Quaternary Science Reviews 28 (2009) 2150–2164

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Latest Pleistocene and Holocene glacier fluctuations in the Himalaya and Tibet

Lewis A. Owen*

Department of Geology, University of Cincinnati, Cincinnati, OH 45221, USA

ARTICLE INFO

Article history:
Received 16 April 2008
Received in revised form
14 October 2008
Accepted 15 October 2008

ABSTRACT

The timing and extent of latest Pleistocene and Holocene alpine glacier fluctuations in the Himalaya and Tibet are poorly defined due to the logistical and political inaccessibility of the region, and the general lack of modern studies of the glacial successions. Nevertheless, renewed interest in the region and the aid of newly developing numerical dating techniques have provided new insights into the nature of latest Pleistocene and Holocene glacier oscillations. These studies provide abundant evidence for significant glacial advances throughout the Last Glacial cycle. In most high Himalayan and Tibetan regions glaciers reached their maximum extent early in the Last Glacial cycle. However, true Last Glacial Maximum glacier advances were significantly less extensive. Notable glacier advances occurred during the Lateglacial and the early Holocene, with minor advances in some regions during the mid-Holocene. There is abundant evidence for multiple glacial advances throughout the latter part of the Holocene, although these are generally very poorly defined, and were less extensive than the early Holocene glacier advances. The poor chronological control on latest Pleistocene and Holocene glacial successions makes it difficult to construct correlations across the region, and with other glaciated regions in the world, which in turn makes it hard to assess the relative importance of the different climatic mechanisms that force glaciation in this region. The Lateglacial and Holocene glacial record, however, is particularly well preserved in several regions, notably in Muztag Ata and Kongur, and the Khumbu Himal. These successions have the potential to be examined in detail using newly developing numerical dating methods to derive a high-resolution record of glaciation to help in paleoclimatic reconstruction and understanding the dynamics of climate and glaciation in the Himalaya and Tibet.

1. Introduction

The Himalaya and Tibet are the most glaciated regions outside of the polar realm. The glaciers in this region are receding faster than in any other part of the world and are likely to disappear by at least the AD 2035 (Intergovernmental Panel on Climate Change, 2007). These glaciers are the source for innumerable rivers that flow across the Indo-Gangetic Plain and the Central and East China, providing freshwater to billions of people. Yet the nature and dynamics of these glaciers are not well understood. In particular, the timing and extent of past glacier fluctuations are poorly defined, specifically for the latest Pleistocene and Holocene. Furthermore, other geologic proxies for climate change are sparse, particularly for the Holocene, which is well illustrated by Mayewski et al.'s (2004) compilation of data for Holocene rapid climate change that show major gaps in data for the region (Fig. 1). This paucity in paleoclimatic data is partially due to the logistical and political inaccessibility of the region, and the apparent lack of funding for modern studies of the glacial successions.

In recent years, however, renewed interest in the region, especially with the aid of novel remote-sensing technologies and newly developing numerical dating techniques, such as optically stimulated luminescence (OSL) and terrestrial cosmogenic nuclide (TCN) surface exposure dating, have provided new insights into the nature of latest Pleistocene and Holocene glacial oscillations. In compiling and assessing these studies, this paper will review the current knowledge on the nature and timing of latest Pleistocene and Holocene alpine glacier fluctuations for the high mountains of the Himalaya and Tibet. Unless otherwise stated all radiocarbon ages have been converted to calibrated years using Reimer et al. (2004). This paper builds on several recent research and review papers that focus on the Quaternary glacial geology of Central Asia, including three volumes of Quaternary International (Owen and Lehmkuhl, 2000; Owen and Zhou, 2002; Yi and Owen, 2006), summaries for the Global Mapping Project of INQUA on the glacial geology of each country in central Asia (Ehlers and Gibbard, 2004), and regional syntheses and reviews by Lehmkuhl (1997), Owen et al. (1998, 2008), Lehmkuhl and Owen (2005), and Owen and

* Tel.: +1 513 556 3732; fax: +1 513 556 6931.
E-mail address: lewis.owen@uc.edu

0277-3791/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.quascirev.2008.10.020

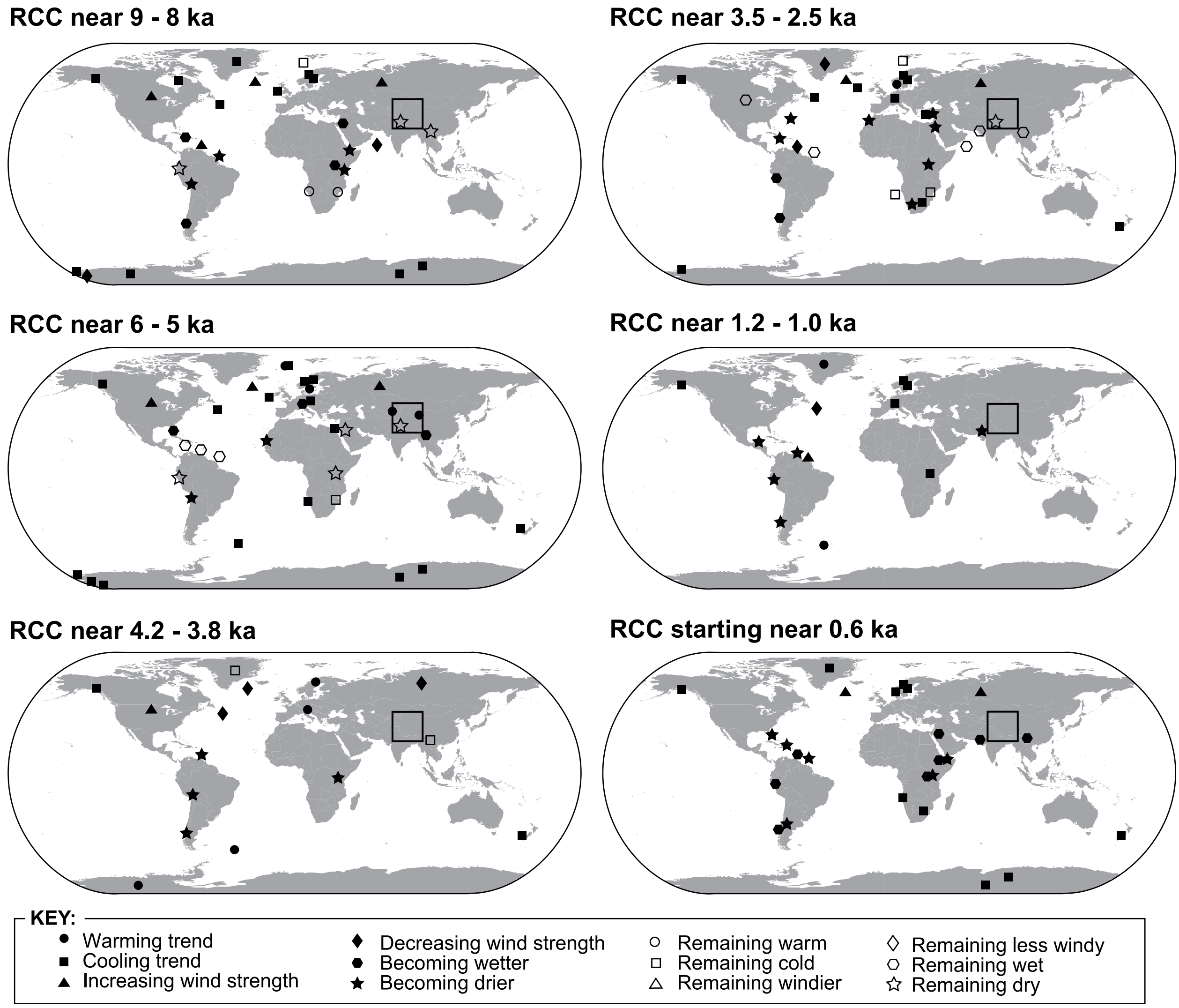

Fig. 1. Map displaying state of climate proxies during six periods of significant rapid climate change (RCC) (~9.0–8.0, 6.0–5.0, 4.2–3.8, 3.5–2.5, 1.2–1.0, and since 0.6 ka) identified by Mayewski et al. (2004) showing the location of the study area. Note the paucity of data covering the Himalaya and Tibet.

Benn (2005). This paper differs, however, in focusing on summarizing and highlighting the current, and gaps in, knowledge of the latest Pleistocene and Holocene glacial record for the region. Furthermore, this paper highlights the potential of using the Holocene record in understanding the nature of climate change in the mountains of central Asia.

2. Regional setting

The mountains of Central Asia discussed in this paper include: the Himalaya, Transhimalaya, Tibet and Pamir (Fig. 2). These mountain ranges are essentially the consequence of the collision of the Indian and Eurasian continental plates, which initiated ~50 Ma (Yin and Harrison, 2000). Most of these mountain ranges, however, have a longer geologic history and comprise a complex assemblage of rocks of different ages (Yin and Harrison, 2000). The region considered in this paper stretches ~2000 km east–west and ~2500 km north–south and has an average altitude of ~5000 m above sea level (asl).

The region is influenced by two dominant climatic systems: the mid-latitude westerlies and the south Asian monsoon (Benn and Owen, 1998). Numerous studies have attempted to link long-term (thousands of years) variations in these climatic systems, influenced by changes in Northern Hemisphere insolation, and shorter-term variations (years to decades), explained by changes within the climate system, to mountain glacier fluctuations throughout the Quaternary (for overviews see Lehmkuhl and Owen, 2005; Owen and Benn, 2005; Owen et al., 2008). The influence of the two climatic systems varies spatially such that most of the southern and eastern region experiences a pronounced summer precipitation maximum, reflecting moisture advected northwards from the Indian Ocean by the southwest monsoon, while summer precipitation declines sharply northward across the main Himalayan chain and is very low over western Tibet. The mid-latitude westerlies are responsible for a winter precipitation maximum at the extreme west of the Himalaya, Transhimalaya and Tibet, as a consequence of moisture being advected from the Mediterranean, Black, and Caspian Seas. As a corollary of these moisture gradients, snow and ice accumulation across the region varies considerably and has a profound effect on glaciations, with equilibrium-line altitudes (ELAs) varying from 4300 m asl in southeast Tibet to over 6000 m asl in western Tibet (Owen and Benn, 2005). Furthermore, variations in the relative roles of these climatic systems would be expected to result in dramatic differences in extent of glaciations across the region and possibly result in asynchronous glaciation throughout the Quaternary (Benn and Owen, 1998).

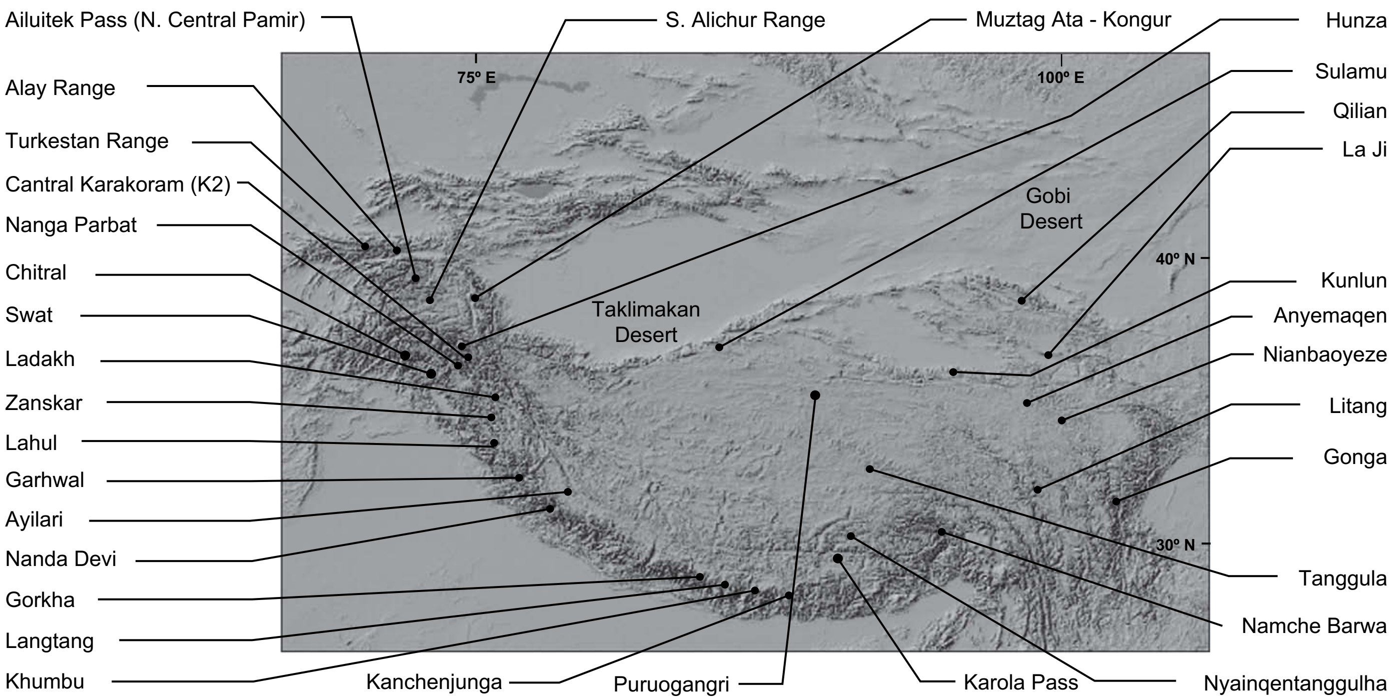

Fig. 2. Digital elevation model of Tibet and the bordering mountains showing the main regions discussed in this paper.

