ROBERT HARVEY/NATURAL WORLD PHOTOGRAPHY

THE BATTLE FOR COMMON GROUND

Ancient genomes are revolutionizing the study of human prehistory but sometimes straining the relationships between archaeologists and geneticists.

BY EWEN CALLAWAY

Thirty kilometres north of Stonehenge, through the rolling countryside of south-west England, stands a less-famous window into Neolithic Britain. Established around 3600 BC by early farming communities, the West Kennet long barrow is an earthen mound with five chambers, adorned with giant stone slabs. At first, it served as a tomb for some three dozen men, women and children. But people continued to visit for more than 1,000 years, filling the chambers with relics such as pottery and beads that have been interpreted as tributes to ancestors or gods.

The artefacts offer a view of those visitors and their relationship with the wider world. Changes in pottery styles there sometimes echoed distant trends in continental Europe, such as the appearance of bell-shaped beakers — a connection that signals the arrival of new ideas and people in Britain. But many archaeologists think these material shifts meshed into a generally stable culture that continued to follow its traditions for centuries.

"The ways in which people are doing things are the same. They're just using different material culture — different pots," says Neil Carlin at University College Dublin, who studies Ireland and Britain's transition from the Neolithic into the Copper and Bronze Ages.

But last year, reports started circulating that seemed to challenge this picture of stability. A study[1] analysing genome-wide

The West Kennet long barrow served as a tomb and ceremonial site for more than a millennium.

data from 170 ancient Europeans, including 100 associated with Bell Beaker-style artefacts, suggested that the people who had built the barrow and buried their dead there had all but vanished by 2000 BC. The genetic ancestry of Neolithic Britons, according to the study, was almost entirely displaced. Yet somehow the new arrivals carried on with many of the Britons' traditions. "That didn't fit for me," says Carlin, who has been struggling to reconcile his research with the DNA findings.

The Bell Beaker 'bombshell' study appeared in *Nature*[2] in February and included 230 more samples, to make it the largest ancient-genome study on record. But it is just the latest example of the disruptive influence that genetics has had on the study of the human past. Since 2010, when the first ancient-human genome was fully sequenced[3], researchers have amassed data on more than 1,300 individuals (see 'Ancient genomes'), and used them to chart the emergence of agriculture, the spread of languages and the disappearance of pottery styles — topics that archaeologists have laboured over for decades.

Some archaeologists are ecstatic over the possibilities offered by the new technology. Ancient-DNA work has breathed new life and excitement into their work, and they are beginning once-inconceivable investigations, such as sequencing the genome of every individual from a single graveyard. But others are cautious.

"Half the archaeologists think ancient DNA can solve everything. The other half think ancient DNA is the devil's work," quips Philipp Stockhammer, a researcher at Ludwig-Maximilians University in Munich, Germany, who works closely with geneticists and molecular biologists at an institute in Germany that was set up a few years ago to build bridges between the disciplines. The technology is no silver bullet, he says, but archaeologists ignore it at their peril.

Some archaeologists, however, worry that the molecular approach has robbed the field of nuance. They are concerned by sweeping DNA studies that they say make unwarranted, and even dangerous, assumptions about links between biology and culture. "They give the impression that they've sorted it out," says Marc Vander Linden, an archaeologist at the University of Cambridge, UK. "That's a little bit irritating."

