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A PRELIMINARY ASSESSMENT OF THE GEOLOGICAL EVIDENCE OF THE MEGA FLOODS IN THE UPPER ZANSKAR CATCHEMENT, NW HIMALAYA

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ABSTRACT

Mega floods generated due to catastrophic lake outburst in the Tsrap Lingti Chu (upper Zanskar valley) indicate that the Glacial Lake Outburst was the major factor which is popularly known as Glacial Lake Outburst Floods (GLOFs). Optical chronology suggests that the floods occurred during the later part of the Marine Isotopic Stage-3 dated to ~39 ka and during post Last Glacial Maximum (LGM) dated to ~15 ka. Flow velocity using the sedimentological criteria and employing empirical methods provides a broad estimate of 9.98±1.5 m/s for the flood deposits dated to 15 ka. The minimum paleo discharge of 39 ka flood event is estimated to be 9702.67±537.3 m^3/s. The study suggests that the floods occurred during the wet and warm climate conditions.

Keywords: Paleo flood, Paleo discharge, GLOFs, Optical chronology, north western Himalaya.

INTRODUCTION

Catastrophic mega-floods which are associated with spontaneous release of large amount of impounded water, like landslide lake outbrust floods (LLOFs), Glacial lake outbrust floods (GLOFs) and floods due to extreme weather conditions, intensively affect the morphology of the orogeny (Baker *et al*., 1993; Richardson and Reynolds, 2000; Korup and Clague, 2009; Dortch *et al*., 2011; Sundriyal *et al*., 2015; Poonam *et al*., 2017). Seasonal flooding, which are associated with increase in temperature and precipitation and have a nearly fixed frequency of every year, are mainly responsible for transportation–deposition of sediment within the channel limits, as their velocity and discharge are in the lower flow regime. Whereas, mega flood events are accompanied by large-scale mass movement causing lateral and vertical incision; however transient storage of sediments from these floods provides an evidence of their occurrence and intensity. As compared to Ganga plains and Tibetan Plateau, Himalayan orogen is known to witness for the higher extreme events. These events are more frequent in the dry Trans Himalayan region (Bookhagen, 2010). For example, to name a few, on August 6th, 2010 a cloud burst triggered debris flow generated flash flood, having peak discharge of >1000 m^3/s, that virtually devastated the Leh Valley (Hobley *et al*., 2012; Thayyen *et al*., 2013). On 7th May 2015, due to damming of Tsarap Lingti Chu near Phugtal, which stored nearly 35×10^6 m^3 water, a LLOF was generated in the Zanskar causing unprecedented damage in the valley. Considering that the arid Trans Himalayan region of NW India is witnessing rapid urbanization (> 20% over a time period of two decades, from 1981 to 2001) (Goodall, 2004), it is considered as one of the most vulnerable terrain in terms of its susceptibility towards unusual weather events (Ziegler *et al*., 2016). It has been suggested that under the warm earth scenario, there would be an increase both in frequencies and magnitude of floods in the Himalayan region (Agnihotri *et al*., 2017, Wasson *et al*., 2013). In view of this, it is important to understand the causes of the floods both during the historical (geological archives) and in the recent past in order to generate the data so that it can feed to the model of simulation for future prediction. Towards this, beyond the instrumental records, sedimentary archives of paleo floods becomes important that are used extensively in the recent times (Kochel and Baker, 1982; Kale, 2000; Wasson *et al*., 2013; Sharma *et al*., 2017; Srivastava *et al*., 2017). Sedimentary records of large flood over a time scales of 10^3-10^4 year are wide spread in the Himalayan ranges (Burbank, 1983; Cornwell, 1998; Richardson and Reynolds, 2000; Seong *et al*., 2009; Wasson *et al*., 2013; Sharma *et al*., 2017; Srivastava *et al*., 2017; Panda *et al*., 2020). These archives can be preserved as Slack water deposits (SWDs) (Wasson *et al*., 2013; Sharma *et al*., 2017; Srivastava *et al*., 2017), massive sand beds on fluvial terraces (Montgomery *et al*., 2004; Lang *et al*., 2013; Panda *et al*., 2020), and debris flow deposits (Bookhagen *et al*., 2005). Paleo- hydrological assessment of these archives provides the information about the intensity of these events. In the present study an attempt has been made to generate paleo-flood data, using sedimentary archives of past floods that are preserved along the Tsarap Lingti Chu, which is one of the tributary of the Zanskar River (Fig. 1). The objective of the study is to understand the causes of the paleo-floods and their geomorphic implications on the terrain. To achieve the above objective we used the conventional sedimentological criteria supported by the Optical Stimulated Luminescence (OSL) dating.