Glacier types vary considerably across the region as a consequence of these sharp climatic gradients. Derbyshire (1982) recognized three main glacial regimes, which include: a continental regime that span the Transhimalaya and western and central Tibet, the Tien and Altai; a maritime regime in the Himalaya and eastern Tibet; and a transitional regime in northeastern Tibet (Derbyshire, 1982). Derbyshire (1982) highlighted the differences in the geomorphology, lithofacies and landsystem types associated with each glacial region. This regional variability has been expanded by Owen and Derbyshire (1988, 1989) and Benn and Owen (2002) who provide detailed studies of the glacial geomorphology and sedimentary throughout Tibet and the Himalaya.

3. Reconstructing the former extent of glaciations

The extent of Late Quaternary glaciation throughout the Himalayan–Tibetan region has been reconstructed by numerous researchers, most notably Klute (1930), Frenzel (1960), Kuhle (1985) and Shi (1992). Lehmkuhl and Owen (2005) and Owen et al. (2008) discuss these studies and favor the reconstruction of Li et al. (1991) (Fig. 3). In stark contrast to other researchers, Kuhle (1985, 1986, 1987, 1988a,b, 1990a,b, 1991, 1993, 1995) argued for an extensive ice sheet covering most of the Tibetan Plateau during the Last Glacial. Numerous studies in the past few decades, however, have presented evidence against an extensive ice sheet on Tibet (Derbyshire, 1987; Zheng, 1989; Burbank and Kang, 1991; Derbyshire et al., 1991; Shi, 1992; Shi et al., 1992; Hövermann et al., 1993a,b; Lehmkuhl, 1995, 1997, 1998; Rutter, 1995; Lehmkuhl et al., 1998; Zheng and Rutter, 1998; Schäfer et al., 2002; Owen et al., 2003a). The differences in interpretation between Kuhle (1985, 1986, 1987, 1988a,b, 1990a,b, 1991, 1993, 1995) and other researchers are a consequence of different interpretation of landforms and sediments, the misuse of ELAs for determining former ice extent, and poor chronological control. This difference in interpretation is discussed in more detail in Lehmkuhl et al. (1998), Owen et al. (2008) and Seong et al. (2008). It is now generally accepted that a large ice sheet did not cover the Tibetan Plateau, at least not during the past few glacial cycles. The Tibetan ice sheet hypothesis, therefore, will not be discussed further in this paper.

Li et al.'s (1991) reconstruction of the maximum extent of glaciation for the entire Himalaya and Tibetan Plateau, which is based on field mapping, is an extremely impressive compilation and provides an excellent framework to examine the nature of Late Quaternary glaciation. However, the compilation lacks strong temporal control and it is unlikely that the reconstructed glaciers reached their maximum extents at the same time during the Last Glacial (Lehmkuhl and Owen, 2005; Owen et al., 2008).

Numerous studies provide detailed reconstructions of former glacier extent throughout the Himalaya and Tibet. These tend to focus on classic geographic areas, for example, Mount Everest, Nanga Parbat, and Xixabangma, and there is often little correlation between regions. Many of these studies are summarized in Ehlers and Gibbard (2004). The extent of glaciation between regions can vary significantly. Owen et al. (2008) illustrate this variation by providing an example for the Lateglacial at the western end of the Himalaya, where they highlighted that in the Hunza valley, in the northeastern part of the region, glaciers only advanced a few kilometers from their present position, whereas in the Central Karakoram to the east an extensive valley glacier system extended more than 100 km from the present ice margin. To the southeast of these regions, in Ladakh, there is little evidence of a glacier advance during the Lateglacial, and when glaciers did advance they were restricted to not more than a few kilometers from their present ice margins. In contrast, south of Ladakh, in the Lahul Himalaya, glaciers advanced many tens of kilometers beyond their present positions during the Lateglacial. Owen et al. (2005, 2008) argued that the contrast in the extent of glaciation throughout the Himalaya and Tibet, and within relatively small regions, is a consequence of steep climatic gradients and strong topographic controls.

In summary, Late Quaternary glaciation in the region was exemplified by expanded ice caps and extensive valley glacier systems, but not an overriding ice sheet. The details of local variability for selected times throughout the Late Quaternary will be summarized below.

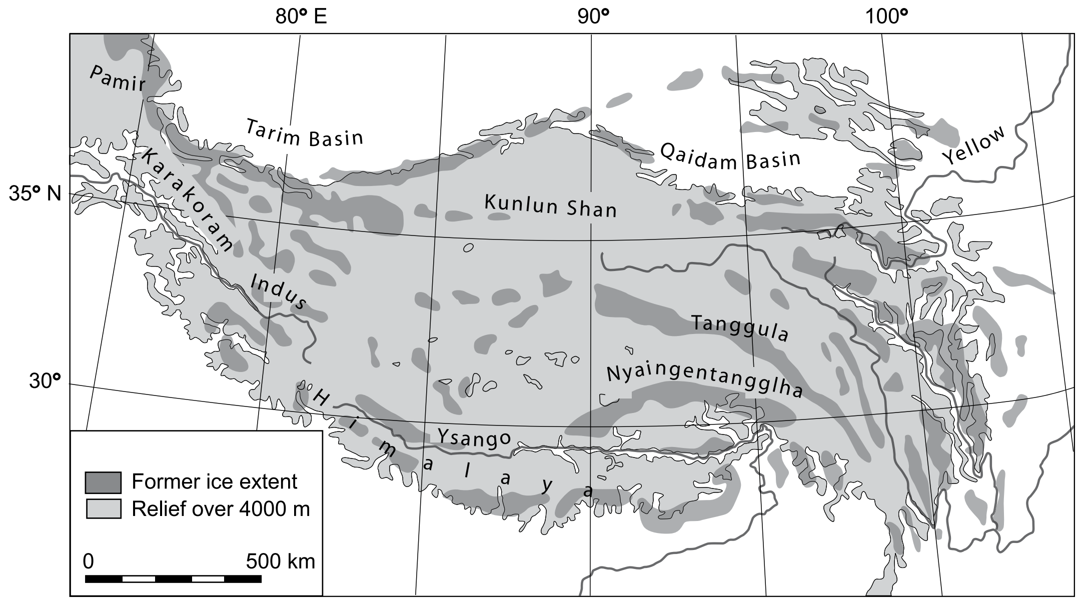

Fig. 3. Reconstruction for the former extent of glaciation across Tibet and the bordering mountains for the maximum extent of glaciation during the Last Glacial (after Shi, 1992). This reconstruction was based on detailed field mapping of glacial and associated landforms and sediments.

4. Dating glacial successions

Dating glacial successions in the Himalaya has been challenging, which is mainly because of lack of organic material needed for radiocarbon dating throughout most study areas. In recent years, however, the application of OSL and TCN methods has expanded the number of glacial chronologies throughout the region. Richards (2000) and Owen et al. (2008) discuss the application of OSL methods for dating glacial successions throughout the Himalaya. They highlight the problems associated with partially bleached sediments in glacial environments and warn that luminescence ages can overestimate the true age of deposits. Examples of extensive programs of luminescence dating in the Himalaya include the studies of Richards et al. (2000b) and Spencer and Owen (2004) in northern Pakistan, Richards et al. (2000a) in the Khumbu Himal, and Tsukamoto et al. (2002) in the Kanchenjunga Himal.

Owen et al. (2008) discuss and evaluate the application of TCN methods for dating Himalayan and Tibetan glacial successions. In particular, they highlight how the method is limited by the uncertainty in the scaling models used to calculate ages and, more important, the geologic uncertainty imposed by processes of moraine formation and alteration that conspire to limit the resolution on which correlations can be made to Milankovitch timescales. Nevertheless, by recalculating all the published TCN ages for moraine boulders and glacially eroded surfaces in the Himalaya and Tibet Owen et al. (2008) were able to make broad generalizations regarding the synchronicity of glaciation throughout the region. Owen et al. (2008) argued that glaciers throughout monsoon-influenced Tibet, the Himalaya, and the Transhimalaya were likely synchronous both with climate change resulting from oscillations in the South Asian monsoon and with Northern Hemisphere cooling cycles. In contrast, glaciers in Pamir in the far western regions of the Himalaya and Tibet regions likely advanced asynchronously relative to the other regions and appear to be mainly in phase with the Northern Hemisphere cooling cycles.

5. Timing and nature of latest Pleistocene and Holocene glaciation

The style and timing of glaciation for the latest Pleistocene and Holocene is outlined in this section with key examples to illustrate the chronologies.

5.1. Last Glacial Maximum

Confusion exists over the defining the extent of glaciation during the Last Glacial Maximum (LGM) in the Himalaya and Tibet because of the problems of dating glacial successions. But this confusion has also been hindered because of the misuse of the LGM to describe the maximum extent of glaciation for the Last Glacial cycle. By strict definition the LGM is defined chronologically based on ages 19–23 ka (Chronozone level 1) or 18–24 ka (Chronozone level 2) within Marine Oxygen Isotope Stage 2 (MIS-2) (Mix et al., 2001). However, numerous researchers, not knowing the ages of moraines, have considered prominent moraines to have been formed during the LGM. Gillespie and Molnar (1995) highlighted this problem and stressed that glaciers in many mountain regions may have reached their maximum extent during the early part of the Last Glacial cycle. Strictly speaking these glacial advances and the landforms they produce should be informally assigned to the Local Last Glacial Maximum (llgm) until they have been dated and shown to be LGM in age.

This LGM dating problem is well illustrated in the Ladakh Range where impressive end moraines at the mouth of valleys that face into the Indus Valley were originally assigned to the LGM by Burbank and Fort (1985) on the basis of form and relative weathering criteria (Fig. 4). Furthermore, Kuhle (2004) attributed this moraine to a Lateglacial advance. Subsequence TCN dating by Brown et al. (2002) and Owen et al. (2006a), however, has shown these moraines to be considerably older, having formed in the penultimate glacial cycle or earlier (with TCN ages clustering at $\sim$160 ka).

Owen et al. (2002a) provided the first comprehensive review of the nature and timing of glaciation at the LGM for the Himalaya that showed the llgm occurred during the early part of the Last Glacial cycle, and that in most areas during MIS-3. They argued that the MIS-3 was a time of increased insolation, when the South Asian summer monsoon strengthened and penetrated further north into the Himalaya, resulting in increased precipitation, occurring as snow at high altitudes, which produced positive glacier mass balances and thereby allowed glaciers to advance. In contrast, during the LGM, Himalayan glaciation was very restricted in extent, generally extending $<$10 km from contemporary ice margins. The lower insolation at this time produced a weaker monsoon cycle, which in turn resulted in lower snow fall and snow accumulation at

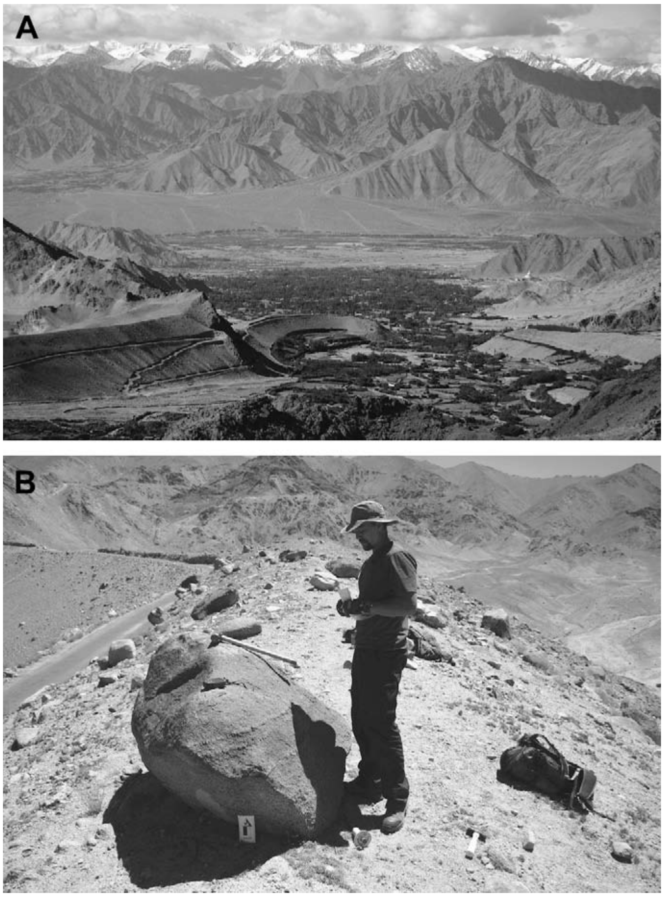

Fig. 4. Leh Glacial Stage moraine of Owen et al. (2005) near the city of Leh in Ladakh. (A) View looking south from the Ladakh Range towards the Indus Valley, with Zanskar range in the distance, and (B) view of the moraine crest. This moraine was originally considered to have formed during the LGM, but TCN dating shows that this moraine formed during the penultimate glacial cycle or earlier.

high altitudes. Nevertheless, Owen et al. (2002a) showed that the modest glacial advances did occur at the LGM likely as the result of reduced temperatures.

