone (Gruber 2012), with a surface

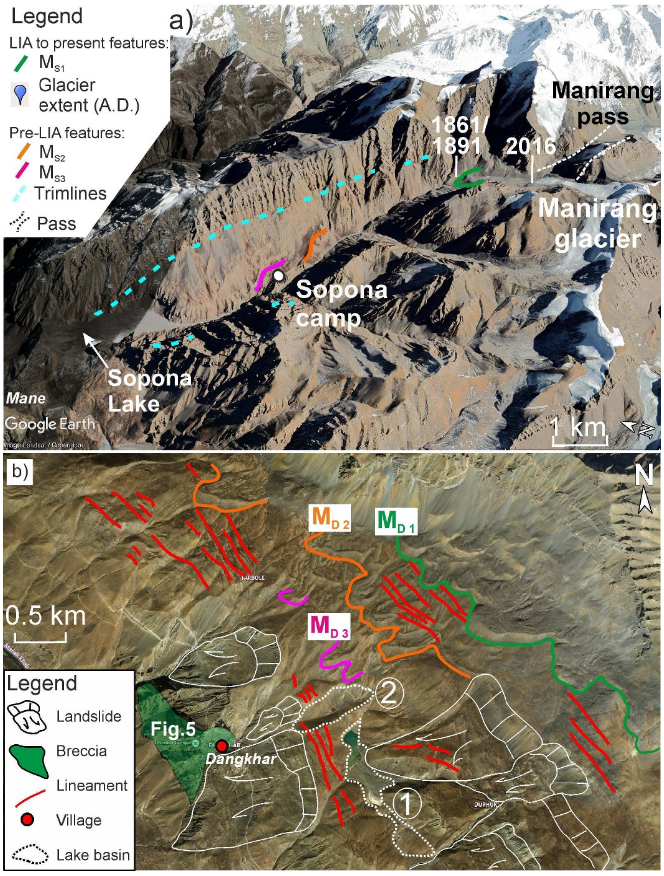

Fig. 3. Characteristic landforms of the Sopona Valley and the Dangkhar landslide. (a) Moraines and trimlines associated with the Manirang glacier. (b) Pulses of glacial advances on the Dangkhar Landslide, partly affected by lineaments and local landsliding. A large carbonate breccia patch occurs in the lower part of the slope. 1 – Dangkhar lake basin; 2 – empty lake basin.

