The projected states are composed of two sublattice components in the emitter and collector. As a result, momentum-dependent constructive ($\varphi_{e(c)} = 0$) or destructive ($\varphi_{e(c)} = \pi$) interference between sublattice components is governed by $|\psi_A + \psi_B|^2 \propto 1 + \cos\varphi_{e(c)}$, for the states both in emitter (φ_e) and collector (φ_c) and manifests itself in the tunneling characteristics $I(V_b)$. Because the magnetic field selects the pairs of particular plane wave states probed by tunneling at a particular gate or bias voltage (Fig. 4, A and B), the measured asymmetry provides a direct visualization of the pseudospin polarization of the Dirac fermions.

In the presence of the magnetic field, each resonance peak represents tunneling from a particular corner of the BZ. This allows one to inject electrons with a particular valley polarization, and from a selected corner of the BZ. We use the experimental parameters to calculate the amount of polarization achieved in our experiment (Fig. 3, J and M), and estimate that the valley polarization, $P = (I_K - I_{K'})/(I_K + I_{K'})$ [where $I_K(I_{K'})$ is the current injected into the K(K′) valley] can be as high as 30% (40%) for the particular Gr/3hBN/Gr (Gr/5hBN/BGr) devices. The main limit to the degree of polarization is the energy broadening of states at the Fermi levels caused by inelastic tunneling processes. However, even for the current level of disorder, with the resonances at around $V_b \approx 0$ V (e.g., resonances marked by yellow dashed lines on Fig. 2D at $V_g > 50$ V), which maximizes the number of states participating in tunneling and sensitive to magnetic field, a polarization close to 75% could be achieved (*19*). By using devices with smaller misalignment between the graphene electrodes [on the order of 0.2°, now within the reach of the current technology (*19*)], valley polarization close to 100% is possible (*19*).

The same mechanism can also be used to select electrons with a particular pseudospin polarization. In Fig. 4, C to R, we present results of a calculation of the contribution of different electronic states in k-space to the tunnel current for the Gr/3hBN/Gr (Fig. 4, C to I) and Gr/5hBN/BGr (Fig. 4, J to R) devices. We choose the position of the Fermi levels in the emitter and collector to be very close to a resonance at $B = 0$ T. Then, for certain directions of B, the resonant conditions are achieved only in one valley and for only a very narrow distribution in k-space (Fig. 4, G to I). Tunneling of the electrons from other parts of k-space is prohibited either because they are off-resonance or because of the pseudospin selection rule. Alternatively, for the Gr/5hBN/BGr device and exploiting the difference in curvature of monolayer and bilayer electronic bands, we can choose the overlap between the bands in such a way that the magnetic field reduces the overlap in one valley and increases it for the other (Fig. 4, M to R). In this case, momentum conservation at $B = 0$ T is fulfilled for the states marked by white dashed lines (Fig. 4O). However, only one of those lines contributes to tunneling, owing to pseudospin interference (Fig. 4, M and N).

Our technique, which enables tunneling of valley-polarized electrons in monolayer and bilayer graphene, also allows one to selectively inject carriers propagating in the same direction and to probe pseudospin-polarized quasi-particles. In principle, the technique can be extended to tunneling devices in which surface states of topological insulators are used as electrodes; then, all-electrical injection of spin-polarized current (*28*) with noninvasive tunneling contacts could reveal a number of exciting phenomena (*29*–*31*).