Owen and Benn (2005) provide a review of ELAs for Himalayan and Tibetan glaciation and concluded that the ELA depression during the LGM was small, in the order of a few hundred meters for most regions of Tibet and the Himalaya (Owen and Benn, 2005). They also highlighted that few LGM moraines had been dated by numerical methods, and that in only two regions, the Khumbu Himal and Hunza valley, there are comprehensive sets of ages determined by two different dating methods. In summary, the extent of LGM glaciation in the Himalaya and Tibet is very poorly defined.

5.2. Lateglacial

Significant Lateglacial glacier advances are evident within most glaciated valleys throughout the Himalayan–Tibetan region. These include impressive, often sharp-crested, latero-frontal moraines (Fig. 5). Owen et al. (2005, 2008) showed that the majority of these TCN ages cluster around 16–15 ka, and individual studies suggest that these glacial advances might be coincident with Heinrich 1 event (Owen et al., 2002b, 2003b,c, 2005). However, given the uncertainty (maybe as much as 20%) associated with the dating methods it is difficult to assign these moraines to a specific time during the Lateglacial, except to argue that they likely occurred early. A Younger Dryas glacial advance has yet to be identified in the Himalaya and Tibet. Owen and Benn (2005) summarize the ELA depressions for the Lateglacial, which vary considerably from small ELA depressions (<200 m) in the more arid regions of the Himalaya and Tibet, for example, Hunza and Khumbu Himal, to large (>500 m) in the monsoon-influenced ranges, such as the Lahul Himal, and at the westernmost end of the Transhimalaya, for example, in the Central Karakoram (Seong et al., 2007).

Fig. 5. Lateglacial moraine at Muztag Ata in western Tibet. That was dated by Seong et al. (in press) using ^{10}Be TCN surface exposure dating to 13.7 ± 0.5 ka.

5.3. Holocene

Comprehensive studies of Holocene glaciation throughout the Himalaya and Tibet have only been undertaken in a few study areas. Furthermore, detailed studies within a specific area have been somewhat limited because of the sparse record due to the generally poor preservation of moraines. Nevertheless, Holocene moraines are better preserved than Pleistocene moraines, and they offer the potential to derive a high-resolution (sub-millennial scale) record of glaciation for paleoclimatic change.

The first significant quantitative study of Holocene moraines (in addition to examining LGM and Lateglacial moraines) was undertaken by Röthlisberger and Geyh (1985), who presented 68 radiocarbon ages from around 16 different glaciers in Pakistan, India and Nepal. Röthlisberger and Geyh (1985) showed that glaciers advanced during the Holocene at approximately 8.3 ka, 5.4–5.1 ka, 4.2–3.3 ka, 2.7–2.2 ka (7400, 4900–4600, 3700–3100, 2700–2100 ^{14}C years BP) with a relatively small extension at 2.6–2.4 ka (2500–2300 ^{14}C years BP), 1.7–1.4 ka, 1.3–0.9 ka, 0.8–0.55 ka and 0.5–0.1 ka (1700–1500, 1200–950, 800, 550 and 400–100 ^{14}C years BP) in the Himalaya and Karakoram (Fig. 6).

In a review of Holocene environmental change in China, Zhou et al. (1991) showed that continental glaciers advanced at approximately 9.3 ka, 6.4 ka, 4.5 ka, and 0.5 ka (~8300, 5700, 4000 and 400 ^{14}C years BP) in northwestern China, while maritime-influenced glaciers in southeastern Tibet advanced at 3.1 ka, 1.9 ka, 0.9 ka, and 0.3 ka (~3000, 2000, 1000, and 200 ^{14}C years BP; Fig. 7). Zhou et al. (1991) argued that the glacial record was recording a ~2500-year climate cycle at approximately 9.3 ka, 6.4 ka, 3.2 ka, and 0.3 ka (8300, 5700, 3000 and 200 ^{14}C years BP), and an ~1000-year climate cycle at 3.2 ka, 1.9 ka, 0.9 ka, and 0.3 ka (~3000, 2000, 1000, and 200 ^{14}C years BP).

The most recent review of Holocene glaciation in Tibet and the surrounding mountains was undertaken by Yi et al. (2008). They compiled 53 radiocarbon ages and identified glacial advances at 9.4–8.8 ka, 3.5–1.4 ka, and 1.0–0.13 ka (calibrated by Yi et al., 2008

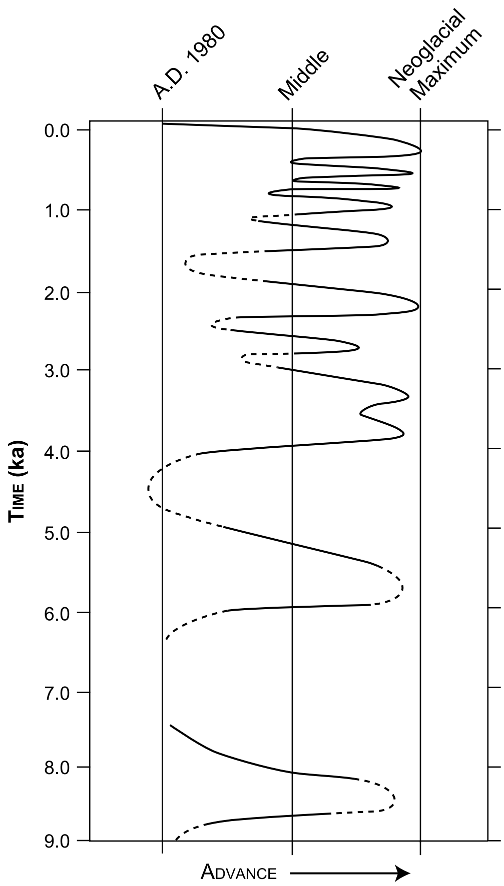

Fig. 6. Glacier fluctuations in the Himalaya and Karakoram defined by radiocarbon dating (modified from Röthlisberger and Geyh, 1985). The original curves illustrate broad advances and retreats that were plotted on a radiocarbon timescale. These have been redrafted for calibrated years using Reimer et al. (2004).

using Stuvier and Reimer, 1993). Yi et al. (2008) suggest that the timing of Holocene glacier advances is synchronous with cooling periods identified in the $\delta^{18}O$ record in ice cores. However, the timing and pattern of glaciation are likely more complex and will be discussed in more detail below.

The most detailed TCN study of Holocene moraines was undertaken by Seong et al. (in press) in Muztag Ata and Kongur in westernmost Tibet, where they showed that glaciers advanced at approximately 11.2 ka, 10.2 ka, 8.4 ka, 6.7 ka, 4.2 ka, 3.3 ka, 1.4 ka, and at a few hundred years before the present (Fig. 8). Seong et al. (in press) suggested that since the LGM, glaciers in western Tibet likely responded to Northern Hemisphere climate oscillations, with minor influences from the south Asian monsoon, responding to rapid climate changes (cf. Bond et al., 1997, 2001; Mayewski et al., 2004) on millennial timescales throughout the Lateglacial and Holocene (Fig. 8).

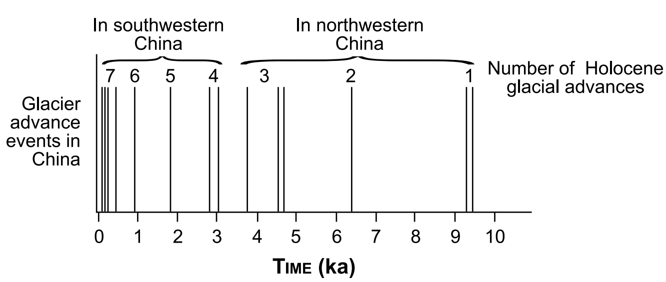

Fig. 7. Glacier fluctuations in northwestern and southwestern Tibet (modified from Zhou et al., 1991). The original figure was plotted on a radiocarbon timescale, which has been redrafted for calibrated years using Reimer et al. (2004).

These data support the view that Himalayan and Tibetan glaciers oscillated at a comparable frequency to that recognized in ice cores from the Greenland Ice Sheet and in deep-sea sediment cores from the North Atlantic, where a quasi-periodicity of ~1470 years is apparent throughout the Lateglacial and Holocene (Bond et al., 1997, 2001). Similar quasi-periodicity of glacial oscillations throughout the Holocene is recognized in other regions of the world (Mayewski et al., 2004), which suggests that regional climate change in Tibet that is teleconnected via westerlies with Atlantic climate changes. As a consequence, it is likely that as many as eight significant glacial advances would be expected to have occurred throughout the Holocene in most Himalaya regions. This rapid climate change is also supported by the ice core data from Tibetan ice sheets, which show short (millennial-centennial) abrupt oscillations in climate throughout the Late Quaternary (Thompson et al., 1989, 1997; Thompson, 2000).

The preservation of a complete Holocene moraine record, however, is rare in most regions, largely because more significant/extensive glacial advances may be preferentially preserved and more extensive later glacial advances may destroy the evidence of early glaciations. Furthermore, glaciers might not respond to subtle changes in climate in some regions that may not be very sensitive to climate change.

The discussion below is simplified by dividing Holocene into the early, mid- and late to consider further the available data on alpine glacier oscillations. But it is emphasized that the Holocene glacial record in the Himalaya and Tibet is more complex than a simple tripartite division.

5.3.1. Early Holocene

Moraines representing early Holocene (~11.5–8.0 ka) glacial advances are apparent throughout most Himalayan–Tibetan regions, and are usually impressive sharp-crested ridges, some many tens of meters high (Fig. 9). The moraines have been dated in numerous regions using TCN, OSL and radiocarbon methods (Shiraiwa, 1993; Sharma and Owen, 1996; Phillips et al., 2000; Richards et al., 2000a; Owen et al., 2001, 2002b, 2003a,c, 2005, 2006a,b; Finkel et al., 2003; Zech et al., 2003, 2005; Barnard et al., 2004a,b, 2006a,b; Spencer and Owen, 2004; Abramowski et al., 2006; Jiao and Shen, 2006; Seong et al., 2007, in press). Owen et al. (2005, 2008) summarize these studies, in particular the TCN dating, and Yi et al. (2008) compile many of the radiocarbon ages on moraines for the Tibet and the surrounding mountains.

Early Holocene ELA depressions vary considerably between regions, from <200 m (e.g. Muztag Ata and Hunza) to >500 m in the Central Karakoram (Owen and Benn, 2005; Seong et al., 2007). As a consequence the distance that glaciers advanced downvalley varies considerably up to many tens of kilometers.

Richards et al. (2000a) and Owen et al. (2001, 2005) suggested that the early Holocene glaciation was a result of increased monsoon precipitation, falling as snow, at this time as a consequence of increased insolation at low latitudes. The increased snow fall at high altitudes resulted in positive glacier mass balances. An increase in monsoon precipitation over the Himalaya and Tibet during the early Holocene is supported by climatic simulation models (Bush, 2004; Li and Harrison, 2008; Rupper et al., in press). However, Rupper et al. (in press) argue that an increase in cooling due to a decrease incoming shortwave radiation at the surface of the glacier due to an increase in cloudiness accounts for more of the ELA lowering than an increase monsoon precipitation.

5.3.2. Mid-Holocene/Hypsithermal

Mid-Holocene (~8.0–3.0 ka)/Hypsithermal moraines have been dated in several regions of the Himalaya and Tibet, and generally