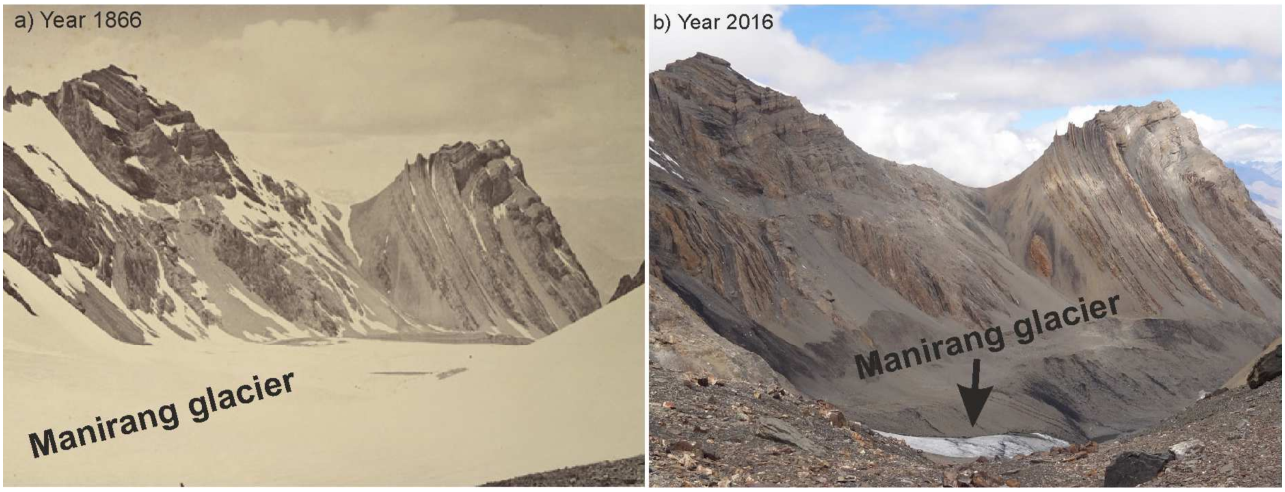

Fig. 4. Glacier situation at the Manirang pass. a) Glacier extent in late August 1866. b) Glacier extent on August 9th, 2016 (after Bourne, 1870; Sathya, 2016).

characterized by fresh ridges and furrows, while further downhill these deposits are less well preserved. The elevation of these rock glaciers is in the range of the glacial advances at the Manirang area from 4,300 to 5,000m. The rock glacier deposits exhibit cross cutting relationships with landslide lineaments, indicating stages of episodic slope deformation following glacial advances. M_{D2} and M_{D3} are displaced by the lineaments, whereas M_{D1} overrides the lineaments. Localized, secondary landslides displace some of the M_{D2} deposits. The extent of the Dangkhar lake bed and the empty lake point to larger quantities of meltwater in the past, filling the lakes on the mid-slope bench. Currently, the Dangkhar lake accounts only for approximately 15% of the lake sediment area. A second, empty lake exists north of Dangkhar lake with an open outlet ditch projecting towards Dangkhar village. Erosional valley glaciation evidence is preserved in the marked change of Spiti Valley curvature from convex to concave. Bedrock outcrops near Siluk located in the convex profile section exhibiting polished surfaces, are attributed to movement of a Spiti valley paleo-glacier. The toe of the basal slip surface is located in this convex profile section, indicating the Dangkhar landslide was initiated after the Spiti valley glacier recession.

Carbonate Breccia: Macro- and Micro Properties

Near the toe area, patches of breccia line up in map view at elevations of 200 to 450m above the valley floor. Commonly forming precipitous cliffs standing out of the surrounding area, they abruptly terminate in an almost vertical drop towards the Spiti valley. Their position lies at the marked change of Spiti Valley curvature from convex to concave. The breccia occurs in several outcrops within the study area and can be traced along the flanks of the Spiti valley at elevations between 3,600 and 3,900m. The outcrops mostly show a triangular to vermiform shape similar to a fan or embankment, respectively. Breccia occurrence and extent is laterally limited and restricted to areas where ephemeral streams descend from the slopes. The carbonate breccia exhibits a brownish coloured weathered surface and has black limestone clasts derived from the surrounding bedrock formations. The deposit around Dangkhar village forms the largest outcrop of carbonate breccia (Fig.5). It is composed of three layers showing different properties regarding grainsize, roundness, and stratification. Locally, local salt precipitation, normal faulting, loading structures and cavities having diameters of up to 10 to 15m exist (Fig.5a)

The bottom layer is a compact, massive diamictite (Dmm), composed of a sandy to gravelly matrix with rounded boulders as well as subrounded blocks. The presence of rounded and subangular components embedded within a compact fine grained matrix suggests that the bottom layer has formed involving both, fluvial and gravitational processes acting on the sediment. The bottom layer has a marked contact to an overlying, locally occurring fine grained layer (Sh) with a thickness of two to three meters (Fig.5b). The mid layer shows a sharp erosional contact to the fine grained layer. The mid layer exhibits crude stratification (Dms) dipping towards the slope approximately between 25° to 40° and locally exhibits wet/soft sediment deformation structures (Sd) expressed as contorted, smeared layers and flow structures (Fig.5c). The wet sediment deformation structures suggest water rich conditions for the formation of this layer. The top layer exhibits a coarsening upwards trend (Dmg with inverse grading) with angular blocks up to ten meters in size and forms the foundation rock of the circa 1,000-year-old, Ancient Dangkhar Monastery. Cathodoluminescence imaging revealed zoned crystal growth of the cements between split clasts and the breccia is primarily composed of micritic dolomite and limestone clasts and calcite spar cements (Fig.6). Stable oxygen and carbon isotope values of cements range from $\delta^{18}O$ -22.78 to -20.23 ‰ VPDB and $\delta^{13}C$ 2.37 to 2.82 ‰ VPDB, respectively. The clasts exhibit values of $\delta^{18}O$ -10.25 to -17.45 ‰ VPDB and $\delta^{13}C$ 2.37 to 3.51 ‰ VPDB.

