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Late Pleistocene glacial advances in the western Tibet interior

William H. Amidon [a,*], Bodo Bookhagen [b], Jean-Philippe Avouac [c], Taylor Smith [b], Dylan Rood [d]

[a] Geology Department, Middlebury College, Middlebury, VT 05753, United States
[b] Geography Department, University of California Santa Barbara, Santa Barbara, CA 93106, United States
[c] Department of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, United States
[d] Scottish Universities Environmental Research Center, Glasgow, Scotland, G12 8QQ, United Kingdom

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ABSTRACT

It has long been observed that the timing of glacial advances is asynchronous across the Himalaya–Karakoram–Tibet Plateau (HKTP) but the climatic implications, if any, remain unclear. Resolving this question requires additional glacial chronologies from unique spatial and climatic regimes as well as an analysis of how glaciers within different regimes are likely to have responded to past climate changes. This study presents a ^{10}Be–^{21}Ne chronology from the Mawang Kangri range of western Tibet (∼34°N, 80°E); an arid high-elevation site. We identify advances at ∼123, 83, and 56 kyr, which agree reasonably well with sites in the immediate vicinity, but are asynchronous relative to sites across the entire HKTP, and relative to sites in the western HKTP. To evaluate HKTP-wide asynchroneity, we compile dated glacial chronologies and classify them by the approximate timing of their maximum recent advance. This result shows a strong spatial clustering of young (MIS 1–2) relative to older (MIS 3–5) maximum advances. Further comparison with modern precipitation, temperature, and topographic data show that the pattern of HKTP-wide asynchroneity is broadly independent of topography and can potentially be explained by local responses to changes in temperature at either very warm-wet or cold-dry sites. Sites that receive intermediate amounts of precipitation are more ambiguous, although spatial clustering of MIS 1–2 vs. MIS 3–5 advances is suggestive of past variations in precipitation at these sites. In western Tibet, no spatial or climatic correlation is observed with the timing of maximum glacial advances. We suggest this could arise from mis-interpretation of disparate boulder ages generated by a prolonged MIS-3/4 glacial advance in the western HKTP.

1. Introduction

Glaciers on the Himalaya–Karakoram–Tibet Plateau (HKTP) span a wide range of climatic conditions, from temperate maritime glaciers in the south and east, to dry-cold continental glaciers in the north and west. This variability is due to topography and to the climatic influences of the East Asian and Indian Monsoons in the east and south, and the mid-latitude westerlies, and Siberian high-pressure systems to the west and north (Benn and Owen, 1998; Rupper et al., 2009; Scherler et al., 2010; Seong et al., 2007). Because glacial chronologies are the most ubiquitous and easily accessible climate proxy on the HKTP, they hold a potentially useful record of how these climate systems changed over time. Cosmogenic nuclide dating of moraines has recently expanded the number of well-dated moraine sequences available on the HKTP, revealing that glacial advances throughout the HKTP are asynchronous (Chevalier et al., 2011; Heyman et al., 2011a; Owen et al., 2010, 2012). For example, many glaciers in the HKTP interior experienced maximum advances during Marine Isotope Stage (MIS) 3 or 4 (∼73–28 ka), whereas many glaciers on the HKTP margins peaked during MIS-2 (∼28–12 ka). The paleoclimatic interpretation of this asynchroneity remains unclear. Recent studies have proposed a range of explanations, calling upon changes in the strength of climatic systems (e.g. Benn and Owen, 1998; Owen et al., 2005), temperature variations (e.g. Rupper et al., 2009; Shi, 2002), topographic/hypsometric differences between neighboring catchments (Derbyshire, 1996; Owen et al., 2005), or a combination of several climatic parameters acting at different timescales (Scherler et al., 2010).

