TECHNICAL RESPONSE

ARCHAEOLOGY

Response to Comment on "Permanent human occupation of the central Tibetan Plateau in the early Holocene"

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We show that Zhang and Li's sedimentological model for the Chusang travertine neglects the three-dimensional information from multiple outcrops and that their optically stimulated luminescence (OSL) age of about 20,000 years for the human imprints is untenable. We highlight the robustness of our chronology and explore reasons why Zhang and Li's OSL age is a gross overestimation of the real depositional age of the imprinted travertine.

Zhang and Li's basic claim is that there is no stratigraphic relation between the imprinted travertine area and the rest of the depositional succession because this very area was precipitated from a separate spring (*1*). They further believe that the imprinted travertine lacks the underlying colluvial layers Dms (diamict matrix supported) #1 to #4 (*2*, *3*) and postulate hiati for travertine sheets that obviously reveal lateral continuity. The problem with these claims is that Zhang and Li (i) ignore a series of outcrops that clearly demonstrate otherwise and (ii) neglect fundamental stratigraphic principles—namely, the law of superposition and Walther's law of facies (stating that facies that occur in conformable vertical successions of strata also occur in laterally adjacent environments) (*4*, *5*). Figure 1 shows the upper part of the Chusang travertine in May 2016. The imprinted area is situated on top of this travertine complex next to the chorten, and laterally continuous sheets of travertine that originate from the top of the complex drape the slope (Fig. 1). Colluvium layer Dms #4 is visible in a fresh road cut at 4253 m above sea level (masl), 50 m downslope from the imprints, and can also be logged along the entire gully 1 and in an additional roadcut at 4214 m (Fig. 1 and Fig. 2, A and B). Dms #4 has been radiocarbon dated to ~15 thousand to 16 thousand years ago (*3*). In Fig. 2C, Dms #4 is overlain by ~4-m-thick travertine that can be traced upslope directly to the chorten and imprinted area and under Dms #1

(Fig. 1). Following the law of superposition, the travertine succession above Dms #4 must thus be younger than ~15 thousand to 16 thousand years old. Figure 1 also shows that the topmost (imprinted) travertine sheet is underlain by colluvium Dms #1 that has been radiocarbon dated to 8 thousand to 12 thousand years ago (*3*). This stratigraphic relation is particularly obvious in Fig. 2D and visible in numerous additional outcrops plotted as red dots in Fig. 2B. We emphasize that Dms #1 can be traced along the northern, western, and southern margins of the imprinted travertine sheet, allowing full three-dimensional reconstruction (*2*, *3*). Construction work at Chusang in the past 2 years also exposed Dms #1 directly below the imprints H5 and H6 and F11 to F13 (Fig. 2, B and E).

Throughout their comment, Zhang and Li confuse the concept of stratigraphy and facies distribution with the idea of spatial proximity. In their attempt to reestablish an age of 20 thousand years for the imprints, they try to reduce our data set to an area 1 by 1 m in size (i.e., to sample QS-T-2) but ignore that the hand and footprints themselves are already spread out over a 40- by 25-m-large area and occur on the surface of a travertine sheet that reveals lateral continuity for at least 100 m into the eastern direction (diagonal upslope) and the northeastern direction (slope parallel) (Fig. 2B). The slope inclination stays constant in these directions, no break in slope or incision occurs, and the same degree of erosion of the travertine surface can be observed [i.e., slight surface spalling due to frost weathering (*2*, *3*)]. Multiple travertine mounds in the vicinity of the hand and footprints that precipitated travertine during vastly different time periods (Zhang and Li's assumption) are absent.

Sedimentology and geomorphology thus suggest stratigraphic integrity and lateral continuity (*2*), and we maintain that optically stimulated luminescence (OSL) sample CS-T-2 and ^{14}C sample P12 (63 m and 87 m from the imprints, respectively) (Fig. 2B) can be firmly linked into the established succession (*3*).