Carbonate Breccia Formation Environment

The bottom layer of the carbonate breccia is interpreted as a lodgment till deposited at the base of a receding glacier on the Dangkhar landslide (Fig.7). Locally the fine grained sediments were deposited as proglacial stream outwash on top of the lodgment till. The mid layer is formed by flow and supraglacial meltout tills. Soft sediment deformation structures and crude stratification are commonly preserved in such deposits of debris rich glaciers (Bennett and Glasser, 2009). The cavities could be the result of melted incorporated ice within the sediment. Additionally, normal faulting within sediments can occur after melting of incorporated ice (Bennett and Glasser, 2009). The preservation of the wet sediment structures points to a cementation soon after the emplacement. The top layer is a debris flow deposit, potentially originating from a lake burst flood in the midslope area after the downslope levee of the empty lake breached. Negative shifts in isotope signatures also indicates a strong meteoric water influence on the cements. The distribution of the breccia patches in map view outlines the former shape of a Spiti valley glacier.

Block Theory Analysis

In order to gain insight as to why such a massive landslide occurred at this particular geographic location, rigorous kinematic and stability analyses were performed using block theory (Goodman and Shi, 1985).

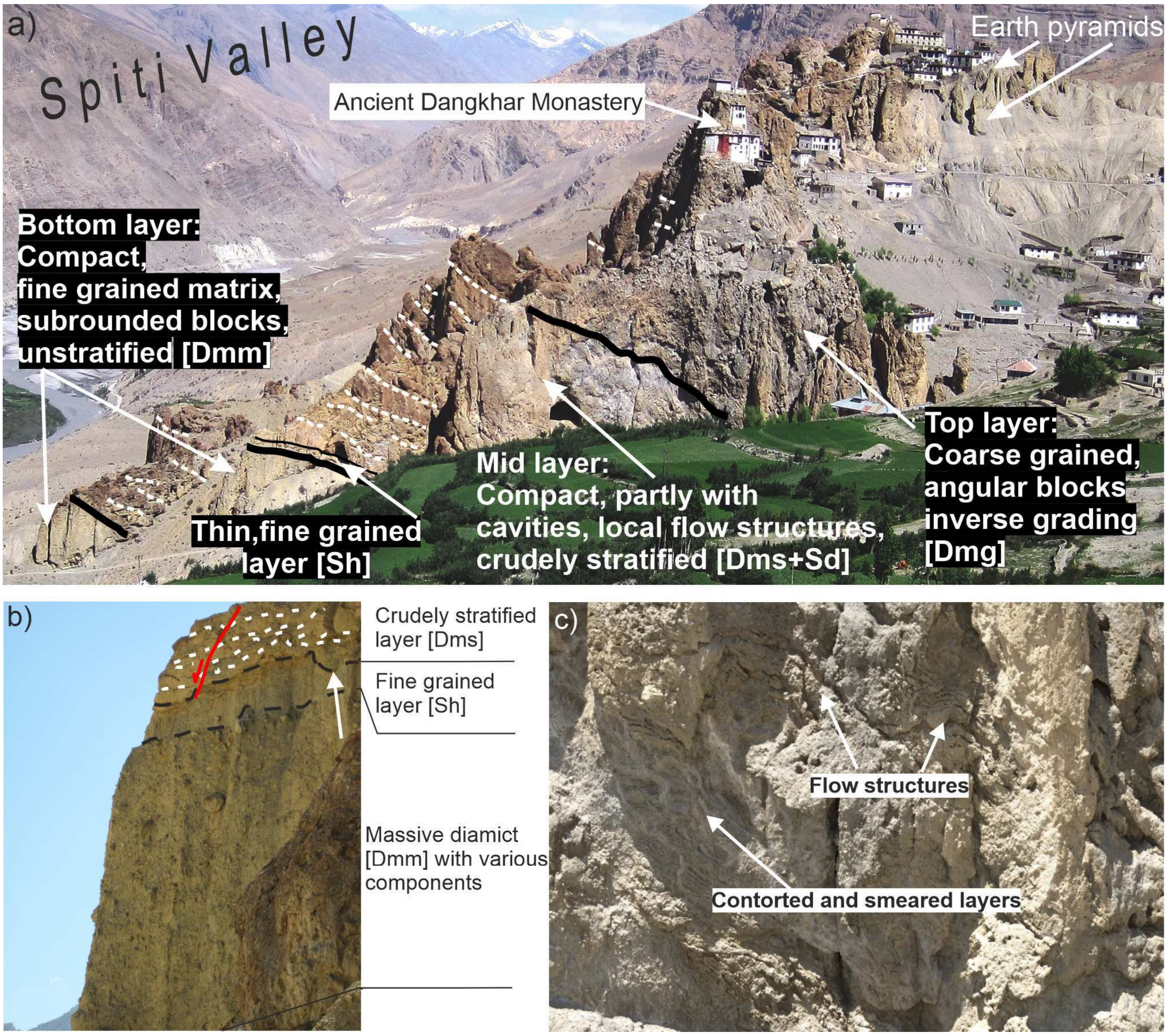