An alternative explanation for regional asynchroneity in some parts of the HKTP is incorrect interpretation of cosmogenic boulder ages. Most MIS-3/4 moraines in arid parts of the HKTP yield wide-ranging cosmogenic boulder ages, making it difficult to assign a mean age to each moraine (e.g. Chevalier et al., 2011; Hedrick et al., 2011). Variability in boulder ages is often attributed to post-depositional moraine degradation, implying that older boulder ages are more likely to record the timing of maximum glacial

* Corresponding author. Tel.: +1 802 443 5988.
E-mail address: wamidon@middlebury.edu (W.H. Amidon).

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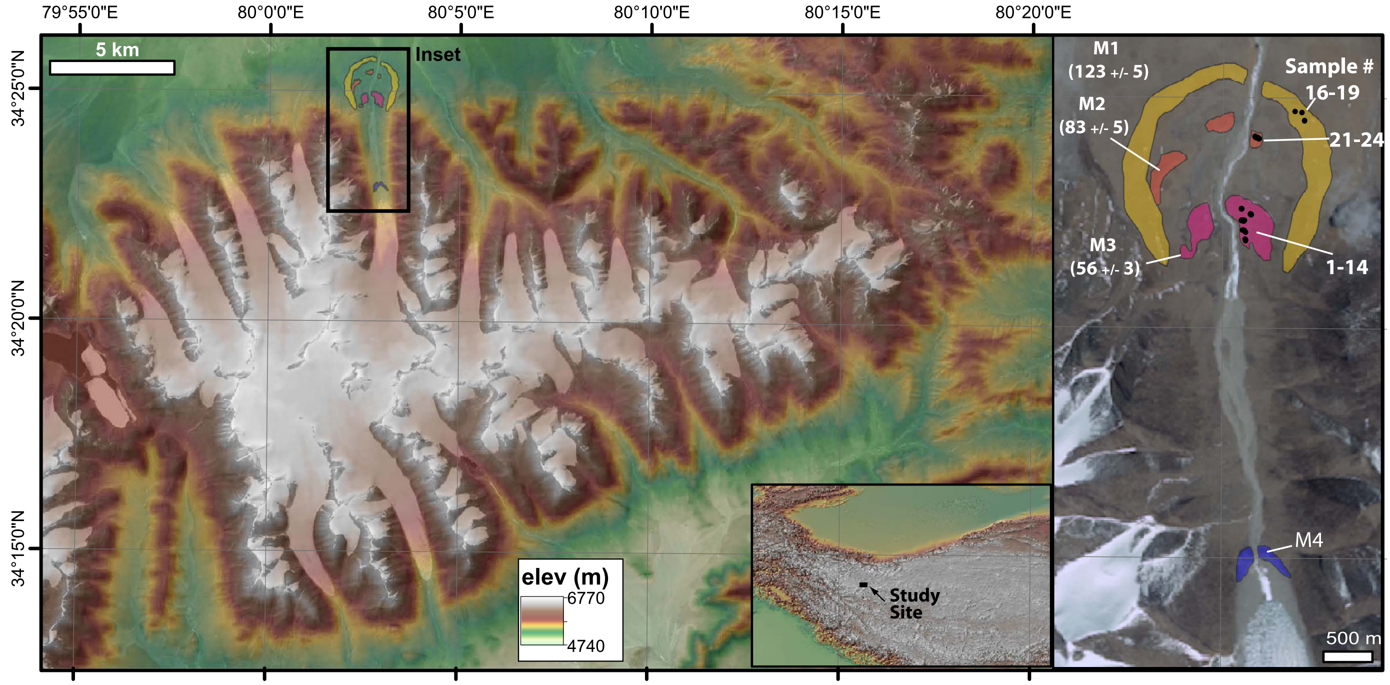

Fig. 1. Shaded-relief digital elevation model (DEM) of the Mawang Kangri range. Right panel shows close-up of Mawang Kangri (MK) ice cap and outlet glaciers on a SPOT-5 satellite image. The three-dated moraines are shown with 1σ age uncertainties. The highest moraine (M4) is the presumed, but yet undated, MIS-1/2 moraine near the glacier terminus.

advance (Heyman et al., 2011b; Putkonen and Swanson, 2003). In some cases, large age spreads may be related to glacial dynamics, such as the slow retreat of glacier termini in arid regions (Zech et al., 2005b). Thus, although testing asynchroneity requires robust moraine ages, it is possible that the quality of ages may be directly related to the climatic setting and mass balance response time of the glacier. Determining whether asynchroneity on the HKTP arises from paleoclimatic variations or poorly interpreted data is a difficult problem requiring additional well-dated moraine sequences and comparison with modern climatic data.