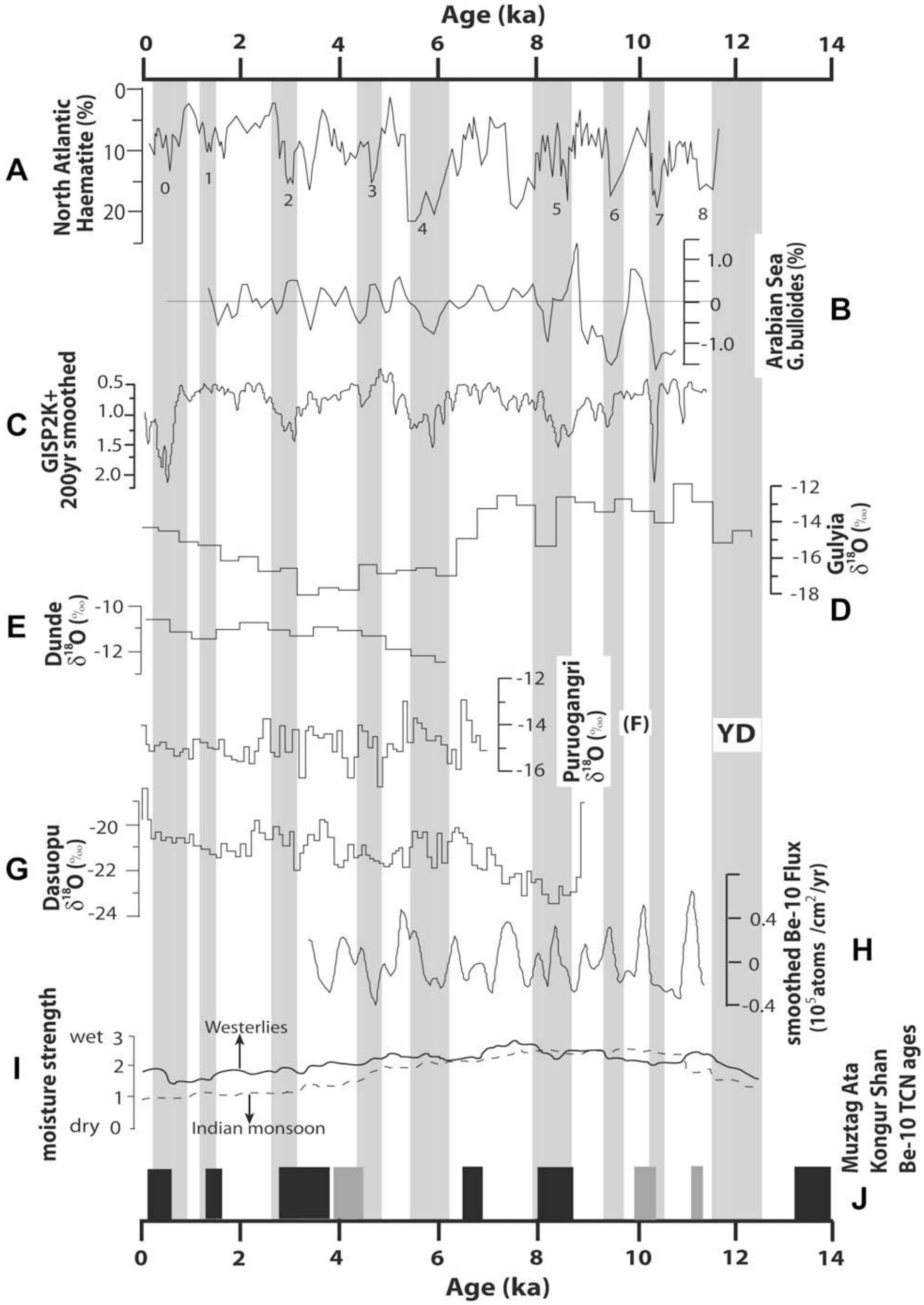

Fig. 8. Holocene glacial succession for Muztag Ata and Kong compared with multiple paleoclimate proxy records of the Northern Hemisphere and the Tibetan Plateau during the Holocene (after Seong et al., in press). The light gray bands indicate times of rapid climate change as suggested by Denton and Karlén (1973). (A) Haematite percentage change in core MC52-VM29-191 from the North Atlantic, and events labeled 1–8 in Bond et al. (2001). (B) Percentage change in *Globigenina bulloides* in Bore Hole 723 A from the Arabian Sea (after Gupta et al., 2003). (C) Gaussian smoothed (200 year) GISP2 potassium (K+: ppb) ion proxy for the Siberian High Pressure System (after Meeker and Mayewski, 2002). (D, E, F and G) δ^{18}O record from Guliya, Dundee, Purogangri, and Dasuopu ice core (after Thompson et al., 1989, 1997, 2005; Thompson, 2000). (H) ^{10}Be production in the GISP2 (Finkel and Nishizumi, 1997). (I) Effective moisture variability reconstructed from the paleoclimate proxies records of the Tibetan Plateau during the Holocene (Herzschuh, 2006). Solid and dotted curves refer to the westerlies and Indian monsoon, respectively. (J) Holocene glacial events of Muztag Ata–Kongur Shan. Each box in the lower row shows glacial events of centered on 13.7 ka, 11.2 ka, 10.2 ka, 8.4 ka, 6.7 ka, 4.2 ka, 3.3 ka, 1.4 ka and Little Ice Age. The black boxes indicate moraine ages that are present in two or more valleys, whereas the gray boxes indicate moraine ages that have only been dated in one valley. The center of each box marks the mean age of the event and the width of each box for error range. The Younger Dryas Stade is shown as YD.

comprise latero-frontal moraine complexes that are relatively well preserved (Fig. 10). Porter (2000) notes that the Hypsithermal interval is a time-stratigraphic unit with temporal boundaries that encompass zones V–VIII of the Danish pollen sequence (ca 10.2 to 2.7–2.5 ka; ca 9000 to 2500 ^{14}C years BP). However, it has long been recognized that the timing of the Hypsithermal varies regionally, for example, in Britain it spans ∼8.0–4.5 ka (Simmons et al., 1981), in the western U.S. it spans 10–7 ka (Barnosky et al., 1987), and in the Midwest U.S. it spans ∼8–5 ka (Semken, 1984). The Hypsithermal has yet to be adequately defined by glacial geologic proxies for the Himalaya and Tibet, which is essentially because the glacial geologic and associated record is sparse. The use of the term Hypsithermal in the Himalaya and Tibet should therefore be used very conservatively. Significant glacial advances have been recognized, however,

Fig. 9. Early Holocene moraine at the mouth of the Kulti valley in the Lahul Himal. Similar moraines in this region were dated by Owen et al. (2001) using ^{10}Be TCN surface exposure dating.

for selected glaciers in Tibet (Zhou et al., 1991), in the Khumbu Himal (Finkel et al., 2003), Diancang Mountain in the Hengduan Range (Yang et al., 2006), Qilian (Wu, 1984), and in Muztag Ata and Konga (Seong et al., in press). ELA depressions during this time were small (<200 m; Owen and Benn, 2005) which resulted in glaciers advances a few hundred to several kilometers beyond their present positions. Climatic simulations support the view of increased monsoon precipitation and summer cooling over the Himalaya and Tibet that would have helped force glaciation during the mid-Holocene, albeit not as great as during the early Holocene (Bush, 2002, 2004; Li and Harrison, 2008; Rupper et al., in press).

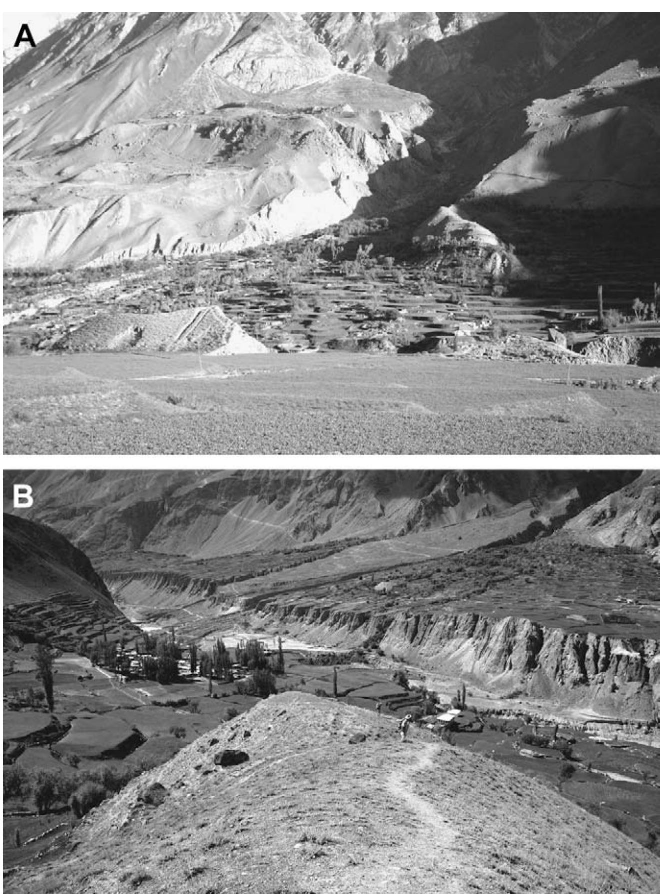

Fig. 10. Mid-Holocene moraines at Askole in the Central Karakoram, (A) viewed looking south and (B) looking north along the moraine crest. These were dated by Seong et al. (2007) to around 5.7 ± 0.5 ka using ^{10}Be TCN surface exposure dating.

Lake and pollen records from Tibet and the Himalaya suggest that the Hypsithermal was diachronous. In NE Tibet, Qinghai Lake records suggest climatic deterioration from ∼11.3 ka to 10.8 ka, with warm wet conditions prevailing between 10.4 and 6.0 ka, culminating at ∼6.5 ka, and ending at ∼4.5 ka (Shen et al., 2005). At Lake Koucha in NE Tibet, Mischke et al. (2008) showed that the Hypsithermal was between 7.3 and 4.3 ka, whereas in central Tibet Herzschuh et al. (2006) and Wu et al. (2006) showed it to be at 8.6–5.7 ka at Lake Zigetang and Cuoe Lake. These ages are broadly supported by palynological data from peats in central Tibet and the Indian Himalaya, which indicates the Hypsithermal occurred at 8.3–3.2 ka (7500–3000 ^{14}C years BP) and at 6.0–4.5 ka, respectively (Wang and Fan, 1987; Phadtare, 2000). In contrast, the Hypsithermal was earlier at sites to the west and includes Lakes Kuhai between ∼7.1 and 2.8 ka, Bangong at 10.9–7.2 ka, and Sumxi at 8.3–6.8 ka (Gasse et al., 1991, 1996; Van Campo and Gasse, 1993).

Lake records show that maximum aridity during the mid-Holocene occurred at ∼4.9 ka in Lake Sumxi and between 4.5 and 3.2 in Lake Bangong (Van Campo and Gasse, 1993; Gasse et al., 1996). In central Tibet, the Cuoe Lake record shows a cool dry stage at ∼5.8–4.0 ka and suggests that precipitation decreased since ∼7.5 ka at Ahung Co (Morrill et al., 2006; Wu et al., 2006). Drier conditions prevailed at 4.3–2.0 ka at Lake Koucha in NE Tibet, and after 4.4 ka at Lake Zigetang in central Tibet (Herzschuh et al., 2006; Mischke et al., 2008). Furthermore, the pollen record in Himalayan peats in India suggests cooling at 4.3–2.0 ka (Phadtare, 2000). The diachronous nature of Holocene lake-level history across Tibet likely reflects a complex respond to climate change and suggests that glacier response throughout Tibet and the Himalaya should be complicated and may be asynchronous across the region.

5.3.3. *Late Holocene/Neoglaciation*

Sharp-crested well-preserved moraines within a kilometer of the present glacier margins are present throughout most Himalayan and Tibetan regions (Fig. 11). Many of these moraines have been assigned to the Neoglaciation (e.g. Derbyshire et al., 1984; Wu, 1984; Zheng, 1997; Richards et al., 2000a; Finkel et al., 2003; Jiao and Shen, 2006). Few of these moraines have been dated and can be truly correlated to this geologic-climate unit. Porter and Denton (1967) suggested that Neoglaciation is characterized by glacial advances, defined on physical geological evidence, which post-date the Hypsithermal, that is, after ∼2.7 ka (∼2500 ^{14}C years BP).

Fig. 11. Neoglacial moraines at Muztag Ata dated by Seong et al. (in press) to 3.3 ± 0.6 ka using ^{10}Be TCN surface exposure dating.

However, numerous studies in many of the world's high mountain ranges have shown that most glaciers reached their maximum during Neoglaciation, which is usually the case (e.g. Grove, 1988; Clapperton, 1993; Porter, 2000). In most regions the recognized evidence of Neoglaciation post-dates the classically defined Hypsithermal interval; however, in some areas Neoglaciation and the Hypsithermal interval overlap. Neoglaciation for the Himalaya and Tibet, however, has not been adequately defined using glacial geologic proxies because of the paucity of dated moraines throughout the region.

Pu (1991) also cited in Lehmkuhl (1997) for example, describes Neoglacial advances (Neoglaciation I–IV) in western China including Tibet that date to ~9.2–7.8 ka, 6.7–5.6 ka, 3.6–2.4 ka, and 0.5–0.03 ka (~7000–8200, 4900–5800, 2400–3320 and 450–30 ^{14}C years BP). Denton and Karlén (1973) noted that an early Neoglacial advance occurred in many places around the global at 5.2 ka (~5000 ^{14}C years BP). So for the first of Pu's (1991) advances (Neoglaciation I) it occurred earlier than the conventionally recognized Neoglaciation. Moraines that have been dated, however, suggest that Neoglaciation in the Himalaya and Tibet is complex and its onset may be asynchronous throughout the Himalaya and Tibet. ELA depressions during Neoglaciation were small (~100 m; Owen and Benn, 2005).

The Khumbu Himal has one of the best defined chronologies for Neoglaciation. In this region, Finkel et al. (2003) dated oldest Neoglacial moraines to ~3.6 ka using TCN methods. Other Neoglacial moraines, around the Khumbu Glacier, were dated to ~1 ka by radiocarbon, OSL and ^{10}Be TCN methods (Benedict, 1976; Fushimi, 1978; Müller, 1980; Richards et al., 2000a; Finkel et al., 2003). Benedict (1976), Müller (1980) and Fushimi (1978) also dated younger moraines to between ~0.55 and 0.40 ka (~550 and 410 ^{14}C years BP), and Finkel et al. (2003) provided ^{10}Be ages of several hundred years for these moraines.

Gonga Shan in southeasternmost Tibet provides another reasonable Neoglacial chronology, where Zheng (1997) dated Neoglacial moraines in this region at the Hailuoguo glacier at ~3.3 ka and 2.7 ka (~3080 and 2430 ^{14}C years BP) for the oldest moraines. These moraines were subsequently dated by Owen et al. (2005) to 2.4–0.9 ka using TCN methods. Younger moraines were also dated in the region by both methods and have returned ages of a few hundred years BP, but these are poorly defined because of the large analytical uncertainties associated with dating very young surfaces using TCN methods.

In addition to these key chronologies, Yang et al. (2008), compiled radiocarbon dating of fossil wood buried in moraines, along with lichenometric and dendrochronologic data for moraines in the Hengduan Mountains, the central and eastern parts of the Himalaya and the eastern Nyainquentanghlha Range of SE Tibet, and identified three main periods of glacier advance. These occurred at around 1.8–1.4 ka, 1.2–1.15 ka, and 0.6–0.08 ka, with the glacier advance at about 1.8–1.4 being the most widespread.