Fig. 5. The carbonate breccia of Dangkhar. (a) Overview of the main layers of the breccia. Dashed line indicates crude stratification. (b) Section exposing the bottom, fine grained and mid layer. (c) soft sediment deformation structures expressed as smeared layers and flow structures.

For kinematic and failure mode analyses, input parameters include the orientations of the: (i) free slope surfaces; (ii) basal landslide slip surfaces; and (iii) resultant force acting on the landslide mass. As shown in Figure 1b, the hillslope has a complex geometry by virtue of the developed stream pattern of the Spiti and Lingti valleys. For this reason, the free slope surface is modelled as a composite surface composed of three best fit tangent planes. Similarly, the curved nature of the basal slip surface is modelled as a composite surface composed of two best fit tangent planes. According to Shi's Theorem, a block is removable only if its joint pyramid (JP) has no intersection with the excavation pyramid formed by the slope. Figure 8 shows that JP 00 forms a kinematically removable block with planar sliding along the basal slip surface 1 under gravity loading. The developed stream pattern is the critical factor in forming the kinematically removable block, as the pattern provides for effective lateral releases at the upstream and downstream boundaries of the landslide.

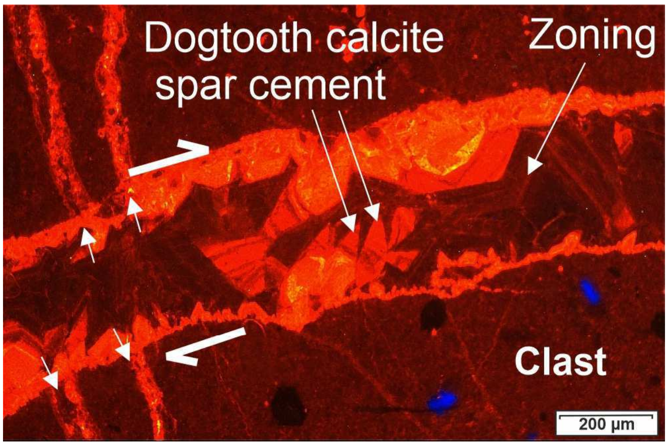

Fig. 6. CL image of zoned growth lamellae of the cements and displaced split clasts.

