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Reply to comment received from J. Herget et al. regarding "Complex patterns of glacier advances during the late glacial in the Chagan Uzun Valley, Russian Altai" by Gribenski et al. (2016), Quaternary Science Reviews 149, 288–305

1. Introduction

We thank Herget et al. (2017) for their keen interest in our study about the paleoglacial history of the Chagan Uzun Valley, in the Russian Altai (Gribenski et al., 2016). In our study, we proposed a detailed chronological and glaciodynamic reconstruction of a succession of glacial events represented by prominent moraine complexes, based on remotely-sensed data and field-geomorphological mapping, sedimentological logging, and cosmogenic ^{10}Be and ^{26}Al surface exposure dating of glacially-transported boulders. Herget et al. (2017) express skepticism about the outermost moraine complex dated in our study (CUMC 1; Gribenski et al., 2016), which slightly predates 19 thousand years (ka), during marine isotope stage (MIS) 2. To quote: "*we suspect that their claim of regional climatic significance—that the ~19 ka Chagan-Uzun moraine they dated can be used to show that the local LGM and regional LGM were the same, and occurred during MIS 2—may be premature*" (Herget et al., 2017: p. 1). Their comment appears to relate to an ongoing debate regarding the timing of maximum glaciation in Central Asia during the last glacial cycle, however it is based on misinterpretations of our paper.

2. Maximum extent in the Chagan Uzun Valley vs local LGM

A main argument made in Herget et al. (2017) is that we underestimated the maximum extent of the Chagan-Uzun Glacier, and that the moraine we dated that was furthest down the valley cannot represent the local last glacial maximum (LGM).

We note that the term "*local LGM*" does not appear in our paper. We deliberately sought to avoid this nomenclature and instead use "last maximum extent" to refer to the outermost moraine complex of a set of well-defined moraine complexes formed during successive advances and retreats of the Chagan Uzun glacier system, slightly before 19 ka (MIS 2). We inadvertently use the term "last glacial maximum" once in association with the Chagan Uzun Valley and an MIS 2 timing in the manuscript, but otherwise we consistently refer to this in terms of the maximum extent of the last prominent glacier advance. This outermost moraine complex reflects the maximum extent the glacier reached during its last prominent advance, as evidenced by its much higher degree of preservation compared with glacial sediment-landform associations lower in the basin. Although this does not preclude the presence of an earlier and larger glacier system in the Chagan Uzun Valley during the last glacial cycle, poor landform preservation and poorly constrained timing (see below and section 3) make any such claim highly speculative.

Herget et al. (2017) deplore that we "*did not recognize an extensive moraine*" well beyond the moraine complexes we mapped and dated, while that had been reported in previous studies based on the presence of widespread glacially-reworked coarse lag deposits and glacial diamicton outcrops. To the contrary, we did in fact map an older and more extensive moraine deposit (cf. Figs. 1 and 4 in Gribenski et al., 2016), and labeled it as "suggested penultimate glacial extent" based on its highly degraded appearance in the satellite imagery (Landsat 7 ETM+ and SPOT 6; Gribenski et al., 2016)

and in the field. Our mapped limit (marked by a dashed line in our figures, to indicate uncertainty) does not match in detail the limits proposed in the studies referenced by Herget et al. (2017). However, in the absence of well-preserved ice-marginal glacial landforms (e.g. moraine ridges), the geometry of this larger glacier extent remains unclear and speculative. This also casts some doubts on the implicit assumption that the ice that delivered the sediment for this degraded deposit was solely sourced from the Chagan Uzun Valley (and tributaries). Because of the lack of clear geomorphic evidence for glacial extent reconstruction, and because this deposit could not be dated using the techniques employed in our study, it was not a focus of our study. While we do not reject the possibility that this deposit is associated with a glacial extent which occurred earlier in the last glacial cycle (and therefore could potentially be labeled as local LGM), we question the chronological markers used by Herget et al. (2017) to argue for a possible pre-MIS 2 last glacial maximum extent of the Chagan Uzun Glacier.

