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Chronology of late Quaternary glaciation and landform evolution in the upper Dhauliganga valley, (Trans Himalaya), Uttarakhand, India

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ABSTRACT

Detailed field mapping of glacial and paraglacial landforms supported by optical and radiocarbon dating is used to reconstruct the history of late Quaternary glaciation and landform evolution in the Trans Himalayan region of the upper Dhauliganga valley. The study identifies four events of glaciations with decreasing magnitude which are termed as Purvi Kamet Stage -Ia (PKS-Ia), PKS-Ib, PKS-II, PKS-III and PKS-IV respectively. The oldest PKS-Ia and Ib are assigned the Marine Isotopic Stgae-3 (MIS-3), the PKS-II to the Last Glacial Maximum (MIS-2), PKS-III dated to 7.9 ± 0.7 ka, and the PKS-IV is dated to 3.4 ± 0.3 ka and 1.9 ± 0.2 ka respectively.

The largest valley glaciations viz. the (PKS-Ia) occurred during the strengthened summer monsoon corresponding to the MIS-3, following this, the recessional moraines (PKS-Ib) represent the gradual decline in summer monsoon towards the later part of MIS-3. The valley responded to the global Last Glacial Maximum (LGM), which is represented by the PKS-II moraine implying the influence of strengthened mid-latitude westerlies during the LGM. The post-LGM deglaciation was associated with the onset of summer monsoon and is represented by the deposition of four distinct outwash gravel terraces. The early Holocene PKS-III glaciation occurred around 7.9 ± 0.7 ka and broadly coincides with the early Holocene cooling event (8.2 ka). This was followed by the deposition of stratified scree deposits and the alluvial fan (between 5.5 ka and 3 ka) during the mid to late Holocene aridity. This was followed by marginal re-advancement of the valley glacier (viz. PKS-IV) during the late Holocene cool and moist climate. Although glaciers respond to a combination of temperature and precipitation changes, however during the Holocene it seems that temperature played a major role in driving the glaciation.

1. Introduction

Timing, geographic extent and magnitude of Quaternary glaciations of the Himalaya, Tibetan Plateau and the surrounding mountains has attracted significant interest in order to understand the climatic implications of past glaciations. The region holds the most contemporary glaciers outside the Polar Regions, and these glaciers provide melt water for several of the largest Asian rivers (Heyman, 2014). Moreover, and particularly with a projected future warming, (Christensen et al., 2007) a significant impact will occur on contemporary glaciers, climate variability and society. Therefore, it is very important to characterize and quantify past glacial changes for a better assessment of regional and global forcing factors of future glacier behavior, which will provide important insights on glacier response to climate change (Heyman, 2014, Scherler et al., 2010). Although some progress has been made in generating the glacial chronological data, however, the exact mechanism and forcing factors of glaciation is yet to be established in the Himalayan region (Scherler et al., 2010; Owen and Dortch et al., 2014).

The relict glaciogenic sediments can be used to reconstruct the temporal and spatial variability of the late Quaternary glaciations (Duncan et al., 1998; Owen, 2009). The Himalaya is fed by the summer monsoon precipitation and the mid-latitude westerlies (Benn and Owen, 1998; Yang et al., 2008), and the influence of these weather systems vary spatially such that most of the southern and

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eastern part of Himalaya experiences a pronounced summer precipitation which sharply declines northward across the main Himalaya, the mid-latitude westerlies are responsible for a winter precipitation maximum at the extreme west of the Himalaya, Trans-Himalaya and Tibet (Benn and Owen, 1998; Owen, 2009). Previous studies have suggested that the Himalayan glaciers advanced and receded asynchronously with those of the Northern Hemisphere (Benn and Owen, 1998; Richards et al., 2000), emphasizing the role of enhanced summer monsoon. The studies from the Himalaya and the southern Tibet have showed that the glaciers have attained their maximum extension, during MIS-3 for which the strengthened summer monsoon is implicated (Gayer et al., 2006; Owen et al., 2002b; Finkel et al., 2003; Benn and Owen., 1998; Richards et al., 2000; Zhang et al., 2006). However, in a recent exhaustive review on the timing and driver of glaciation across the western Himalaya and Tibet, Dortch et al. (2013) suggested that glacial stages older than 21 ka are correlated with strong monsoons whereas those around 21 ka or younger broadly correlate with global ice volume given by marine Oxygen Isotope Stages, and northern hemisphere climatic events.

Evidence from Higher Central Himalaya indicated that the maximum valley glacier advance occurred during the MIS-3 (Sharma and Owen, 1996; Barnard et al., 2004; Pant et al., 2006; Bali et al., 2013; Ali et al., 2013) followed by the later part of MIS-2 (after LGM) and Holocene (Sati et al., 2014; Scherler et al., 2010; Mehta et al., 2014; Murari et al., 2014). This would imply that monsoon seems to be the major driving factor of glaciation in the Central Himalayan region. However, recent study in the monsoon dominated Goriganga valley by Ali et al. (2013), Pindari valley (Bali et al., 2013), Tons valley (Scherler et al., 2010; Mehta et al., 2014) and Karakoram (Dortch et al., 2013) demonstrated that contrary to the earlier sugestion, a reasonable valley glacier expansion ocurred during the LGM which was ascribed to the eastward penetration of the mid-latitude westerlies.