SUMMARY AND CONCLUSION

The study of landforms of glacial, mass movement and structural origin provide insight to the local conditions and environmental changes in the area. Several key conclusions can be made regarding the setting and evolution of the Dangkhar landslide:

- Block Theory showed that kinematic removability of the Dangkhar landslide is given by the Lingti and Spiti river pattern and bedrock structure.
- Glacial remnants of four stages on/around the Dangkhar

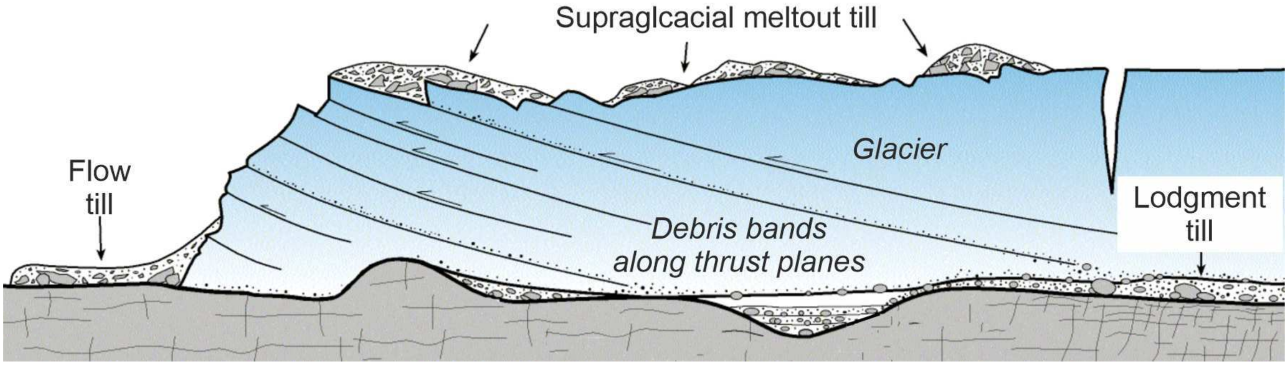

Fig. 7. Depositional settings of glacial deposits. Modified after British society for geomorphology.

landslide and in the Sopona valley, document the glacial history of the area. The oldest one by erosional features such as ice-polished bedrock surfaces, valley morphology and lithified diamictons/tectomicts (breccia), and three by rock glaciers and moraines. The glacial features fall in the timeframe from the last glacial cycle to the LIA, presumably between MIS 3 to 5 and end of the 19th century.

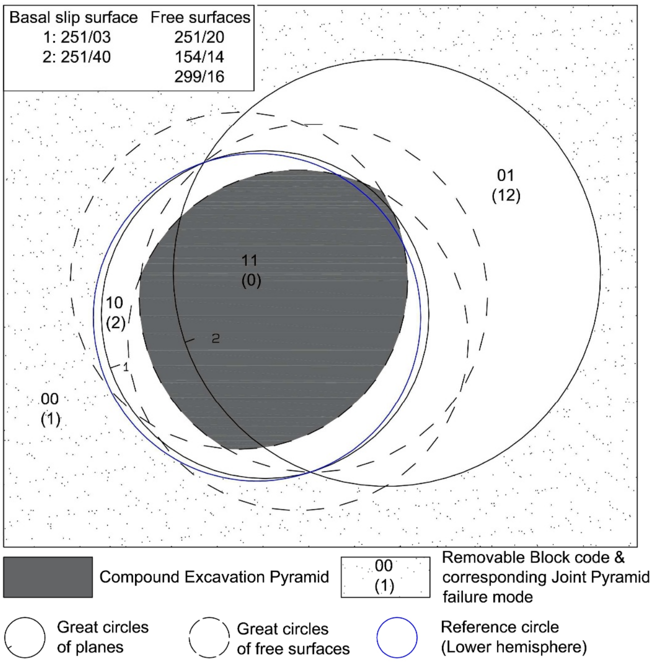

Fig. 8. Block theory plot identifying JP 00 with associated failure mode (1) as removable block of the Dangkhar Landslide.