3. Morphostratigraphy and absolute ages

Herget et al. (2017) invoke the intermittent development of large ice-dammed paleolake(s), with ages spanning from MIS 2 to MIS 4, to support the occurrence of extensive glaciation(s) throughout the last glacial cycle. They also report two pre-MIS 2 ages (~58 ka from TL and ~36 ka from ^{14}C) from a glacial sedimentary unit in an exposure close to the Beltir settlement in the Chagan Uzun Valley to support a pre-MIS 2 local LGM. Although we acknowledge earlier glaciation(s) than the MIS 2 glaciation in the Kuray and Chuja basins area, we argue that the chronological framework presented in Herget et al. (2017) is not appropriate for deciphering the timing of the maximum extent in the Chagan Uzun Valley: The main ice dam associated with the development of the large paleolakes was located across narrow gorges at the exit of the Kuray Basin, >60 km downstream from the Chagan Uzun Valley. Because of the distance separating both glacier systems, and the contrast between their respective terminal settings and catchment geometries, it is likely that these systems operated differently (e.g. Haeberli, 1995; Kirkbride and Winkler, 2012, and references therein) during various phases of lake events. Therefore, even if the paleolake events indicate the occurrence of multiple glacial advances directly downstream of the Kuray Basin, these can not be correlated with specific extents of the Chagan Uzun Glacier, and equally can not be used to argue for a specific age for the furthest extent of ice expansion out of the Chagan Uzun Valley. Similarly, no specific extent of the Chagan Uzun Glacier can be correlated with the glacial unit identified along the Beltir exposure, which is located well upstream of the CUMC 1. Finally, but significantly, we have considerable concerns about the general lack of information surrounding the dating methods and sampling sites for the chronological data referred to by Herget et al. (2017). Much of this data is published in journals, field guides, and conference proceedings that are difficult to access and/or not subject to the same peer review standards as used in international journals.

4. Regional aspect

Herget et al. (2017) also contend that it is premature to correlate the "*local LGM*" (purportedly represented by the lowermost ~19 ka Chagan Uzun moraine) with the regional LGM, and argue that we overlooked previous studies suggesting that other glacial maxima in Central Asia predate MIS 2.

This is an over-interpretation of what we wrote. We did not attribute a regional significance to the glacial chronology established in the Chagan Uzun Valley, and never showed, contrary to their claim, "*that the regional LGM occurred in the Altai during MIS 2*". Rather, we compared our chronology with other local and regional paleo-environmental proxies and showed that the MIS 2 cold climate and the ~19 ka onset of warming conditions inferred from the Chagan Uzun paleoglacial reconstruction is not an isolated instance.

Although the regional LGM did not constitute the focus of our study, we agree that numerous paleoglacial reconstructions in Central Asia have concluded that there were pre-MIS 2 glacial maximas. However, MIS 2 glacial maximas have also been reported in Central Asia, including in the Altai (e.g. Lehmkuhl et al., 2007; Kong et al., 2009; Grin et al., 2016; Smith et al., 2016), and in some cases the timing remains unclear due to uncertainties related to the dating method (e.g. Li et al., 2011). Finally, current chronological data sets which underpin pre-MIS 2 glaciations are commonly associated with large uncertainties and currently unfit to attempt regional correlations (Heyman, 2014; Blomdin et al., 2016). Overall, the pattern of glaciation throughout the last glacial cycle in this region remains unclear and additional detailed and well-constrained paleoglacial chronologies are required before we can draw robust conclusions about the timing of the regional LGM in Central Asia. We particularly encourage future studies integrating and fully reporting geomorphological, sedimentological, and geochronological data in the Altai, because the timing and extent of glaciations in this area is particularly poorly understood compared to other Central Asian regions.

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