REFERENCES AND NOTES

1. K. S. Novoselov *et al.*, *Nature* **438**, 197–200 (2005).
2. Y. Zhang, Y. W. Tan, H. L. Stormer, P. Kim, *Nature* **438**, 201–204 (2005).
3. A. H. Castro Neto, F. Guinea, N. M. R. Peres, K. S. Novoselov, A. K. Geim, *Rev. Mod. Phys.* **81**, 109–162 (2009).
4. M. I. Katsnelson, K. S. Novoselov, A. K. Geim, *Nat. Phys.* **2**, 620–625 (2006).
5. M. I. Katsnelson, *Eur. Phys. J. B* **51**, 157–160 (2006).
6. A. F. Young, P. Kim, *Nat. Phys.* **5**, 222–226 (2009).
7. F. V. Tikhonenko, D. W. Horsell, R. V. Gorbachev, A. K. Savchenko, *Phys. Rev. Lett.* **100**, 056802 (2008).
8. E. McCann *et al.*, *Phys. Rev. Lett.* **97**, 146805 (2006).
9. M. L. Sadowski, G. Martinez, M. Potemski, C. Berger, W. A. de Heer, *Phys. Rev. Lett.* **97**, 266405 (2006).
10. X. L. Qi, S. C. Zhang, *Rev. Mod. Phys.* **83**, 1057–1110 (2011).
11. S. Y. Zhou *et al.*, *Nat. Phys.* **2**, 595–599 (2006).
12. A. Bostwick, T. Ohta, T. Seyller, K. Horn, E. Rotenberg, *Nat. Phys.* **3**, 36–40 (2007).
13. M. Mucha-Kruczyński *et al.*, *Phys. Rev. B* **77**, 195403 (2008).
14. A. K. Geim, I. V. Grigorieva, *Nature* **499**, 419–425 (2013).
15. G. H. Lee *et al.*, *Appl. Phys. Lett.* **99**, 243114 (2011).
16. A. Mishchenko *et al.*, *Nat. Nanotechnol.* **9**, 808–813 (2014).
17. B. Fallahazad *et al.*, *Nano Lett.* **15**, 428–433 (2015).
18. L. Pratley, U. Zulicke, *Phys. Rev. B* **88**, 245412 (2013).
19. Supplementary materials are available on *Science* Online.
20. R. K. Hayden *et al.*, *Phys. Rev. Lett.* **66**, 1749–1752 (1991).
21. V. I. Fal'ko, S. V. Meshkov, *Semicond. Sci. Technol.* **6**, 196–200 (1991).
22. A. V. Kretinin *et al.*, *Nano Lett.* **14**, 3270–3276 (2014).
23. L. Britnell *et al.*, *Science* **335**, 947–950 (2012).
24. F. Amet *et al.*, *Phys. Rev. B* **85**, 073405 (2012).
25. S. Jung *et al.*, *Sci. Rep.* **5**, 16642 (2015).
26. E. E. Vdovin *et al.*, *Phys. Rev. Lett.* **116**, 186603 (2016).
27. T. L. M. Lane, J. R. Wallbank, V. I. Fal'ko, *Appl. Phys. Lett.* **107**, 203506 (2015).
28. C. H. Li *et al.*, *Nat. Nanotechnol.* **9**, 218–224 (2014).
29. D. Culcer, E. H. Hwang, T. D. Stanescu, S. Das Sarma, *Phys. Rev. B* **82**, 155457 (2010).
30. O. V. Yazyev, J. E. Moore, S. G. Louie, *Phys. Rev. Lett.* **105**, 266806 (2010).
31. D. Pesin, A. H. MacDonald, *Nat. Mater.* **11**, 409–416 (2012).

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SUPPLEMENTARY MATERIALS

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ARCHAEOLOGY

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

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China's historiographical traditions tell of the successful control of a Great Flood leading to the establishment of the Xia dynasty and the beginning of civilization. However, the historicity of the flood and Xia remain controversial. Here, we reconstruct an earthquake-induced landslide dam outburst flood on the Yellow River about 1920 BCE that ranks as one of the largest freshwater floods of the Holocene and could account for the Great Flood. This would place the beginning of Xia at ~1900 BCE, several centuries later than traditionally thought. This date coincides with the major transition from the Neolithic to Bronze Age in the Yellow River valley and supports hypotheses that the primary state-level society of the Erlitou culture is an archaeological manifestation of the Xia dynasty.

