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Preliminary optical chronology suggests significant advance in Nubra valley glaciers during the Last Glacial Maximum

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Optical stimulated luminescence chronology obtained on moraines suggests that the Nubra valley was extensively glaciated during the Last Glacial Maximum. We attribute this to the enhanced moisture contribution from the mid-latitude westerlies. Our study negates the suggestion that glaciation in Ladakh and Nubra valley was non-existent due to the weak summer monsoon during the Last Glacial Maximum. Further chronology of the recessional moraines proximal to the present-day Siachen glacier snout suggests insignificant recession in the glacier snout since the last 1 ka.

Keywords: Optical chronology, Last Glacial Maximum, moraines, Nubra Valley, Siachen Glacier.

THE elevated mountains environments are significantly affected by global climate change[1]. The Himalayan mountains and Tibetan Plateau which have significant effect on global climate may have played a key role in the beginning of the Quaternary glaciations[2]. The elevated topography facilitated the development of glaciers during the Quaternary[3] and such records can be used to reconstruct the temporal and spatial variations in the intensity of glaciations[4]. Himalayan glaciers are nurtured by two major moisture sources, viz. the mid-latitude westerlies and the Indian Summer Monsoon (ISM). The influence of westerlies-dominated moisture source to the Himalayan glaciers decreases from northwest (Karakoram) at the spread of ISM as one move eastwards[5].

In the Himalaya, late Quaternary climate variability produced successive glaciations as evidenced by the presence of relict glacial landforms and moraines, which provide an opportunity for reconstructing the regional and global climatic changes provided they are supported by numeric dating[6]. Studies have suggested that the Himalayan glaciers advanced and retreated asynchronously with that of the Northern Hemisphere glaciations[7,8], thus emphasizing the role of ISM as a major driving force of glaciations in the Himalaya[9]. It has been suggested that the valley glaciers during the global Last Glacial Maximum (LGM) were less extensive in the Himalaya[10] and virtually absent in Ladakh[11] and Nubra valley[12].

In the northwestern Himalaya five glacial advances of decreasing magnitude have been identified[11] in the Ladakh Range (Trans-Himalaya) since < 430 ka. This is attributed to the reduction in moisture flux (both by ISM and the westerlies) in the glacier accumulation areas due to uplift of the Himalayan ranges to the south and the Karakoram ranges to the west. A recent study[12] in the Nubra valley failed to locate glacial moraines corresponding to LGM, instead the three glacial stages identified by them were dated to 45 ka, 81 ka and 144 ka respectively. This is contrary to the suggestion made[13] that the Siachen glacier probably occupied the entire Nubra valley (up to Nubra–Shyok confluence) during the LGM. Considering that the major source of moisture in Nubra valley is from the mid-latitude westerlies[14], and the westerlies were known to be enhanced during LGM[5,15], it was reasonable to accept that Nubra valley glaciers should have expanded during LGM. In a recent synthesis of the existing chronometric data[16], it has been suggested that the stratigraphic and chronometric data are too meagre to make any definite inference in favour or against any specific moisture regime for

