TECHNICAL COMMENT

ARCHAEOLOGY

Comment on "Outburst flood at 1920 BCE supports historicity of China's Great Flood and the Xia dynasty"

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By analyzing the data and methodology of Wu *et al*. (Reports, 5 August 2016, p. 579), I find that their conclusions about the scale of the dammed lake, the dating of the lake, and the peak discharge at the point of dam failure and at the Lajia site cannot be validated. The conjecture of the supposed Great Flood and its impact on the formation of the early Chinese dynasty is not substantiated.

Wu *et al*. (*1*) reported on a reconstruction of a paleo-flood caused by a landslide dam failure in the upper reach of the Yellow River and its implication for early Chinese history. I find that the evidence for their case is lacking and that some of the data contain errors.

Let us examine the water level of the dammed lake first. The authors claim that the landslide dam, and the water level, reached as high as 210 m, or 2025 m above sea level (asl), but the following evidence contradicts this claim: (i) The most important evidence supporting the existence of a dammed lake is that there is a leveled lacustrine sediment layer upstream of Jishi Gorge. However, the layer is below 1890 m asl, far from 2025 m asl. (ii) The remnant dam on the right bank is only as high as 85 m. Wu *et al*. (*2*) conducted a careful analysis of the composition and lacustrine sediment layer on it and concluded that the dam might be as high as 85 m. (iii) A very similar case of a landslide-dammed lake shows an extremely uneven dam height (Fig. 1A). (iv) In any case, the water level could not exceed 1975 m asl. (See Fig. 1B.)

Their dating of the dammed lake is also problematic. The ^{14}C dating samples in (*1*) were collected above the lacustrine sediment layer [figure S1 in (*1*)], which would only be formed hundreds of years after the high dam failed, according to the scenario described in (*1*). Using these samples to date the time of the supposed high dam failure is a contradiction. In addition, dating data from six other studies contradict the results of Wu *et al.* These data show that the dammed lake was not coeval with the Lajia disaster (see Table 1).

As for the peak discharge at dam failure, table S3 in (*1*) reports six estimates. The first two equations ($Q = 24\ d^{1.73}$ and $Q = 3.4\ V^{0.46}$) are modified forms of equations originally reported in (*3*) ($Q = 6.7\ d^{1.73}$ and $Q = 1.6\ V^{0.46}$). The third equation [$Q = 0.3\ (Vd)^{0.49}$] is wrongly used because it is for the moraine dam. The equation for the landslide dam [$Q = 1.9\ (Vd)^{0.4}$] should be used instead. Even though the modified equations might in theory be appropriate, in reality they produce a larger error. Table 2 shows the standard error and percentage of standard error calculated using the data in (*3*). The original equations are more accurate in predicting peak discharge and therefore should be employed. The fourth equation [$Q = 296\ (HV)^{0.51}$] is again wrongly used because it is applicable to artificially constructed dams. The original author provides an equation for calculating landslide dam [$Q = 181\ (HV)^{0.43}$], which should be used in this case (*4*). The fifth equation [$Q = 0.063\ (PE)^{0.42}$] is an "envelop" formula for all dam failures in the data set (*5*). The author of (*5*) has specifically recommended the use of $Q = 0.0158\ (PE)^{0.41}$ for landslide dams. The sixth equation is for flow through a box culvert, not related to dam failure flow whatsoever. Wu *et al.*

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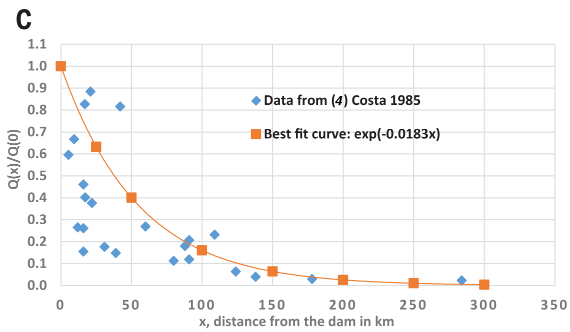

