Differences to this relatively simple picture of the Arctic Ocean used to exist in the western Eurasian Basin (north and east of Svalbard, north of Norway) where Atlantic water entering the Arctic through the Fram Strait (between Svalbard and northeast Greenland), at or near the surface, remained in contact with the atmosphere. In a previous study (*4*), the Atlantic character was seen to be extending eastward, toward eastern Siberia, between the early 2000s and the mid-2010s, leading to the notion of Arctic Ocean "Atlantification." It was shown that sea ice reductions, weakening of the halocline, and reduction in the depth of the Atlantic water layer were together making the eastern Eurasian Basin, north of Siberia, resemble the western basin in terms of its Atlantification. The consequent increased ocean heat flux was reducing the winter sea-ice formation rate, thus explaining the then-recent reduction in Arctic sea ice cover in the eastern basin. The hypothesis was that Atlantification was moving part of the Arctic Ocean toward a new climate state.

Polyakov *et al.* build on these observed changes in atmospheric circulation and in ice and ocean behavior. After decades of Arctic sea ice decline, they show that ice area and thickness have been stable, although variable since 2007. The decadal-scale variability of the atmospheric circulation explains this sea ice behavior.

Atmospheric circulation variability is described by using normal modes: patterns of variability in which all parts of the system change together. In the Arctic, the leading mode, the Arctic Oscillation, represents the variability of the polar high-pressure system. The second mode, the Arctic Dipole, is associated with anticyclonic winds over North America and cyclonic winds over Eurasia. The Arctic Dipole was roughly neutral before 2007 and increasingly positive thereafter. In its positive phase, the Arctic Dipole weakens inflows to the Arctic Ocean across the Fram Strait while strengthening inflows through the Barents Sea, northeast of northern Norway. The resulting stronger Arctic Ocean circulation has been responsible for increased freshwater accumulation in the Amerasian Basin, which in turn has increased stratification and reduced upward oceanic heat fluxes, slowing Arctic sea ice loss. This atmospheric forcing is consistent with observed and modeled variability of Arctic Ocean freshwater accumulation and export (*5*, *6*). An eventual return to dominance of the Arctic Oscillation mode would reinstate the faster sea ice reduction. Regardless of the mode in place, both the Arctic atmosphere and the Arctic Ocean are predicted to continue to warm faster than the rest of the planet through the 21st century (*1*,*7*).

There remain unexplored and plausible ocean mechanisms that may further accelerate Arctic warming, with consequences for the Arctic ice and ocean system, and with possible atmospheric feedbacks. When the Arctic Ocean is completely covered by sea ice, stresses exerted by winds are largely absorbed by the ice and ultimately transmitted to land, greatly reducing the mechanical forcing of the ocean, hence the slow circulation. When the sea ice declines, more of the ocean will be directly exposed to wind, increasing the efficiency of atmosphere-to-ocean momentum transfer and accelerating the ocean circulation, called ocean "spin-up." Consequently, parts of the ocean, particularly where it flows over rough topography around the edge of the continental shelf, would become more turbulent, increasing the upward heat flux out of the Atlantic water layer (*8*) and likely spinning off more eddies (circular currents), carrying that heat toward the North Pole (see the figure). The strength of the Coriolis force—the force on a fluid that results from the rotation of Earth—in high latitudes changes the balance of physical processes. Exotic turbulence mechanisms such as unsteady lee (standing) waves can be expected to dominate (*9*, *10*), and they would be less season-dependent, further threatening Arctic sea ice survival outside summertime. Such mechanisms are not represented in any current forced ocean or coupled climate models and are the subject of ongoing research.

In the Arctic Ocean, Atlantic-layer heat is presently trapped below the halocline, except where Atlantification has been taking place. However, ocean spin-up will increase turbulence and mixing, which might release this heat more widely and in turn may accelerate the year-round sea ice decline. This would bring further and unknown consequences for both Arctic and mid-latitude weather, climate, and extreme events. ■

REFERENCES AND NOTES

1. Intergovernmental Panel on Climate Change, *Climate Change 2021: The Physical Science Basis* (Cambridge Univ. Press, 2021).
2. J. A. Screen *et al.*, *Nat. Geosci.* **11**, 155 (2018).
3. I. V. Polyakov *et al.*, *Science* **381**, 972 (2023).
4. I. V. Polyakov *et al.*, *Science* **356**, 285 (2017).
5. A. Proshutinsky, D. Dukhovskoy, M.-L. Timmermans, R. Krishfield, J. L. Bamber, *Philos. Trans.- Royal Soc., Math. Phys. Eng. Sci.* **373**, 20140160 (2015).
6. C. Florindo-López *et al.*, *J. Clim.* **33**, 8849 (2020).
7. Q. Shu *et al.*, *Sci. Adv.* **8**, eabn9755 (2022).
8. T. P. Rippeth *et al.*, *Nat. Geosci.* **8**, 191 (2015).
9. T. P. Rippeth *et al.*, *Geophys. Res. Lett.* **44**, 12,349 (2017).
10. L. E. Baker, A. Mashayek, *J. Geophys. Res.* **127**, e2022JC018995 (2022).