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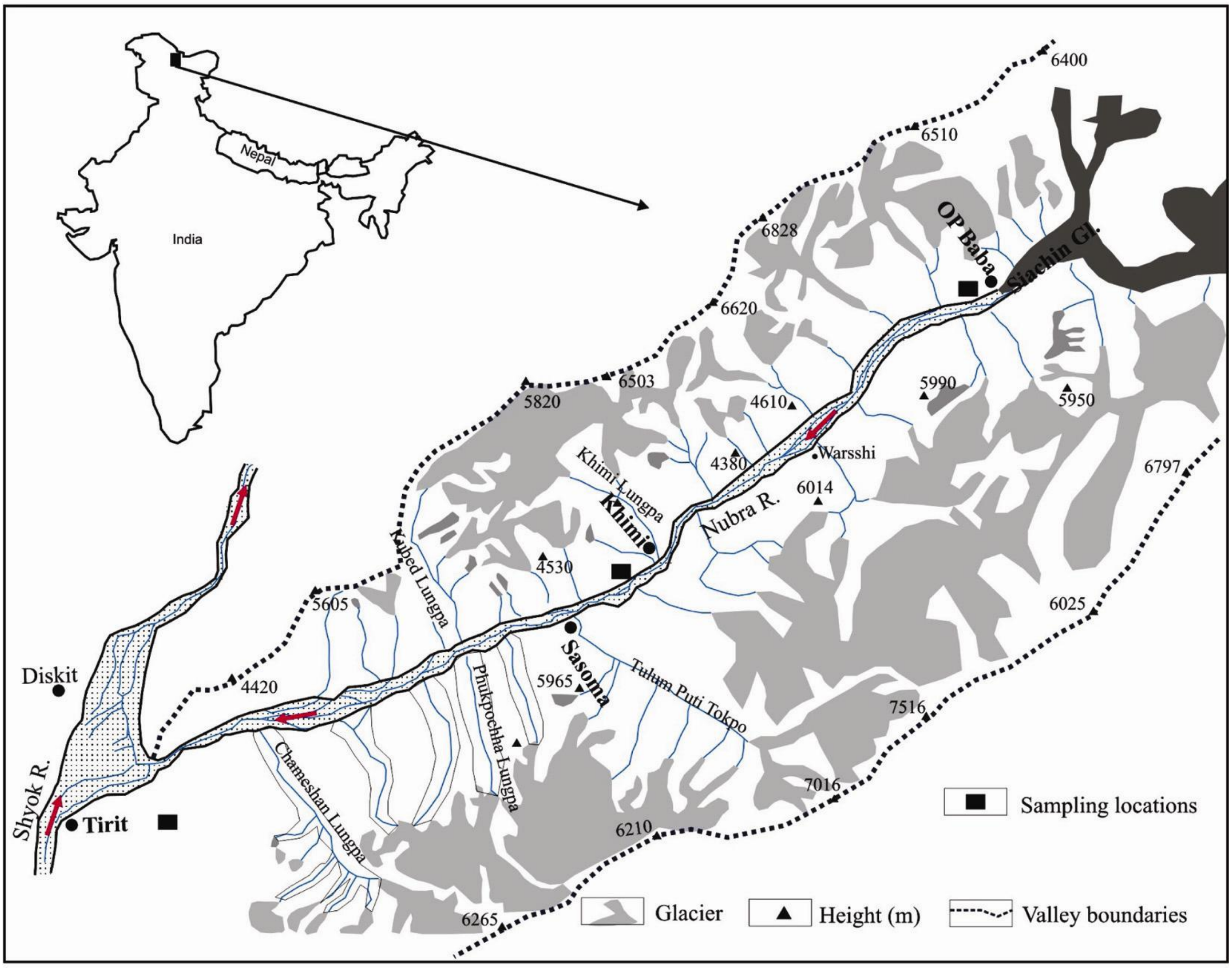

Figure 1. Map showing the Nubra valley. Location of the sections studied and sampled for optical dating is marked as filled cubes.

glacier dynamics in the Zanskar, Ladakh and Karakoram regions. Instead, it is essential to enhance our efforts towards generating a more chronometric database on the glacial deposits for reconstructing the past climate variability. This will help in ascertaining the role of various climatic processes as also correlating events at regional and global scale. In the past the chronology largely relied upon the conventional radiocarbon dating which had limited applicability on moraines due to lack of appreciable carbon. However, with the advent of optical stimulated luminescence (OSL) dating technique, it is now possible to generate reliable age estimate on ice contact sediment (moraines), thus providing direct age of past glaciations[8,17,18].

