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Short Paper

Late Quaternary glaciation of the Tianshan, Central Asia, using cosmogenic ^{10}Be surface exposure dating

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ABSTRACT

Glacial deposits are present at the head of the Ürümqi River valley, Tianshan, Central Asia. ^{10}Be surface exposure ages of 15 boulders from three sites along a 12 km valley transect range from 9 to 21 ka suggesting emplacement by glacial retreat and advance commencing at the global last glacial maximum (LGM) and most likely abating in the early Holocene. Although the age spread for a given locality is not small, perhaps indicating post-depositional reworking, maximum ages per site are either coeval with or are post-LGM and inconsistent with previous pre-LGM electron spin resonance ages.

Introduction

Regional- and synoptic-scale processes modulate the effects of hemispheric global climate change. Understanding the coupling between regional climate events and global forcing systems requires multiple paleoclimate records from neighboring localities and regions. This information is essential to validate future climate change predictions from global circulation models based on evidence from paleoclimate proxies. This work contributes to the increasing database of paleoclimate change studies for Central Asia and to the reconstruction of its glacial geochronology allowing a better regional inter-comparison of Quaternary climate change with that of continental northern Europe.

Second only to the polar ice sheets, the glaciated terrains of the Himalaya and Tibetan plateau are the most extensively glaciated landscapes on Earth. Despite the excellent potential to reconstruct the nature of late Quaternary climate change from its extensive glacial geologic evidence, little chronological control is available, due mostly to minimal preservation of organic material for radiocarbon dating. In some earlier studies, controversy persists over the extent and timing of former glaciations because of the difficulties in securing reliable glacial chronologies (see discussions in Lehmkuhl and Owen (2005), and Owen et al. (2008)).

In this paper we apply ^{10}Be cosmogenic nuclide surface exposure dating of moraines in the upper section of Ürümqi River valley (43.1°N, 86.8°E) of the Tianshan range, which lies at the northern border of the Taklimakan desert in the Tarim basin (Fig. 1A). Because of its northerly and central-continental location, the glacial history of the region is strongly linked to its precipitation regime controlled largely by the mid-latitude westerly and Siberian systems (Koppes et al., 2008). Moreover as a far-field extreme continental environment, it may be possible to provide inferences related to the hemispheric, or even global, character of major climate change modes across the Tibetan Plateau (Benn and Owen, 1998; Owen et al., 2005; Owen et al., 2008).

Geological setting and sampling sites

The Tianshan range is located centrally within the Eurasian continent. It spans latitudes from ~40° to 44°N and stretches east-west over 2500 km from 70° to 96°E (Fig. 1A). Some peaks exceed 7000 m above sea level (asl), and this remote area is one of the driest regions in the world. Its current climate is semi-arid (650 mm/yr precipitation in the Ürümqi region, mostly in summer). The westerly jet stream prevails high above Tianshan (Lee et al., 2003).

The Ürümqi River drains the northern Tianshan, flowing north to north-east in a deep gorge. Modern recharge is by local precipitation and, to a lesser extent, by glacial melt sourced from cirque and upper valley glaciers confined to elevations of ~4000 m asl. Figure 1B shows the glacial landforms and sampling sites in the upper Ürümqi River valley. All samples are from the upper surfaces of granitic or gneissic boulders (standing >1 m above local till matrix) and were easily distinguished from local rockfall, which consists of schist or gabbro-diabase.