In this study we use in-situ cosmogenic ^{10}Be and ^{21}Ne dating of moraine boulders to develop a glacial chronology from the Mawang Kangri (MK) range in western Tibet (Fig. 1). Although the timing of advances (~123, 83, and 56 kyr) agrees well with some nearby sites, they do not match advances elsewhere in the western HKTP, suggesting asynchroneity. This may be partially because the MK site is one of the highest, coldest, driest, and most interior sites yet dated on the HKTP (glacial terminus at 5445 m asl). To understand the apparent asynchroneity, we perform a spatiotemporal analysis of maximum glacial advances on the entire HKTP. We explore two spatiotemporal cases of asynchroneity. First, we confirm the HKTP-wide asynchroneity mentioned above by showing maximum advances at interior and western sites occurred during MIS-3–5, earlier than maximum MIS 1/2 advances at many sites along the margin of the HKTP (Owen et al., 2005, 2002). Second, a western-HKTP asynchroneity is shown by the disagreement between the timing of MIS-3/4 advances at sites within the western HKTP. We explore the spatiotemporal dynamics causing these two cases by extracting modern precipitation, temperature, and topography data at well-dated glacial sites. We interpret the data in the context of two end-member hypotheses. First, does asynchroneity reflect unique local responses to broad-scale systematic changes in climatic forcing (e.g., temperature) across the entire HKTP? Alternatively, is asynchroneity caused by changes in the spatial pattern of precipitation or temperature over time? Our four main findings are: (1) the HKTP-wide asynchroneity can be explained by local responses to a systematic drop in temperature at end-member warm-wet and cold-dry sites; (2) advances at intermediate precipitation sites may reflect changes in spatial patterns of precipitation during MIS-1/2; (3) apparent western HKTP asynchroneity cannot be explained by either hypothesis, and may arise from the effects of prolonged glacial advances on moraine stability; and (4) topography does not exert a first order control on the timing of maximum glacial advances on the HKTP.

2. Geographic and climatic setting

2.1. Mawang Kangri (MK) field site

The MK mountain range sits in the far western interior of the Tibetan Plateau, consisting of several ~6400 m high peaks protruding above a small ice cap, which feeds multiple incised glacial valleys (Figs. 1 and 2). This study focuses on an unnamed valley near 34.3°N and 80.1°E, with a drainage area of ~44 km^2, and ~916 m of relief between the modern glacial terminus at 5445 m and the highest peak at 6368 m. The accumulation zone is dominated by firn basins, with a mean slope of ~15°. The current glacier has an ELA of ~6090 m, based on evaluation of the snow line in satellite imagery from August and September 2004, 2009, and 2010 (SPOT and WorldView imagery accessed via Google Earth). The oldest moraine (M1) is a semi-circular piedmont moraine crest, reaching a minimum elevation of ~5300 m and sparsely adorned with large (>1.5 m) moraine boulders. The intermediate moraine (M2) is a terminal moraine fragment ~380 m upstream from M1, reaching ~5285 m elevation and adorned with smaller, ~0.5 m dimension boulders. The youngest dated hummocky moraine (M3) covers ~0.2 km^2, defined by a sharp southern edge, giving way to a low-relief surface with several hummocky crests. We interpret this deposit as having formed during a period of glacial stagnation, characterized by minor retreats and advances, and deposition of a large sediment load. A younger, undated terminal moraine (M4) is found ~3.5 km upstream from M3, ~0.58 km from the toe of the modern glacier.