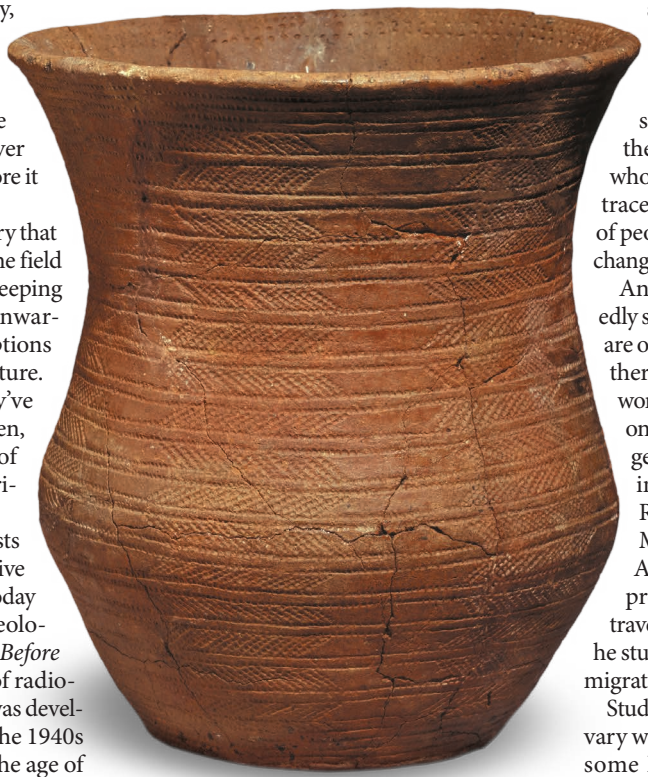
This isn't the first time archaeologists have had to contend with transformative technology. "The study of prehistory today is in crisis," wrote Cambridge archaeologist Colin Renfrew in his 1973 book *Before Civilization,* describing the impact of radiocarbon dating. Before the technique was developed by chemists and physicists in the 1940s and 50s, prehistorians determined the age of sites using 'relative chronologies', in some cases relying on ancient Egyptian calendars and false assumptions about the spread of ideas from the Near East. "Much of prehistory, as written in the existing textbooks is inadequate: some of it, quite simply wrong," Renfrew surmised.

It wasn't an easy changeover — early carbon-dating efforts were off by hundreds of years or more — but the technique eventually allowed archaeologists to stop spending most of their time worrying about the age of bones and artefacts and focus instead on what the remains meant, argues Kristian Kristiansen, who studies the Bronze Age at the University of Gothenburg in Sweden. "Suddenly there was a lot of free intellectual time to start thinking about prehistoric societies and how they are organized." Ancient DNA now offers the same opportunity, says Kristiansen, who has become one of his field's biggest cheerleaders for the technology.

Genetics and archaeology have been uneasy bedfellows for more than 30 years — the first ancient-human DNA paper[4], in 1985, reported sequences from an Egyptian mummy (now thought to be contamination). But improvements in sequencing technology in the mid-to-late 2000s set the fields on a collision course.

In 2010, scientists led by Eske Willerslev at the Natural History Museum of Denmark used DNA from a lock of hair from a 4,000-year-old native Greenlander to generate the first complete sequence of an ancient-human genome[3]. Seeing the future of the field before his eyes, Kristiansen asked Willerslev to team up on a prestigious European Research Council grant that would allow them to examine human mobility as the late Neolithic gave way to the Bronze Age, some 4,000–5,000 years ago.

> "THESE RESULTS WERE A SHOCK TO THE ARCHAEOLOGICAL COMMUNITY."



ASHMOLEAN MUSEUM/UNIV. OXFORD/BRIDGEMAN

Bell Beaker pots signal a period of unprecedented cultural intermingling for early Europeans.