China's earliest historiographies, including *Shujing* (*Book of Documents*) and *Shiji* (*Records of the Grand Historian*, by Sima Qian), tell of the Great Flood, a lengthy, devastating flood of the Yellow River. The culture hero Yu eventually tamed this flood by dredging, earning him the divine mandate to establish the Xia dynasty, the first in Chinese history, and marking the beginning of Chinese civilization. Because these accounts laid the ideological foundations for the Confucian rulership system, they had been taken as truth for more than 2500 years until challenged by the "Doubting Antiquity School" in the 1920s. Within a decade, archaeological excavations demonstrated the historicity of the second dynasty, Shang, and the search for similar evidence for Xia began (*1*, *2*). Archaeological fieldwork since the 1950s on the Early Bronze Age Erlitou culture (~1900 to 1500 BCE) has led many scholars to associate it with the Xia (*1*–*6*) because it overlaps with the spatial and temporal framework of the Xia dynasty. Traditionally, historians have dated the start of Xia to ~2200 BCE, whereas the government-sponsored Xia-Shang-Zhou Chronology Project adopted the date as 2070 BCE (*5*), leaving a chronological gap in associating Erlitou with Xia (*7*–*9*). Other scholars see Xia purely as a myth fabricated to justify political succession (*10*, *11*).

Scholars also have long sought a scientific explanation of the Great Flood (*12*–*14*), with even Lyell mentioning it (*15*), yet no evidence for it has been discovered. Here, we present geological evidence for a catastrophic flood in the early second millennium BCE and suggest that it may be the basis of the Great Flood, thereby lending support to the historicity of the Xia dynasty. The evidence found in our investigations along the Yellow River in Qinghai Province includes remains of a landslide dam, dammed lake sediments (DLS) upstream, and outburst flood sediments (OFS) downstream (Fig. 1 and figs. S1 to S5) that allow us to reconstruct the size of the lake and flood (*16*).

Field observations (fig. S2B) show that the ancient landslide dam deposits reach an elevation of 240 m above present river level (arl) and stretch for 1300 m (fig. S2A) along Jishi Gorge (Figs. 1A and 3A). We estimate that the saddle of the dam would have been 30 to 55 m lower than the highest preserved remnants, so the lake would have filled to an elevation of 185 to 210 arl [2000 to 2025 m above sea level (asl)] (fig. S2B), impounding 12 to 17 km^3 of water (*16*) (table S1). Based on typical river discharge values, the dam would have completely blocked the Yellow River for 6 to 9 months before overtopping (*16*). DLS distributed widely upstream of the dam are up to 30 m thick and have a highest elevation of ~1890 m asl (Fig. 1B and figs. S1 and S3A). We interpret this as indicating that the catastrophic breach dropped the water level 110 to 135 m (Fig. 1B), releasing ~11.3 to 16 km^3 of water (*16*) (table S1), tens of times that estimated by a previous study (*17*). After the breach, DLS infilled a residual lake behind the lowest part of the dam that remained.

Outburst flood sediments are found downstream at elevations from 7 to 50 m arl in the lower Jishi Gorge and in Guanting Basin (Fig. 1 and figs. S1 and S4). They are characterized by high-concentration suspension deposition and consist exclusively of angular clasts of greenschist and purple-brown mudrock sourced from Jishi Gorge (table S2). At the mouth of the gorge, where the Yellow River enters Guanting Basin, the sediments reach 20 m thickness and include boulders up to 2 m in diameter (Fig. 1B and figs. S1 and S4, C and D). We also identified the OFS at the earthquake-destroyed prehistoric Lajia site (fig. S5), a settlement of the Qijia culture (*18*, *19*) known for its early noodle remains (*20*), 25 km downstream from the dam. OFS at Lajia covered the settlement's last Qijia culture occupation and filled in collapsed cave dwellings (fig. S5, A and B), pottery vessels (fig. S5B), and earthquake fissures (fig. S5C), mixing with pottery sherds (fig. S5D) and other Qijia cultural materials, with heights of up to 38 m arl.

Stratigraphic relationships of the OFS, remnant dam, DLS, loess, and other deposits in Jishi Gorge and neighboring basins, along with destruction features at the Lajia site (fig. S1), allow us to reconstruct and date a sequence of events ending in the outburst flood. First, they show that the damming and outburst flood event occurred during the archaeological Qijia culture period (~2300 to 1500 BCE) after the collapse of the Lajia cave-houses. Ground fissures caused by the earthquake at the Lajia site were entirely filled with OFS (fig. S5C) before silts from surface runoff during the annual rains could enter them, indicating that the outbreak flood must have occurred less than 1 year after the earthquake and collapse of the houses. It is likely that the same earthquake that destroyed Lajia also triggered the landslide that dammed the river, along with widespread contemporaneous rock avalanches whose deposits lay directly beneath the DLS (fig. S3A).