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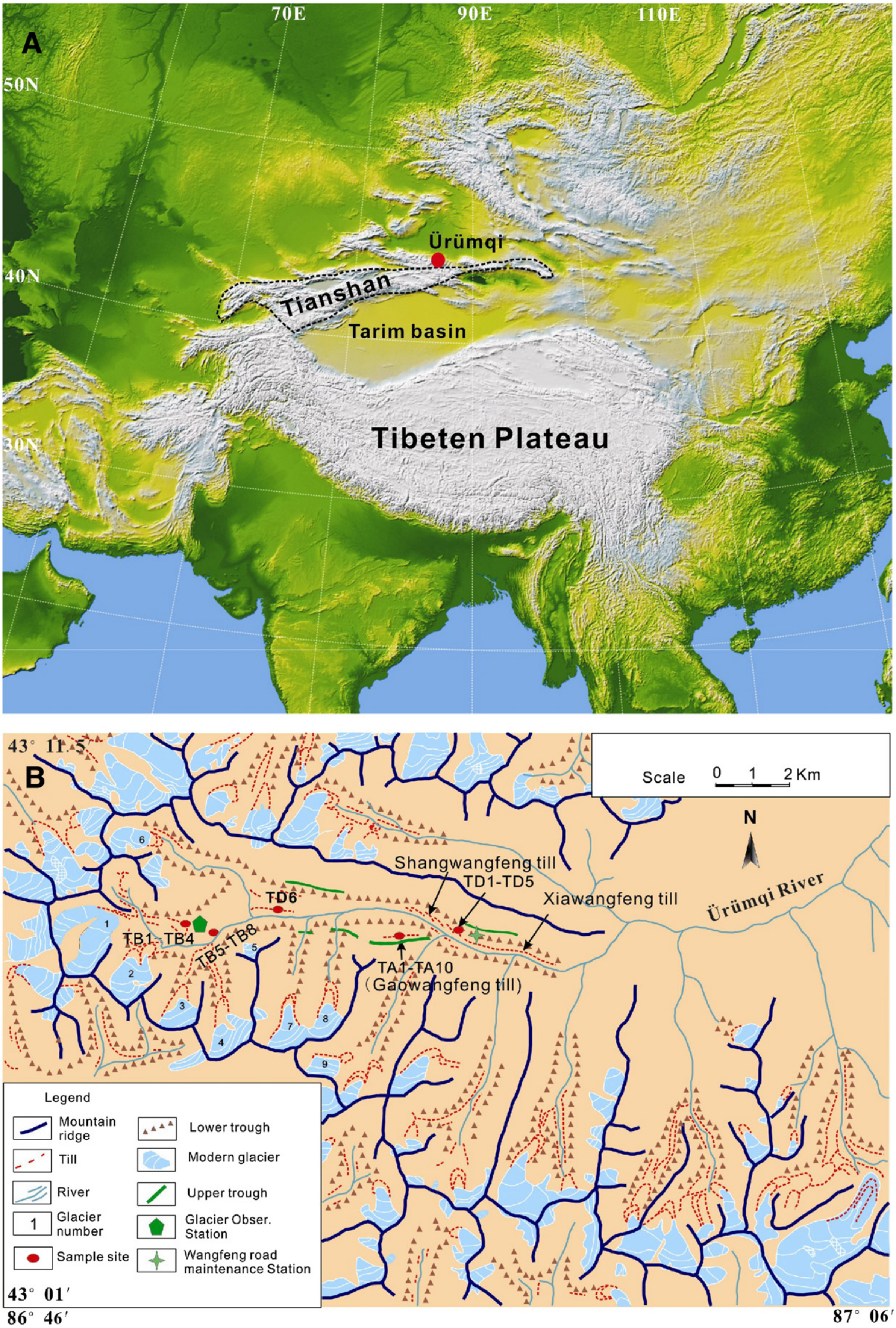

Figure 1. (A) Location of the Ürümqi River valley within the Tianshan range. (B) Detailed map of the Ürümqi River headwaters showing locations of Glacier #1, Glacier Observation Station and Wangfeng Road Maintenance Station and the three sites sampled for ^{10}Be cosmogenic surface exposure dating (TB1–8, TA1–10 and TD2–6).

