Response to Comments on “Outburst flood at 1920 BCE supports historicity of China’s Great Flood and the Xia dynasty”

Qinglong Wu,1,2,† Zhijun Zhao,1,2 Li Liu,3,† Darryl E. Granger,4 Hui Wang,5 David J. Cohen,6 Xiaohong Wu,7 Maolin Ye,7 Offer Bar-Yosef,6 Bin Lu,8 Jin Zhang,9 Peizhen Zhang,1 Daoyang Yuan,12 Wuyun Qi,1 Linhai Cai,13 Shibiao Bai1,2

Wu et al., Han, and Huang et al. question our reconstruction of a large outburst flood and its possible relationship to China’s Great Flood and the Xia dynasty. Here, we clarify misconceptions concerning geologic evidence of the flood, its timing and magnitude, and the complex social-cultural response. We also further discuss how this flood may be related to ancient accounts of the Great Flood and origins of the Xia dynasty.

Our discovery of a tremendous outburst flood of the Yellow River, which can possibly be tied to China’s Great Flood legend (1), has provoked controversy among scholars, represented by the three Comments by Wu et al., Han, and Huang et al. (2–4) to which we respond here.

Outburst flood sediments (OFSs) described in (1) provide direct evidence of the flood but have been overlooked or misinterpreted by (2–4). At the Lajia site, OFSs are deposited over the ground surface, filled in collapsed cave dwellings, and even are found within pottery vessels [Fig. S5 in (1)]. Previous studies (5, 6) called the OFS “black sands” and took them to be sand boils from earthquake liquefaction or gully flood deposits. However, these “black sands,” with abundant greenschist and little quartz, are very different from other Yellow River sediments that would significantly affect the fossil record. They could only have originated in Jishi Gorge, because it is the only place in the adjacent upper Yellow River watershed with the appropriate rock types.

We did not, as suggested by (4), confuse the OFS with landslide deposits (Fig. 1) or the typical fluvial gravel of the Yellow River (Fig. 2F in (4)). On the other hand, the well-sorted coarse sand bed (Fig. 1E) [Fig. 2G in (4)] misidentified as a tributary flash flood deposit in (4) bears abundant greenschist clasts and is actually OFSs. Contrary to Comments (2, 4), we did notice the red mud beds at the Lajia site [Figures S1 and S5C in (1)], which are easily distinguishable from OFSs. We never took the red mud matrix surrounding some skeletal remains [figure 1, G and I, in (4)] as OFS as Huang et al. note (4). Previous studies (5, 6) wrongly identified the red mud as deposits from extreme flooding of the Yellow River induced by climate change and also as responsible for destroying the Lajia settlement. Actually, the red mud beds are locally derived from mudflows (7, 8) or gully floods that occurred at Lajia before, during, and after the Qijia culture occupation period. We simply did not discuss the mudflow deposits overlying the OFS because they are unrelated to the outburst flood.

Wu et al. (2) argue that the skeletons within the houses at the Lajia site show in situ burial features instead of “flooding burial scenarios.” We are arguing that the collapsed cave dwellings buried the victims during the earthquake, protecting their buried remains from reworking by the outburst flood ~6 to 9 months later.

Han (3) and Huang et al. (4) seem to have been confused by the maximum lake level at the time of flooding [2000 to 2025 m above sea level (asl)] versus the level of the remnant lake (~1890 m asl) that persisted after the dam failure. We reconstruct the level of the initial landslide dam from its remnants preserved on the left bank of the Yellow River [figure S2A in (1)]. Han argues that the lake level could not exceed 1975 m asl (25 to 50 m lower than we reconstruct) due to a low divide upstream of the dam (3); however, Han’s datum is obtained from Google Earth, whereas a more accurate 1:50,000 topographic map shows that it is ~2010 m asl, within our range. Moreover, the sharp crest at this site suggests that it may have been lowered by mass wasting over the past 4000 years.

Huang et al. (4) argue that there is no sedimentary evidence to support the maximum level of the dammed lake. This is true because the lake with level above 1890 m asl only existed for a few months, and at its peak (~2000 to 2025 m asl), only for a few days, too short to leave behind sediments that would have survived subsequent subaerial exposure. The lacustrine (not fluvial) sediments in Jishi Gorge represent the remnant lake, which persisted long after the breach and was gradually filled in (1).