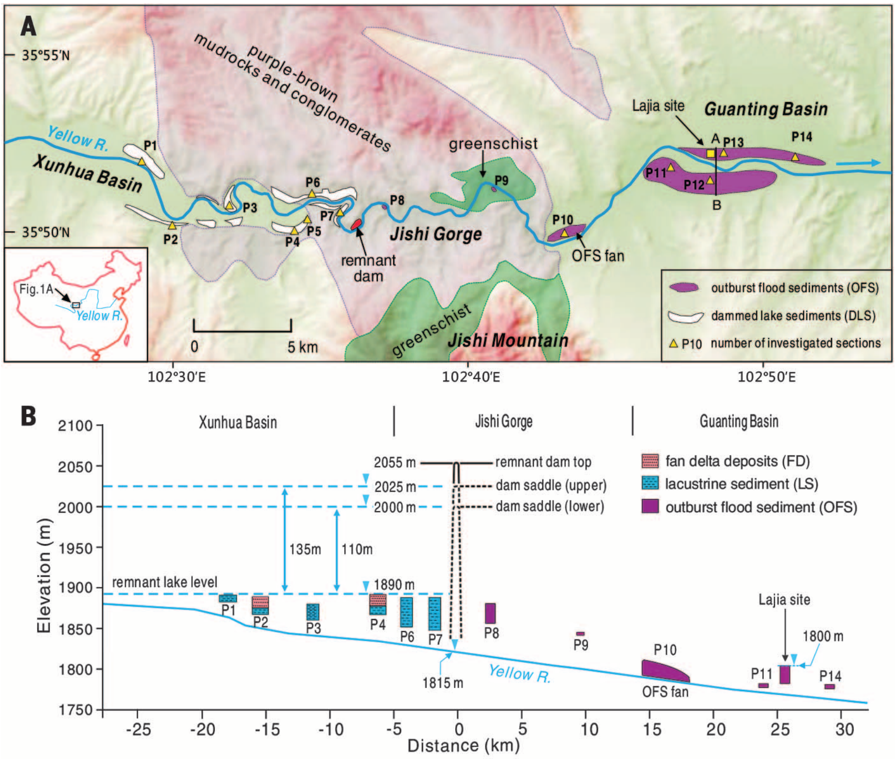

Fig. 1. Evidence of the exceptional outburst flood in the upper valley of the Yellow River. (**A**) Distributions of OFS, DLS, and landslide dam. Light purple and dark green shaded areas indicate purple-brown mudrock and greenschist, respectively. Line AB across the Lajia site shows the location of the reconstructed cross section in fig. S6C. (**B**) The vertical distribution of the OFS, landslide dam, DLS, Lajia site and reconstructed lake levels relative to the longitudinal profile of the present Yellow River. DLS are classified into lacustrine sediments (LS) and fan delta deposits (FD).

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To date the outburst flood, we collected carbon samples for accelerator mass spectrometry (AMS) ^{14}C dating (*16*). Seventeen charcoal samples from the OFS and the only charcoal sample from a layer overlying the OFS (fig. S1) indicate that the age for the flood is between 2129 and 1770 cal. BCE [95% confidence interval (CI)] (Fig. 2A and table S5) (*16*). Charcoal samples from DLS upstream of the dam (fig. S1) yield calibrated ^{14}C results (95% CI) spanning 2020 to 1506 BCE (Fig. 2A and table S5), demonstrating that the DLS is coeval with or younger than the outburst flood and confirming that it is fill from the remnant lake. The best dating for the flood comes from the Lajia site (*16*), because it was destroyed within 1 year before the outburst flood. Radiocarbon determinations of bone samples from three human victims, aged 6 to 13 years old, in collapsed Lajia dwellings (Fig. 2B) agree to within uncertainty (Fig. 2A and table S5), consistent with that of two victims reported previously (*21*) as well. Because the radiocarbon calibration curve is linear in this region and the bones are the same age, we use the inverse variance weighted mean of the three measurements. This yields a calibrated age with a median of 1922 ± 28 BCE (1 SD) and a 95% CI of 1976 to 1882 BCE (Fig. 2C). To simplify this range, we use 1920 BCE to indicate the approximate date of the flood.

