Paleoclimate of the Nepal Himalayas during the Last Glacial: Reconstructing from glacial equilibrium-line altitude

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Himalayas could be characterized by the existence of the glaciers which lies higher than about 5200 m in altitude. In the Ice age, glaciers covered vast area rather than those of the present, and many of the high altitude regions in the Nepal Himalayas have been glacierized earlier. Glacial landforms indicate the existence of the past glaciation, and the limits of glacier extent may suggest paleoclimatic conditions. As widely known-well, the Nepal Himalayas experiences a strong summer monsoon environments, and monsoon precipitation plays an important role in glacier accumulation and fluctuation. And a study about the past glaciation can reveal the monsoon fluctuations in the Himalayas. However, in western Nepal, the amount of winter precipitation, which delivered by the westerlies, should be considered for the glaciation. The western Nepal Himalayas are particularly an important region because they make the junction between the westward summer monsoon and eastward winter westerlies along the southern flank of the great Himalayas. Hence a comparative study on glaciation limit between eastern and western Nepal will lead to understand the relative importance of the monsoon and westerlies during the Last Glacial.

Glacial equilibrium-line altitude (ELA) is the elevation where the accumulation and ablation of the glacier is balanced. This is generally regarded as the snowline altitude on glacier and therefore, it is an appropriate indicator for glaciation and local climate. Where modern glaciers exist, the lowering altitude of ELA can be used as a high resolution proxy of air temperature and precipitation changes. This study addresses on the ELA of the present glaciers in eastern and western Nepal, comparing with that of the last Glacial ones. The aim of this study is to speculate on the climatic change during the global Last Glacial Maximum (LGM). The study sites were the Kanchenjunga and Khumbu Himals in eastern Nepal and Chandi and Api Himals in western Nepal (**Figure 1**).

The present ELA of each glacier was identified by the surface topography of glacier using the latest aerial photo interpretation. ELAs during the global LGM were estimated by the maximum elevation of lateral moraines (MELM) method as described in Dahl and Nesje (1992). In this study, at first, geomorphic maps of glacial landforms were delineated using aerial photographs throughout each region. Successive moraine development designates reiterated glaciations. Stratigraphical relationship and the configuration of these moraines, however, discriminate only those formed during the global LGM. Numerical dating data were inferred from OSL age by Richards et al. (2000) and cosmogenic radionuclide age by Finkel et al. (2003) in the Khumbu Himal and OSL age by Tsukamoto et al. (2002) in the Kanchenjunga Himal. Several methods have been adopted in order to estimate past ELA. However, reconstructed ELA during the LGM is commonly overestimated in the Himalayas due to the steep topography and the influence of blown snow. In this study, the distinguished higher altitudes of the MELM were selected to estimate the ELAs during the LGM. It can demonstrate the minimum amount of ELA depression and it implies paleoclimate practically rather than previous studies.

In **Figure 2**, smaller points and the solid regression lines denote the present ELAs both in eastern and western Nepal. Latitudinal profiles of equilibrium-line display steep gradients in both regions, as a result of the reduction in precipitation by monsoon humid wind blow into the high Himalayas (Müller 1980). Meanwhile glaciers are mainly maintained by sources of summer monsoon moisture. Monsoon vapors were brought as rainfall or snowfall depending on the altitude. Then ELAs at the southern margin in both regions would be subject to the summer air temperature. This is the typical feature of the ELA under the strong summer monsoon environment.

During the global LGM period, the latitudinal ELA profiles show same southward inclination tendency. They suggest that monsoon precipitation is likely to be ruling resource of glacier accumulation. The Nepal Himalayas, hence, were under summer monsoon environment during the LGM as today, even if the monsoon was weakened. Some paleoenvironmental studies suggest a weakening or even a possible loss of the Indian summer monsoon during the LGM. Glaciers were extended, however, by monsoon precipitation and cooling air temperature. In eastern Nepal, the inclination of equilibrium-line enhanced southward (**Figure 2B**), interpreted as a consequence of the decreased precipitation northward and arid condition toward Tibet. In contrast, in western Nepal, glacial equilibrium-line inclined southward equally as today (**Figure 2A**). Therefore western Nepal is expected to belong under similar climatic condition, even though summer precipitation was decreased. Winter precipitation delivered by mid-latitude westerlies, possibly sifted farther to the south and was enhanced. It affected the glacier maintenance in western Nepal. In this way, relative climatic enhancement or weakening between monsoon and westerlies controlled the style and timing of glaciations in the Nepal Himalayas.

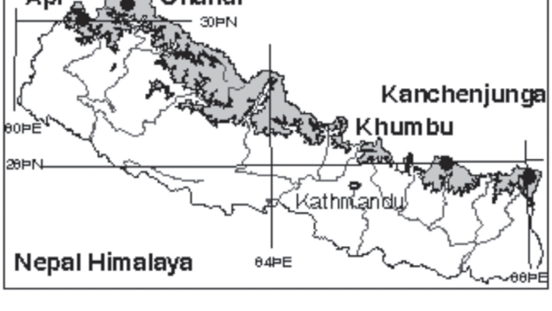

FIGURE 1. Location of the study area in the Nepal Himalayas

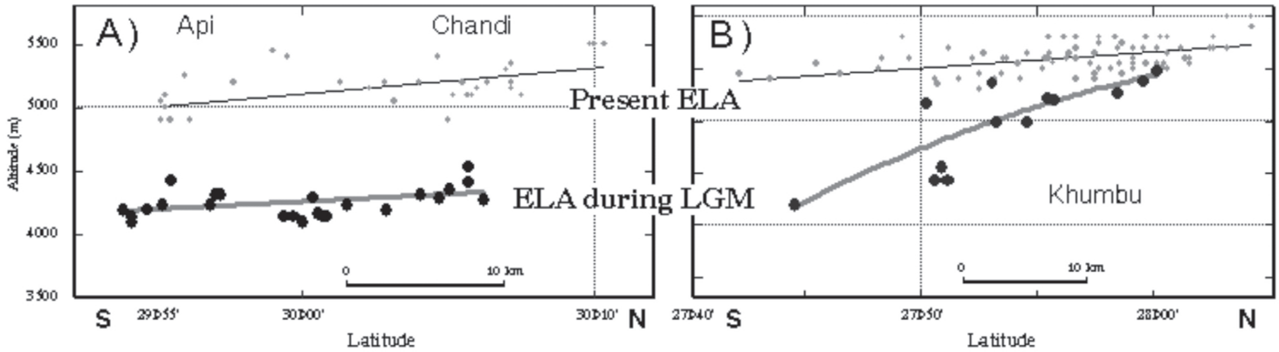

FIGURE 2. Latitudinal profiles of glacial equilibrium-line altitudes (ELAs) of the present and the global LGM in the southern flank of the Nepal Himalayas. A) Api and Chandi Himals from western Nepal, B) Khumbu Himal from eastern Nepal

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