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Comment on 'Very Large Cryoturbation Structures of Last Permafrost Maximum Age at the Foot of Qilian Mountains (NE Tibet Plateau, China): a Discussion' by Stuart A. Harris, Huijun Jin and Ruixia He in PPP

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It is good to see that the section (Huangcheng, not Huangchengzi) near Menuyan (at the foot of the Qilian Shan, northern China), in which we recently described giant load casts (cryoturbations) (Vandenberghe *et al.*, 2016), is recognised as a key section for palaeo-permafrost reconstruction in China. We thank the editor of *Permafrost and Periglacial Processes* for giving us the opportunity to comment directly on the new results presented by Harris *et al.* (2017) on that same section. Rather than rectifying some detailed quotations from former literature on periglacial deformations, we limit ourselves to clarifying and discussing three major points of general importance for reconstructing past permafrost, particularly in China (Zhao *et al.*, 2014).

AGE DETERMINATIONS

In addition to the OSL ages that we have published (Wang *et al.*, 2013; Vandenberghe *et al.*, 2016), three new OSL ages, although without precise locations, are provided by Harris *et al.* (2017). We agree with these authors that more ages are desirable to pinpoint the sequence of events that took place at the time of permafrost development and degradation in the study region. In recent decades, luminescence dating has probably become the second most widely used Quaternary radiometric method after radiocarbon (Duller, 2011). It is well known to have its own problems and limitations.

To allow the reader to evaluate the significance and reliability of the ages, it is essential to detail how the ages were obtained, rather than focusing only on standard field-sampling procedures. The chosen minerals and grain-size fraction, and also specific analytical techniques (e.g. detection and stimulation windows/facilities, procedural tests, measurement protocol and configuration) have long been known to strongly influence the ultimate age derivation. Such information is, however, completely missing in Harris *et al.* (2017). As such, no comparison is possible with what we consider the more robust age information currently available for these deposits and associated features in the studied section (Wang *et al.*, 2013; Vandenberghe *et al.*, 2016).

This is not a technical and unimportant aspect; it has consequences. As appears from Harris *et al.*'s table 1, their OSL ages do not fit within the expected stratigraphical sequence: assuming that systematic sources of uncertainty are largely shared (and samples 'well away from the involutions'), the middle sample should be older than the upper sample. This apparent discrepancy does not hinder Harris *et al.* (2017) from using the age of that single middle sample (19.6 ka), without further discussion, to suggest long-distance links with sea-level rise in the China Sea and conclusions on related changes in precipitation. Similarly, a discussion of depositional rates based on questionable and imprecise age determinations makes little sense. It would have been desirable to see a site description of the samples, claimed to be unaffected by involutions by Harris *et al.* (2017), especially as the complete section was indeed involuted according to their figure 1 and our own detailed observations. Furthermore, it is not clear why these OSL ages are considered as 'minimum ages' for sediment deposition; underestimation would imply (partial) resetting of the luminescence clock following original deposition, upsetting the whole line of reasoning. Thus, we suggest that the authors should be more cautious in their interpretations.

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Finally, Harris *et al.* (2017) report a fourth age of 2.7 ± 0.4 ka, which is omitted from their table 1. Probably this age is the result obtained for sample HC-1 by Wang *et al.* (2013) and Vandenberghe *et al.* (2016); however, any reference to that age is missing.

THE SEDIMENTARY AND GEOMORPHOLOGICAL HISTORY

We agree that the age of the fluvio-glacial gravel should exceed 30 or 26 ka, according to dating of the overlying silt layer by Harris *et al.* (2017) and Vandenberghe *et al.* (2016), respectively. Coarse-grained material is often deposited at times of maximum ice extent along glacier-fed rivers. The required high energy to transport this coarse-grained load is realised by steepening of the longitudinal gradient. However, this does not lead to river downcutting, as stated by Harris *et al.* (2017), but instead to sediment accumulation (e.g. Schumm, 1977; Vandenberghe and Woo, 2002). The gravel accumulation is followed by increased snow- and ice-melt during deglaciation under stable or decreasing sediment supply by the glacier, as shown by many field observations and measurements in present-day glacio-fluvial environments (e.g. Marren and Toomath, 2013). To restore a dynamic equilibrium, the river lowers its energy potential by decreasing its longitudinal gradient, which is realised by downcutting, transforming the former floodplain of the glacio-fluvial river into a terrace (Vandenberghe, 2015). However, peak discharges may episodically flood the former gravel plain and deposit finer-grained alluvium (floodloam), while the pebbles mostly remain in the channel bed (Vandenberghe, 2015). That is exactly what happened at the Menuyan site, in the region of the foothill rivers along the Qilian Shan (Wang *et al.*, 2013). The overbank origin of the silty sediments is convincingly demonstrated by their sandy grain size and the presence of gravel stringers and sand laminae. In contrast, Harris *et al.* (2017) propose a so-called 'accumulation of mineral nuclei of snow'. The low rate of deposition derived by the latter authors may easily be explained by the temporary character of overbank deposition. In addition, no sedimentary hiatus (and also no soil) should be expected between the two kinds of fluvial deposition. Finally, this sedimentary succession, from gravel to sandy silt, does not require a major climatic shift other than the initial warming responsible for the glacier retreat