The lake records throughout Tibet show that warmer and wetter conditions prevailed after ~3.7 ka, but became drier and colder after ~3.0 ka. However, the timing of this climatic transition varies throughout Tibet, starting at Lake Cuoe at ~3.0 ka, Lakes Kuhai and Koucha at ~2.7 ka, Qinghai Lake at ~2.5 ka, and Lake Zigetang at 1.4–1.1 ka (Shen et al., 2005; Herzschuh et al., 2006; Wu et al., 2006; Mischke et al., 2008). This complexity suggests that glaciers likely would have been responding to climate change throughout Tibet and the surrounding mountains in a complex manner, maybe asynchronously, during the Late Holocene.

5.3.4. Little Ice Age

Numerous studies have mapped and described Little Ice Age (LIA) moraines in the Himalaya and Tibet (see summary in Grove, 2004). However, few of these studies provide any numerical ages on the moraines to substantiate the claim that they formed during the LIA, from about 14th to 19th centuries as defined by Grove (1988) and specifically for Tibet defined using multiproxy data by Bao et al. (2003) as between AD 1400 and AD 1900. Rather the studies attribute fresh bouldery and sharp-crested moraines within a few hundred meters of the contemporary glacier to the LIA (Fig. 12). Notable exceptions are the moraines in the Khumbu Himal that have been dated by both radiocarbon and TCN methods (Benedict, 1976; Fushimi, 1978; Müller, 1980; Finkel et al., 2003). Yang et al. (2008) provide the most recent radiocarbon ages for LIA moraines in SE Tibet and suggest that glaciers advanced at AD 1400–1430, AD 1550–1850 and during the 19th century. In addition, Yi et al. (2008) summarize radiocarbon ages for LIA moraines from Nyainqentanglha (after Zheng and Li, 1986; Jiao and Iwata, 1993), Karakoram (after Derbyshire et al., 1984), Langtang (after Shiraiwa and Watanabe, 1991), the western slopes of Namjagbarwa Peak in the eastern Himalaya (after Zhang, 1988) and Gonga in SE Tibet (after Zheng and Ma, 1994) and argue that the LIA in Tibet had three substages from 1.0 to 0.13 ka.

Dendrochronology has been limited for dating moraines in the Himalaya and Tibet because of the general paucity of trees or appropriate trees in the region, therefore most studies focus on paleoclimate reconstruction rather than glacial chronology (Wu, 1992). However, in the wetter eastern and southeastern margins of Tibet Bräuning (2006) has successfully applied dendrochronology to date moraines. In eastern Tibet, Bräuning (2006) yielded minimum ages of AD 1760 and AD 1780 for moraine formation, with subsequence moraines dated to the beginning of the 19th century and the beginning of the 20th century. In southeastern Tibet Bräuning (2006) showed that glaciers advanced from 1580 to 1590, from the end of the 18th century to the beginning of the 19th century. Furthermore, Bräuning (2006) was able to identify a glacier advance between AD 1951 and AD 1987 on Mt. Gyalaperi near Namche Barwa.

ELA depressions during the LIA were small (usually <100 m; Owen and Benn, 2005; Yang et al., 2008). The LIA glacial advances in the Himalaya are generally much less extensive than the early Holocene glacier advances, with glacier advances less than a few hundred meters from their present positions.

Morainic and protalus rock glaciers are common throughout the Transhimalaya and are restricted altitudinally and climatically to sites above ~4000 m asl and in regions where annual precipitation is <1000 mm. Most of the rock glaciers are still active and some are actively advancing over historic river terraces and highways. The morainic rock glaciers are large (often >1 km long and >15 m thick) and commonly occur beyond sharp-crested moraines adjacent to

Fig. 12. Typical LIA moraines inset into large Neoglacial moraines in front of the Batal Glacier in the Lahul Himalaya.

contemporary glaciers (Fig. 13). Owen and England (1998) attributed the formation of these rock glaciers to reduced precipitation during the LIA that resulted in relatively increased debris supply to the ice by rockfall processes that swamped the glacier ice with debris. The rock glaciers continued to advance following the retreat of glaciers after the LIA. Alternatively, increase precipitation could lead to increase avalanching that in turn might supply more debris to glaciers. However, since many of Himalayan glaciers are essentially feed by avalanching, an increase in the frequency of avalanches would more likely lead to positive glacier mass balances and not the development of rock glaciers. Dating rock glaciers is extremely difficult, but Seong et al. (in press) provide the first TCN ages for rock glaciers in Muztag Ata and Konga Shan, dating surface boulders to a few hundred years before present.

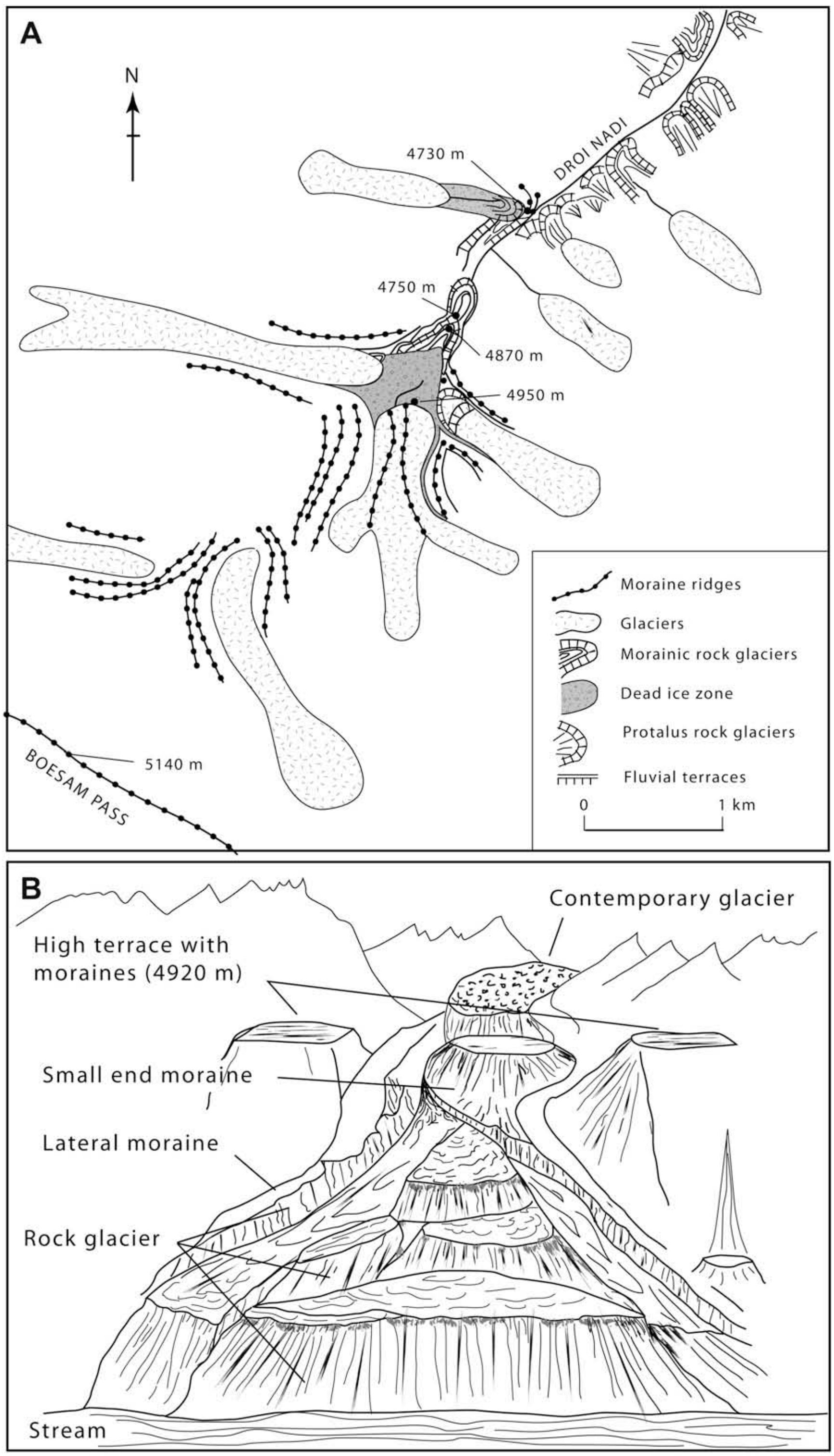

Fig. 13. Late Holocene and active rock glaciers in the Karakoram of Northern Pakistan (after Owen and England, 1998). (A) Geomorphological map showing rock glaciers and Holocene moraines in the Drui Nadi valley. (B) Typical view of rock glaciers, associated moraines and the contemporary glacier on the western side of the Chapchingal Nadi valley immediately SW of the Chapchingal Pass.

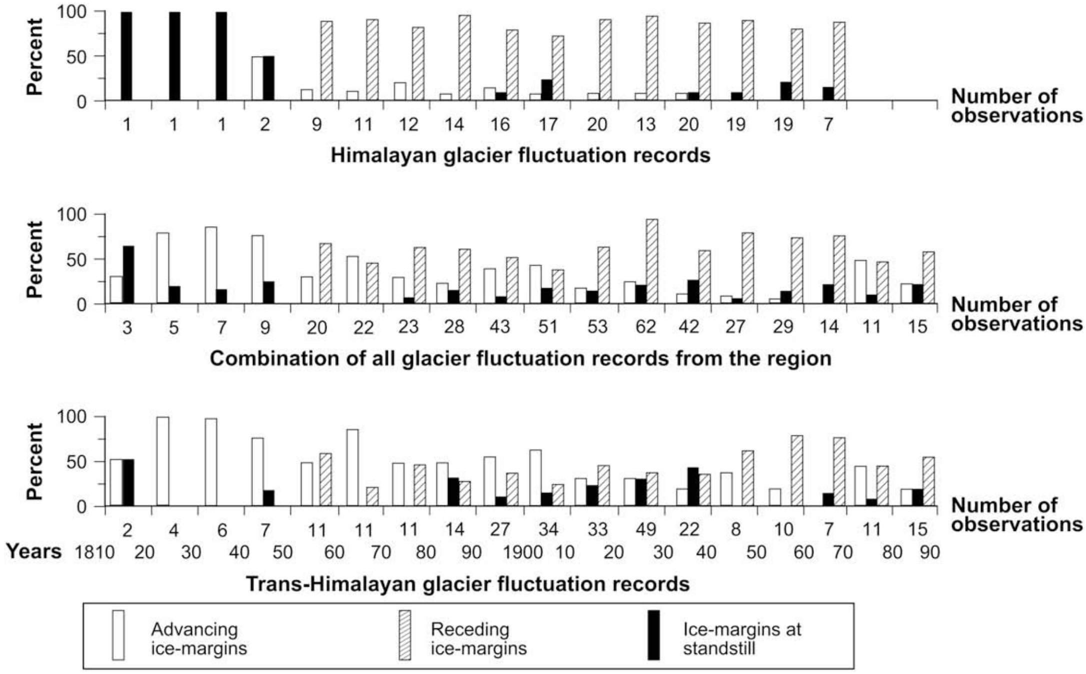

Fig. 14. Glacier activity frequencies for glaciers throughout the Himalaya (after Mayewski and Jeschke, 1979).

5.3.5. Historical and recent glacier fluctuations

The most comprehensive study published on historical glacier fluctuations was undertaken by Mayewski and Jeschke (1979) and Mayewski et al. (1980). They examined the fluctuations of 112 glaciers in Pakistan, India and Nepal for the period between AD 1810 and AD 1970. Their studies showed that glacier fluctuations are asynchronous on decadal timescales in different parts of the Himalaya. Furthermore, their data since 1850 showed that high percentages of Himalayan glaciers have been in retreat by comparison with the Transhimalayan glaciers, which have undergone periods when glacier advance was the dominant mode (Fig. 14). Mayewski et al. (1980) compared the glacier fluctuation records with the strength of the South Asian monsoon circulation and precipitation. However, there was no consistent pattern between variations in the monsoon and glacier fluctuations, with the exception of the 1900–1909 period of glacier advance in the Transhimalaya, which coincided with a peak in the monsoon.

In a study of maritime-influenced glaciers in monsoon-influenced southeastern Tibet, Su and Shi (2002) showed that since the LIA the mean temperature of monsoonal temperate glaciers in China has increased by 0.8 °C and the glacier area has decreased by ~4000 km^2, an amount equivalent to 30% of the modern glacier area.

Throughout the last few decades most glaciers have been retreating in the Himalaya and Tibet. According to the Intergovernmental Panel on Climate Change (2007), glaciers in the Himalaya are receding faster than in any other part of the world. The Intergovernmental Panel on Climate Change (2007) argues that if the present rate continues, Himalayan glaciers are very likely to disappear by AD 2035 and perhaps sooner if Earth keeps warming at the current rate. Of particular, note is Gangotri Glacier, which is located at the source of the Ganges River. Gangotri Glacier receded at a rate of 7.3 m/a between AD 1842 and AD 1935 and at a rate of 23 m/a between AD 1985 and AD 2001 (Hasnain, 2002; Intergovernmental Panel on Climate Change, 2007). Fig. 15 shows the reconstruction of the ice positions and thickness for Gangotri Glacier throughout the Late Quaternary.

Su and Shi (2002) predict that the maritime-influenced glaciers of southeastern Tibet will also dramatically decrease in extent, estimating that the aerial reduction may be as much as 75% (~9900 km^2) by AD 2100, associated with an estimated temperature rise of 2.1 °C. Furthermore, they argue that if the precipitation decreases, retreat of the glaciers will be even faster, reducing the area by as much as 80%.