ASSOCIATION PROBLEMS

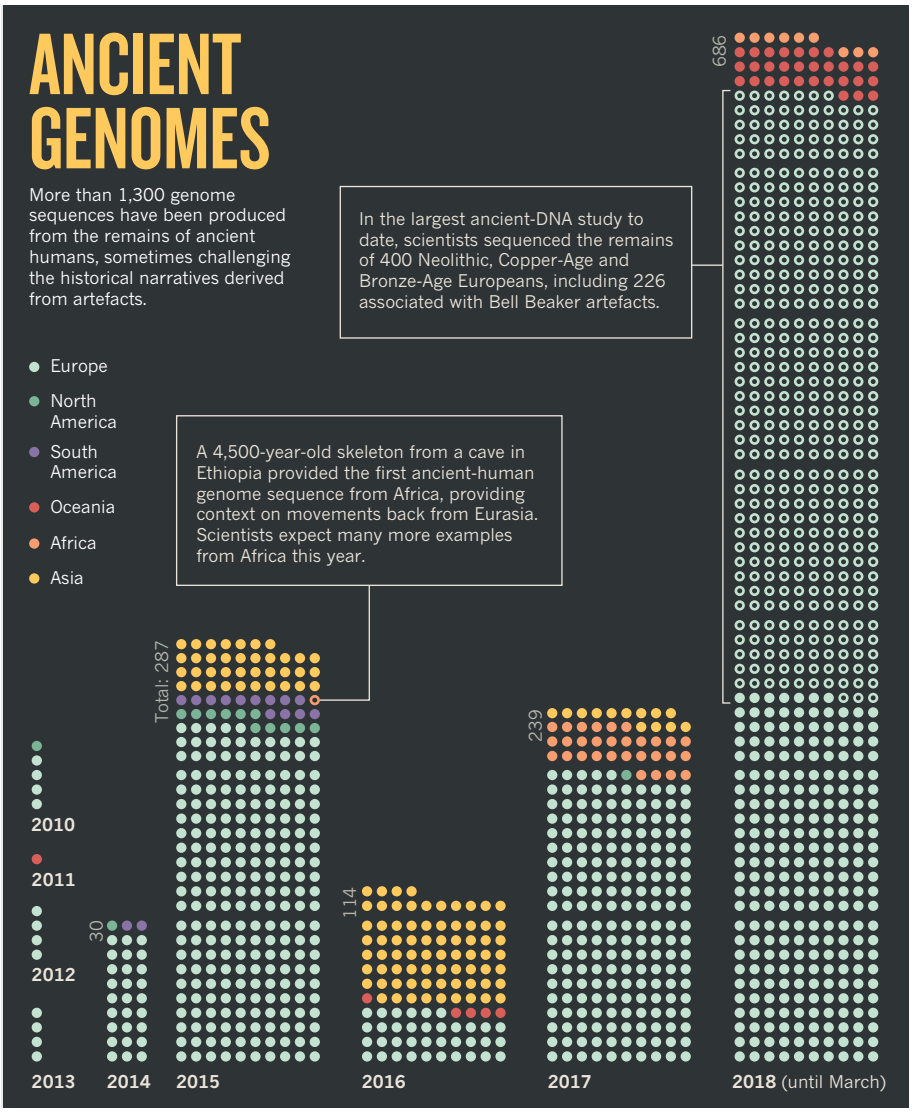
Migration has been a major source of tension for archaeologists. They have debated at length whether human movements are responsible for cultural changes in the archaeological record, such as the Bell Beaker phenomenon, or whether it is simply the ideas that are moving through cultural exchanges. Populations identified by the artefacts they associated with came to be seen as a remnant of the science's colonial past, and one that imposed artificial categories. "Pots are pots, not people," goes a common refrain.

Most archaeologists have since cast aside the view that prehistory was like a game of *Risk*, in which homogenous cultural groups conquer their way across a map of the world. Instead, researchers tend to focus on understanding a small number of ancient sites and the lives of the people who lived there. "Archaeology had moved away from these grand narratives," says Tom Booth, a bioarchaeologist at the Natural History Museum in London, who is part of a team using ancient DNA to trace the arrival of farming in Britain. "A lot of people thought you needed to understand change regionally to understand people's lives."

Ancient-DNA work — which has repeatedly shown that a region's modern inhabitants are often distinct from populations that lived there in the past — promised, for better or worse, to bring back some of the broad focus on migration to human prehistory. "What genetics is particularly good at is detecting change in populations," says David Reich, a population geneticist at Harvard Medical School in Boston, Massachusetts. Archaeologists, Kristiansen says, "were prepared to accept that individuals had travelled". But for the Bronze Age period that he studies, "they were not prepared for major migrations. That was a new thing."