We estimate the peak discharge of the flood in two ways. Empirical formulas considering the volume of the lake and the height of the dam lead to estimates ranging from 0.08 to 0.51×10^6 m^{3}s^{-1}, with large uncertainties (*16*) (table S3). We also reconstruct the flood channel cross section from detailed surveys in Guanting Basin and use Manning's equation to estimate a peak discharge of 0.36 to 0.48×10^6 m^{3}s^{-1} (*16*) (fig. S6 and table S4), consistent with the dam break estimations (*16*) (table S3). The calculated peak discharge of $\sim 0.4 \times 10^6$ m^{3}s^{-1} is more than 500 times the average discharge of the Yellow River at Jishi Gorge. This ranks globally among the largest freshwater floods of the Holocene (*22*).

We do not explicitly model the inundation and effect of this outburst flood in the lower reaches of the river, but analogous events demonstrate that outburst floods from landslide dams can propagate long distances. In 1967, an outburst flood with a volume of just ~0.64 km^3 propagated at least 1000 km along the Yalong-Yangtze Rivers (*23*), so the Jishi prehistoric outburst flood, with a volume of ~11 to 16 km^3, could have easily travelled more than 2000 km downstream. The Jishi flood would have breached the natural levees of the Yellow River, resulting in rare, extensive flooding. It is possible that this outburst flood was also the cause of a major avulsion of the lower Yellow River (Fig. 3A) inferred from archaeological data, with a previously estimated date of ~2000 BCE (*24*, *25*). Widespread destruction of levees and deposition of tributary mouth bars may have destabilized the main river channel, leading to repeated flooding until a new river channel was established. Extensive flooding on the lower Yellow River plain would have had a great effect on societies there. We argue that this event and its aftermath likely would have survived in the collective memories of these societies for generations, eventually becoming formalized in the received accounts of the Great Flood in the first millennium BCE. In fact, early texts such as the *Shujing* and *Shiji* even record that a place called Jishi (the same characters as the gorge where the outburst flood began) was where Yu began his dredging of the Yellow River; whether this is a coincidence will require further historical geographical research.

The ~1920 BCE flood shares the main characteristics of the Great Flood described in ancient texts. Apart from its huge peak discharge, the secondary flooding on the lower plains may have been long-lasting, just as the Great Flood remained uncontrolled for 22 years until it was managed by dredging (rather than by blocking breaches in natural levees). There is also the issue of whether the Great Flood could have been caused by exceptional meteorological flooding, but a speleothem record shows a generally weakened Asian summer monsoon from 8000 to 500 years before the present (*26*), and proxies from lake and loess records also indicate that a cool, dry climate regime begins 2000 BCE along the lower Yellow River (*27*), so this would be unlikely. Furthermore, the early textual records make no mention of frequent, extreme storms related to the Great Flood.

The discovery and reconstruction here of the massive outburst flood originating in Jishi Gorge provide scientific support that the ancient Chinese textual accounts of the Great Flood may well be rooted in a historic natural event. They also shed light on the potential