Figure 1 Photograph of typical involutions in the Huangcheng section, near Menuyan. Note the regular repetition of pockets of sandy silt that have subsided and diapirs of gravel that have risen. All involutions have a common depth. See Vandenberghe *et al.* (2016) for further illustrations. [Colour figure can be viewed at wileyonlinelibrary.com]

and is certainly not an indication towards dry conditions. The latter warming event should have taken place before 26 or 30 ka, but permafrost conditions persisted subsequently.

THE LOAD CASTING

In the process of sediment loading, the volumes of sinking and rising material should be equal, as also appears from experiments (e.g. Dzulinski, 1966; Anketell *et al.*, 1970; Talbot and Jackson, 1987). Although Harris *et al.* (2017) state in the caption of their figure 2 that 'similar volumes of silt and gravel have been displaced', they report also that (probably at other locations?) 'the volume of gravel disturbed is far less than that of sandy silt tonguing downwards in the deeper involutions'. This contradicts our observations, which consistently and clearly show equal volumes of updomed and subsided material (Figure 1 and figures in Vandenberghe *et al.*, 2016). Unequal involuted masses may appear at single places but are caused by specific intersections of the exposure. Upheaval of the gravel may reach some 3 m, which is exactly the depth of subsided silt. The sediment–structural appearance, illustrated by the common depth of the subsided pockets (Figure 1), supports the interpretation of loading of the sediments in supersaturated conditions, as explained by Vandenberghe (1992) and Vandenberghe *et al.* (2016).

There is no evidence at all for collapse of undisturbed sediment in hollows created by melting of buried blocks of ice. Nowhere along a 100-m-long section were such collapse structures (involving small faults) observed. Instead, flow lineations and vertically orientated pebbles were common, both in subsided and updomed sediments, even in the gravel layer (Figures 1 and figures 3c and 4a, b in Vandenberghe *et al.*, 2016):

From their figure 3, Harris *et al.* (2017) infer from the large mass of silt and its flat bottom a presumed hollow cast. However, both features are characteristic of the loading process: the flat bottom corresponds with the top of the perennial frozen subsoil at the time of loading, while subsiding material is displaced horizontally where it cannot penetrate deeper because of permafrost; often such a layer is composed of more than one subsided pocket (Vandenberghe and Van den Broek, 1982; Vandenberghe, 1992; Kasse, 1993). The latter process may result in a complete stratigraphic overturning and layer reversal, as observed both in laboratory experiments and in the field (the originally upper layer is moved completely below the originally lower layer) (e.g. Talbot and Jackson, 1987). Finally, it would have been a strange coincidence that the supposed hollows occurred at exactly the same depth as all involuted pockets.

CONCLUSIONS

1. We agree with Harris *et al.* (2017) that the exposure near Menuyan provides excellent information on the presence of permafrost during the Last Permafrost Maximum in China and related palaeoclimatic conditions.
2. In view of the stratigraphic inconsistency in the sequence of OSL ages reported by Harris *et al.* (2017), we believe it is risky to use such data to derive far-reaching hypotheses that link the paleoclimate on the Tibetan Plateau and sea-level changes in the China Sea.
3. It is unrealistic to derive robust sedimentation rates because of the imprecision generally associated with OSL ages.
4. The sedimentary sequence from gravel to sandy silt deposition is a typical fluvial record from channel to floodplain activity, originally initiated by river downcutting because of glacier retreat. Such fluvial behaviour does not necessarily require a palaeoclimatic change towards drier conditions.
5. All involutions, without exception, show the structural characteristics of cryoturbations (periglacial load casts), namely the repetitive sequences of equal amounts of subsided and updomed sediment reaching a common deformational depth with locally flat-bottomed shape. Typically, the gravel layer is characterised by vertically orientated pebbles. Moreover, undisturbed and collapsed gravel bodies, occurring coincidentally at the same depth as the involutions, were not observed along the entire section.

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