There is increasing evidence through the use of remote sensing, however, that glaciers are beginning to advance and thicken throughout many parts of the Himalaya as a consequence of enhanced monsoon precipitation associated with global warming (Michael Bishop, 2008, pers. comm.). This relationship may be analogous to the glacial advances associated with time of insolation maxima, such as during the early Holocene.

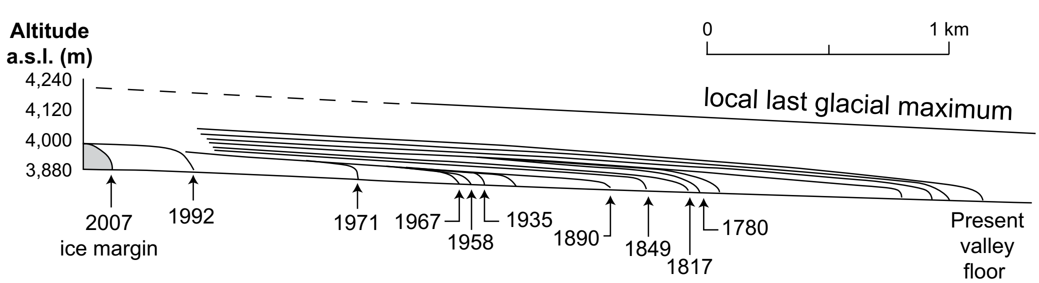

Fig. 15. Reconstruction of former ice positions for Gangotri Glacier, which were dated using historical and optically stimulated luminescence methods (adapted from Sharma and Owen, 1996).

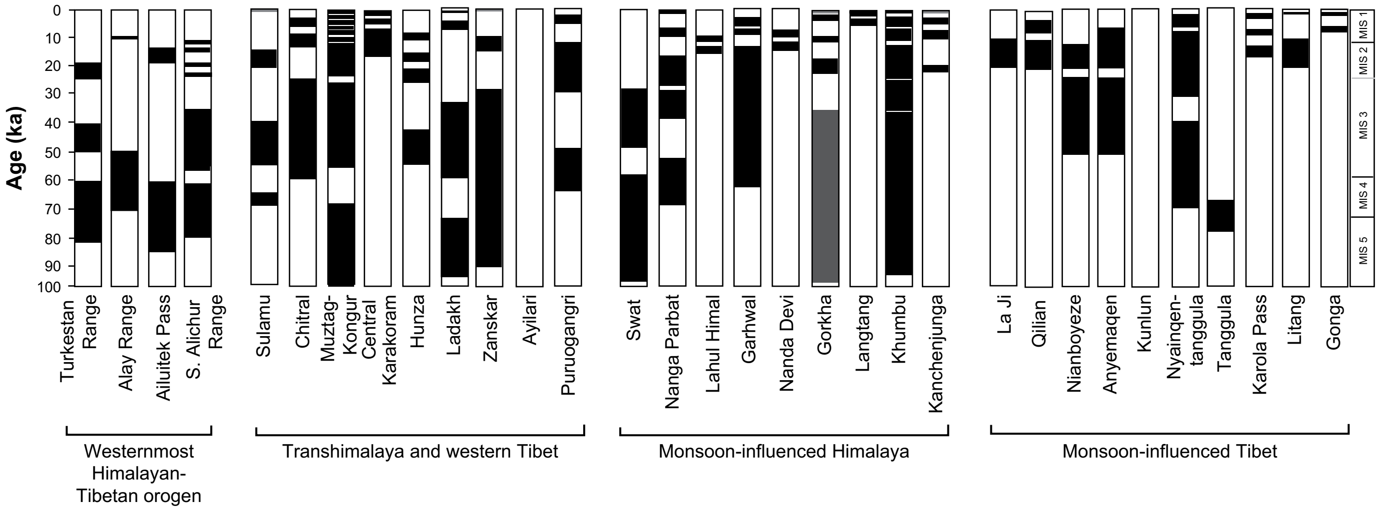

Fig. 16. Simplified glacial chronologies for the Late Quaternary (back to 100 ka) that have been numerically dated throughout the Himalaya and Tibet (adapted from Owen et al., 2008; data from Shiraiwa, 1993; Sharma and Owen, 1996; Phillips et al., 2000; Richards et al., 2000a,b; Owen et al., 2001, 2002b,c, 2003a,b,c, 2005, 2006a,b; Schäfer et al., 2002; Tsukamoto et al., 2002; Yi et al., 2002; Finkel et al., 2003; Zech et al., 2003, 2005; Barnard et al., 2004a,b, 2006a,b; Meriaux et al., 2004; Spencer and Owen, 2004; Chevalier et al., 2005; Abramowski et al., 2006; Colgan et al., 2006; Seong et al., 2007, in press). See Fig. 2 for the locations of each study area. The Marine Oxygen Isotope Stages (MISs) are taken from Martinson et al. (1987).

6. Conclusions

The timing and extent of latest Pleistocene and Holocene glacier fluctuations are poorly defined for most regions of the Himalaya and Tibet. As a consequence many moraine successions have been assigned climatostratigraphic ages based on relative dating methods. Taken together with confusion over the definition of stratigraphic terminology and the likely inter-regional differences in the timing and extent of glaciation it is difficult to correlate glacial successions throughout the region. In turn it is difficult to elucidate the relative role of different climate forcing factors in driving glaciation in this region.

Nevertheless, new studies, particularly aided by newly developing numerical dating methods, allow broad patterns for glaciation and correlations to emerge. Fig. 16 summarizes the data for study areas where numerical dating programs have been successfully used to determine the timing of Late Pleistocene and Holocene glaciation. Multiple glacier advances are apparent in most regions for the latest Pleistocene and Holocene. Assigning glacial advances to the specific climatostratigraphic times, however, is difficult because of the large errors associated with most dating methods. Moreover, the studies show that in most high Himalayan and Tibetan regions, glaciers reached their maximum extent early in the Last Glacial cycle. In contrast, LGM glacier advances were significantly less extensive.

Notable glacier advances occurred in most Himalayan and Tibetan regions during the Lateglacial and the early Holocene. Minor mid-Holocene moraines have been recognized and dated in several regions. There is also abundant evidence through most Himalayan and Tibetan regions for multiple glacial advances throughout the late Holocene. However, these are generally very poorly defined, and were less extensive than the early Holocene glacial advances.

These studies suggest that since the LGM glaciers in Himalaya and Tibet have responded to oscillations in the south Asia monsoon that are forced by insolation changes, and climate changes resulting from teleconnections with rapid climate oscillations in the Northern Hemisphere oceans and ice sheets.

The best studied and preserved glacial successions are present in the Karakoram Mountains of northern Pakistan, the massifs of Muztag Ata and Kongur in westernmost Tibet, the Greater Himalaya of northern India, and the valleys on the southern slopes of Mount Everest. These glacial successions have the potential to be examined to derive a high-resolution record of glaciation to help in paleoclimatic reconstruction and for understanding the dynamics of glaciation and climate change. Continued research using radiocarbon, OSL, TCNs, dendrochronology and lichenometry on well-preserved latest Quaternary, and particularly Holocene moraine successions will refine the chronologies to aid in identifying the forcing factors of glaciation in Central Asia.

Acknowledgements

Thanks to Tim Phillips for drafting figures for this paper. Special thanks to Thompson Davis, Jerry Osborn and Brian Menounos for organizing the symposium at the 2007 INQUA Congress where this paper was presented and for editing this special volume of Quaternary Science Reviews. Particular thanks to Edward Derbyshire, Alan Gillespie and Nat Rutter for their very constructive and useful comments on the manuscript. Thanks also to Jason Dortch and Kate Hedrick for commenting on an early draft of this paper.

References

Abramowski, U., Bergau, A., Seebach, D., Zech, R., Glaser, B., Sosin, P., Kubik, P.W., Zech, W., 2006. Pleistocene glaciations of Central Asia: results from ^{10}Be surface exposure ages of erratic boulders from the Pamir (Tajikistan) and the Alay–Turkestan range (Kyrgyzstan). Quaternary Science Reviews 25, 1080–1096.

Bao, Y., Bräuning, A., Shi, Y., 2003. Late Holocene temperature fluctuations on the Tibetan Plateau. Quaternary Science Reviews 22, 2335–2344.

Barnard, P.L., Owen, L.A., Finkel, R.C., 2004a. Style and timing of glacial and paraglacial sedimentation in a monsoonal influenced high Himalayan environment, the upper Bhagirathi Valley, Garhwal Himalaya. Sedimentary Geology 165, 199–221.

Barnard, P.L., Owen, L.A., Sharma, M.C., Finkel, R.C., 2004b. Late Quaternary landscape evolution of a monsoon-influenced high Himalayan valley, Gori Ganga, Nanda Devi, NE Garhwal. Geomorphology 61, 91–110.

Barnard, P.L., Owen, L.A., Finkel, R.C., 2006a. Quaternary fans and terraces in the Khumbu Himal south of Mount Everest: their characteristics, age and formation. Journal of Geological Society of London 163, 383–399.

Barnard, P.L., Owen, L.A., Finkel, R.C., Asahi, K., 2006b. Landscape response to deglaciation in a high relief, monsoon-influenced alpine environment, Langtang Himal, Nepal. Quaternary Science Reviews 25, 2162–2176.

Barnosky, C.W., Anderson, P.M., Bartlein, P.J., 1987. The northwestern U.S. during deglaciation: vegetational history and palaeoclimatic implications. In: Ruddiman, W.F., Wright Jr., H.E. (Eds.), The Geology of North America. North