The present study is therefore a contribution towards improving our understanding of Nubra valley glaciations, particularly to ascertain the role of mid-latitude westerlies and the southwest summer monsoon in driving the late Quaternary glaciations. Nubra valley is located in the Trans-Himalaya and covers the Central Karakoram and Ladakh range in the extreme northwest of India (Figure 1). The major source of moisture in the region is the mid-latitude westerlies with majority of the precipitation occurring during winter[14,19].

A total of five samples have been analysed for OSL dating in the present study. These samples were collected from (i) two recessional moraines near OP Baba shrine (proximal to Siachen glacier snout), (ii) supraglacial fluvial deposits associated with lateral moraine near Khimi village (~30 km downstream of the Siachen glacier snout), (iii) a sand lens embedded in lateral moraines and (iv) supraglacial fluvial deposit associated with the recessional moraines located north of Tirit village (~90 km downstream of the Siachen glacier snout). Figure 1 shows the study area along with the sampling sites. Basic principles of optical dating can be found in Aitken[20]. OSL dating method relies on the principle that during the transportation of sediment, geological luminescence (trapped charges) is reduced to a residual level (bleaching). Once the sediment is buried, accumulation of luminescence occurs due to the ionizing radiation arising from the ambient radioactivity. Hence the luminescence build-up in quartz and feldspar is a function of burial time and the concentration of the radioactivity in the sample environment. Thus, the time elapsed since mineral grains were buried can be determined by measuring both the luminescence signal and estimating the flux of ionizing radiation to which it has been exposed since burial[21]. In case of moraine bleaching of mineral grains remain a suspect because at the depositional site, the sediment will be admixture of whole continuum of environmental conditions, e.g. basal lodgment, melt-out till, englacial and supraglacial till[22]. Therefore, we have to ensure that the sample collected for OSL dating is adequately bleached before deposition. This can be to some extent ensured by sampling the finely laminated and graded sand that occurs as lenses within the moraines and superaglacial fluvial deposits[23,24]. Further with the advent of the Single Aliquot Regeneration (SAR) technique, it is now possible to isolate the well-bleached aliquot from that of the poorly bleached one.

Laminated sand samples within the moraines were collected in specially designed opaque cylindrical tubes made of aluminum or galvanized iron. Samples were analysed in a Riso TL-DA-20 reader using the Blue Light Stimulated Luminescence (BLSL). The detection optics comprised 2×U-340 and BG-39 filters. Beta irradiation was made using a 25 mCi ^{90}Sr/^{90}Y source. The dose-rate estimates relied on XRF analysis for elemental concentrations of uranium, thorium and potassium. A constant cosmic ray dose was used.

The pure quartz extract obtained, after the sequential pretreatment, was analysed using the five-point SAR protocols[25]. The equivalent doses (D_e) were measured using modified single aliquot regeneration method[25,26]. The preheat temperature was decided based on preheat plateau test[25]. The result showed a plateau of D_e in the preheat temperature range 200–240°C (Figure 2); hence preheat of 240°C for 10 sec and cut heat of 200°C were used. The BLSL was measured at 125°C for 40 sec and prior to every BLSL measurement, infrared stimulated luminescence (IRSL) was measured at 50°C for 100 sec to remove any contribution from feldspar. Dose growth curve was constructed using five regeneration dose points, including one point to estimate the recuperation and another point to estimate reliability of sensitivity correction (recycling ratio). A typical OSL decay curve and regeneration growth curve are shown in Figure 3 *a* and *b* respectively. The recuperations were <1% of the natural signal and only those aliquots were considered for age estimation in which the recycling ratio was within 10% of unity. The applicability of the above-mentioned protocol was tested by means of dose recovery test. A known beta dose was given to 10 optically bleached discs and the given dose was measured using the SAR protocol. The average of the ratios of recovered dose to the given dose was 1.05 ± 0.04. The ratios were indistinguishable from unity