Lacustrine sediment in Jishi Gorge was previously dated to ~8000 to 5500 years before the present (B.P.) (e.g., (9, 10)) using optically stimulated luminescence (OSL) and radiocarbon. However, due to incomplete bleaching, OSL ages may be considerably older than their true depositional ages. Also, because total organic carbon samples (e.g., (10)) may include older carbon, and because charcoal samples may have been redeposited (i.e., they are in secondary deposits after having been moved postdepositionally by water), they only provide a maximum 14C age (or terminus post quem) for the lake sediment, as we demonstrate in (1). The younger charcoal material (2020 to 1056 BCE, calibrated) within the dammed-lake sediments (1) therefore supersedes these previous limiting ages (e.g., (9, 10)) and provides a closer boundary.

The estimation of maximum discharges both at the dam and the Lajia site are questioned by Han (3). We note that the first five formulas in table S3 in (1) are empirical equations mainly based on relatively small outburst floods and that all are based on logarithmic regressions through data with a spread of >0.3 log units at 95% confidence. The uncertainty in any particular model is thus a factor of two or more at 95% confidence. As for Han’s challenge of our estimation of the maximum discharge with the Ritter formula (3), we clearly explained our rationale that this is a maximum estimate (3). The peak stage of an outburst flood, especially for those from natural landslide dams, is not transient, so that Manning’s formula is applicable in estimating the peak discharges of outburst floods. To avoid overestimating the peak discharge, we deduct the portion AE of the cross section near Lajia [figure S6C in (1)], which likely eroded after this outburst flood.

Han obtained an empirical attenuation equation for discharge of outburst floods from published data, and, using it, he calculates discharge at the Lajia site as 10,800 m³ s⁻¹ (3). This value can be falsified right away because it is too small to reach the height of the observed OFS (1). The reliability of his equation (3) can also be disproven by comparison with a well-gauged large outburst flood (11) (Fig. 2).
Fig. 1. Photos of OFS in Jishi Gorge and in the Guanting Basin, in comparison with landslide deposits. (A) Landscape of Jishi Gorge ~1.3 km downstream from the landslide dam (from Google Earth), in which B and C represent the locations of OFS and landslide deposition in (B) and (C), respectively. The center of this figure is located at 35°50.3′N, 102°37.3′E. (B) OFS seated on the valley slope [located at P8 in figure 1 in (J)]. The OFS here is devoid of greenschist clasts because it is upstream from the greenschist bedrock. (C) Outcrop of landslide deposit [the same as that in figure 2E in (4)]. (D) Outcrop of OFS fan east to the outlet of Jishi Gorge. (E) Coarse sandy OFS buried by mudflow deposits in the Guanting Basin [at location P12 in figure 1A in (J)].

Wu et al. (2) suggest that the radiocarbon data for the bone samples in (J) were incorrectly averaged. Inverse variance weighting is a standard method for combining radiocarbon determinations (22), and its margin of error can be smaller than those of the original multiple samples. Using OxCal 4.2 with the IntCal13 calibration curve (13), the result of 3573 ± 18 years B.P. (1 σ) yields a calibrated age range of 1941 to 1896 BCE (68.2%) and 1974 to 1882 BCE (94.9%), or 1922 ± 28 BCE (68.2%) as a Gaussian approximation. To simplify further discussions, we chose to use 1920 BCE as a shorthand to indicate the approximate date of the flood, but the uncertainty of ±28 years (1 σ) remains implicit.

The duration of 22 years for China's Great Flood that we adopt is according to Shiji (Records of the Grand Historian, by Sima Qian, first century BCE), which places it only in the lives of the father-son pair of Gun and Yu. This duration is subject to debate, but it is traditionally considered the most reliable. Wu et al.'s (2) belief that the Great Flood lasted more than 100 years is rooted in later legend. On a related note, the earliest written record concerning Yu is an inscription on a bronze vessel dating to the Western Zhou dynasty (~900 BCE) (14) and not to the Warring States period (475 to 221 BCE), as argued by Han (3).

Wu et al. (2) also criticize us for excluding climate change as a possible cause. However, the earliest classical accounts of the Flood, in the Shujing (Book of Documents, approximately mid-first millennium BCE) and Shiji, contain no mention of heavy rains. Furthermore, lake sediment pollen-based reconstruction of annual precipitation in northern China (15) and speleothem oxygen isotope records in southern China (16) both show a decline of the summer monsoon during ~4200 to 3900 years B.P. So far as we know, there is no convincing archaeological or geological evidence of repeated disastrous meteorological floods in the Yellow River valley around 4000 years ago.