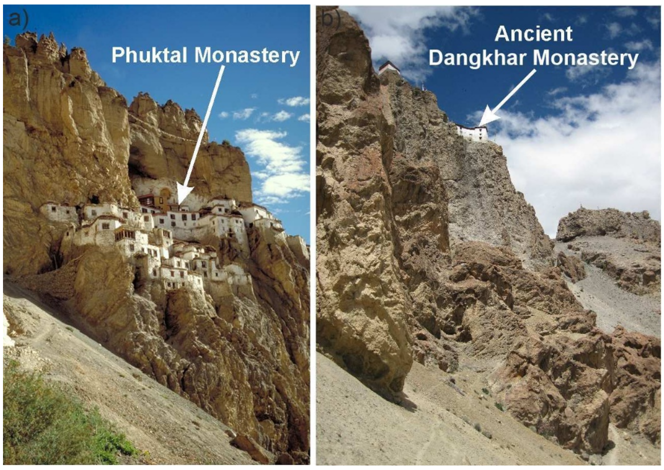

Fig.9. The Buddhist monasteries of Phuktal (a) in Zanskar and Dangkhar (b) in Spiti built on lithified deposits assigned to the Chandra glacial stage.

- Glacial reshaping of valley profiles may have been a potential preconditioning factor for the Dangkhar Landslide initiation (exposing of future basal slip surface location in the toe area and associated debuttressing). The exact onset and minimum age of the of landslide initiation is not known, but suspected to have occurred after recession of a vast valley glacier after the last local glacial highstand.
- Episodic, landslide activity until M_{D2} as indicated by lineaments cutting M_{D2} and M_{D3} deposits. Localized landsliding affects M_{D2}, M_{D1} overrides the lineaments.
- The breccia has acombination of moraine and mass wasting features recording the changes from glacial to paraglacial conditions. After decoupling from the receding valley glacier, the deposits remained as isolated bluffs. Today the outcrop distribution still outlines the shape of the valley glacier. Taylor and Mitchell (2000) report a similar setting from the neighbouring Zanskar area, where lithified tillite rests on Chandra stage paleosurfaces approximately 280m above the present valley floor. Just like at Dangkhar, a monastery (Phuktal Gompa) stands on this lithified rock (Fig.9a,b).
- Meltwater accumulations on the landslides mid-slope bench area were released during flood events. Associated debris flow deposits are recorded in the top layer of the breccia. Stable isotopes document the freshwater influence on the cementation of the breccia.

It is revealed that glacial, paraglacial, fluvio-glacial and mass wasting processes are often connected and interrelated. Modifications of the local terrain morphology in combination with structural kinematics are important factors with regard to landslide development. Identifying erosional and depositional landforms and structural features allow reconstructing past conditions, and serve as proxies for identifying potential settings for future events. Understanding of large-scale phenomena, such as the Dangkhar landslide is of great importance in the longer-term context of alpine, paraglacial environments. Regions affected by glacial recession may experience similar events in the future.

Acknowledgements: The authors thank the reviewer for the constructive comments and suggestions that helped improving the quality of the manuscript. Gratitude is also expressed to the hospitable and supportive people of Dangkhar, which made the stay during the field work a memorable lifetime experience.

References

Ameta, S.S. (1979) Some observations on geomorphology of the Spiti Valley, Lahaul and Spiti district, Himachal Pradesh. Himalayan Geology, v.9(2), pp.646–656.

Anoop, A., Prasad, S., Basavaiah, N., Brauer, A., Shahzad, F., Deenadayalan, K. (2012) Tectonic versus climate influence on landscape evolution: A case study from the upper Spiti valley, NW Himalaya. Geomorphology, v.145–146, pp.32–44.