Zhang and Li claim that our chemical procedures are inappropriate or our U-Th age uncertainties underestimated. There is no basis for this claim. First, the samples are not dissolved in strong acids. The samples are mixed with 1.5 mL water before sufficient acid is added. In this study, we added 0.03 mL 7 M HNO_3 and 0.07 mL spike (in 7 M HNO_3). The resulting acid is weak (around 0.5 M) but strong enough to fully dissolve the $CaCO_3$ with minimum leaching of the nonsolvable fraction during equilibration of dissolved sample and spike.

We use established protocols, published in (*6*), designed for isochron analyses on pedogenic carbonates with high detrital fraction and possibly more than two endmembers. These protocols are also appropriate for the travertine samples used here.

We disagree with Zhang and Li that total dissolution would be a more appropriate approach. This was already demonstrated by (*7*), who showed that best results for isochrons were obtained from leachate data alone. This was confirmed by the study on lake carbonates (*6*). Therefore, we maintain our position that leachate results are better to obtain isochrons.

The uncertainty for 6 out of 11 samples is dominated by the detrital correction. The bulk earth value was used for detrital correction (^{238}U/^{232}Th activity ratio of 0.8 ± 0.4; ^{230}Th and ^{234}U in secular equilibrium with ^{238}U), which is supported by our isochron results (always within 0.8 ± 0.4). The additional uncertainty due to the correction is fully propagated for U-Th ages of individual samples. Contrary to Zhang and Li's comment, the remaining five samples yielded ^{230}Th/^{232}Th activity ratios acceptable for Holocene samples, between 9.2 and 45.3. The correction for these five samples is small, and the resulting U-Th ages fully supported by our independent age control and stratigraphic model; e.g., the dense travertine P4 (U-Th age 11.4 ± 0.5 thousand years) is directly underlain by Dms #4 (^{14}C age 15 to 16 thousand years) [Fig. 2 of (*3*)].

There is no scientific base for the suggestion of Zhang and Li to remove the high equivalent dose (De) values from the single-grain De distribution to reduce the overdispersion (OD) value and thus align our OSL age, which is based on single-grain measurements, with their multigrain age. The petrographic observations for sample CS-T-2 (composed of mostly subrounded to angular clasts and detrital grains) [figure S5, D to F, of (*3*)] and our OD value of 37% (that would potentially be much higher if the Chusang quartz would reveal higher sensitivity) rather (and strongly) suggest that partial bleaching is compromising this sample and that a minimum age solution is appropriate (*8–13*).

The concerns of Zhang and Li regarding the implementation of the minimum age model (MAM) are straightforward to address. The single-grain dose recovery tests for the low and high preheat regime yielded OD values of 0% and 8%, respectively. Nevertheless, we opted for 20% OD (the sigma value) to be added to the single-grain De data set before running the MAM (common practice in single-grain MAM modeling, as correctly