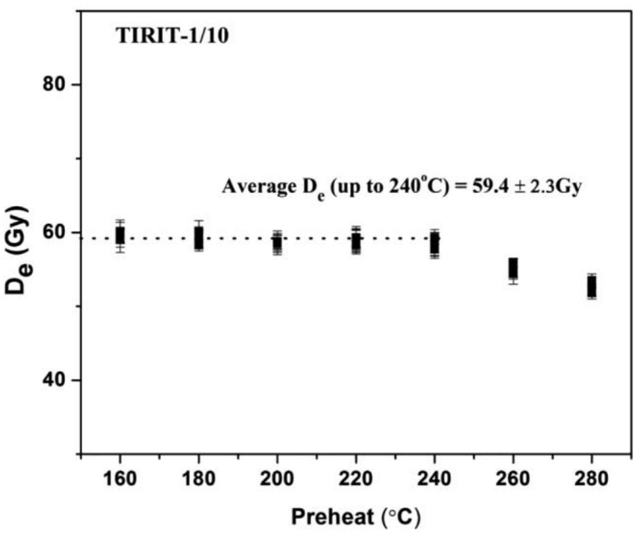

Figure 2. Preheat plateau test performed for the sample TIRIT-1/10.

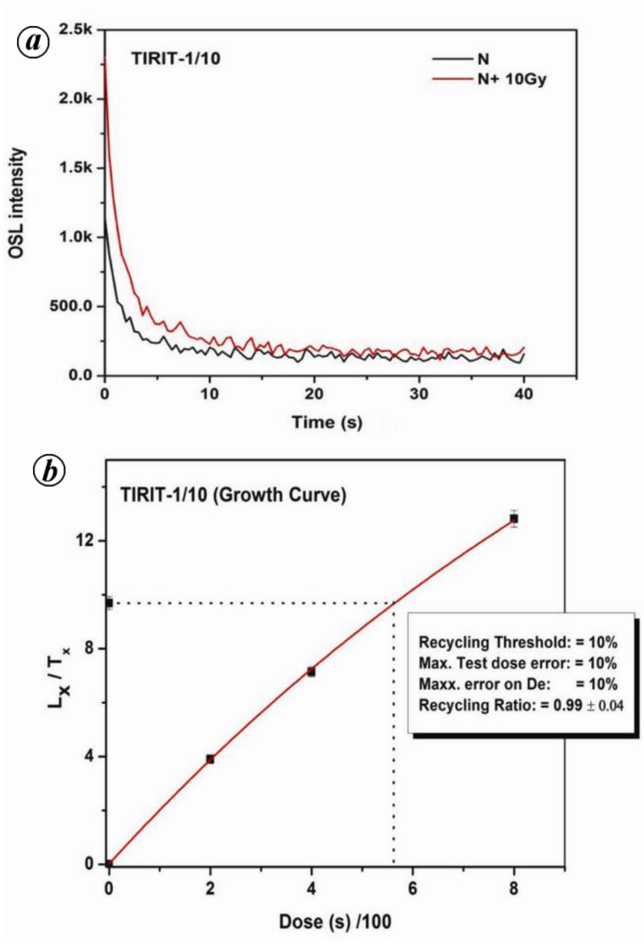

Figure 3. ***a***, OSL shine-down curve of TIRIT-1/10 (natural and with 10 Gy of Beta dose). ***b***, Dose response curve of TIRIT-1/10.

Table 1. Radioactivity data, palaeodose, dose rate and BLSL ages obtained on the samples collected from Nubra valley