Anoop, A., Prasad, S., Krishnan, R., Naumann, R., Dulski, P. (2013) Intensified monsoon and spatiotemporal changes in precipitation patterns in the NW Himalaya during the early-mid Holocene. Quaternary Internat., v.313-314, pp.74-84.

Ballantyne, C.K. (2002) Paraglacial geomorphology. Quaternary Sci. Rev., v.21, pp.1935–2017.

Bennett, M.M., Glasser, N.F. (2009) Glacial Geology: Ice Sheets and Landforms, John Wiley & Sons, New York, 2nd ed., pp.1–400.

Bhargava, O.N. (1990) Holocene tectonics south of the lndus suture, Lahaul-Ladakh Himalaya, India: a consequence of Indian plate motion. Tectonophysics, v.174, pp.315–320.

Bhargava, O.N., Bassi, U.K. (1998) Geology of Spiti Kinnaur Himachal Himalaya. Geol. Surv. India Mem., v.124, pp.1–210.

Bhargava, O.N. (2008) An updated introduction to the Spiti geology. Jour. Paleont. Soc. India, v.53(2), pp.113–129.

Bhattacharyya, A., Ranhotra, P.S., Shah, S.K. (2006) Temporal and spatial variations of Late Pleistocene-Holocene climate of the Western Himalaya based on pollen records and their implications to monsoon dynamics. Jour. Geol. Soc. India, v.68, pp.507–515.

Bookhagen, B., Thiede, R.C., Strecker, M.R. (2005) Late Quaternary intensified monsoon phases control landscape evolution in the northwest Himalaya. Geology, v.33, pp.149–152.

Bourne, S. (1870) A photographic journey through the Higher Himalaya. View from the top of the Manirung Pass. Image No. 1469, copyright Victoria & Albert Museum, London. British Jour. Photography v.17, pp.39–40.

Eugster, P., Scherler, D., Thiede, R.C., Codilean, A.T., Strecker, M.R. (2016) Rapid Last Glacial Maximum deglaciation in the Indian Himalaya coeval with midlatitude glaciers: New insights from ^{10}Be-dating of ice-polished bedrock surfaces in the Chandra Valley, NW Himalaya. Geophys. Res. Lett., v.43, pp.1589–1597.

Eyles, N., Eyles, C.H., Miall, A.D. (1983) Lithofacies types and vertical profile models; an alternative approach to the description and environmental interpretation of glacial diamict and diamictite sequences. Sedimentology, v.30, pp.393–410.

Goodman, R.E., Shi, G-H. (1985) Block Theory and its application to rock engineering. Prentice-Hall Inc., pp.1–338p.

Griesbach, C.L. (1891) Geology of the Central Himalayas. Geol. Surv. India Mem., v.23, pp.1–232.

Gupta, V., Sah, M.P. (2008) Impact of the Trans-Himalayan Landslide Lake Outburst Flood (LLOF) in the Satluj catchment, Himachal Pradesh, India. Nat. Haz., v.45, pp.379–390.

Gruber, S. (2012) Derivation and analysis of a high-resolution estimate of global permafrost zonation. The Cryosphere, v.6,. pp.221–233.

Hughes, P.D., Gibbard, P.L., Ehlers J. (2013) Timing of glaciation during the last glacial cycle: evaluating the concept of a global 'Last Glacial Maximum' (LGM). Earth Sci. Rev., v.125, pp.171–198.

Kaspar, M., Kieffer, D.S. (2015) Preliminary engineering geological characterization of the ca. 20 km³ Dangkhar Landslide in the Spiti Valley, Himachal Pradesh, India. *In:* Lollino, G., Giordan, D., Crosta, G.B., Corominas, J., Azzam, R., Wasowski, J., Sciarra, N. (Eds.) Engineering Geology for Society and Territory, v.2, pp.891–894.

Kaspar, M. (2020) Geomorphology, geomechanics, and geochronology of the Dangkhar Landslide, Himachal Pradesh, India. PhD Dissertation Graz University of Technology, pp.1–199.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. (2006) World Map of the Köppen-Geiger climate classification updated. Meteorol. Zeitsch., v.15, pp.259–263.