REGIONAL SETTING

Tsarap Lingti Chu is a major tributary of upper Zanskar catchment flowing in a deep narrow gorge and has ~8570 km^2 of catchment area. It follows the strike of Zanskar shear Zone, which is north dipping extensional structure and is a part of 2000 km long South Tibetan Detachment system (STDs) (Herren, 1987; Dèzes *et al*., 1999). Tsarap Lingti Chu has Indian Summer Monsoon (ISM) dominated Higher Himalayan Crystalline (HHC) sequence toward south and relatively dry Zanskar ranges at the north. The paleo-flood deposit in the form of massive sand bodies are preserved on the southern bank of Tsarap Lingti

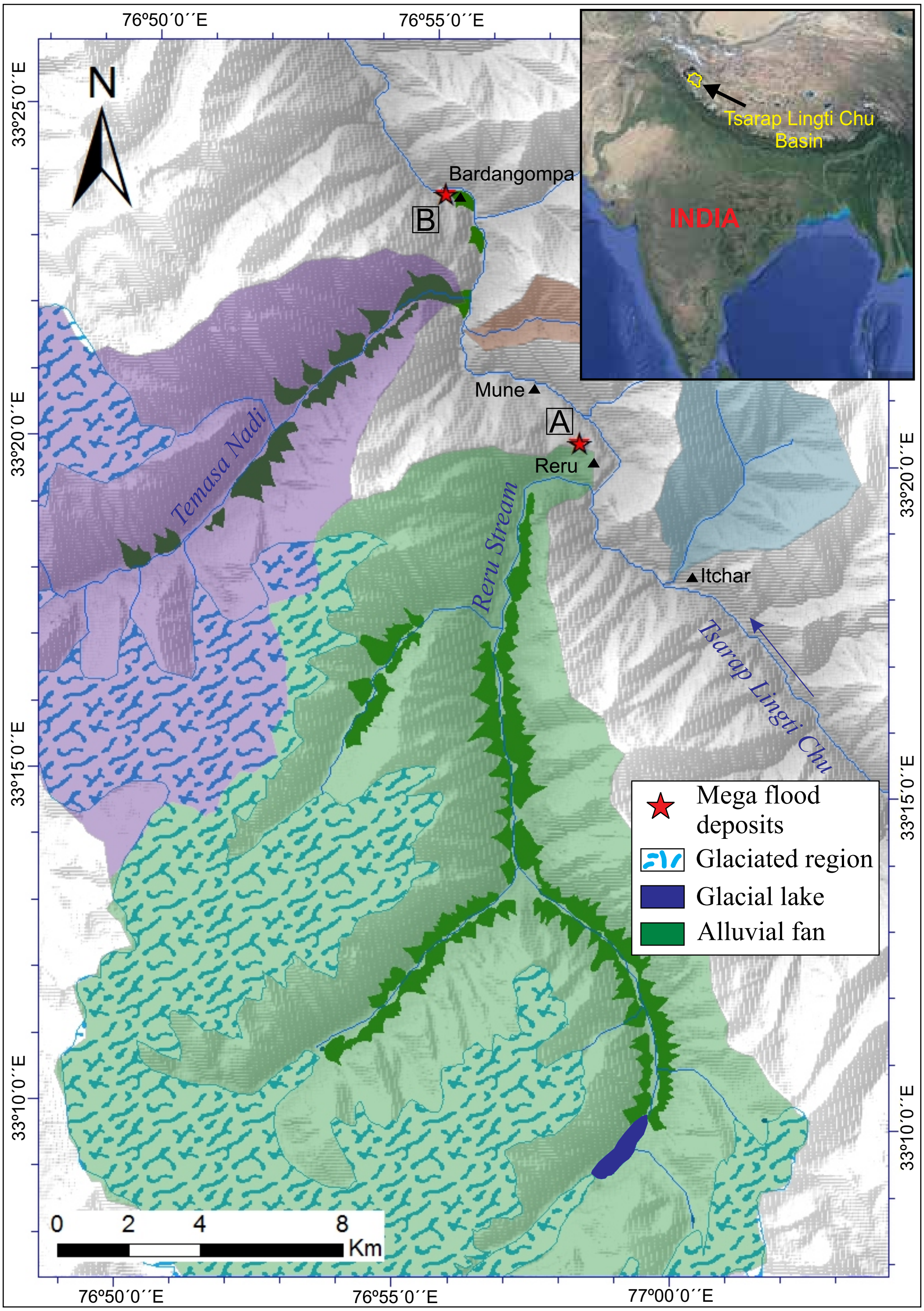

Fig. 1. Geomorphology of the study area and location of mega flood deposits. Inset is map of India showing location of Tsarap Lingti Chu catchment.

Chu at Reru village and Bardangompa village (Fig. 1; site A and B). Two streams- Reru Phu and Temsa Nadi meet the trunk stream near the location of paleo-flood deposits. Headwaters of tributaries draining from the southern slopes of the Tsarap Lingti Chu are extensively glaciated, having very large catchment areas (~340 km^2 and ~171 km^2) as compared to northern slope tributaries (~9 km^2 and ~25 km^2). The glaciers of Reru Phu and Temsa Nadi have few smaller and larger glacial lakes, which are formed due to impounding of glacial meltwater. A proglacial lake, ~2 km long and 400 m wide, is located at 33°09'32.56''N 76°59'05.38''E and 4500 (m above the sea level (m a.s.l.), near the snout of an un-named glacier of Reru Phu (Raj, 2010) (Fig. 1). Climatically, the area lies in cold to arid climate zone with temperature ranging from -14° C to -2.8° C in winter and

Table 1. Optical stimulated luminescence chronology of the mega flood deposits.