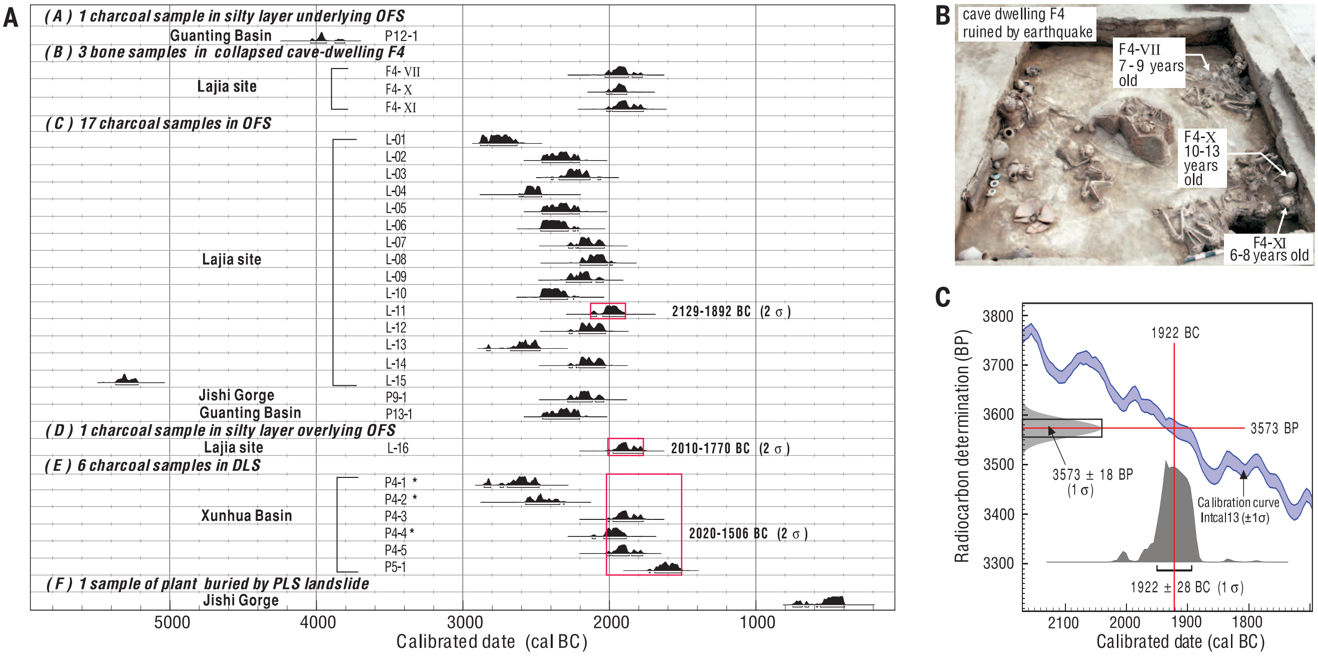

Fig. 2. Radiocarbon chronology of the prehistoric outburst flood on the Yellow River. (**A**) Calibrated age probabilistic histograms of radiocarbon data. The outliers of the ages inconsistent with stratigraphic sequences and indicating reworking are denoted with asterisks. Samples best constraining the age of the outburst flood are boxed in red. See fig. S1 for sample locations. (**B**) The radiocarbon dated skeletons in cave dwelling F4 at the Lajia site. The skeletons were identified by reference (*30*). (**C**) The calibration of the inverse variance weighted mean for three bone samples on calibration curve IntCal13 (*31*). All radiocarbon dates were calibrated individually with IntCal13 (*31*) and OxCal 4.2 (*32*).