Sample ID	U (ppm)	Th (ppm)	K (%)	D_e (Gy)	Dose rate (Gy/ka)	Age (ka) (min. 10%)	Age (ka) (MAM*)	Age (ka) (CAM#)
OPB 1/10	2.7 ± 0.1	9.3 ± 0.2	2.2 ± 0.1	2.7 ± 0.2	2.8 ± 0.2	0.90 ± 0.10	1.0 ± 0.4	2.1 ± 0.2
OPB 2A/10	4.5 ± 0.2	12.8 ± 0.3	2.9 ± 0.1	2.1 ± 0.2	3.9 ± 0.3	0.50 ± 0.04	1.0 ± 0.3	2.0 ± 0.2
KHIMI 1/10	1.6 ± 0.1	10.4 ± 0.2	2.5 ± 0.1	71.2 ± 4.0	2.9 ± 0.2	24.0 ± 2.0	27.8 ± 2.5	34.3 ± 3.0
NSC2A/10	2.1 ± 0.1	14.7 ± 0.4	1.9 ± 0.1	69.0 ± 4.0	2.8 ± 0.2	24.0 ± 2.0	28.3 ± 2.4	29.2 ± 2.5
TIRIT 1/10	2.8 ± 0.1	16.1 ± 0.4	1.9 ± 0.1	59.2 ± 3.0	3.2 ± 0.2	18.0 ± 1.0	20.5 ± 2.0	24.0 ± 3.0

BLSL, Blue light stimulated luminescence; *MAM, Minimum age model; #CAM, Centre age model.

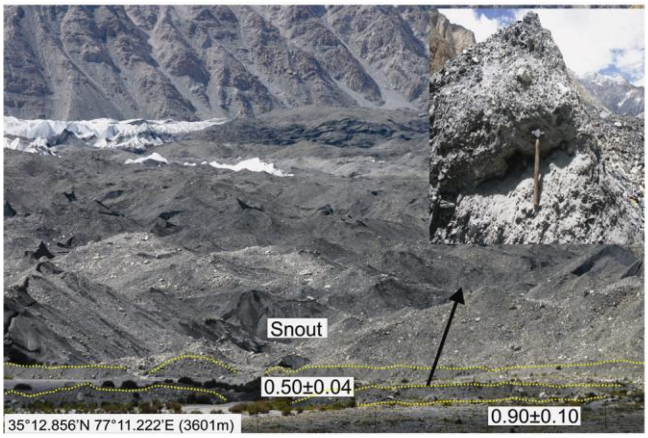

Figure 4. Siachen glacier snout along with the three recessional moraines (highlighted with yellow dotted lines). Optical ages obtained on two recessional moraines are also marked. (Inset) Close-up of the moraine sediment.

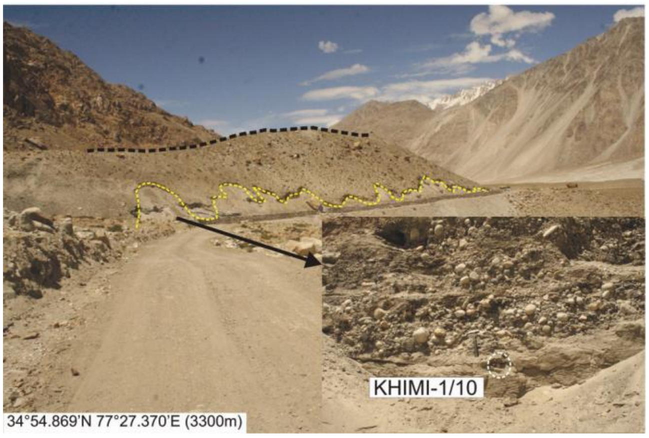

Figure 5. Lateral moraine ridge (marked with black dotted line) near Khimi village. Supraglacial fluvial deposits butting the lateral moraine are also shown (yellow dotted line). (Inset) Close-up of the supraglacial fluvial deposit. White circle marks the sample collected for optical dating.