Field name	Lab no.	Latitude	Longitude	Depth (m)	U (ppm)	Th (ppm)	K (%)	Weighted mean Paleodose (Gy)	Over dis-persion (%)	Least Paleodose (Gy)	Dose rate (Gy/a)	Weight Mean Age (ka)	Least Age (ka)
PD-19-s	LD - 2057	33°20'38.19"N	76°57'16.91"E	1.5	1.5	7.9	1.89	67±65 N=18	84.8±3.4	43±9 N=6	2.8±0.1	24±23	15±3
D-13	LD-3166	33°23'52.04"N	76°55'14.26"E	0.5	1.64	5	1.20	65±10 N=34	14.5±0.4	--	2.0±0.1	32±5	--
D-14	LD-3167	33°23'52.04"N	76°55'14.26"E	2	2.04	10.2	1.85	138±21 N=23	11.3±0.8	117±6 N=7	3.0±0.2	46±8	39±3

10.2° C to 24.7° C in summers (Taylor and Mitchell, 2000). Annual rainfall in the area, derived from the TRMM data, is ~145 mm/year (Bookhagen *et al*., 2009).

MATERIAL AND METHODS

Field stratigraphy depicting the sedimentary texture is prepared in order to understand the pattern of sedimentation/ hydrological condition during the deposition. Survey of India (SOI) toposheets, Google Earth and Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) 1 arc seconds (30 meter resolution) are used to demarcate geomorphological feature of the area using tools of Arc GIS 10.3. Hand held THALES Mobile Mapper is used to measure the elevation of the landscape. Using SRTM DEM, Global Mapper and field data, valley cross-section profiles of the sections are drawn.

OSL Chronology

Chronology of the sedimentary deposits is achieved using OSL dating technique, at the Wadia Institute of Himalayan Geology, Dehradun, India. Three samples were collected in 20 cm long and 3.5 cm diameter metallic tube, preventing the exposure of sediments to the day light. Sequential pre-chemical treatment, with 10% HCl and 30% H_2O_2 to remove carbonate and organic matter is done (Srivastava *et al*., 2008). Oven dried samples were sieved, and heavy minerals and feldspar grains were separated using sodium polytungstate (density 2.62 g/cm^3 and 2.67 g/cm^3). The quartz grains thus separated were etched with 40% HF for 80 min followed by 20 min of 35% HCl to remove the α-effected skin (10-20µm). Infrared stimulated luminescence (IRSL) measurement was done to check the feldspar contamination and the samples showing IRSL counts higher than 150 counts/sec were subjected to another 10 minutes of HF treatment (Fig. 2). An automated Risø TL-OSL DA-20 system with blue LEDs stimulation is used to measure the luminescence signals on the separated quartz grains, which is called paleodose (De). Paleodose (De) estimation is obtained using Single aliquot regeneration (SAR) protocol (Murray and Wintle, 2000). A preheat temperature of 220 °C for 10 s was obtained from preheat plateau for estimation of palaeodose (D_E) and is calculated from the aliquots having recycling ration between 0.9-1.1 (±10%) and recuperation ratio <5%. The OSL measurements were done at an elevated temperature of 125°C for 40s. The over dispersion (OD) of the paleodose represents the scattering of the data. For sample PD-19-s, OD is more than ~85% (Table 1), which shows heterogeneity in bleaching. Hence least age model is selected for the sample. Although, the OD for sample D-14 is in acceptable limits but the paleodose

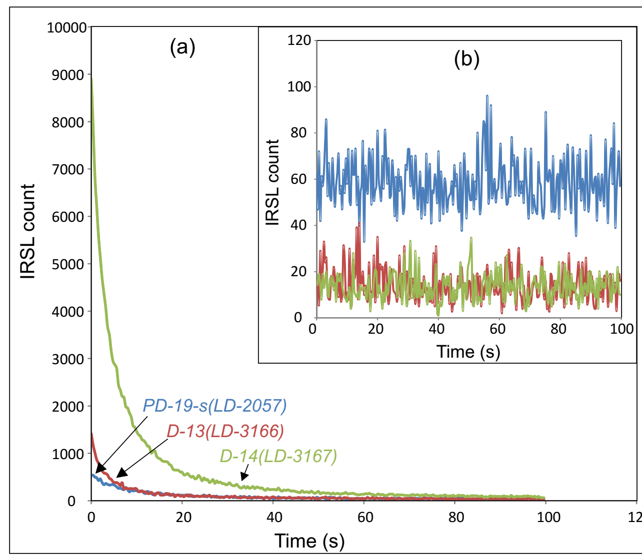

Fig. 2: (a) Infrared Stimulated Luminescence response of the dated samples. (b) Accepted IRSL response after Re-etching the sample.

error is more than 20%, therefore the least age model is selected for this sample too. Partial bleaching of the grains is a major problem in Himalayan samples (Ray and Srivastava, 2010; Kumar and Srivastava, 2017). In case of rapid extreme events it is very common that grains are not fully exposed to the day light before deposition, which leads to over estimation of their age. This problem is tackled by taking least age model (Galbraith *et al*., 1999). Radial plot of all the samples used in the present study are shown in figure 3. Moisture content was assumed to be 10±5% by weight as the study area lies in dry climatic zone. To determine dose rate elemental concentration of U, Th and K in the sample is determined using X-Ray Fluorescence and contribution of cosmic gamma was estimated using Prescott and Hutton, (1994).