Studies of strontium isotopes in teeth[5], which vary with local geochemistry, had hinted that some Bronze Age individuals had moved hundreds of kilometres over their lifetimes, Kristiansen says. He and Willerslev wondered

SOURCE: DAVID REICH



whether DNA analysis might detect movements of whole populations during this period.

They would have competition. In 2012, David Anthony, an archaeologist at Hartwick College in Oneonta, New York, loaded his car with boxes of human remains that he and his colleagues had excavated from the steppes near the Russian city of Samara, including bones associated with a Bronze Age pastoralist culture called the Yamnaya. He was bringing them to the ancient-DNA lab just established by Reich in Boston. Like Kristiansen, Anthony was comfortable theorizing about the past on a grand scale. His 2007 book *The Horse, the Wheel and Language* proposed that the Eurasian steppe had been a melting pot for the modern developments of horse domestication and wheeled transport, which propelled the spread of a family of languages called Indo-European across Europe and parts of Asia.

In duelling 2015 *Nature* papers[6,7], the teams arrived at broadly similar conclusions: an influx of herders from the grassland steppes of present-day Russia and Ukraine — linked to Yamnaya cultural artefacts and practices such as pit burial mounds — had replaced much of the gene pool of central and Western Europe around 4,500–5,000 years ago. This was coincident with the disappearance of Neolithic pottery, burial styles and other cultural expressions and the emergence of Corded Ware cultural artefacts, which are distributed throughout northern and central Europe. "These results were a shock to the archaeological community," Kristiansen says.

CORD CUTTERS

The conclusions immediately met with push-back. Some of it began even before the papers were published, says Reich. When he circulated a draft among his dozens of collaborators, several archaeologists quit the project. To many, the idea that people linked to Corded Ware had replaced Neolithic groups in Western Europe was eerily reminiscent of the ideas of Gustaf Kossinna, the early-twentieth-century German archaeologist who had connected Corded Ware culture to the people of modern Germany and promoted a '*Risk* board' view of prehistory known as settlement archaeology. The idea later fed into Nazi ideology.

Reich won his co-authors back by explicitly rejecting Kossinna's ideas in an essay included in the paper's 141-page supplementary material[7]. He says the episode was eye-opening in showing how a wider audience would perceive genetic studies claiming large-scale ancient migrations.

Still, not everyone was satisfied. In an essay[8] titled 'Kossinna's Smile', archaeologist Volker Heyd at the University of Bristol, UK, disagreed, not with the conclusion that people moved west from the steppe, but with how their genetic signatures were conflated with complex cultural expressions. Corded Ware and Yamnaya burials are more different than they are similar, and there is evidence of cultural exchange, at least, between the Russian steppe and regions west that predate Yamnaya culture, he says. None of these facts negates the conclusions of the genetics papers, but they underscore the insufficiency of the articles in addressing the questions that archaeologists are interested in, he argued. "While I have no doubt they are basically right, it is the complexity of the past that is not reflected," Heyd wrote, before issuing a call to arms. "Instead of letting geneticists determine the agenda and set the message, we should teach them about complexity in past human actions."

Ann Horsburgh, a molecular anthropologist and prehistorian at Southern Methodist University in Dallas, Texas, attributes such tensions to communication problems. Archaeology and genetics say distinct things about the past, but often use similar terms, such as the name of a material culture. "It's C. P. Snow all over again," she says, referring to the influential 'Two Cultures' lectures by the British scientist lamenting the deep intellectual divide between the sciences and the humanities. Horsburgh complains that genetic results are too often given precedence over inferences about the past from archaeology and anthropology, and that such "molecular chauvinism" prevents meaningful engagement[9]. "It's as though genetic data, because they're generated by people in lab coats, have some sort of unalloyed truth about the Universe."