America and Adjacent Oceans During the Last Deglaciation, vol. K-3. Geological Society of America, Colorado, pp. 289–321.
Benedict, J.B., 1976. Khumbu glacier series, Nepal. Radiocarbon 18, 177–178.
Benn, D.I., Owen, L.A., 1998. The role of the Indian summer monsoon and the mid-latitude westerlies in Himalayan glaciation: review and speculative discussion. Journal of the Geological Society 155, 353–363.
Benn, D.I., Owen, L.A., 2002. Himalayan glacial sedimentary environments: a framework for reconstructing and dating former glacial extents in high mountain regions. Quaternary International 97/98, 3–26.
Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., deMenocal, P., Priore, P., Cullen, H., Hajdas, I., Bonani, G., 1997. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. Science 278, 1257–1266.
Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, I., Bonani, G., 2001. Persistent solar influence on North Atlantic climate during the Holocene. Science 294, 2130–2136.
Bräuning, A., 2006. Tree-ring evidence of 'Little Ice Age' glacier advances in southern Tibet. The Holocene 16, 369–380.
Brown, E.T., Bendick, R., Bourles, D.L., Gaur, V., Molnar, P., Raisbeck, G.M., Yiou, F., 2002. Slip rates of the Karakoram fault, Ladakh, India, determined using cosmic ray exposure dating of debris flows and moraines. Journal of Geophysical Research 107 (B9), 7-1–7-8. 2192.
Burbank, D.W., Fort, M.B., 1985. Bedrock control on glacial limits: examples from the Ladakh and Zanskar ranges, north-western Himalaya, India. Journal of Glaciology 31, 143–149.
Burbank, D.W., Kang, J.C., 1991. Relative dating of Quaternary moraines, Rongbuk Valley, Mount Everest, Tibet: implications for an ice sheet on the Tibetan Plateau. Quaternary Research 36, 1–18.
Bush, A.B.G., 2002. A comparison of simulated monsoon circulations and snow accumulation in Asia during the mid-Holocene and at the Last Glacial Maximum. Global and Planetary Change 32, 331–347.
Bush, A.B.G., 2004. Modelling of late Quaternary climate over Asia: a synthesis. Boreas 33, 155–163.
Chevalier, M.-L., Ryerson, F.J., Tapponnier, P., Finkel, R.C., Van Der Woerd, J., Haibing, L., Qing, L., 2005. Slip-rate measurements on the Karakoram Fault may imply secular variations in fault motion. Science 307, 411–414.
Clapperton, C., 1993. Quaternary Geology and Geomorphology of South America. Elsevier, Amsterdam.
Colgan, P.M., Munroe, J.S., Zhou, S., 2006. Cosmogenic radionuclide evidence for the limited extent of last glacial maximum glaciers in the Tanggula Shan of the central Tibetan Plateau. Quaternary Research 65, 336–339.
Denton, G.H., Karlén, 1973. Holocene climatic variations – their pattern and possible cause. Quaternary Research 3, 155–205.
Derbyshire, E., 1982. Glacier regime and glacial sediment facies: a hypothetical framework for the Qinghai–Xizang Plateau. In: Proceedings of Symposium on Qinghai–Xizang (Tibet) Plateau, Beijing, China. Geological and Ecological Studies of Qinghai–Xizang Plateau, vol. 2. Science Press, Beijing, pp. 1649–1656.
Derbyshire, E., 1987. A history of the glacial stratigraphy in China. Quaternary Science Reviews 6, 301–314.
Derbyshire, E., Li, J.J., Perrott, F.A., Xu, S.Y., Waters, R.S., 1984. Quaternary glacial history of the Hunza valley, Karakoram Mountains, Pakistan. In: Miller, K. (Ed.), International Karakoram Project. Cambridge University Press, Cambridge, UK, pp. 456–495.
Derbyshire, E., Shi, Y., Li, J., Zheng, B., Li, S., Wang, J., 1991. Quaternary glaciation of Tibet: the geological evidence. Quaternary Science Reviews 10, 485–510.
Ehlers, J., Gibbard, P. (Eds.), 2004. Quaternary glaciations – extent and chronologies. Part III: South America, Asia, Africa, Australia, Antarctica. Developments in Quaternary Science, 2, p. 380.
Finkel, R.C., Nishizumi, K., 1997. Beryllium-10 concentrations in the Greenland Ice Sheet Project 2 ice core from 3–40 ka. Journal of Geophysical Research 102, 26699–26706.
Finkel, R.C., Owen, L.A., Barnard, P.L., Caffee, M.W., 2003. Beryllium-10 dating of Mount Everest moraines indicates a strong monsoonal influence and glacial synchroneity throughout the Himalaya. Geology 31, 561–564.
Frenzel, B., 1960. Die vegetations- und Landschaftszonen Nordeurasiens während der letzten Eiszeit und während der Postglazialen Warmezeit. Akademie der Wissenschaften und der Literatur in Mainz, Abhandlungen der Mathematisch-Naturwissenschaftlichen Klasse 13, 937–1099.
Fushimi, H., 1978. Glaciations in the Khumbu Himal. Seppyo 40, 71–77.
Gasse, F., Arnold, M., Fontes, J.C., Fort, M., Gibert, E., Huc, A., Li, B., Li, Y., Lui, Q., Mélières, F., Van Campo, E., Wang, F., Zhang, Q., 1991. A 13,000-year climate record from western Tibet. Nature 353, 742–745.
Gasse, F., Fontes, J. Ch., Van Campo, E., Wei, K., 1996. Holocene environmental changes in Bangong Co basin (Western Tibet). Part 4: discussion and conclusions. Palaeogeography, Palaeoclimatology, Palaeoecology 120, 79–92.
Gillespie, A., Molnar, P., 1995. Asynchronous maximum advances of mountain and continental glaciers. Reviews of Geophysics 33, 311–364.
Grove, J.M., 1988. The Little Ice Age. Methuen, London.
Grove, J.M., 2004. The Little Ice Age: Ancient and Modern, vol. 1. Routledge, London, second ed., p. 432.
Gupta, A.K., Anderson, D.M., Overpeck, J.T., 2003. Abrupt changes in the Asian southwest monsoon during the Holocene and their links to the North Atlantic Ocean. Science 421, 354–357.
Hasnain, S.J., 2002. Himalayan glaciers meltdown: impacts on South Asian Rivers. In: van Lanen, H.A.J., Demuth, S. (Eds.), FRIEND 2002-Regional Hydrology: Bridging the Gap Between Research and Practice, vol. 274. IAHS Publications, Wallingford, pp. 417–423.
Herzschuh, U., 2006. Paleo-moisture evolution in monsoonal Central Asia during the last 50,000 years. Quaternary Science Reviews 25, 163–178.
Herzschuh, U., Winter, K., Wunnemann, B., Li, S., 2006. A general cooling trend on the central Tibetan Plateau throughout the Holocene recorded by the Lake Zigetang pollen spectra. Quaternary International 154–155, 113–121.
Hövermann, J., Lehmkuhl, F., Pörtge, K.-H., 1993a. Pleistocene glaciations in Eastern and Central Tibet – preliminary results of the Chinese–German joint expeditions. Zeitscrift Für Geomorphologie 92, 85–96.
Hövermann, J., Lehmkuhl, F., Süssenberger, H., 1993b. Neue Befunde zur Paläoklimatologie Nordafrikas und Zentralasiens. Abhandlungen der Braunschweigischen Wissenschaftlichen Gesellschaft 43, 127–150.
Intergovernmental Panel on Climate Change, 2007. In: Parry, M., Canziani, O., Palutikof, J., Van der Linden, P., Hanson, C. (Eds.), Climate change 2007: impacts, adaptations and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 976 pp.
Jiao, K.Q., Iwata, S.J., 1993. The glacier variation in Kunlun pass area and southeast Tibet area since last glaciation. In: Yao, T.D., Ageda, Y. (Eds.), Glaciation Climate and Environment in Qinghai–Tibet Plateau. Science Press, Beijing, pp. 120–129.
Jiao, K.Q., Shen, Y.P., 2006. Quaternary glaciations in Tanggulha Mountains. In: Shi, Y.F., Su, Z., Cui, Z.J. (Eds.), The Quaternary Glaciations and Environmental Variations in China. Science and Technology Press, Hebei Province, Shijiazhuang, pp. 326–356.
Klute, F., 1930. Verschiebung der Klimagebiete der letzten Eiszeit. Petermanns Geographische Mitteilungen, Ergänzungs-Heft 209, 166–182.
Kuhle, M., 1985. Ein subtropisches Inlandeis als Eiszeitauslöser, Südtibet un Mt. Everest expedition 1984. Geogia Augusta, Nachrichten Aus Der Universität Gottingen May, 1–17.
Kuhle, M., 1986. The upper limit of glaciation in the Himalayas. GeoJournal 13, 331–346.
Kuhle, M., 1987. The problem of a Pleistocene inland glaciation of the Northeastern Qinghai–Xizang Plateau. In: Hövermann, J., Wang, W. (Eds.), Reports of the Qinghai–Xizang (Tibet) Plateau, Beijing, pp. 250–315.
Kuhle, M., 1988a. Geomorphological findings on the built-up of Pleistocene glaciation in Southern Tibet and on the problem of inland ice. GeoJournal 17, 457–512.
Kuhle, M., 1988b. Topography as a fundamental element of glacial systems. GeoJournal 17, 545–568.
Kuhle, M., 1990a. The cold deserts of high Asia (Tibet and contiguous mountains). GeoJournal 20, 319–323.
Kuhle, M., 1990b. Ice marginal ramps and alluvial fans in semiarid mountains: convergence and difference. In: Rachocki, A.H., Church, M. (Eds.), Alluvial Fans: A Field Approach. John Wiley and Sons, Chichester, pp. 55–68.
Kuhle, M., 1991. Observations supporting the Pleistocene inland glaciation of High Asia. GeoJournal 25, 131–231.
Kuhle, M., 1993. A short report of the Tibet excursion 14-A, Part of the XIII INQUA Congress 1991 in Beijing. GeoJournal 29, 426–427.
Kuhle, M., 1995. Glacial isostatic uplift of Tibet as a consequence of a former ice sheet. GeoJournal 37, 431–449.
Kuhle, M., 2004. The high glacial (last ice age and LGM) ice cover in high and Central Asia. In: Ehlers, J., Gibbard, P.L. (Eds.), Quaternary Glaciation – Extent and Chronology, Part III. Elsevier, Amsterdam, pp. 175–199.
Lehmkuhl, F., 1995. Geomorphologische Untersuchungen zum Klima des Holozäns und Jungpleistozäns Osttibets. Göttinger Geographische Abhandlungen 102, 1–184.
Lehmkuhl, F., 1997. Late Pleistocene, Late-glacial and Holocene glacier advances on the Tibetan Plateau. Quaternary International 38/39, 77–83.
Lehmkuhl, F., 1998. Extent and spatial distribution of Pleistocene glaciations in Eastern Tibet. Quaternary International 45/46, 123–134.
Lehmkuhl, F., Owen, L.A., 2005. Late Quaternary glaciation of Tibet and the bordering mountains. A review. Boreas 34, 87–100.
Lehmkuhl, F., Owen, L.A., Derbyshire, E., 1998. Late Quaternary glacial history of northeastern Tibet. Quaternary Proceedings 6, 121–142.
Li, B., Li, J., Cui, Z. (Eds.), 1991. Quaternary glacial distribution map of Qinghai–Xizang (Tibet) Plateau 1:3,000,000. Shi Y. (Scientific Advisor). Quaternary Glacier, and Environment Research Center, Lanzhou University.
Li, Y., Harrison, S.P., 2008. Simulations of the impact of orbital forcing and ocean on the Asian summer monsoon during the Holocene. Global and Planetary Change 60, 505–522.
Martinson, D.G., Pisias, N.G., Hays, J.D., Imbrie, J., Moore, T.C., Shackleton, N.J., 1987. Age dating and the orbital theory of ice ages: development of a high resolution 0 to 300,000-year chronology. Quaternary Research 27, 1–29.
Mayewski, P.A., Jeschke, P.A., 1979. Himalayan and Trans-Himalayan glacier fluctuations since AD 1812. Arctic and Alpine Research 11 (3), 267–287.
Mayewski, P.A., Pregent, G.P., Jeschke, P.A., Ahmad, N., 1980. Himalayan and Trans Himalayan glacier fluctuations and the South Asian Monsoon record. Arctic and Alpine Research 12, 171–182.
Mayewski, P.A., Rohling, E.E., Stager, C.J., Karlén, W., Maasch, A., Meeker, L.D., Meyerson, E.A., Gasse, F., Van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R., Steig, E.J., 2004. Holocene climate variability. Quaternary Research 62, 243–255.
Meeker, L.D., Mayewski, P.A., 2002. A 1400-year high-resolution record of atmospheric circulation over the North Atlantic and Asia. The Holocene 12, 257–266.
Meriaux, A.-S., Ryerson, F.J., Tapponnier, P., Van der Woerd, J., Finkel, R.C., Xu, X., Xu, Z., Caffee, M.W., 2004. Rapid slip along the central Altyn Tagh Fault:

morphochronologic evidence from Cherchen He and Sulamu Tagh. Journal of Geophysical Research 109 B06401.
Mischke, S., Kramer, M., Zhang, C., Shang, H., Herzschuh, U., Erzinger, J., 2008. Reduced early Holocene moisture availability in the Bayan Har Mountains, northeastern Tibetan Plateau, inferred from a multi-proxy lake record. Palaeogeography, Palaeoclimatology, Palaeoecology 267, 59–76.
Mix, A.C., Bard, E., Schneider, R., 2001. Environmental processes of the ice age: land, ocean, glaciers (EPILOG). Quaternary Science Reviews 20, 627–657.
Morrill, C., Overpeck, J.T., Cole, J.E., Liu, K., Shen, C., Tang, L., 2006. Holocene variations in the Asian monsoon inferred from the geochemistry of lake sediments in Central Tibet. Quaternary Research 65, 232–243.
Müller, F., 1980. Present and late Pleistocene equilibrium line altitudes in the Mt. Everest region—an application of the glacier inventory. World Glacier Inventory 126, 75–94.
Owen, L.A., Benn, D.I., 2005. Equilibrium-line altitudes of the Last Glacial Maximum for the Himalaya and Tibet: an assessment and evaluation of results. Quaternary International 138/139, 55–78.
Owen, L.A., Derbyshire, E., 1988. Glacially deformed diamictons in the Karakoram Mountains, northern Pakistan. In: Croots, D. (Ed.), Glaciotectonics: Forms and Processes. Balkema, Rotterdam, pp. 149–176.
Owen, L.A., Derbyshire, E., 1989. The Karakoram glacial depositional system. Zeitschrift Für Geomorphologie 76, 33–73.
Owen, L.A., Lehmkuhl, F. (Eds.), 2000. Late Quaternary glaciation and paleoclimate of the Tibetan Plateau and bordering mountains. Quaternary International 65/66, 212.
Owen, L.A., Zhou, S. (Eds.), 2002. Glaciation in monsoon Asia. Quaternary International 97/98, 179.
Owen, L.A., England, J., 1998. Observations on rock glaciers in the Himalayas and Karakoram Mountains of northern Pakistan and India. Geomorphology 26, 199–213.
Owen, L.A., Derbyshire, E., Fort, M., 1998. The Quaternary glacial history of the Himalaya. Quaternary Proceedings 6, 91–120.
Owen, L.A., Gualtieri, L., Finkel, R.C., Caffee, M.W., Benn, D.I., Sharma, M.C., 2001. Cosmogenic radionuclide dating of glacial landforms in the Lahul Himalaya, northern India: defining the timing of Late Quaternary glaciation. Journal of Quaternary Science 16, 555–563.
Owen, L.A., Finkel, R.C., Caffee, M.W., 2002a. A note on the extent of glaciation throughout the Himalaya during the global Last Glacial Maximum. Quaternary Science Reviews 21, 147–157.
Owen, L.A., Finkel, R.C., Caffee, M.W., Gualtieri, L,, 2002b. Timing of multiple Late Quaternary glaciations in the Hunza Valley, Karakoram Mountains, northern Pakistan: defined by cosmogenic radionuclide dating of moraines. Geological Society of America Bulletin 114, 593–604.
Owen, L.A., Kamp, U., Spencer, J.Q., Haserodt, K., 2002c. Timing and style of Late Quaternary glaciation in the eastern Hindu Kush, Chitral, northern Pakistan: a review and revision of the glacial chronology based on new optically stimulated luminescence dating. Quaternary International 97/98, 41–55.
Owen, L.A., Finkel, R.C., Ma, H., Spencer, J.Q., Derbyshire, E., Barnard, P.L., Caffee, M.W., 2003a. Timing and style of Late Quaternary glaciations in NE Tibet. Geological Society of America Bulletin 115, 1356–1364.
Owen, L.A., Ma, H., Derbyshire, E., Spencer, J.Q., Barnard, P.L., Zeng, Y.N., Finkel, R.C., Caffee, M.W., 2003b. The timing and style of Late Quaternary glaciation in the La Ji Mountains, NE Tibet: evidence for restricted glaciation during the latter part of the Last Glacial. Zeitschrift Für Geomorphologie 130, 263–276.
Owen, L.A., Spencer, J.Q., Ma, H., Barnard, P.L., Derbyshire, E., Finkel, R.C., Caffee, M.W., Zeng, Y.N., 2003c. Timing of Late Quaternary glaciation along the southwestern slopes of the Qilian Shan, Tibet. Boreas 32, 281–291.
Owen, L.A., Finkel, R.C., Barnard, P.L., Haizhou, M., Asahi, K., Caffee, M.W., Derbyshire, E., 2005. Climatic and topographic controls on the style and timing of Late Quaternary glaciation throughout Tibet and the Himalaya defined by ^{10}Be cosmogenic radionuclide surface exposure dating. Quaternary Science Reviews 24, 1391–1411.
Owen, L.A., Caffee, M.W., Bovard, K.R., Finkel, R.C., Sharma, M.C., 2006a. Terrestrial cosmogenic nuclide surface exposure dating of the oldest glacial successions in the Himalayan orogen. Ladakh Range, northern India. Geological Society of America Bulletin 118, 383–392.
Owen, L.A., Finkel, R.C., Ma, H., Barnard, P.L., 2006b. Late Quaternary landscape evolution in the Kunlun Mountains and Qaidam Basin, Northern Tibet: a framework for examining the links between glaciation, lake level changes and alluvial fan formation. Quaternary International 154/155, 73–86.
Owen, L.A., Caffee, M.W., Finkel, R.C., Seong, B.S., 2008. Quaternary glaciation of the Himalayan–Tibetan orogen. Journal of Quaternary Science 23, 513–532.
Phadtare, N.R., 2000. Sharp decrease in summer monsoon strength 4000–3500 cal yr B.P. in the Central Higher Himalaya of India based on pollen evidence from alpine peat. Quaternary Research 53, 122–129.
Phillips, W.M., Sloan, V.F., Shroder Jr., J.F., Sharma, P., Clarke, M.L., Rendell, H.M., 2000. Asynchronous glaciation at Nanga Parbat, northwestern Himalaya Mountains, Pakistan. Geology 28, 431–434.
Porter, S.C., 2000. Onset of neoglaciation in the Southern Hemisphere. Journal of Quaternary Science 15, 395–408.
Porter, S.C., Denton, G.H., 1967. Chronology of neoglaciation in the North American cordillera. American Journal of Science 265, 177–210.
Pu, Q., 1991. Quaternary glaciers in China. In: Zhang, Z., Shao, S., Tong, G., Cao, J. (Eds.), The Quaternary of China. China Ocean Press, Beijing, pp. 240–273.
Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C.J.H., Blackwell, P.G., Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Hogg, A.G., Hughen, K.A., Kromer, B., McCormac, G., Manning, S., Ramsey, C.B., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., Weyhenmeyer, C.E., 2004. INTCAL04 terrestrial radiocarbon age calibration, 0–26 Cal Kyr BP. Radiocarbon 46, 1029–1058.
Richards, B.W.M., 2000. Luminescence dating of Quaternary sediments in the Himalaya and High Asia: a practical guide to its use and limitations for constraining the timing of glaciation. Quaternary International 65/66, 49–61.
Richards, B.W.M., Benn, D., Owen, L.A., Rhodes, E.J., Spencer, J.Q., 2000a. Timing of Late Quaternary glaciations south of Mount Everest in the Khumbu Himal, Nepal. Geological Society of America Bulletin 112, 1621–1632.
Richards, B.W.M., Owen, L.A., Rhodes, E.J., 2000b. Timing of Late Quaternary glaciations in the Himalayas of northern Pakistan. Journal of Quaternary Science 15, 283–297.
Röthlisberger, F., Geyh, M., 1985. Glacier variations in Himalayas and Karakoram. Zeitschrift Für Gletscherkunde Und Glazialgeologie 21, 237–249.
Rupper, S., Roe, G., Gillespie, A. Spatial patterns of Holocene glacier advance and retreat in central Asia. Quaternary Research, in press.
Rutter, N.W., 1995. Problematic ice sheets. Quaternary International 28, 19–37.
Schäfer, J.M., Tschudi, S., Zhizhong, Z/, Xihao, W., Ivy-Ochs, S., Wieler, R., Baur, H., Kubik, P.W., Schluchter, C., 2002. The limited influence of glaciation in Tibet on global climate over the past 170,000 yr. Earth and Planetary Science Letters 194, 287–297.
Semken, H.A., 1984. Holocene mammalian biogeography and climatic change in the eastern and central United States. In: Wright Jr., H.E. (Ed.), Late Quaternary Environments of the United States. The Holocene, vol. 2. Longman, London, pp. 182–207.
Seong, Y.B., Owen, L.A., Bishop, M.P., Bush, A., Clendon, P., Copland, P., Finkel, R.C., Kamp, U., Shroder, J.F., 2007. Quaternary glacial history of the Central Karakoram. Quaternary Science Reviews 26, 3384–3405.
Seong, Y.B., Owen, L.A., Bishop, M.P., Bush, A., Clendon, P., Copland, P., Finkel, R.C., Kamp, U., Shroder, J.F., 2008. Reply to comments by Matthias Kuhle on Seong, Y.B., Owen, L.A., Bishop, M.P., Bush, A., Clendon, P., Copland, P., Finkel, R.C., Kamp, U., Shroder, J.F., 2007. Quaternary glacial history of the Central Karakoram. Quaternary Science Reviews 27, 1656–1658.
Seong, Y.B., Owen, L.A., Yi, C., Finkel, R.C. Quaternary glaciation of Muztag Ata and Kongur Shan: evidence for glacier response to rapid climate changes throughout the Late-glacial and Holocene in westernmost Tibet. Geological Society of America Bulletin, in press.
Sharma, M.C., Owen, L.A., 1996. Quaternary glacial history of the Garhwal Himalaya, India. Quaternary Science Reviews 15, 335–365.
Shen, J., Liu, X., Wang, S., Ryo, M., 2005. Palaeoclimatic changes in the Qinghai Lake area during the last 18,000 years. Quaternary International 136, 131–140.
Shi, Y., 1992. Glaciers and glacial geomorphology in China. Zeitschrift Für Geomorphologie 86, 19–35.
Shi, Y., Zheng, B., Li, S., 1992. Last glaciation and maximum glaciation in the Qinghai–Xizang (Tibet) Plateau: a controversy to M.Kuhle's ice sheet hypothesis. Zeitschrift Für Geomorphologie 84, 19–35.
Shiraiwa, T., 1993. Glacier Fluctuations and Cryogenic Environments in the Langtang Valley, Nepal Himalaya. Contributions from the Institute of Low Temperature Science. The Institute of Low Temperature Sciences, Hokkaido University, Sapporo, Japan, 98 pp.
Shiraiwa, T., Watanabe, T., 1991. Late Quaternary glacial fluctuations in the Langtang Valley, Nepal Himalaya, reconstructed by relative dating methods. Arctic and Alpine Research 23, 404–416.
Simmons, I.G., Dimbleby, G.W., Grigson, C., 1981. The mesolithic. In: Simmons, I.G., Tooley, M.J. (Eds.), The Environment in British Prehistory. Duckworth, London, pp. 82–124.
Spencer, J.Q., Owen, L.A., 2004. Optically stimulated luminescence dating of Late Quaternary glaciogenic sediments in the upper Hunza valley: validating the timing of glaciation and assessing dating methods. Quaternary Sciences Reviews 23, 175–191.
Stuvier, M., Reimer, P.J., 1993. CALIB radiocarbon calibration program. Radiocarbon 35, 215–230.
Su, Z., Shi, Y., 2002. Response of monsoonal temperate glaciers to global warming since the Little Ice Age. Quaternary International 97–98, 123–132.
Thompson, L.G., 2000. Ice core evidence for climate change in the Tropics: implications for our future. Quaternary Science Reviews 19, 19–35.
Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Bolzan, J.F., Dai, J., Yao, T., Gundestrup, N., Wu, X., Klein, L., Xie, Z., 1989. Holocene–Late Pleistocene climatic ice core records from Qinghai–Tibetan Plateau. Science 246, 474–477.
Thompson, L.G., Yao, T., Davis, M.E., Henderson, K.A., Mosley-Thompson, E., Lin, P.-N., Beer, J., Synal, H.A., Cole-Dai, J., Bolzan, J.F., 1997. Tropical climate instability: the last glacial cycle from a Qinghai–Tibetan ice core. Science 276, 1821–1825.
Thompson, L.G., Davis, M.E., Mosley-Thompson, E., Lin, P.-N., Henderson, K.A., Mashiotta, T.A., 2005. Tropical ice core records: evidence for asynchronous glaciation on Milankovitch timescales. Journal of Quaternary Science 20, 723–733.
Tsukamoto, S., Asahi, K., Watanabe, T., Kondo, R., Rink, W.J., 2002. Timing of past glaciation in Kanchenjunga Himal, Nepal by optically stimulated luminescence dating of tills. Quaternary International 97/98, 57–68.
Van Campo, E., Gasse, F., 1993. Pollen- and diatom-inferred climatic and hydrological changes in Sumxi Co Basin (Western Tibet) since 13,000 yr B.P. 1993. Quaternary Research 39, 300–313.

Wang, F.-B., Fan, C.Y., 1987. Climatic changes in the Qinghai–Xizang (Tibetan) region of China during the Holocene. Quaternary Research 28, 50–60.
Wu, G.H., 1984. The preliminary observation of Neoglacial in the Qilian Mountains (in Chinese with English summary). Journal of Glaciology and Geocryology 6, 53–60.
Wu, X.D., 1992. Dendroclimatic studies in China. In: Bradley, R.S., Jones, P.D. (Eds.), Climate Since 1500 A.D. Routledge, London, pp. 432–445.
Wu, Y., Lucke, A., Jin, Z., Wang, S., Schleser, G.H., Batterbee, R.W., Xia, W., 2006. Holocene climate development on the central Tibetan Plateau: a sedimentary record from Cuoe Lake. Palaeogeography, Palaeoclimatology, Paleoecology 234, 328–340.
Yang, B., Brauning, A., Dong, Z., Zhang, Z., Keqing, J., 2008. Late Holocene monsoonal temperate glacier fluctuations on the Tibetan Plateau. Global and Planetary Change 60, 126–140.
Yang, J.Q., Zhang, W., Cui, Z.J., Yi, C.L., Liu, K.X., Ju, Y.J., 2006. Late Pleistocene glaciation of Diancang Mountains and Gongwang Mountains, southeastern margin of the Tibetan Plateau. Quaternary International 154–155, 52–62.
Yi, C., Owen, L.A., 2006. Quaternary palaeoenvironmental change in Tibet and the bordering mountains. Quaternary International 154/155, 157.
Yi, C., Li, X., Qu, J., 2002. Quaternary glaciation of Puruogangri – the largest modern ice field in Tibet. Quaternary International 97/98, 111–123.
Yi, C., Chen, H., Yang, J., Liu, B., Fu, P., Liu, K., Li, S., 2008. Review of Holocene glacial chronologies based on radiocarbon dating in Tibet and its surrounding mountains. Journal of Quaternary Science 23, 533–558.
Yin, A., Harrison, T.M., 2000. Geologic evolution of the Himalayan–Tibetan orogen. Annual Reviews of Earth and Planetary Sciences 28, 211–280.
Zech, W., Glaser, B., Abramowski, U., Dittmar, C., Kubik, P.W., 2003. Reconstruction of the Late Quaternary Glaciation of the Macha Khola valley (Gorkha Himal, Nepal) using relative and absolute (^{14}C, ^{10}Be, dendrochronology) dating techniques. Quaternary Science Reviews 22, 2253–2265.
Zech, R., Abramowski, U., Glaser, B., Sosin, P., Kubik, P.W., Zech, W., 2005. Late Quaternary glacier and climate history of the Pamir Mountains derived from cosmogenic ^{10}Be exposure ages. Quaternary Research 64, 212–220.
Zhang, Z.S., 1988. The glacier variations on the northwestern slope in Namche Barwa since the last glaciation (in Chinese with English summary). Journal of Glaciology and Geocryology 10, 180–188.
Zheng, B., 1989. Controversy regarding the existence of a large ice sheet on the Qinghai–Xizang (Tibetan) Plateau during the Quaternary period. Quaternary Research 32, 121–123.
Zheng, B., 1997. Glacier variation in the monsoon maritime glacial region since the last glaciation on the Qinghai-Xizang (Tibetan) plateau. In: The Changing Face of East Asia During the Tertiary and Quaternary. Center of Asian Studies, The University of Hong Kong, pp. 103–112.
Zheng, B.X., Li, J.J., 1986. Regional divisions of existing glaciers in Xizang region. In: Li, J.J., Zheng, B.X., Yang, X.J. (Eds.), Glaciers of Xizang (Tibet). Science Press, Beijing, pp. 130–148.
Zheng, B., Ma, Q.H., 1994. The glacier variation, climate change and the river development in the Holocene on the Gonga Mountain (in Chinese with English summary). Acta Geographica Sinica 49, 500–508.
Zheng, B., Rutter, N., 1998. On the problem of Quaternary glaciations, and the extent and patterns of Pleistocene ice cover in the Qinghai–Xizang (Tibet) Plateau. Quaternary International 45/46, 109–122.
Zhou, S.Z., Chen, F.H., Pan, B.T., Cao, J.J., Li, J., Derbyshire, E., 1991. Environmental change during the Holocene in western China on a millennial timescale. Holocene 1, 151–156.