Flood velocity and discharge calculation

Minimum flow velocity required to overturn the boulders, at Reru village is calculated following equation (8) and (10) of (Costa, 1983):

$V= 0.20d_i^{0.455}$ ——— (1)

$V=0.18d_i^{0.487}$ ——— (2)

And equation (7) of (O'Connor, 1993):

$V=0.29d_i^{0.60}$ ——— (3)

where, d_i is intermediate axis (in mm) of boulders. Average of all velocity is taken as effective velocity. Paleo-discharge, at Bardangompa section, during flooding is calculated using following empirical formula (Bjerklie *et al*., 2005):

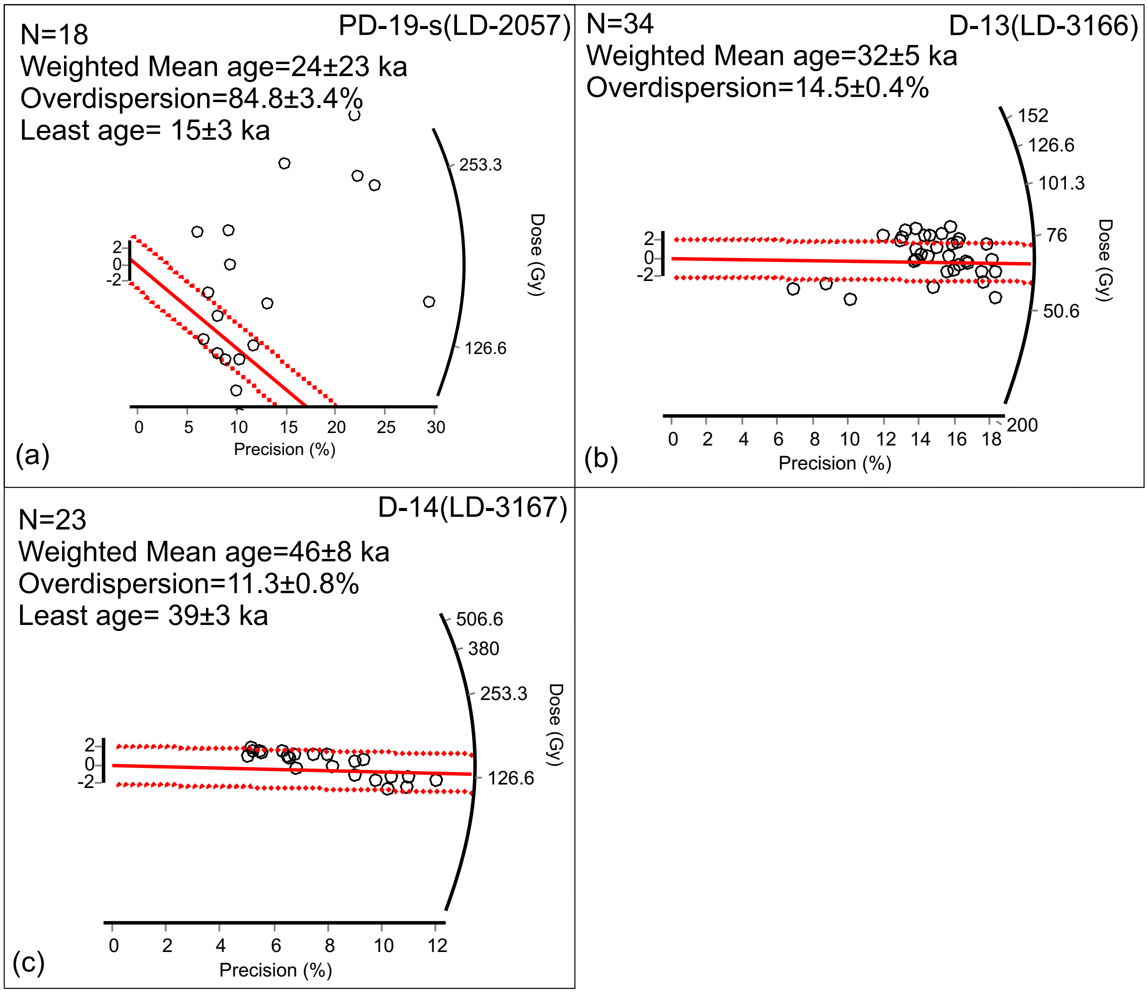

Fig. 3. Radial plots of the OSL samples showing over dispersion and calculated ages for all the samples.

$Q= 7.14 \times WY^{1.67}S^{0.33}$ ——————————————(4)

where, Q is discharge (m^3s^{-1}), S is dimensionless slope, W is channel width (m), and Y is mean channel depth (m). Srivastava *et al*. (2017) used hydraulic radius (R) in place of mean channel depth (Y), because the hydraulic radii are approximately equal to the channel depth for wide valleys. But, in this study we are using the original equation as the valley of Tsrap Chu river is very narrow.

SRTM (DEM) and 1:50,000 SOI toposheets were used to determined value of slope (S) (0.0237 averaged over a distance of 29 km) and valley width (W) (at Bardangompa section). Average thickness of the sand deposit is considered as the minimum possible channel depth. Standard deviation in the value of valley width (averaged over 6 measurements) and channel depth (averaged over 3 measurements) is used to calculate percentage uncertainty associated with the discharge and flood velocity computation.

RESULT

Lithofacies and Sedimentation

Landforms associated with catastrophic outburst flooding events are flood scoured channel ways, giant bars and gravel wave trains (Baker *et al*., 1993). Based on the nomenclature suggested by (Miall, 1996) following gravel and sand lithofacies were identified in the field and classified in five major lithofacies:

Matrix supported massive gravels (Gmm): This lithofacies consist of 3-5 m thick deposits of angular to sub-rounded, unsorted to moderately sorted, matrix supported massive clasts. It has sharp erosional contact with the top and bottom units. Matrix is composed of clay, silt, fine to gritty sand and angular fragments, contributing 50-60% of the bulk volume. Depositional geometry of the facies is lensoidal as well as bedded and 50-200 meters latterly extended. This lithofacies is formed by landslide and/or debris flows from hillslopes (Miall, 1996). Crude orientation of clasts is indicative of transportation under the action of gravity and high sediment-water ratio (Srivastava *et al*., 2017).