Horsburgh, who is seeing her own field of African prehistory start to feel the tremors of ancient genomics, says that archaeologists frustrated at having their work misinterpreted should wield their power over archaeological remains to demand more equitable partnerships with geneticists. "Collaboration doesn't mean I send you an e-mail saying 'hey, you've got some really cool bones. I'll get you a *Nature* paper.' That's not a collaboration," she says.

Many archaeologists are also trying to understand and engage with the inconvenient findings from genetics. Carlin, for instance, says that the Bell Beaker genome study sent him on "a journey of reflection" in which he questioned his own views about the past. He has pored over the selection of DNA samples included in the study as well as the basis for its conclusion that the appearance of Bell Beaker artefacts coincided with a greater than 90% replacement in

Britain's gene pool. "I didn't want to be questioning it from a position of ignorance," Carlin says.

Like Heyd, he accepts that a shift in ancestry occurred (although he has questions about its timing and scale). Those results, in fact, now have him wondering about how cultural practices such as leaving pottery and other tributes at the West Kennet long barrow persisted in the face of such upheavals. "I would characterize a lot of these papers as 'map and describe'. They're looking at the movement of genetic signatures, but in terms of how or why that's happening, those things aren't being explored," says Carlin, who is no longer disturbed by the disconnect. "I am increasingly reconciling myself to the view that archaeology and ancient DNA are telling different stories." The changes in cultural and social practices that he studies might coincide with the population shifts that Reich and his team are uncovering, but they don't necessarily have to. And such biological insights will never fully explain the human experiences captured in the archaeological record.

Reich agrees that his field is in a "map-making phase", and that genetics is only sketching out the rough contours of the past. Sweeping conclusions, such as those put forth in the 2015 steppe migration papers, will give way to regionally focused studies with more subtlety.

This is already starting to happen. Although the Bell Beaker study found a profound shift in the genetic make-up of Britain, it rejected the notion that the cultural phenomenon was associated with a single population. In Iberia, individuals buried with Bell Beaker goods were closely related to earlier local populations and shared little ancestry with Beaker-associated individuals from northern Europe (who were related to steppe groups such as the Yamnaya). The pots did the moving, not the people.

Reich describes his role as that of a 'midwife' delivering ancient-DNA technology to archaeologists, who can apply it as they see fit. "Archaeologists will embrace this technology and will not be Luddites," he predicts, "and they'll make it their own."

A STRONGER PARTNERSHIP

Nestled in a sleepy valley in the state of Thuringia in former East Germany, the city of Jena has become an unlikely hub for the convergence of archaeology and genetics. In 2014, the prestigious Max Planck Society established an Institute for the Science of Human History there and installed a rising star in ancient-DNA research, Johannes Krause, as a director. Krause was a protégé of the geneticist Svante Pääbo, at the Max Planck Institute for Evolutionary Anthropology in Leipzig. There, Krause worked on the Neanderthal genome[10] and helped discover a new archaic human group, known as Denisovans[11].

Whereas Pääbo was focused on applying genetics to biological questions about ancient humans and their relatives, Krause saw a wider scope for the technology. Before leading the Jena institute, his team identified DNA from plague-causing bacteria in the teeth of people who died from the Black Death in the fourteenth century, the first direct evidence of a potential cause for the pandemic[12]. At Jena, Krause hoped to bring genetics to bear, not just on 'prehistorical' periods such as the Neolithic and the Bronze Age, where archaeological methods are the main tool for reconstructing the past, but also on more-recent times. Outreach with historians is still a work in progress, but archaeology and genetics are thoroughly embedded at the institute. The department Krause directs is even called archaeogenetics. "We have to be interdisciplinary," he says, because geneticists are addressing questions and time periods that archaeologists, linguists and historians have been poring over for decades.

"ARCHAEOLOGISTS WILL EMBRACE THIS TECHNOLOGY AND WILL NOT BE LUDDITES."

Krause and his team have been heavily involved in the map-making phase of ancient genomics (he worked closely with Reich's team on many such projects). But a study published late last year[13] that focused on the transition between the Neolithic and Bronze Age in Germany won plaudits from archaeologists who have been dubious of the larger-scale ancient-DNA studies.