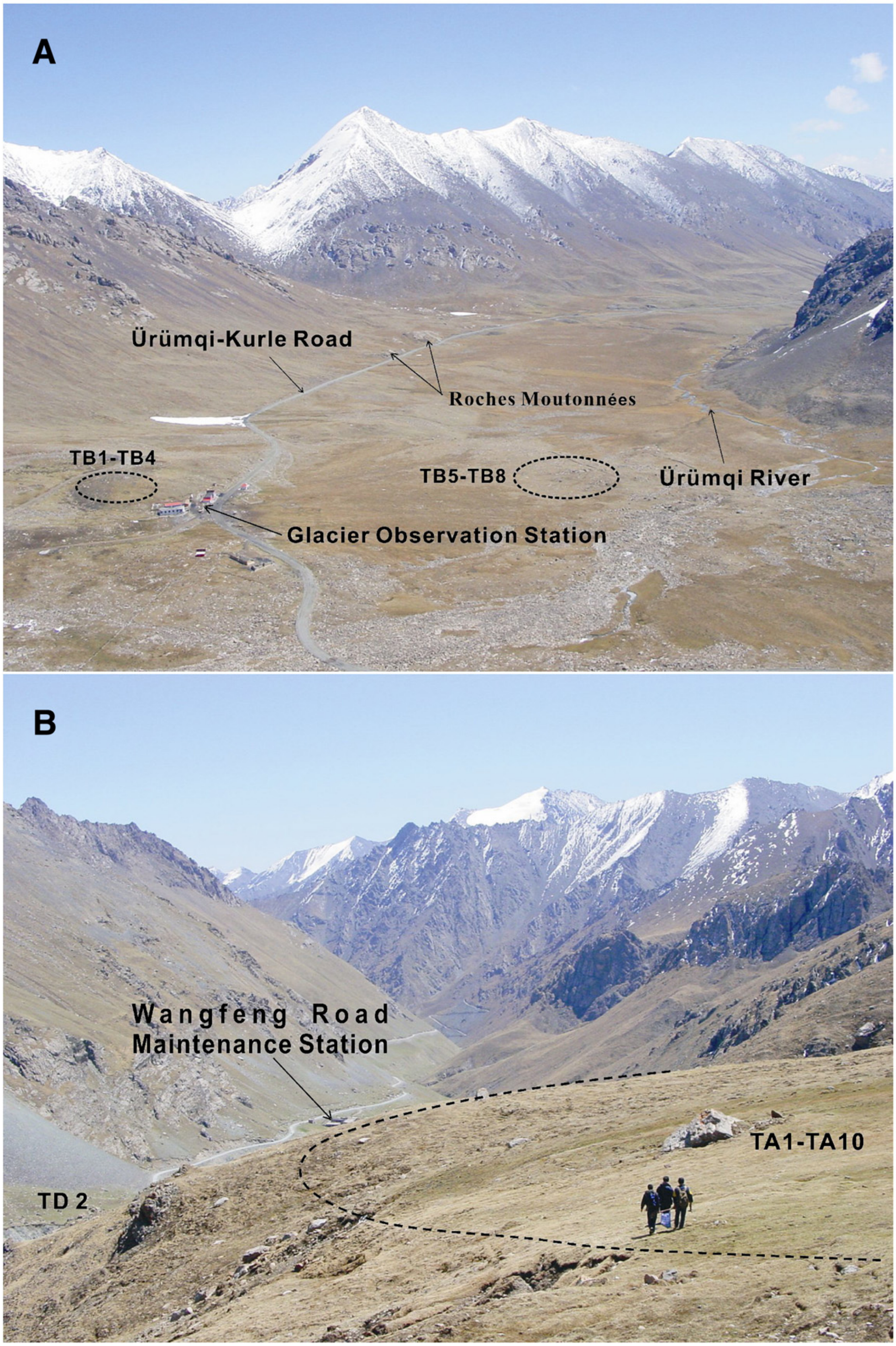

Figure 2. (A) View of the Ürümqi River valley looking east from the Glacier Observation Station towards Wangfeng Road Maintenance Station. Samples TB1 to TB8 are from late Quaternary moraines, 1–2 km east of the modern Glacier #1. (B) View looking eastward from a preserved section of the upper trough on the southern side of the Ürümqi River valley. The foreground shows the bench-like platform (outlined by dashed line) elevated ~230 m above the present valley floor. Samples TA1–10 are large erratics collected from the glacial till which drapes the bench. TD2–6 are from the Shangwangfeng latero-frontal moraine on the main valley floor next to the Wangfeng Road Maintenance Station.

Table 1
Sample information and ^{10}Be exposure ages for moraine boulders at the head of the Ürümqi River valley.

Sample name	Altitude (m asl)	Latitude (N)	Longitude (E)	Thickness (cm)	Shielding	^{10}Be concentration ($\times 10^4$ atoms/g)[a]	^{10}Be age (ka) (Stone, 2000)[b]
Lateral moraine, Glacier Observation Station							
TB1	3558	43°06.83	86°50.57	3	0.99	59.8 ± 3.8	9.6 ± 0.9
TB2	3567	43°06.83	86°50.55	3	0.99	90.9 ± 4.2	14.6 ± 1.2
TB3	3562	43°06.83	86°50.55	3	0.99	111.7 ± 7.2	17.9 ± 1.7
TB4	3561	43°06.83	86°50.55	3	0.99	129.7 ± 7.1	20.9 ± 1.9
Ground moraine, Glacier Observation Station							
TB5	3530	43°06.77	86°50.68	3	0.99	93.4 ± 2.3	15.3 ± 1.1
TB7	3511	43°06.83	86°50.83	3	0.99	88.8 ± 4.2	14.7 ± 1.2
TB8	3511	43°06.83	86°50.83	3	0.99	83.9 ± 4.9	13.9 ± 1.3
Latero-terminal moraine, lower trough, Shangwangfeng							
TD2	3164	43°06.98	86°55.75	3	0.98	98.7 ± 4.3	20.1 ± 1.7
TD5	3170	43°06.00	86°55.68	3	0.98	75.7 ± 4.5	15.4 ± 1.4
TD6	3449	43°07.25	86°51.35	3	0.99	88.7 ± 2.5	15.2 ± 1.2
Elevated platform, Gaowangfeng							
TA1	3389	43°06.82	86°55.27	3	1	57.3 ± 4.2	10.1 ± 1.0
TA2	3405	43°06.80	86°55.22	3	1	29.7 ± 3.0	5.2 ± 0.6
TA4	3408	43°06.78	86°55.22	3	1	95.4 ± 8.8	16.6 ± 1.9
TA6	3423	43°06.75	86°55.20	3	1	52.7 ± 5.4	9.1 ± 1.1
TA10	3324	43°06.78	86°55.42	3	1	53.9 ± 4.0	9.8 ± 1.0