Horizontally laminated sand (Sh): This lithofacies is made up of parallel laminated fining upwards, medium to coarse sand. Individual units are 5 cm to 1 m thick and occur in bedded as well as lensoidal geometry and extending laterally up to ~ 150 m.

This lithofacies is deposited during the waning phase of floods under very shallow water depth. The Sh facies can also be deposited during an extreme event like flash flood, when flow

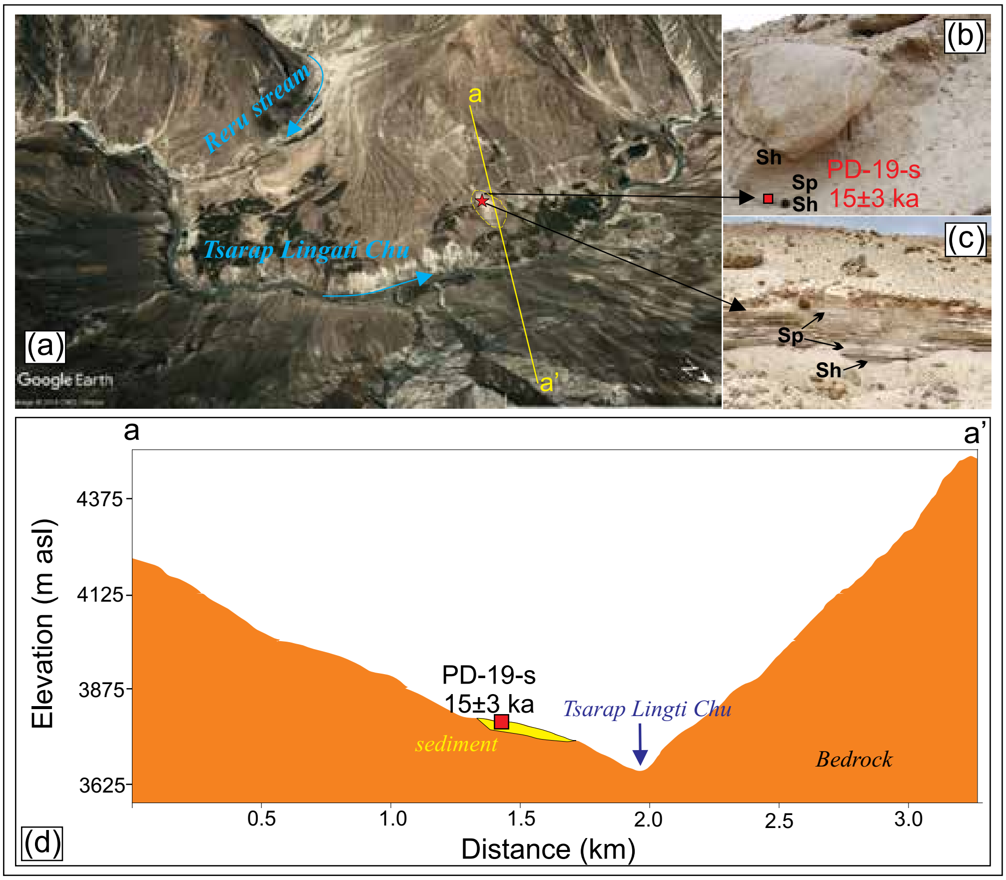

Fig. 4: (a) Google earth image of GLOF deposit at Reru village (shown as A in Fig. 1); (b,c) identified lithofacies of the deposit; (d) Cross-section profile of the Tsrap Lingti Chu at Reru village.

conditions remain in critical stage for many hours, such as when water is in nearly stagnant state results in the formation of sand-silt couplets (Miall, 1996).

Planar cross bedded sand (Sp): The Sp facies is composed of 50 cm to 1 m thick planner cross bedded medium to coarse sand, exhibits lensoidal and bedded geometry extending up to 150 m laterally.

This lithofacies is developed by migration of 2-D dunes. 2-D forms occur at lower flow speed, with simple prismatic cross section giving rise to planar-tabular cross bedding which is bounded by more or less planar surfaces (Miall, 1996).

Rippled Sand (Sr): This facies is composed of fine rippled sand, having thickness varying from 1-5 cm. The wavelength of individual ripple is varied up to 1-2 cm. This lithofacies develops at very low flow speed (<1 m/s) under few decimeters water depth (Miall, 1996).

Laminated clayey silt and sandy silt (Fl): Vertical thickness of this lithofacies varies from 5 to 50 cm with a lateral extension up to 150 m. This facies has lamination of very fine sand, silt and clay. It shows gradational basal contact and sharp top contact. This facies also preserved pene-contemporaneously deformed layers at places.

Fl lithofacies represents deposition from suspension and weak traction current (Miall, 1996). Pene-contemporaneous deformation structures may results due to overloading of sediments and/ or entrapment of ice mass, which on melting results in breaking and slumping of otherwise layered sediments (Reineck and Singh, 1980).