ACKNOWLEDGMENTS

S.B. receives funding from the UK Natural Environment Research Council CANARI (Climate change in the Arctic–North Atlantic region and impacts on the UK) project (NE/W004984/1).

10.1126/science.adj8469

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ANTHROPOLOGY

Did our ancestors nearly die out?

Genetic analyses suggest an ancient human population crash 900,000 years ago

By **Nick Ashton**[1] *and* **Chris Stringer**[2]

Earth's climate system began to change during the Middle Pleistocene transition, which is associated with a severe cooling phase about 900,000 years ago. How this change might have affected human populations is difficult to determine, because the human fossil and archaeological records are relatively sparse for this period and lie beyond the reach of ancient DNA recovery. On page 979 of this issue, Hu *et al.* (*1*) use a new method of analysis called FitCoal to project current human genetic variation backward in time, to estimate the size of populations at specific points in the past. The results suggest that our ancestors suffered a severe population bottleneck that started around 930,000 years ago and lasted for almost 120,000 years. This is estimated to have reduced the number of breeding individuals to ~1300, bringing our ancestors close to extinction.

Hu *et al.* argue that the proposed bottleneck correlates with a chronological gap in the African and Eurasian fossil records and may have led to the evolution of a new human species, ancestral to *Homo sapiens*. They favor a widely defined *H. heidelbergensis* as this ancestral species, probably emerging in Africa by 800,000 years ago. Two lineages of large-brained humans have long been recognized in the later Pleistocene: *H. sapiens* and Neanderthals (*H. neanderthalensis*). A third group—Denisovans—was identified more recently from ancient DNA in fossils and sediments at Denisova Cave in Siberian Russia (*2*). Considering how the inferred bottleneck might have affected human evolution inevitably leads to debate about the nature of the last common ancestor of *H. sapiens*, Neanderthals, and Denisovans, and when and where this ancestor lived.

It is not yet clear whether the last common

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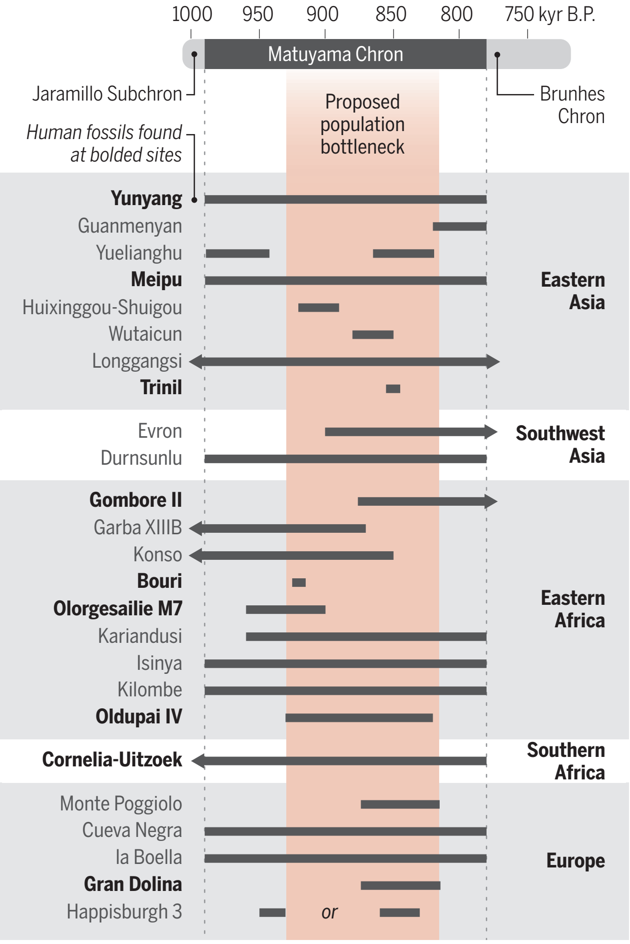
ancestor lived in Europe, Asia, or Africa. Hu *et al.* attributed the East Asian fossil record from that time to the more ancient human species *H. erectus*. However, there is evidence from sites such as Yunyang, China, of a distinct species that is morphologically closer to later humans from Eurasia and Africa such as *H. sapiens* and Neanderthals (*3*), suggesting their ancestral lineage(s) might already have diverged from *H. erectus* by the time of the Yunyang fossils, which are dated at 800,000 to 1,100,000 years ago. Moreover, some genetic models for the deep ancestry of *H. sapiens* and Neanderthals suggest that concepts of a single last common ancestor in time and space might be illusory (*2, 4*).

Estimates using genomic data from *H. sapiens*, Neanderthals, and Denisovans calibrate the last common ancestor to between about 500,000 and 700,000 years ago (*2*), which would relate the inferred bottleneck to this ancestral population, wherever it lived, with comparable signals expected from Denisovan and Neanderthal genomes as well as from those of *H. sapiens*. However, some recent studies of dental and cranial variation in fossilized skulls place the last common ancestor earlier, between about 800,000 and 1,200,000 years ago (*5, 6*), which might mean that already separated basal lineages of Neanderthals and Denisovans avoided the bottleneck, or suffered it to a different extent. Morphological analysis of fossils suggests that the last common ancestor might be *H. heidelbergensis* (as favored by Hu *et al.*), *H. rhodesiensis*, *H. antecessor*, or *H. bodoensis* (*7*).