The present study was undertaken in the transitional climatic zone of the upper Dhauliganga valley (Juyal et al., 2009, Fig. 1), which has preserved the records of glaciation (moraines) and associated paraglacial landforms such as outwash gravel terraces, proglacial lake, alluvial fan and scree deposits. The study is therefore important, as it would help in understanding the sensitivity of the valley glaciers to the climate variability in the transitional climatic zone (viz. the summer monsoon and mid-latitude westerlies) and the glacial surface processes.

2. Study area

The present study was undertaken between Purvi Kamet glacier and Niti village in the upper catchment of the Dhauliganga river between latitude 30° 45′ 0″–30° 55′ 0″ N and longitude 79° 35′ 0″–79°47′ 0″ E of the Central Himalaya, Uttrakhand (Fig. 1). Climatically, it is located between the dry steppe of the Tibetan plateau in the north and the sub-humid Himalayan climate in the south (Juyal et al., 2009). Based on the TRMM data for year 2000–2014, it is observed that the study area receives ~70% precipitation during the summer monsoon whereas the winter monsoon contributes the remaining 30%. Purvi Kamet is a major glacier which feed the Raikana river. Dhauliganga which originates from Ganesh glacier joins Raikana river at Sapuk and flows N–S in the Goting valley (Fig. 2). Following this, the river takes SE turn after crossing Khal Khurans ridge and continue till Niti village (Fig. 2). The basin has a sixth order drainage system comprising of dendritic pattern.

Structurally, the study area is bounded by the South Tibetan Detachment System (STDS) in the south (Rana et al., 2013). STDS defines the tectonic boundary between the higher Himalayan crystalline in the south and Tethyan sedimentary succession in the north (Fig. 3). The SE turn of the Dhauliganga River near Khal Khurans is the geomorphic expression of the STDS (Pant et al., 1998) and the footwall of the STDS acts as orographic barrier for the northward penetration of the summer monsoon. As a result, the majority of the study area north of Khal Khurans presents a cold

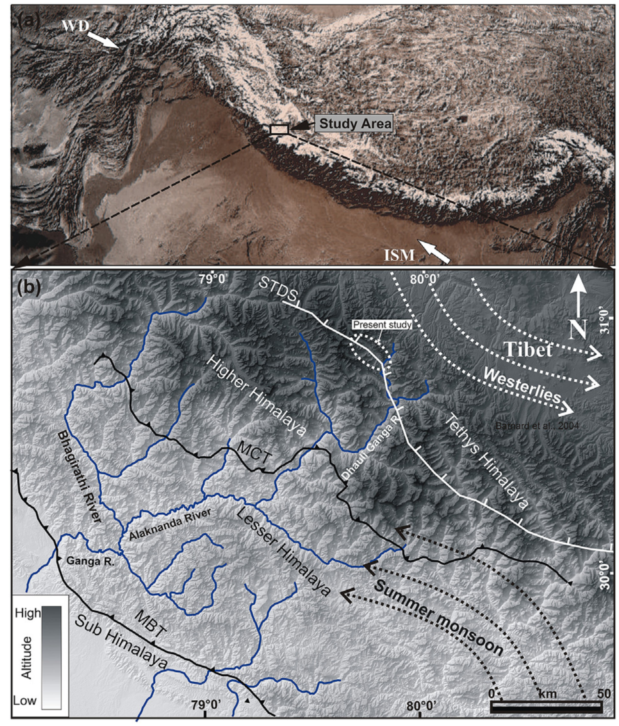

Fig. 1. **(a)** Map showing the regional setup of the area along with the trajectories of weather system viz. the summer monsoon and the mid-latitude westerly. **(b)** ASTER image showing the regional setting of the Uttarakhand Himalaya. Study area is shown as white doted circle.

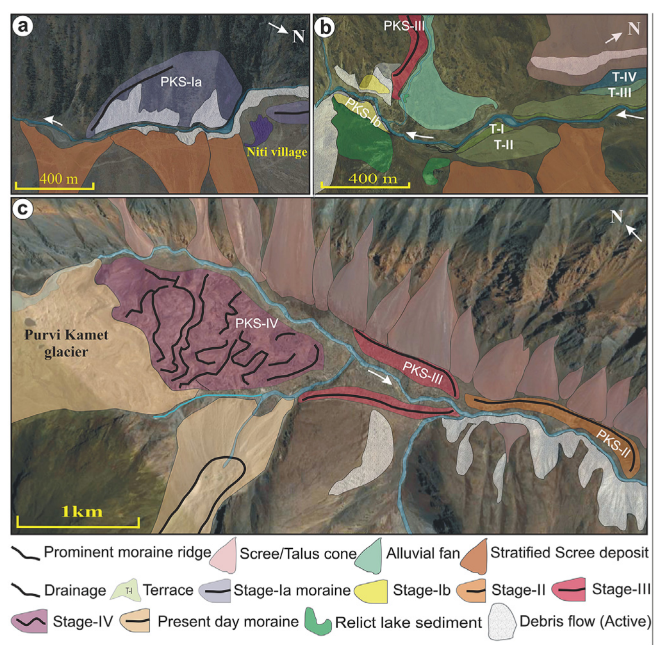

Fig. 2. Detailed geomorphological map of the upper Dhauliganga valley showing the distribution of glacial and paraglacial landforms.