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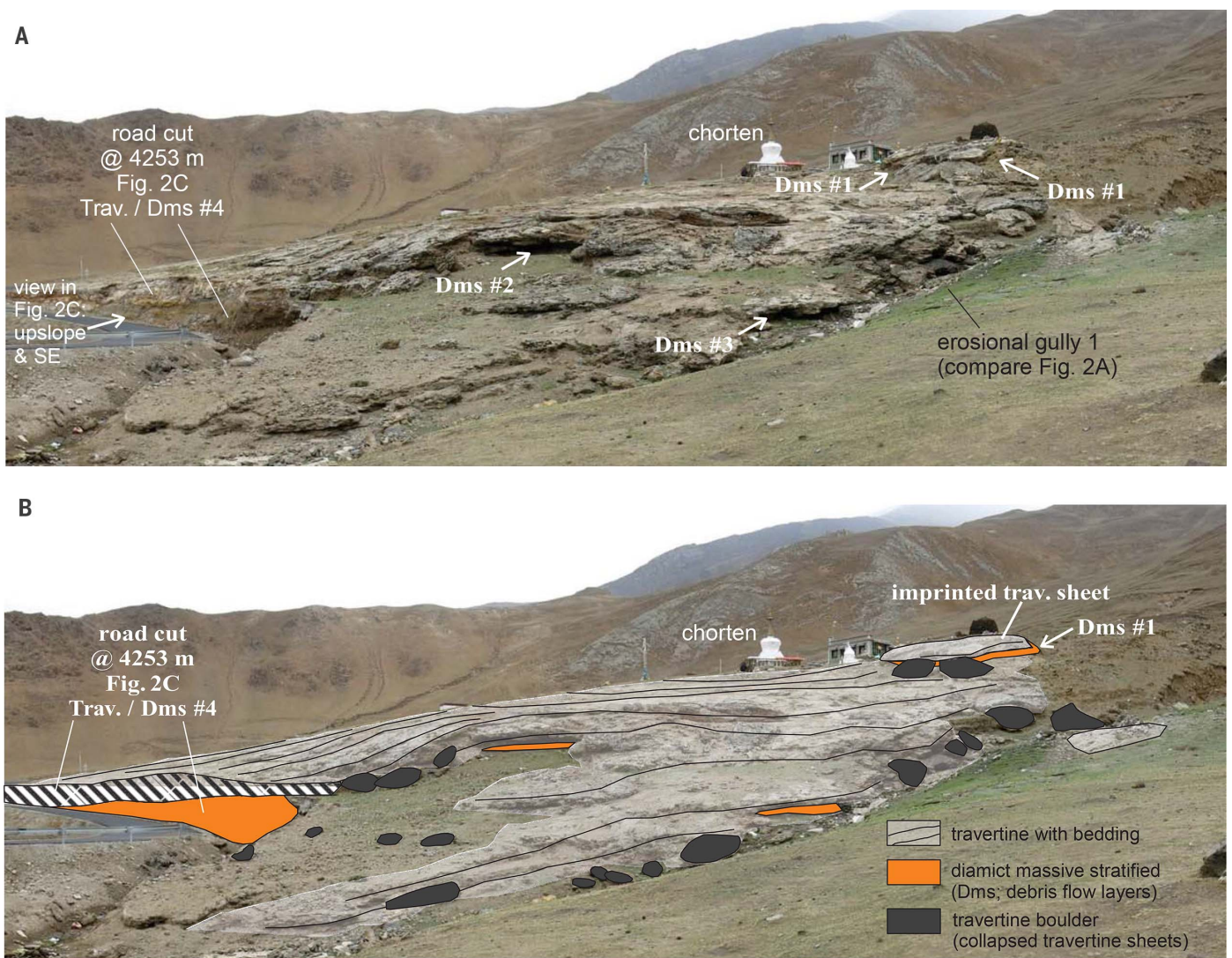*Corresponding author. Email: michael.meyer@uibk.ac.at

Fig. 1. Sedimentary architecture of the Chusang travertine. (**A** and **B**) Sedimentary architecture of the Chusang travertine, with sedimentary features highlighted in (B) (view to the northeast). The human imprints are preserved on the topmost travertine sheet next to the chorten and adjacent to a hill slope (compare Fig. 2B). Note that (i) the imprinted travertine is underlain by Dms #1, and (ii) travertine beds that originate from below Dms #1 and the chorten area are draping the slope. Dms #4 is underlaying this travertine complex as confirmed by a new roadcut at 4235 masl. Stacking of travertine with colluvium becomes particularly important in proximity to the hill slopes, which are the source area for repeated debris flows. Further debris flow layers (Dms #2 and 3) are intercalated into this travertine complex but pinch out into the northwest direction (i.e., toward the left side in the images).

pointed out by Zhang and Li), and the model output parameters and quality criteria were carefully checked (14, 15). We conclude that our single-grain OSL age is an accurate estimate of the depositional age of the imprinted travertine sheet and corroborates the two other independent dating techniques (3).

Zhang and Li's OSL age of 20 thousand years hinges on two assumptions: (i) that the hearth is contemporaneous with the imprints and (ii) that zeroing of the OSL signal was complete for their OSL samples (16).

