and calculations to estimate the distribution of vegetation types and methane emissions, and, finally, the resulting methane concentration in the atmosphere. Using a well-resolved GCM for such an experiment is highly novel: the number of simulations was possible only because of recent advances in computing capacity (and because the BBC funded some of the work as research for a television series).

The model results do a good job of following the upper envelope of methane concentration through the entire period, showing the pattern expected from the orbital precession, similar to that for summer insolation at 30° N. The model diverges from that pattern over the past 5,000 years, however, giving an increase in methane concentration just as shown by the ice-core data. Crucially, no such increase is seen in the model output for the analogous period of the last interglacial, which occurred between about 125,000 and 115,000 years ago.

The model experiments allow the authors to delineate which regions contributed to the global pattern of methane emissions. It appears that the late-Holocene rise was due to an increase in sources from South America south of the Equator that, combined with small increases from other regions, outweighed decreases in Eurasia and East Asia. This South American source reacts to an insolation signal that has a quite different phase from the usually dominant northern one.

At the equivalent time in the last interglacial, larger changes in insolation caused even larger changes in emissions from each region. These were again finely balanced. The experiments in which only orbital forcing was varied do show a small increase in global methane emissions at roughly the equivalent time (in orbital terms) to that in the Holocene. However, the early start of glaciation during the last interglacial induced a further decrease in (high-latitude) Eurasian and North American emissions, preventing an upturn at the global scale.

The trends deduced from the model are the result of a subtle balance between several opposing effects, and it is therefore difficult to know whether the precise result is robust: it will need to be examined using other climate and vegetation models[7]. Nonetheless, Singarayer and colleagues' study[2] provides a satisfactory explanation of both the increase in methane concentration in the late Holocene and the decrease during the last interglacial (Fig. 1) — an 'early anthropogenic' influence on methane is no longer required, although of course it cannot be ruled out. It is also worth noting that the good fit of the model and data over the last interglacial, including the period when the Arctic was apparently several degrees warmer than at present[8], leaves little room for a large influence of additional emissions from methane hydrates in permafrost or marine sediments under such conditions.

Some aspects of the problem remain to be solved. Although this work[2] does a good job of tracing the envelope of observed methane concentrations over the entire glacial cycle, it gives no hint of the large and rapid changes observed at millennial timescales. Finally, in the same paper[5] in which he suggested an early human influence on methane, Ruddiman also suggested that the slow rise in carbon dioxide over the past 8,000 years was a result of human actions. This idea has been strongly rebuffed[9,10], but there is not, as yet, any convincing study showing why the Holocene behaved differently from the last interglacial for carbon dioxide. ■

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ARCHAEOLOGY

Trailblazers across Arabia

What role did the Arabian peninsula play in the expansion of our species out of Africa? An archaeological site in the United Arab Emirates provides tantalizing new evidence that supports an early human migration from Africa.

MICHAEL D. PETRAGLIA

Genetic and fossil information points to Africa as the original homeland of *Homo sapiens*, but the date and path of human movements out of Africa remain unresolved. Fossil evidence indicates that *H. sapiens* had entered the Levant by 130,000 to 120,000 years ago, and that this population survived there until 75,000 years ago[1]. Convincing human fossils from this period have not been found anywhere else in Eurasia, however, suggesting that the early Levantine occupation was geographically limited and temporary. Molecular geneticists have argued that human migrations along the rim of the Indian Ocean occurred rapidly about 65,000 years ago[2], following a coastal route to avoid the hyper-arid deserts of Arabia. Archaeologists have speculated that this coastal migration was accompanied by microblade tool industries — cultures associated with the manufacture of small stone blades — carried from southern Africa[3].

Reporting in *Science*, Armitage *et al.*[4] now describe strong evidence for a human presence 125,000 years ago in what is now the United Arab Emirates: stone-tool assemblages buried in sediments dating from that period. Remarkably, the Arabian tools are similar to those made by anatomically modern humans living in Africa at that time. This implies an early dispersal of *H. sapiens* along a route passing from the Horn of Africa to southern Arabia across the Bab al-Mandab Strait (Fig. 1).

The authors' conclusions are based on sedimentary dating and archaeological finds, with no accompanying human fossils. So how convincing are their evidence and interpretations? Let us first consider the archaeological site. The stone-tool assemblages were under an overhang of rock (known as a rock shelter) situated at the base of a steeply sloping mountain range called Jebel Faya in the southeastern part of the Arabian peninsula (Fig. 1). More specifically, the rock shelter is on a piece of land that juts out near the Strait of Hormuz.

Armitage *et al.* excavated trenches in and around the rock shelter, and discovered three Palaeolithic stone-tool assemblages. They dated the lowest-lying of these, assemblage C, using the optically stimulated luminescence technique. Of the three sedimentary samples taken, two had consistent ages of 127,000 and 123,000 years, but the third was only 95,000 years old. The disparity of the ages may point to some unexplained problems in the stratigraphy and its dating.