Wu et al. (2) and Han (3) criticize us for neglecting a recently refined date of 1750 BCE for the beginning of the Erlitou culture (17). The Erlitou culture refers to an assemblage of material remains distributed across many sites in central China. The Erlitou site—its type site—became the largest center of this culture, but the site itself dates later than the earliest sites of this regional culture. Carbonized seeds from Erlitou culture deposits at the Huizui site, 15 km from the Erlitou site, for example, have yielded calibrated radiocarbon dates of ~1900 BCE (18). Thus, the ~1750 BCE date can represent the beginning of the Erlitou site yet not the start of the Erlitou culture. Of course, further systematic dating of other sites is needed.

Citing (39), Han (3) also argues that the appearance of bronze vessels at the Erlitou site after ~1700 BCE marks the beginning of the Bronze Age in China. We would emphasize that the earliest cast bronze is seen in knives from the Majiayao culture in the Upper Yellow River region by the end of the third millennium BCE, and small-scale copper-based metallurgy (including bronze casting) flourished in Xinjiang and Gansu by ~2000 to 1800 BCE (20–22). Although Erlitou bronzes mark the appearance of large-scale casting under elite patronage (23), this is only one aspect of a larger process of sociopolitical change that begins earlier. We would expect the Xia dynasty to have appeared as part of this process of state formation.

Wu et al. (2) and Han (3) reject that the outburst flood supports the historicity of China's Great Flood and the Xia dynasty. Our considerations are based on both the uniqueness and the magnitude of the flood and its timing: It was exceptionally large and rare, with no similarly devastating flood events ever occurring again during the historical period. Thus, it is the only geological candidate yet found for the origin of China's Great Flood. The early textual record closely associates three events: the Great Flood, Yu's control of the flood, and the establishment of the Xia dynasty. If the Jishi outburst flood demonstrates the historicity of China's Great Flood story, it would also lend greater credence to the historicity of the Xia dynasty.

Wu et al. argue (2) that the Xia people lived in central China; this view is supported by a majority of archaeologists in China who link the Xia to the Erlitou culture (24). Where the Xia people originated before Erlitou is less agreed upon, with contrasting interpretations (e.g., (24, 25)), but many archaeologists see the Erlitou culture, and thus Xia, as originating in the Late Neolithic Henan Longshan culture (e.g., (24)). However, such linear, pottery typology–based views ignore wide-ranging processes of multiregional interaction thought to contribute to the origins of civilization in China (26). Han argues (3) that we did not present any direct evidence for Yu's territory and the Xia dynasty, but such issues fall outside the scope of our geological paper. We would, however, argue that the modern-day notions of territoriality behind his Comment do not fit the nature of sociopolitical structures in the early Bronze Age.
During the Shang dynasty (~1550 to 1046 BCE), for example, and thus perhaps during the Xia, polities were defined through kinship relations and shared religious and other cultural practices. States like the Shang were likely not demarcated by claims to fixed territories such as the borders that are used to define modern nation-states (27). Han’s (3) requirement of defining a delimited territory for the Xia also does not fit descriptions in the textual record, such as the Shiji, of the wide-ranging efforts of Yu across many lands in taming the flood and bringing them into both a cosmological and political order (28).

Although we hypothesize a linkage between the Jishih outburst flood and the Great Flood of ancient China and the founding of the Xia dynasty (7), more research is required to draw further conclusions. Such research must consider that the outburst flood occurs in the Qijia culture region. Although this is outside of Central China, traditionally seen as the homeland of the Xia, this location and the Qijia culture were also key in this time period as important conduits for the eastward transmission of bronze metallurgy (21, 22) and for cultural contact with Central Asia as part of the establishment of what some scholars are now calling the proto-Silk Road (29). Multidisciplinary perspectives are needed to shed new light on such issues as the effect of the flood on the regional Qijia culture and the connections between Qijia and the late Neolithic and early Bronze Age cultures, such as Erlitou, in the Central Plains; the direct effects of the flood on the Middle and Lower Yellow River regions; and the interpretation of the textual record and the historical geography of places associated with the flood, the exploits of Yu, and the Xia dynasty.

In the meanwhile, we thank these commenters and other researchers who have commented on our paper; such discussions deepen everyone's understanding. We hope that our discovery stimulates further cooperative research combining archaeology, geology, history, and other relevant disciplines to more clearly reveal the complex trajectory of the origins of Chinese civilization.

REFERENCES AND NOTES

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