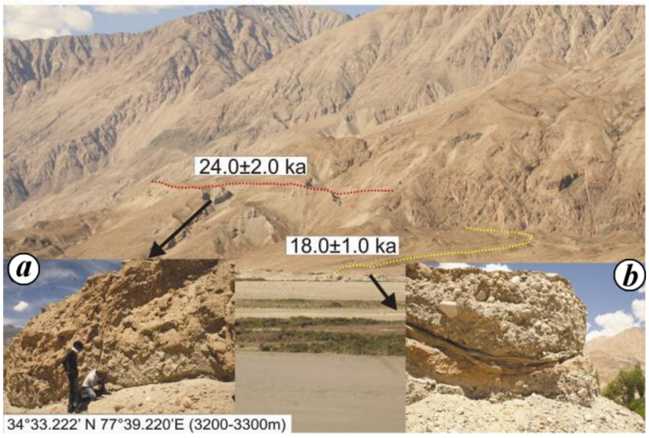

Figure 6. Degraded lateral moraines north of Tirit village at Nubra–Shyok confluence. The older lateral moraine is marked with red dotted line. Sample for optical dating is collected from a sand body present within the tillite (***a***). The younger recessional moraine is shown by yellow dotted line. Sample for optical dating is collected from the supraglacial fluvial deposit (***b***).

and demonstrate the applicability of the protocol. It has been suggested that if the over-dispersion values for multi-grain D_e range from 0% to 35%, the central age model (CAM) is preferred[27–30]. Since the over-dispersion of the D_e values in the present case is >30%, we used both the minimum 10% of D_e with two-sigma error[31] and the minimum age model (MAM)[32]. Table 1 gives the radioactivity data, palaeodose (D_e), dose rate and BLSL ages obtained using CAM, MAM and minimum 10%. As can be seen from Table 1, the ages obtained using minimum 10% and MAM age model are comparable within the errors. Hence, in the subsequent discussion minimum 10% ages are used.

Although the ages are limited, they cover the entire Nubra valley. Two recessional moraines near OP Baba shrine are dated between 0.90 ± 0.1 ka (OPB 1/10) and 0.50 ± 0.04 ka (OPB 2A/10; Figure 4). The lateral moraine below Khimi village opposite Sasoma is dated 24.0 ± 2.0 ka (Khimi 1/10; Figure 5), whereas the lateral and recessional moraines north of Tirit village are dated 24.0 ± 2.0 ka (NSC 2A/10) and 18.0 ± 1.0 ka (TIRIT 1/10) respectively (Figure 6).

Based on the existing chronology it can be suggested that Nubra valley was extensively glaciated during 24 ka and 18 ka, a period corresponding to the LGM. Since the LGM ages are obtained from (i) 30 km below Siachen glacier below Khimi village and (ii) ~90 km downstream near Nubra–Shyok confluence, it is reasonable to speculate that during LGM, the entire Nubra valley glaciated. This is because in addition to the expansion in the trunk