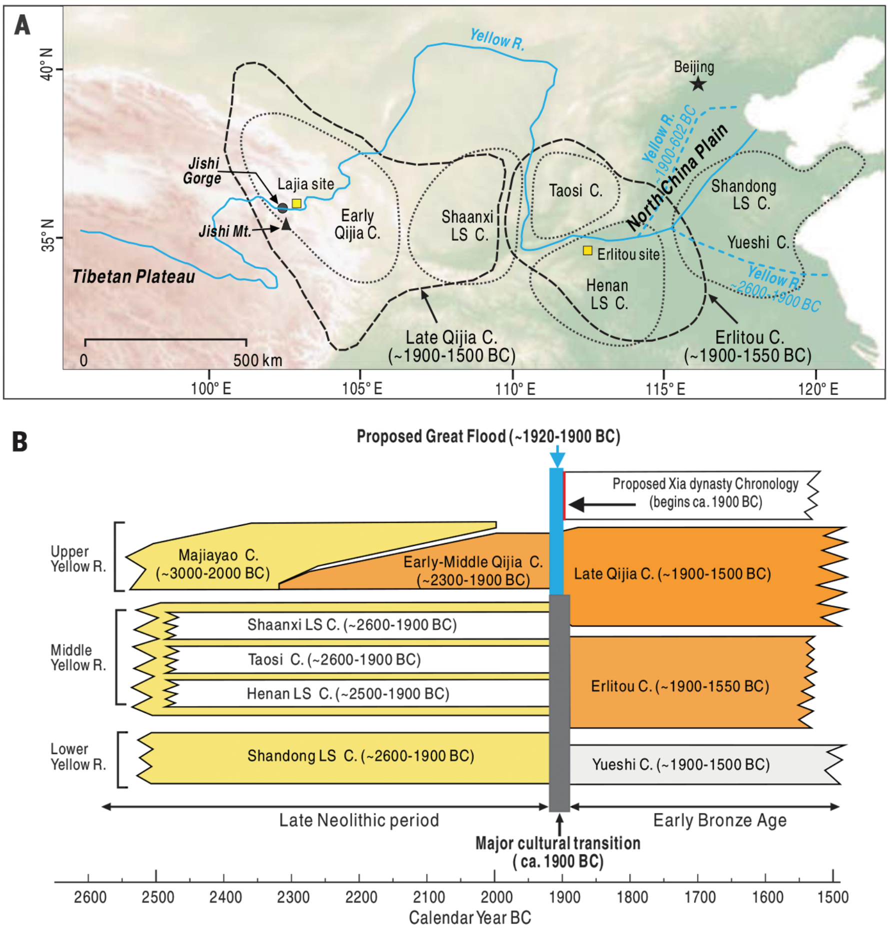

Fig. 3. Major transition of archaeological cultures in the Yellow River valley around 1900 BCE. C, culture; LS C, Longshan culture. (**A**) Distribution of the late Neolithic and early Bronze Age cultures in the Yellow River valley. Blue dashed lines show avulsion of the lower Yellow River channel ~2000 BCE (*24*). (**B**) Timeline showing ages of the archaeological cultures (*6*, *29*) and the proposed Great Flood of China.

historicity of the Xia dynasty itself, as Yu's founding of the dynasty is directly tied to his achievements in controlling the Great Flood. According to the *Shiji*, Yu's father labored unsuccessfully for 9 years to tame the flood before Yu took over for 13 more years. Yu's success led to his mandate to become founding king of the Xia 22 years after the flood started. If the Jishi Gorge outburst flood of ~1920 BCE is the natural cataclysm that came to be known as the Great Flood, then we can propose a new beginning date for the Xia dynasty, ~1900 BCE. This date, some 2 to 3 centuries later than previous reckonings (*1*, *2*, *5*), is compatible with the 1914 BCE date proposed by Nivison based on astro-historiographical evidence (*28*). This 1900 BCE date for the founding of the Xia coincides with the beginning of the Erlitou culture (*6*), so this finding also supports the arguments that the Erlitou culture is the archaeological manifestation of the Xia and that the Erlitou site was a Xia dynastic capital (*1*–*3*). This outburst flood is also coincident with the major sociopolitical transition from Neolithic to Bronze Age in the Yellow River valley (*2*, *6*, *29*) (Fig. 3, A and B), suggesting that the concurrence of these major natural and sociopolitical events known through the geological, historiographical, and archaeological records may not simply be coincidence but rather an illustration of a profound and complicated cultural response to an extreme natural disaster that connected many groups living along the Yellow River.