Fig. 1. Geographical configuration of dammed lakes and flow attenuation equation. (**A**) Vicinity of the Tangjiashan dammed lake. Landslide dam formation is subject to river topology and other random factors and therefore can hardly be of uniform height across the river. A 2008 earthquake of Richter scale 8 in Wenchuan, Sichuan, China created a dammed lake at a sharp turn of the Jianjiang River at Tangjiashan, which eerily resembles the geographic configuration of the Yellow River at Jishi Gorge [compare (A) with fig. S2A in (*1*)]. The landslide mass moved from the southeastern right bank across the river to hit the left bank, very similar to the Jishi Gorge situation (*9*). However, the Tangjiashan dam height ranges from 82 to 124 m, with more than 50% variation. It is reasonable to expect that the low point of Jishi Gorge dam would be well below the high point. (**B**) Google Earth shows that the mountain ridge on the left bank before the Yellow River enters the big turn at Jishi Gorge is not very high. Actually, near (35°50′26.89″N, 102°36′36.74″E), the ridge high point is only about 1975 m asl. The blocked water would have overflown easterly downstream long before it could reach 2025 m asl. (**C**) Peak discharge along a flood route. Using the measured peak discharge data along the flow route for various cases reported in table 4 of (*4*), we have developed a best-fit curve for flow attenuation along the flood route: $Q(x)/Q(0) = \exp(-0.0183\,x)$, where x is the distance from the failed dam in km. For the Lajia site, $x = 25$, so $Q_{Lajia}/Q(0) = 63.3\%$. With $Q(0) = 1.7 \times 10^4\ m^3\ s^{-1}$ from Table 1C, $Q_{Lajia} = 1.08 \times 10^4\ m^3\ s^{-1}$. The peak flow would drop to half of the original at $x = 37.9$ km and 1% of the original at $x = 250$ km.

Table 1. Dating of the lake by others. Before Wu *et al.*'s study (*1*), there were seven sets of dating data on the Jishi Gorge dammed lake in the literature (*2*, *10–15*). With the exception of (*2*), all others dated the lake between 10,500 and 3400 BCE, with both ^{14}C and optically stimulated luminescence (OSL) methods (the calendar year for radiocarbon dating is calculated using the Oxcal program with a 95.4% confidence level). This is far removed from 1900 BCE, when the Lajia village was destroyed. On balance, the evidence that the Lajia disaster had nothing to do with the Jishi Gorge dammed lake can be described as overwhelming. B.P., before the present. ka, thousand years ago.

References	Method	Data range (years B.P.)	Calendar year range (BCE)
(*2*)	^{14}C	3720 ± 40 ~ 3425 ± 35	2275 ~ 1633
(*10*)	^{14}C	8500 ± 400	8622 ~ 6591
(*11*)	^{14}C	7536 ± 36	6464 ~ 6269
(*12*)	^{14}C	10590 ± 50	10740 ~ 10474
(*13*)	^{14}C	8099 ± 369 ~ 7122 ± 371	8167 ~ 5324
(*14*)	^{14}C	7872 ± 65 ~ 4986 ± 72	7030 ~ 3653
(*14*)	OSL	5.87 ± 0.87 ka ~ 5.38 ± 0.45 ka	
(*15*)	OSL	8.25 ± 0.39 ka ~ 5.65 ± 0.21 ka	

Table 2. Comparisons of errors. Comparison of errors produced by the modified equations in Wu *et al.* (*1*) and the original equations in Walder and O'Connor (*3*), using the data in (*3*), where standard error is $SE = \sqrt{\sum[F(Xi)-Yi]^2/N}$, and percentage of standard error is $\%SE = \sqrt{\sum[F(Xi)/Yi-1]^2/N}$, *Y* is the measured peak flow, *F* is the functional form of the formula, and *X* is the predicting variable *d* and/or *V*. Comparing the error terms, it is obvious that the original equations are more accurate. *Formula that should have been used for the landslide dam.

	Original equation from (*3*)			Modified equation used in (*1*)		
Y = *F*(*X*)	$6.7\ d^{1.73}$	$1.6\ V^{0.46}$	$0.99\ (Vd)^{0.4}$	$24\ d^{1.73}$	$3.4\ V^{0.46}$	$1.9\ (Vd)^{0.4}$*
SE	11,899	11,058	11,662	12,472	19,914	18.327
% SE	0.94	0.31	0.28	3.69	0.82	0.67

Table 3. Peak discharge *Q* ($10^6\ m^3\ s^{-1}$) for various cases. It can be seen that the alternative equations give a much more consistent (smaller σ and σ/μ) prediction for peak flow. Calculated using the alternative equations, for the case of *d* = 110 m and $V = 1.13 \times 10^{10}\ m^3$, the expected peak discharge should be ~$5.9 \times 10^4\ m^3\ s^{-1}$. For the base case, which has the same water level as the lacustrine sediment level (*d* = 75 m, $V = 7 \times 10^8\ m^3$), the peak discharge is expected to be ~$1.7 \times 10^4\ m^3\ s^{-1}$.