McMahon, C.A. (1897) Notes of a tour through Hangrang and Spiti. Rec. Geol. Surv. India, v.12, pp.57–69.

Neumayer, J., Wiesmayr, G., Janda, C., Grasemann, B., Draganits, E. (2004) Eohimalayan fold and thrust belt in the NW-Himalaya (Lingti-Pin Valleys): Shortening and depth to detachment calculation. Austrian Jour. Earth Sci. v.95-96, pp.28–36.

Oldham, R.D. (1888) Some notes on the geology of the NW Himalayas. Rec. Geol. Surv. India, v.23, pp.149–159.

Owen, L.A. (2009) Latest Pleistocene and Holocene glacier fluctuations in the Himalaya and Tibet. Quaternary Sci. Rev., v.28, pp.2150–2164.

Owen, L.A., England, J. (1998) Observations on rock glaciers in the Himalayas and Karakoram Mountains of northern Pakistan and India. Geomorphology, v.26, pp.199–213.

Owen, L.A., Benn, D.I. (2005) Equilibrium-line altitudes of the Last Glacial Maximum for the Himalaya and Tibet: an assessment and evaluation of results. Quaternary Internat., v. 138-139, pp.55–78.

Phartiyal, B., Sharma, A., Srivastava, P., Ray, Y. (2009) Chronology of relict lake deposits in the Spiti River, NW Trans Himalaya: implications of Late Pleistocene–Holocene climate tectonic perturbations. Geomorphology, v.108, pp.264–272.

Rawat, S., Gupta, A.K., Sangode, S.J., Srivastava, P., Nainwal, H.C. (2015) Late Pleistocene Holocene vegetation and Indian summer monsoon record from the Lahaul, Northwest Himalaya, India. Quaternary Sci. Rev., v.114, pp.167–181.

Saha, S., Sharma, M.C., Murari, M.K., Owen, L.A., Caffee, M.W. (2016) Geomorphology, sedimentology and minimum exposure ages of streamlined subglacial landforms in the NW Himalaya, India. Boreas, v.45, pp.284–303.

Sathya (2016) Larsawe Pass / Manirang Pass - July to Aug 2016. Trekking Blog, available at http://sathyastravels.blogspot.com/2016/08/larsawe-pass-manirang-pass-july-to-aug.html?view=timeslide

Sharma, S., Shukla, A.D. (2018) Factors governing the pattern of glacier advances since the Last Glacial Maxima in the transitional climate zone of the Southern Zanskar Ranges, NW Himalaya. Quaternary Sci. Rev., v.201, pp.223-240.

Singh, S., Jain, A.K., Sinha, P., Singh, V.N., Srivastava, L.S. (1976) the Kinnaur Earthquake of January 19, 1975: a field report. Bull. Seism. Soc. Amer., v.66(3), pp.887–901.

Srivastava, L.S. (1988) Landslides in rock slopes during January 19, 1975, Kinnaur Earthquake in Himachal Pradesh, India. Int. Conf. Case Hist. Geotech. Eng., No.4.14, pp.779–785.

Srivastava, P., Ray, Y., Phartiyal, B., Sharma, A. (2013) Late Pleistocene-Holocene morphosedimentary architecture, Spiti River, arid higher Himalaya. Internat. Jour. Earth Sci. (Geol. Rundsch.), v.102, pp.1967–1984.

Taylor, P.J., Mitchell, W.A. (2000) Late Quaternary glacial history of the Zanskar Range, Northwest Indian Himalaya. Quaternary Intetnat., v.65-66, pp.81–99.

Theobald, W. (1862) Notes on a trip from Shimla to the Spiti Valley and Chomoriri (Tshomoriri) Lake during the months of July, August and September 1861. Jour. Asiat. Soc. Beng., v.31, pp.480–527.