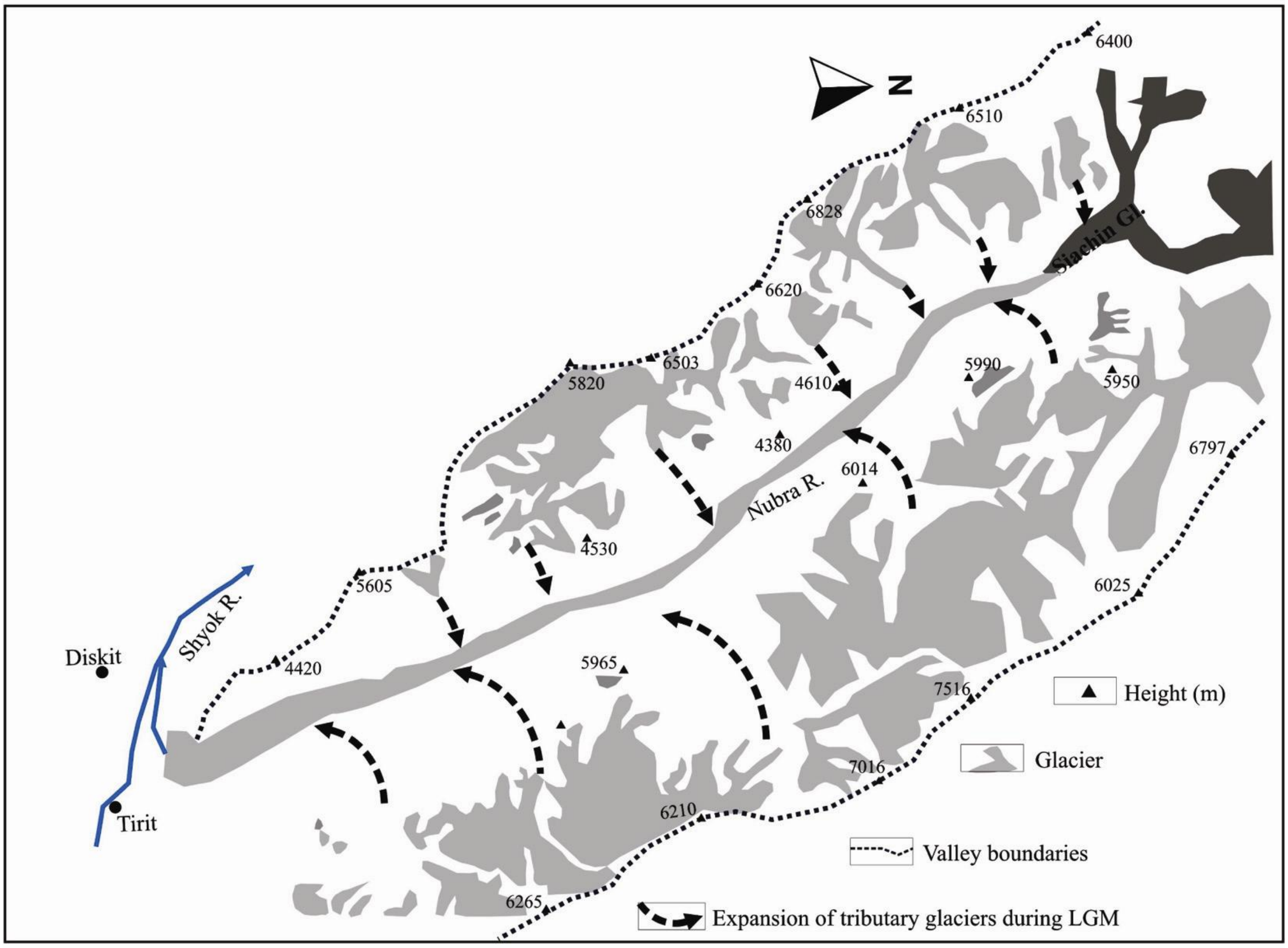

Figure 7. Schematic depiction (based on the optical ages) of the extent of Nubra valley glaciers during the Last Glacial Maximum.

Siachen glacier, a number of north and south draining tributary glaciers would have contributed to the main trunk glacier during the LGM (Figure 7). The above observations from the region suggest that the glaciers responded to the global LGM, thus implying the enhanced role of the mid-latitude westerlies in this Karakoram region during the LGM. Further, the above inference is in conformity with the modern climatic data which show that winter precipitation (westerlies) are the major source of moisture to the glaciers in the Karakoram region[33,34]. In recent times, glaciers in Karakoram region are either marginally advanced or are in standstill condition, which is attributed to the enhanced westerlies[35,36].

On a smaller timescale our chronology on the snout proximal recessional moraines also support the above observation that during the last ~1 ka the Siachen glacier retreated marginally (<500 m), as also suggested in an earlier study[37]. It is worth mentioning here that during the last 1 ka there was a global cooling event called the Little Ice Age (LIA, AD 1600–1850) when the Himalayan glaciers seem to have advanced marginally[38–41]. In view of this suggest that the present position of the Siachen glacier snout is largely climatically driven after the withdrawal of the LIA, with insignificant effect of recent warming trend. The data presented here are preliminary in nature and a more definite inference would wait detailed sedimentological, geomorphological and chronological data, for which study is in progress.

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