REFERENCES AND NOTES

1. X. P. Yuan, W. M. Yan, C. X. Zhang, Y. L. Lou, Eds., *The History of Chinese Civilization*, vol. 1 (Cambridge Univ. Press, New York, 2012).
2. K. C. Chang, *The Archaeology of Ancient China, 4th ed.* (Yale Univ. Press, New Haven and London, 1986).
3. H. Zou, *Henan Wenbo Tongxun* **1**, 34–35 (1978).
4. R. L. Thorp, *Early China* **16**, 1–33 (1991).
5. The Xia-Shang-Zhou Chronology Project Group, *The Xia-Shang-Zhou Chronology Project Report for the years 1996–2000 (abridged)* (World Book Publishing Company, Beijing, 2000).
6. L. Liu, X. C. Chen, *The Archaeology of China: From the Late Paleolithic to the Early Bronze Age* (Cambridge Univ. Press, New York, 2012).
7. A. Lawler, *Science* **325**, 934 (2009).
8. L. Liu, H. Xu, *Antiquity* **81**, 886–901 (2007).
9. Y. K. Lee, *Asian Perspect.* **41**, 15–42 (2002).
10. S. Allan, *J. R. Asiat. Soc. GB. Irel.* **116**, 242–256 (1984) (New Series).
11. M. E. Lewis, *The Flood Myths of Early China* (State Univ. of New York Press, New York, 2006).
12. D. K. Pang, *J. Hydro.* **96**, 139–155 (1987).
13. X. Q. Li, *Zhongguo Lishi Wenwu* **2002**, 4–12 (2002) (Journal of National Museum of Chinese History).
14. W. X. Wu, Q. S. Ge, *Quaternary Science* **25**, 741–749 (2005).
15. C. Lyell, *Principles of Geology*, 9th ed. (Little, Brown & Co., 1853).
16. Methods are available as supplementary materials on *Science* Online.
17. Q. L. Wu, P. Z. Zhang, H. P. Zhang, M. L. Ye, Z. Q. Zhang, *Dokl. Earth Sci.* **39**, 1148–1159 (2009).
18. IA CASS, *Chinese Archaeology* **3**, 1–6 (2003).
19. X. Y. Yang, Z. K. Xia, M. L. Ye, *Chin. Sci. Bull.* **48**, 1877–1881 (2003).
20. H. Lu *et al.*, *Nature* **437**, 967–968 (2005).
21. X. L. Zhang, M. L. Ye, S. H. Qiu, J. Zhong, *Kaogu* **11**, 91–104 (2014).
22. J. E. O'Connor, J. E. Costa, The world's largest floods, past and present: Their causes and magnitudes. U.S. Geological Survey Circular 1254 (U.S. Department of the Interior, 2004); http://pubs.usgs.gov/circ/2004/circ1254/pdf/circ1254.pdf.
23. S. G. Evans, K. B. Delaney, R. L. Hermanns, A. Strom, G. Scarascia-Mugnozza, in *Natural and Artificial Rockslide Dams*, S. G. Evans, K. B. Delaney, R. L. Hermanns, A. Strom, G. Scarascia-Mugnozza, Eds. (Springer, 2011), pp. 1–75.
24. Q. Wang, *Cultural Relics of Central China* **1993**, 63–72 (1993).
25. D. N. Keightley, in *The Cambridge History of Ancient China*, M. Loewe, E. L. Shaughnessy, Eds. (Cambridge Univ. Press, New York, 1999), pp. 30–36.
26. Y. Wang *et al.*, *Science* **308**, 854–857 (2005).
27. A. M. Rosen *et al.*, *Holocene* **25**, 1640–1650 (2015).
28. D. S. Nivison, K. D. Pang, *Early China* **15**, 87–95 (1990).
29. J. Y. Han, *The Environment and Cultural Development in Pre-Qin Northwestern China* (Wenwu Press, Beijing, 2008), pp. 40–468.
30. M. H. Wang, *Kaogu* **2002**, 1081–1084 (2002).
31. P. J. Reimer *et al.*, *Radiocarbon* **55**, 1869–1887 (2013).
32. University of Oxford, OxCal/ORAU; https://c14.arch.ox.ac.uk/oxcal/OxCal.html.

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Flood control initiates Chinese civilization

Around four millennia ago, Emperor Yu the Great succeeded in controlling a huge flood in the Yellow River basin. This is considered to have led to the establishment of the Xia dynasty and the start of Chinese civilization. However, the dates of the events and the links between them have remained uncertain and controversial. Using stratigraphic data and radiocarbon dating, Wu *et al.* verify that the flood occurred and place the start of the Xia dynasty at about 1900 BC, thus reconciling the historical and archaeological chronologies (see the Perspective by Montgomery).

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