Formula in Wu *et al.*	*d* = 110 m, $V = 1.13 \times 10^{10}\ m^3$	Alternative formula	*d* = 110 m, $V = 1.13 \times 10^{10}\ m^3$	*d* = 75 m, $V = 7 \times 10^8\ m^3$
$24\ d^{1.73}$*	0.08	$6.7\ d^{1.73}$‖	0.023	0.012
$3.4\ V^{0.46}$*	0.14	$1.6\ V^{0.46}$‖	0.067	0.019
$0.3\ (Vd)^{0.49}$†	0.25	$0.99\ (Vd)^{0.4}$‖	0.068	0.019
$296\ (HV)^{0.51}$‡	0.38	$181\ (HV)^{0.43}$¶	0.076	0.019
$0.063\ (PE)^{0.42}$§	0.36	$0.0158\ (PE)^{0.41}$#	0.062	0.017
Average (μ)	0.24		0.059	0.017
Standard deviation (σ)	0.13		0.021	0.003
CV (σ/μ)	0.55		0.352	0.176

*Modified form of equations from (*3*). †Applies to moraine dam. ‡Applies to constructed dam. §Envelope equation. ‖Original equations in (*3*). ¶Applies to landslide dam (*4*). #Applies to landslide dam (*5*).

have actually misquoted the equation [it should be $(8/27)^{0.5}Bg^{0.5}d^{1.5}$] and miscalculated the discharge [it should be 2.6×10^6 and 3.5×10^6]. This equation is useless for the case under investigation (see Table 3 for a summary). For the base case, the expected peak discharge from the dam failure is $1.7 \times 10^4\ m^3\ s^{-1}$.

For the Lajia site, the authors employ the Manning equation to predict peak flow. They make some seemingly arbitrary assumptions on river cross-section geometry to come up with their expected peak discharge: The river bed is 8 meters higher than current water level (outburst flood sediments found 7 m above the river upstream); a whole chunk of the left bank (AE) [as shown on Fig. S6C in (*1*)] was washed away by the flood (why AE, and why not right bank?) Moreover, the Manning equation is valid only when the flow is steady, and the gravitational force generated by a constant flow channel slope is balanced by channel friction. It does not apply to a highly transient, shock-wave peak discharge. The peak discharge at a downstream point from a dam failure is not controlled by local conditions but is determined by the peak discharge at the failed dam and the entire geometric and physical characteristics of the flood route. The flood has to fill up the whole upstream route before it reaches a specific point—thus the severe flow attenuation. It can be estimated by using software like the Hydrologic Engineering Center's River Analysis System (HEC-RAS) or using empirical equations for flow attenuation along the flood route. One empirical equation is shown in Fig. 1C. The peak discharge at Lajia is estimated as $1.08 \times 10^4\ m^3\ s^{-1}$.

The evidence of the occurrence of a Great Flood is wanting in (*1*). Figure 3A in (*1*) depicts a Great Flood throughout the whole lower reach of the Yellow River without showing any evidence, either through hydrological modeling or by presenting physical traces that are attributable to the flood from Jishi Gorge dam failure. Actually, according to the empirical flow attenuation equation above, the peak flow would drop to 1% of the initial value at 250 km downstream from a dam failure (Fig. 1C). Data do not support the Great Flood claim. Figure 3A in (*1*) is a speculation.

The document about Yu the Great was composed during the Warring States period. To locate Yu's whereabouts is an industry that attracts multiple contenders throughout China; Jishi Gorge/Lajia is but one among many. Kuaiji Mountain in Zhejiang, Yuhui in Anhui, and King Yu village in Shaanxi, for instance, all have strong documentary or historical claims as Yu's territory. The authors have not provided any new hard evidence to show Yu's territory or the existence of the Xia dynasty; therefore, the claim about a connection between the supposed flood and the Yu or Xia dynasty is but another speculation.

Finally, Figure 3B in (*1*) shows Erlitou culture and the Bronze Age in China starting at 1900 BCE. But the recent dating on Erlitou culture concluded that the Erlitou period I started at about 1750 BCE. Erlitou culture started to have important buildings and relics during Erlitou period II, starting no earlier than 1700 BCE (*6*, *7*). Bronze ritual vessels and bronze manufacturing workshops appeared even later. The Bronze Age could not start until after 1700 BCE in China (*8*).

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