Sample XZ-1 comes from a hearth, for which those authors assume that heating reset the OSL clock completely; two samples (XZ-2 and 3) are from the imprinted travertine layer itself [(16), exact location nowhere specified]. Interestingly, all samples yielded OSL ages of ~21 thousand years. It is very likely that incomplete zeroing is affecting samples XZ-2 and 3 (as was the case for our sample CS-T-2), but with a multigrain approach (applied by Zhang and Li) as opposed to a single-grain approach (applied by us), averaging effects in De determination will unavoidably result in age overestimation (8–15). Zhang and Li argue that their 20 thousand year age must hold because sample XZ-1 was zeroed by heat, but they do not provide any proof for this assumption (neither thin-section observations nor a De versus depth profile for the hearth wall). The very low quartz concentrations in the travertine require large samples to be taken to retrieve enough quartz for dating. As a result, quartz grains distal to the hearth wall might not have been exposed to any substantial degree of heat at all and thus carry a geological dose. In the absence of any tests or data regarding the question of zeroing the OSL signal, Zhang and Li rely on the reddish coloring of the hearth to assert that sufficiently high temperatures were achieved during burning. However, the primary iron content in the Chusang travertine is high [table S5 of (3)], and intensive reddish staining due to weathering of entire travertine beds is ubiquitous (Fig. 2, C to G). We thus caution against the premature conclusion that hearth coloring alone is a guarantee for complete zeroing of an associated OSL sample at Chusang.