Archaeological evidence during the bottleneck

Evidence of human occupation, including fossilized human bones (sites in bold), dated to the proposed population bottleneck [813,000 to 930,000 years before present (kyr B.P.)], is recorded in Asia, Europe, and Africa. Gray bars represent the range of age estimates for when site occupation is thought to have occurred, and arrows indicate that occupation is thought to have extended beyond the date range shown [based on (*3, 8–14*)]. This suggests that the effects of the bottleneck were limited geographically and chronologically. The stone tools from Trinil are disputed.



GRAPHIC: M. HERSHER/SCIENCE

The proposed bottleneck needs to be tested against the human fossil and archaeological evidence by assessing how much of it might lie within the designated time span of 930,000 to 813,000 years before present. Most sites are dated through magneto-stratigraphy, whereby changes in the polarity (normal or reversed) of Earth can be identified, in combination with isotopic dating methods and in some cases changes in the species of mammals present. The putative bottleneck occurred during a reversed phase (end of the Matuyama Chron) between the normal polarity of the Jaramillo Subchron and Brunhes Chron (see the figure). Despite issues with the resolution of dating, there are sites with evidence of human occupation in Africa, Asia, and Europe that have been attributed to this period of reversed polarity and, with varying degrees of certainty, to the inferred time of the bottleneck. These include sites in Kenya such as Kilombe (GqJh1 and Gqjh2), Kariandusi and Isinya (*8*), and locations in Bed IV of Oldupai in Tanzania (*9*). Of particular importance are the human fossils from Gombore II in Ethiopia that have an estimated age of 850,000 years before present (*10*), which lies within the bottleneck window. Sites in Europe, such as Gran Dolina and Boella in Spain, Monte Poggiolo in Italy, and Happisburgh 3 in the UK, have also been attributed to this period (*11*). Of further importance are the increasing number of sites in China, particularly in the Qinling Mountain Range, which cover the time span of the proposed bottleneck (*12*). This includes the human fossils from Yunyang (*3*).

These fossil records dating to the inferred bottleneck period 813,000 to 930,000 years ago suggest that humans were widespread inside and outside of Africa. Therefore, whatever caused the proposed bottleneck may have been limited in its effects on human populations outside the *H. sapiens* lineage, or its effects were short-lived. This also implies that the cause of the bottleneck was unlikely to have been a major environmental event, such as severe global cooling, because this should have had a wide-ranging impact. Nevertheless, the provocative study of Hu *et al.* brings the vulnerability of early human populations into focus, with the implication that our evolutionary lineage was nearly eradicated. Recent work suggests that Europe was probably completely depopulated after a previously unrecognized cold phase about 1,100,000 years ago, before the proposed bottleneck (*11*). If methods such as FitCoal can be further applied to growing data from the genomes of *H. sapiens*, Neanderthals, Denisovans, and hopefully others, this should clarify ancient bottlenecks, and which regions under habitation might have been the most or least affected. However, the genomic data must also be tested against the fossil and archaeological records of early human populations, records that need further enhancement from many regions of the ancient world. ■

REFERENCES AND NOTES

1. W. Hu *et al.*, *Science* **381**, 979 (2023).
2. A. Bergström *et al.*, *Nature* **590**, 229 (2021).
3. D. Lewis, *Nature* **612**, 200 (2022).
4. A. P. Ragsdale *et al.*, *Nature* **617**, 755 (2023).
5. A. Gómez-Robles, *Sci. Adv.* **5**, 1268 (2019).
6. X. Ni *et al.*, *Innovation* (Camb.) **2**, 100130 (2021).
7. E. Delson, C. Stringer, *Evol. Anthropol.* **31**, 233 (2022).
8. S. Hoare *et al.*, *J. Archaeol. Sci.* **125**, 105273 (2021).
9. A. Deino *et al.*, *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **571**, 109990 (2021).
10. R. Gallotti, M. Mussi, *J. Anthropol. Sci.* **95**, 1 (2017).
11. V. Margari *et al.*, *Science* **381**, 693 (2023).
12. D. Liu *et al.*, *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **605**, 119229 (2022).
13. J. Galway-Witham, J. Cole, C. Stringer, *J. Quat. Sci.* **34**, 355 (2019).
14. J. S. Brink *et al.*, in *African Paleoecology and Human Evolution*, S. Reynolds, R. Bobe, Eds. (Cambridge Univ. Press, 2022), pp. 120–134.

ACKNOWLEDGMENTS

The research of the authors is supported by the Calleva Foundation. C.S. also acknowledges the support of the Human Origins Research Fund. The authors thank J. Gowlett and C. Shipton for discussion of the Kenyan sites.

10.1126.science.adj9484