[a] Analytical error in concentration includes 2% error for AMS standard reproducibility, 1% in Be spike assay and quartz mass, and statistical error in $^{10}Be/^{9}Be$ ratio.
[b] ^{10}Be exposure ages based on $T_{1/2}$ of 1.5 Ma and scaling factors from Stone (2000). Exposure age error includes an additional 7% for site-specific production rate. Renormalizing ^{10}Be concentrations to the certified NIST-SRM 4325 value of 2.68×10^{-11} together with a 1.34 Ma half-life and SLHL production rate of 4.528 would alter exposure ages by less than 1%.

Adjacent to the Ürümqi headwaters and ~2 km east of a small, upper valley glacier (Glacier #1), the Chinese Academy of Sciences has established a Glacier Observation Station. Here, local moraines have been assigned a Neoglacial age (Wang, 1981; Yi et al., 2002). Seven boulders were sampled for ^{10}Be surface exposure dating (Fig. 2A); TB1–TB4 (lateral moraine) and TB5, TB7 and TB8 (ground moraine) at ~3550 m asl.

Between the Glacier Observation Station (3550 m asl) and the Wangfeng Road Maintenance Station (~3000 m asl) for a distance of ~8 km, two latero-frontal moraine ridges named "Shangwangfeng" and "Xiawangfeng" (Liu et al., 1991) represent the most extensive glacial advance preserved above the main Ürümqi River valley floor. According to Liu et al. (1991), the Shangwangfeng moraine ridge overrides the Xiawangfeng moraine ridge, and the former ceases at the Wangfeng Road Maintenance Station with the latter extending to ~2800 m asl. Prior to this work, the advances of the two moraine ridges were assigned ages ranging from the global LGM (~20 ka; Yokoyama et al., 2000) to marine oxygen isotope stage (MIS) 6 (~170 ka). Three samples were collected from the Shangwangfeng moraine crest — TD2 and TD5, were taken adjacent to the Maintenance Station and TD6 was located closer to the Glacier Observation Station (Fig. 1B).

A discontinuous platform or bench named Gaowangfeng, elevated 200–400 m above the valley floor along its southern flank (Fig. 2B), is thought to be a remnant of an upper glacial trough (Liu et al., 1991). Five of ten sampled boulders, TA1–TA10, from the Gaowangfeng platform (at ~3400 m) were dated in this work.

Previous studies have attempted to place these glacial deposits in a chronological framework, but with limited success. By radiocarbon dating of inorganic pedogenic carbonate coatings on till clasts near the Glacier Observation Station and within the Shangwangfeng latero-frontal moraine, Yi et al. (2004) obtained ages of 2–7 ^{14}C ka BP and 19–23 ^{14}C ka BP, respectively. However, based on electron spin resonance (ESR), Zhao et al. (2006) obtained ages ranging from 28 to 38 ka for till samples from the Shangwangfeng moraine. The ESR results of 55–73 ka of Yi et al. (2002) for the Xiawangfeng moraine are inconsistent with the three ages from 171 to 185 ka reported by Zhao et al. (2006). Liu et al. (1991) proposed that the Gaowangfeng platform was glacially cut 200–300 ka ago based on its elevation and river down-cutting rate, whereas ESR dating of its ~10 m thick till drape gives an age of 460 ka (Zhao et al., 2006). Gillespie and Burke (2000) reported preliminary ^{10}Be–^{26}Al results suggesting an LGM age for the Shangwangfeng and Xiawangfeng moraines, but on the basis of field study did not regard the Gaowangfeng platform as till-mantled.