Regarding the hearth itself, it is likely to be a modern construction made by local herders, and its design is essentially identical to hearths found in Tibetan homes today. Further, hearths of this
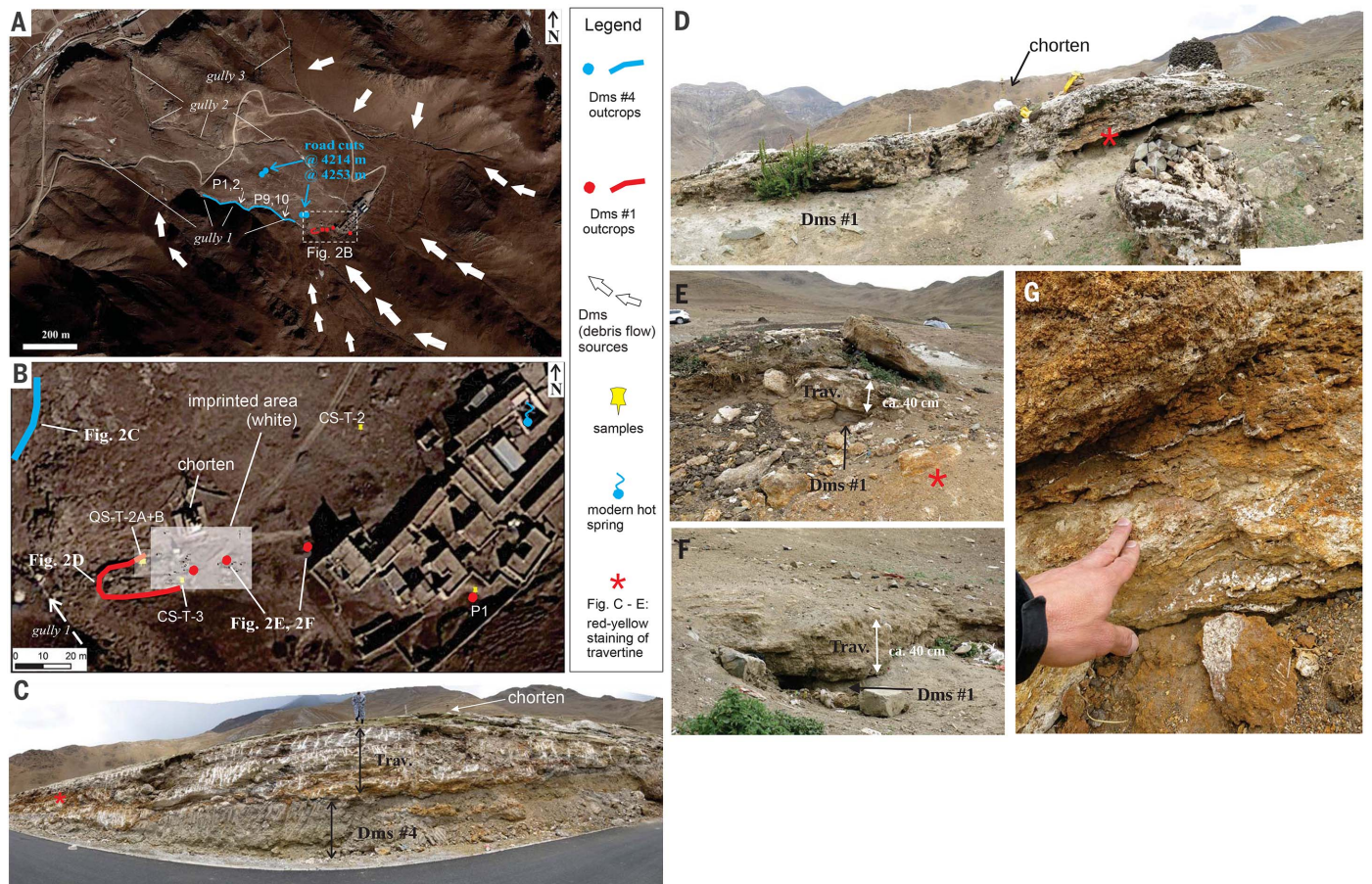
Fig. 2. Geomorphology and outcrop situation at Chusang. (**A**) Overview of the travertine and its catchment. Three gullies dissect the travertine along its entire length and were used for stratigraphic reconstruction (*2*, *3*). The imprinted travertine (white rectangle) is situated adjacent to the hill slope and incised by gully 1. The catchment of gully 1 covers 0.74 km^2 and is thus the same size as the entire area covered by travertine. This and further gullies and hill slopes (white arrows) were thus important source areas for debris flows in the past [particularly during periods of strong monsoon (*2*, *3*)]. Debris flow layer Dms #4 is 15 to 16 thousand years in age and forms the base of the uppermost (i.e., imprinted) travertine complex (*2*, *3*). All Dms #4 outcrops are shown in blue. (**B**) Zoom image of the imprinted travertine area that is directly underlain by Dms #1 with Dms #1 outcrops shown in red. (A) and (B) are Google Earth images from 2013. (**C**) New roadcut at 4253 masl (2016) from ongoing construction work at Chusang.

Dms #4 is overlain by 4-m-thick travertine that can be continuously traced upslope to the imprints (compare Fig. 1). View is upslope and to the southeast; the chorten next to the imprints is visible in the background (50 m from viewpoint). (**D**) Debris flow layer Dms #1 (~0.5 m thick) overlain by the imprinted travertine sheet (~0.4 m thick). View is to the east-northeast. This debris flow layer can be traced for ~50 m around the imprinted travertine sheet [compare (B) for exact outcrop geometry]. (**E**) Construction work partly destroyed the travertine surface that carries the imprints H5 and H6 and F11 to F13 (*16*) [compare (B) and also figure S1B in (*3*)] and exposed the underlying colluvial layer Dms #1. (**F**) Dms #1 outcrop directly in front of bathing house. (**G**) High iron content causes intensive reddish to yellowish staining of the travertine due to weathering. This staining (which is identical to the coloring of the hearth) is ubiquitous at Chusang [further examples marked with red asterisks in (C) to (E)].

design are unknown from the Paleolithic archaeological record of East Asia. The contemporaneity of the imprints and the fireplace (that is remarkably well preserved with almost no signs of surface dissolution or weathering despite a presumed age of 21 thousand years) is thus highly questionable on archaeological and taphonomic grounds alone.

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