Mega flood evidences

Reru village section (33°20'38.19"N 76°57'16.91"E): This section lies at an elevation of 3813 m a.s.l. in a modified U-shaped valley of the Tsarap Lingti Chu, near the Reru village, where the headwaters of several transverse tributaries have active glaciers. This location is fed by the glacier stream called Reru Phu (Fig. 4a) where, a 1-2 m thick medium to coarse, poorly sorted sand deposit covering an area atleast ~54,000 m^2 is preserved on the terrace surface. There are many sub rounded gneissic boulders of varying size range from 0.3 to 2.8 meters; derived from Higher Himalayan Crystallines (HHCs) are noted strewn on the surface, at ~80 m above river level (arl) (Fig. 4b, c). At the bottom Sh lithofacies is deposited with Sp lithofacies towards the top. The sequence is capped by a discontinuous fine grained clayey silt unit. The paleo-current direction derived from the cross beds shows the flows were directed downward from adjacent hillslope. This indicates that flood was generated, possibly, by the breaching of glacial lake in one of the tributary glacial region in the vicinity of Reru Phu. Cross bedded sand yielded OSL age of 15±3 ka (PD-19-s; in the Fig. 4d, Table 1). Intermediate axes of twenty five boulders spread over the sand heap are used to calculate minimum entrainment velocity required to overturn the large boulders during the flood: 4.86±0.8 m/s (Eq. 8 of

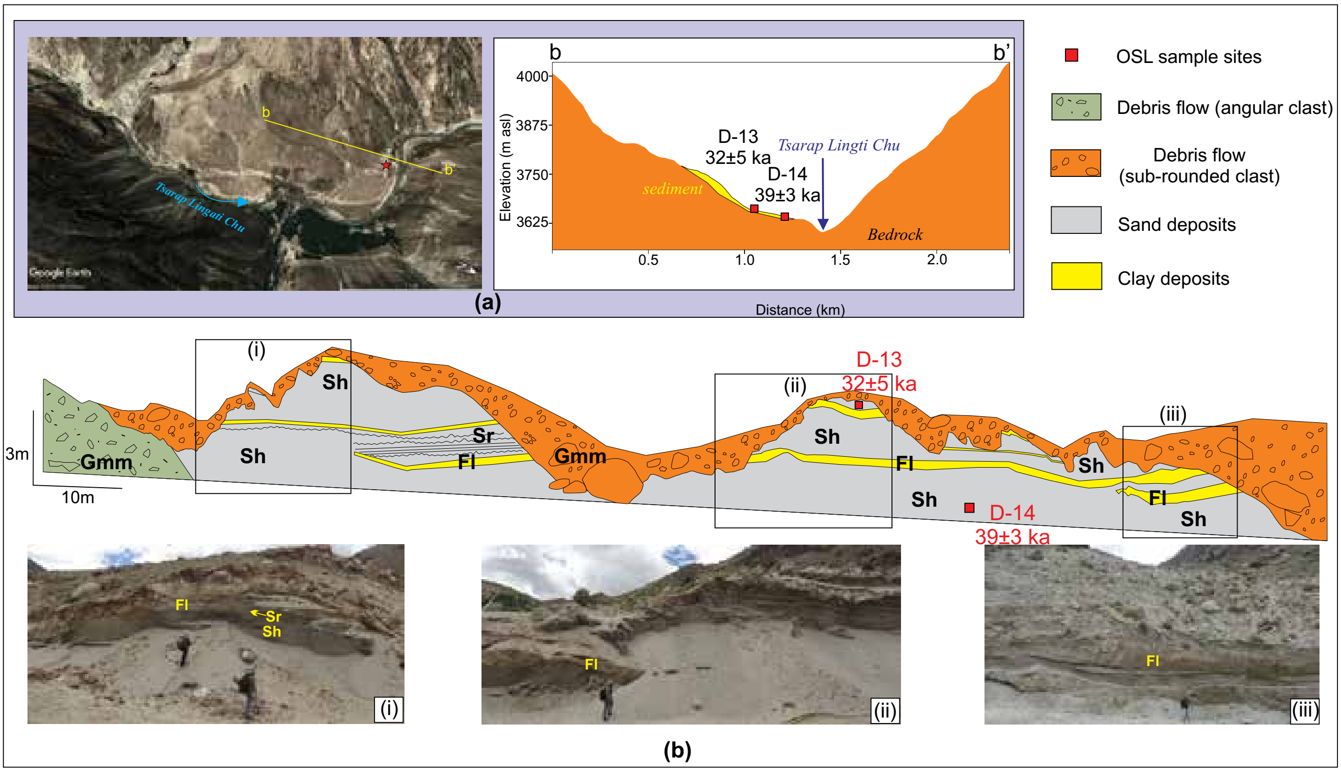

Fig. 5: (a) Google earth image of the outburst deposit and valley cross section profile of Tsrap Lingti Chu at Bardangompa section (b) Lateral litholog of the outburst deposit showing identified lithofacies and field photograph.

Costa, 1983); 5.48±1.0 m/s (Eq. 10 of Costa, 1983); 19.60±4.5 m/s (O'Connor, 1993). An average clast entrainment velocity during the flood was calculated to be 9.98±1.5 m/s, indicates the Reru flood was a catastrophic mega flood.