Methods and results

Chemical preparations, from extraction of quartz to final oxide, were carried out in the cosmogenic nuclide laboratory, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, using the methods described in Kong et al. (2007). ^{10}Be concentrations were measured by Accelerator Mass Spectrometry at the ANTARES facility, ANSTO (Australia). $^{10}Be/^{9}Be$ ratios were corrected for procedural blanks ($5–8 \times 10^{-15}$) and normalized relative to the NIST-4325 SRM standard with an assigned isotopic ratio of 3.02×10^{-11} (Fink and Smith, 2007). Exposure ages (Table 1) are based on scaling factors and a high-latitude sea-level total production rate of 5.1 atoms/g yr (including a 2.5% muonic component) from Stone (2000).

Results for all but one sample (TA2, 5.2 ka) ranged from 9 to 21 ka, suggesting that the most recent record of glacial activity at the head of the Ürümqi River valley either is coeval with or post-dates the LGM, consistent with dating of Gillespie and Burke (2000) but inconsistent with the suite of ESR dating quoted above. Most of the sampled boulders display polished and striated surfaces, indicating limited erosion. Kaplan et al. (2005) obtained an average erosion rate of 1.4 mm/ka for granitic boulders at Lago Buenos Aires, Argentina. Our maximum exposure age of 21 ka (TB4) would increase by 2–10% for 1–5 mm/ka erosion rates. Thus, the differences between cosmogenic nuclide surface exposure ages and the ESR-based ages are unlikely the result of underestimating exposure ages by overlooking the effect of surface erosion.

Discussion and conclusion

The mean exposure age for the ten samples in proximity to the main valley floor and associated with distinct glacial deposits (TB1–8, TD2–6) is 15.9 ± 3.3 ka. Given the age spread per site, no significant trend with upper valley position reflecting timing of glacial retreat can be discerned. The relative age spread for the Gaowangfeng samples (TA1–10, $10.2. \pm 4.1$ ka) is even larger (40% vs. 20% at the 1σ level) and suggests possible post-depositional reworking of the glacial deposits.

Notwithstanding the importance of cosmogenic nuclide surface exposure dating in building a chronology for the glaciation of Central Asia, for example the Karakoram of northern Pakistan (Owen et al., 2002), the Himalaya (Owen et al., 2005; Schaefer et al., 2008), the Kunlun in the northern Tibetan plateau (Clark et al., 2001; Owen et al., 2006), and the Kyrgyz Tianshan (Koppes et al., 2008), complexities in glacial age interpretation are common, arising mainly from larger-than-expected age distributions from a single landform after accounting for analytical errors. Recycling of glacial material and inefficient resetting of previously exposed glacial debris may be a factor in causing high geologic variability. Given the limited number of our samples and their large range of ages, we hesitate to interpret the mean apparent ages at the head of the Ürümqi River valley as firm landform ages. Therefore, chronological comparison to the above-mentioned districts, or to climate records dated by other means, is premature.

We note the vast disparity between the mean ages by surface exposure dating and the range given by ESR dating, especially for the Gaowangfeng moraine. Gillespie and Burke (2000) did not regard the soil surface on the Gaowangfeng platform as moraine. Since the granitic or gneissic boulders within the deposits on the Gaowangfeng platform are distinct from local bedrock, we prefer that they are erratics. Exhumation or reworking of glacial material may complicate the interpretation of surface exposure age, whereas difficulties in resetting of clock for glacial deposits are also a problem in ESR dating (cf. Richards, 2000; Fuchs and Owen, 2008). We propose two possibilities to explain the disparity of deposition ages derived from surface exposure and ESR dating methods for the Gaowangfeng moraine. Firstly, the ESR-based age records the deposition time of the moraine, and the younger exposure ages reflect later exhumation of glacial material. Secondly, the surface exposure age records the time of tributary side-valley glacial retreat, and the old ESR age reflects insufficient resetting of clock for glacial debris. To resolve the discrepancy of the ages more detailed studies are necessary in the future.

Our strongest conclusion is that all mean ages per site post-date the global LGM, with maximum sample ages either coeval with LGM or a few thousand years younger. The presence of strong MIS-3 glaciation and minor global LGM glacial advance in the neighboring Kyrgyz Tianshan (Koppes et al., 2008) stands in contrast to our observations at the head of the Ürümqi River valley. This attests to the critical importance of multi-site local studies in order to assess the significance and impact of regional climate variability and extent.

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