Led by Stockhammer, who also has a post at the Jena institute, the team analysed 84 Neolithic and Bronze Age skeletons from southern Bavaria's Lech River Valley dating to between 2500 and 1700 BC. The diversity in the genomes of cellular structures known as mitochondria, which are inherited maternally, rose during this period, suggesting an influx of women. Meanwhile, strontium isotope levels in teeth — which are set during childhood — suggested that most females weren't local. In one case, two related individuals who lived within a few generations of each other were found buried with different material cultures. In other words, some cultural shifts in the archaeological record could be due not to massive migrations, but to the systematic mobility of individual women.

It is the prospect of more such studies that has archaeologists salivating over ancient DNA. In the near future, says Stockhammer, archaeologists will be able to sequence the genomes of all the individuals at a burial site and build a local family tree, while also determining how individuals fit into larger ancestry patterns. This should allow researchers to ask how biological kinship relates to the inheritance of material culture or status. "These are the big questions of history. They can be solved now only with collaboration," says Stockhammer.

Another glimpse of this approach appeared in February on the bioRxiv preprint server[14]. The paper explores Europe's migration period, when 'barbarian hordes' filled the void left after the fall of the Roman Empire. In the paper, a team of geneticists, archaeologists and historians built family trees of 63 individuals from two medieval cemeteries in Hungary and northern Italy associated with a group known as the Longobards. They found evidence of high-status outsiders buried in the cemetery: most bore central and northern European genetic ancestry that differed from that of local people, who tended to be buried without goods — offering tentative support to the idea that some barbarian groups included outsiders.

Patrick Geary, a medieval historian at the Institute for Advanced Study in Princeton, New Jersey, who co-led the Longobard study, would not comment on the research because it is now being peer reviewed. But he says that genetic studies of historical times, such as the migration period, carry pitfalls, too. Historians are increasingly incorporating data such as palaeoclimate records into their work, and will do likewise with ancient DNA, Geary says. But they share archaeologists' fears that biology and culture will be conflated, and that problematic designations such as Franks or Goths or Vikings will be reified by genetic profiles, overriding insights into how ancient peoples viewed themselves. "These days, what historians want to know about is identity," he says. "Genetics cannot answer these questions."

Reich concedes that his field hasn't always handled the past with the nuance or accuracy that archaeologists and historians would like. But he hopes they will eventually be swayed by the insights his field can bring. "We're barbarians coming late to the study of the human past," Reich says. "But it's dangerous to ignore barbarians." ■ SEE EDITORIAL P.559

Ewen Callaway *writes for* Nature *from London.*

1. Olalde, I. *et al.* Preprint at bioRxiv http://dx.doi.org/10.1101/135962 (2017).
2. Olalde, I. *et al. Nature* **555,** 190–196 (2018).
3. Rasmussen, M. *et al. Nature* **463**, 757–762 (2010).
4. Pääbo, S. *Nature* **314,** 644–645 (1985).
5. Frei, K. M. *et al. Sci. Rep.* **5,** 10431 (2015).
6. Allentoft, M. E. *et al. Nature* **522,** 167–172 (2015).
7. Haak, W. *et al. Nature* **522,** 207–211 (2015).
8. Heyd, V. *Antiquity* **91,** 348–359 (2017).
9. Horsburgh, K. A. *J. Archaeol. Sci.* **56,** 141–145 (2015).
10. Green, R. E. *et al. Science* **328,** 710–722 (2010).
11. Krause, J. *et al. Nature* **464,** 894–897 (2010).
12. Bos, K. I. *et al. Nature* **478,** 506–510 (2011).
13. Knipper, C. *et al. Proc. Natl Acad. Sci. USA* **114,** 10083–10088 (2017).
14. Amorim, C. E. G. *et al.* Preprint at bioRxiv http://dx.doi.org/10.1101/268250 (2018).