Bardangompa section (33°23'52.04"N 76°55'14.26"E): This section is located ~6 km downstream of the previous section, on the left bank of Tsarap Lingti Chu (Fig. 5a). It comprises of 3-5 m thick Sh, Sr and Fl lithofacies, which are laterally persisted up to 150 m on the left bank of Tsarap Lingti Chu. Atleast three pulses of poorly sorted, gritty to medium sand are preserved, of which the lower two unit are capped by ~20-30 cm thick clay deposits. Stratigraphically, the sand deposits are underlain by a ~5 m thick lensoidal Gmm lithofacies composed of angular clasts derived from Tethys Sedimentary Sequences and HHC. On the top of sand layers is another Gmm facies unit, which comprises of 1-2 m of subangular HHC gravels. The lowermost sand unit yielded an OSL age of 39±3 ka (D-14; in Fig. 5b) and top most sand unit is 32±5 ka old (D-13; Fig. 5b). At this section, channel width (W) is 350±6 m; mean channel depth (Y) is 4.72±0.4 m; having cross sectional area of 826±83 m^2. Average slope is calculated over a distance of 29 km along the Tsrap Lingti Chu, which is 0.0237. Estimated paleo-discharge during the mega flood event of 39 ka, was 9703±537 m^3/s.

DISCUSSION

Flood Velocity and discharge

The average entrainment velocity of the GLOF event, which deposited a large quantity of sand along with large sized boulders in Reru village is 9.98±1.5 m/s. Presently, there is a lake near the snout of the glacier of the Reru Phu, which appears to be the source lake of this GLOF event. Estimated discharge for the massive sand deposits of Bardangompa is 9703±537 m^3/s. These deposits could have been their genesis attributed to LLOF or GLOF, in the upstream of Tsrap Lingti Chu. Probability of the source of the outburst is higher in the adjacent Temasa Nadi catchment, which have plenty of sediments deposited by receding glaciers.

In the Ladakh Himalaya, frequency and intensity of outburst flood is much higher than the floods related with extreme weather events. Hewitt (1982) shows that ~70 GLOF/LLOFs events were occurred in the last two century, in the north western Himalaya (Fig. 6). Discharges associated with these outburst flood events are also very high and their effect can be seen over hundreds of km downstream of source lake (Richardson and Reynolds, 2000). For example, Chong Kumdan on Shyok River had 1350×10^6 m^3 of water which burst with a peak discharge of 22,650 m^3/s (Hewitt, 1982). Another outburst event with very high discharge is reported from Braldu valleys of Karakoram Himalaya, where peak discharge of 10^4 m^3/s scale had reworked the landforms, during the early Holocene (~10 ka) (Seong *et al.*, 2009). Outburst of the proglacial Batal lake, in Chandra Valley, Lahul Himalaya, had released 1.496 km^3 of water in 0.72 days, with an estimated peak discharge of 21000-27000 m^3/s (Coxon *et al.*, 1996). Evidence of glacial stages in the Tangtse Valley had been overridden by flash flood which occurred due to partial drainage of Pangong Tso, which had released ~18.3 km^3 of water, with estimated discharge of ~110,000 m^3/s (Dortch *et al.*, 2011) (Fig. 7).

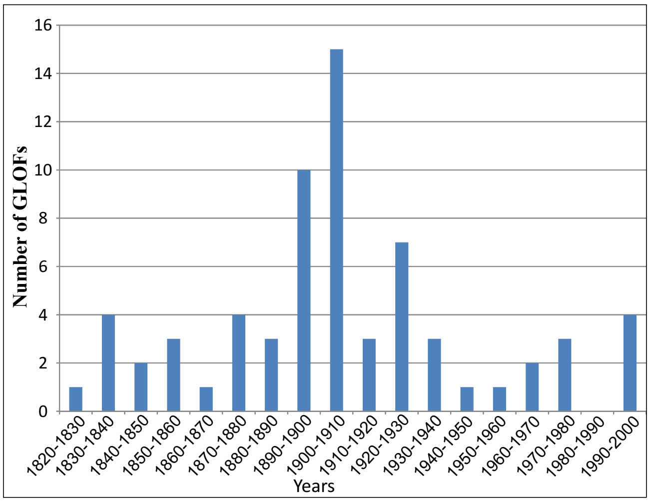

Fig. 6. Frequency of the GLOF event in the upper Indus basin from 1800-2000; after Hewitt, 1982.

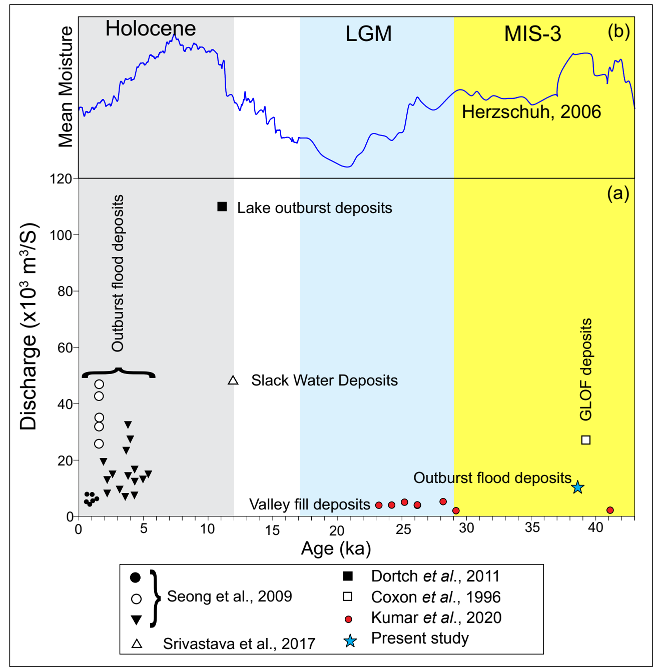

Fig. 7: (a) Outburst flood deposits of NW Himalaya, their estimated discharge and time period of occurrence. (b) Mean effective moisture conditions from Asian monsoon during the last 45 ka (Herzschuh, 2006).

In the Indus valley, discharge during the flooding and non-flooding conditions had been discussed by various workers (Mukhopadhyay and Dutta, 2010; Thayyen *et al.*, 2013; Srivastava *et al.*, 2017; Kumar *et al.*, 2020). Mean discharge of the upper Indus at Leh and Nimu (~40 km downstream) during non-flooding years was estimated to be 189±60 m^3/s and ~850 m^3/s, respectively (Thayyen *et al.*, 2013; Srivastava *et al.*, 2017). During the floods of 2006 and 2010 NHPC (National Hydro Power Corporation) at Alchi (14 km downstream of Nimu) had recorded discharge of 1846 m^3/s and 1940 m^3/s, respectively (Srivastava *et al.*, 2017). And if we see the discharge estimates for the SWD deposits of early Holocene in the same segment of Indus River, it goes up to 47,954 m^3/s (Srivastava *et al.*, 2017). The modelled non flooding discharge from the valley fill deposits of Indus River varies from 834±47 m^3/s to 4457±253 m^3/s during 47-23 ka (Kumar *et al.*, 2020).

The foregoing suggests that the discharge generated by GLOFs and LLOFs is almost twice as experienced by Indus river during phases of valley filling but it is an order of magnitude lower than that generated by breach of large paleolakes (Dortch *et al.*, 2011). However, it must be noted that breach events of large lakes and valley filling phases occur on Milankovitch time scales whereas the GLOFs and LLOFs occur during warmer climatic phases but with much higher frequencies.

Paleo climate and floods

Flash floods in the arid northwest Himalaya, where denudation processes are very slow, have modified the geomorphology widely (Dortch *et al.*, 2011). Lithofacies like matrix supported unsorted gravels (Gmm) indicates chaotic (unsorted) sedimentation which may deposit in high hydrological regime while horizontal sand (Sh) facies are indicators the waning phase of the flood. These facies can be deposited due to GLOFs and LLOFs or due to unusual precipitation. As compared to southern frontal Himalaya, where rainfall is >2000 mm/a and rivers flood almost every year during the monsoon season; Ladakh Himalaya experiences low rainfall <150 mm/a and rivers flood only during the abnormally high ISM and wet and warm climatic conditions (Srivastava *et al.*, 2017). In, the Tsrap Lingti Chu, outburst flooding is observed during wet MIS-3 stage and around 15 ka. Presence of sand deposits capped by finer silt, at Bardangompa village suggests that the sediments were mobilized from the upper reaches (glaciated terrain) before ~39 ka, probably due to the GLOF. The OSL age correspond to the late MIS-3 when the ISM was known to be relatively stronger (Herzschuh, 2006). Similar GLOF events were also active in the Chandra Valley, Lahul Himalaya during the similar time period of ~36-42 ka, which is also related with pluvial wet MIS 3 stage of intensified ISM. OSL chronology of sand deposit with strewed HHC boulders, in the Reru village indicate mobilization of sediment from the northern slopes of the HHC ranges due to breaching of glacial lake present near the snout of unnamed glacier of Reru Phu at ~15 ka. This time period corresponds with the transitional climatic conditions from LGM to Holocene (Herzschuh, 2006). Strengthening of ISM as well as westerlies system during Marine Isotopic Stage 3 (MIS 3) and Holocene time period is also supported by the presence of thick valley fill deposits in the Zanskar and Ladakh Himalaya (Sharma *et al.*, 2016, 2017; Kumar and Srivastava, 2017; Jonell *et al.*, 2018; Chahal *et al.*, 2019). Study carried out in the Lahul Himalaya, also suggests warm and humid climatic conditions dominating in the area during ~18-15 ka (Bohra *et al.*, 2017). Mega floods evidence from the Indus River are recorded in two phases during 14-12 ka and 11-10 ka, which also corresponds with the Holocene Climatic optimum. Deposits of these floods are preserved in the form of SWDs at the Zanskar-Indus confluence (Srivastava *et al.*, 2017). Partial drainage of Pangong Tso, in the Tangtse valley was also reported during the Holocene- phase of intensified ISM, during 9.6-11 ka, although its triggering factor has been discussed to be some seismic activity along the Karakoram Fault (Dortch *et al.*, 2011). Therefore, we surmise that flash flood events like GLOFs and LLOFs occur with high frequency during the phases of warm and wet climatic conditions.

CONCLUSION

Catastrophic floods in the NW Himalaya are generated due to GLOF, LLOF or abruptly intense precipitation mechanism. Presence of outburst flood deposits of ~39 ka, corresponds with relatively wet MIS-3 stage when ISM was intensified and floods with discharge as high as 10^3 m^3/s were generated. Similarly, the presence of ~15 ka old GLOF deposits, suggests retreat of glaciers due to increased temperature and high precipitation during the transitional climatic conditions between LGM to Holocene. Average entrainment velocity of the water was estimated to be 9.98±1.5 m/s which was high enough to carry large boulders having diameters as large as 3 m. The study although preliminary in nature, but nevertheless provides an impetus for detailed investigation in the climate sensitive arid NW Himalaya.

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