The stone artefacts from assemblage C were made using a combination of distinctive manufacturing methods (including the Levallois technique for striking prepared flakes from stones), and included a variety of flake tools, such as scraping implements. Small hand-held axes and thick leaf-shaped objects (foliates) were also made by the Jebel Faya inhabitants. The key point argued by Armitage *et al.* about these tools is that they are similar to those being made by modern humans in East and Northeast Africa at the time, but are unlike those produced by other contemporaneous Levantine groups, including the Neanderthals. The authors are almost certainly correct about this, but a systematic comparison of stone tools from the various regions will be necessary to fully substantiate their claim.

An alternative explanation for the hand axes and thick foliates at Jebel Faya is that a presently unknown human ancestor made them. This might seem a less likely theory, but an archaic species of *Homo* is known to have lived in India in the same time period as that to which the assemblage C tools were dated (archaic *Homo* encompasses primitive forms of humans that are closely related to *H. sapiens*). What's more, assemblage C is underlain by an older, although presently undescribed, sedimentary layer that contains stone tools, underscoring the possibility of an earlier presence of primitive humans at Jebel Faya.

Armitage *et al.*[4] also investigated the two younger assemblages of Palaeolithic implements found at the Jebel Faya rock shelter. Using the luminescence technique, they dated sedimentary samples associated with assemblage A to 40,000 and 38,000 years ago. The authors could not determine an age for assemblage B in this way because no appropriate sediments were available for dating, but on the basis of their stratigraphic position, the tools are clearly somewhere between 95,000 and 40,000 years old. The implements from assemblages A and B do not contain the characteristic hand axes and foliates found among the earlier tools, and the authors observed that the Levallois technique was not used in their manufacture. Instead, different kinds of tools were represented, made using diverse flaking techniques.

What is striking about the types of stone tools in assemblages A and B, and their manufacturing methods, is that they do not resemble those of any known assemblages in Africa, the Levant, or in regions to the north and east of Jebel Faya. The authors compellingly assert that this is evidence for the development of a regional cultural tradition in stone-tool making. Intriguingly, the implied presence of humans at this site between 95,000 and 40,000 years ago opposes the genetic evidence[2] for a rapid dispersal of modern humans from Africa about 65,000 years ago. In addition, the distinctive cultural flair of the Jebel Faya stone-tool assemblages is at odds with the supposition that human migrations into Arabia took a microblade tradition with them[3].

On the basis of their findings, Armitage and colleagues argue[4] that African populations crossed the Bab al-Mandab Strait 125,000 years ago — a time when the strait was at its narrowest because sea levels were low, and when environments in southern Arabia were favourable for human habitation. They speculate that hunter–gatherers then swept across southern Arabia, quickly reaching the tip of southeastern Arabia and Jebel Faya. This is not the only conceivable path of movement, however. During wet periods, Arabia contained an abundance of rivers and lakes, which probably encouraged inland movements in many directions (Fig. 1). Periodic wetting and greening of Arabian landscapes would have facilitated population expansions and interactions, perhaps even leading to interbreeding with Neanderthals[5] in northern areas.

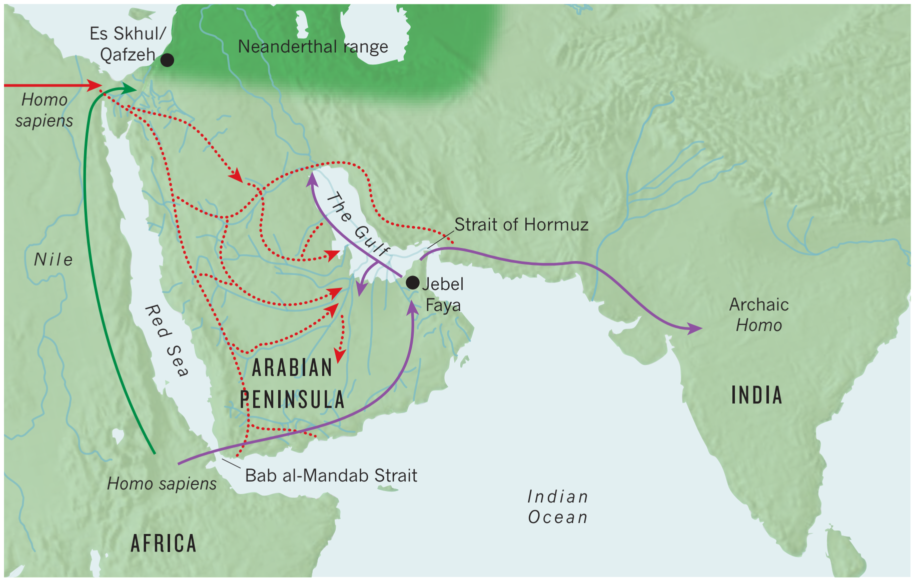

Figure 1 | Routes out of Africa. Armitage *et al.*[4] propose a southern route for the migration of modern humans from Africa into Arabia and beyond (purple arrows). They argue that modern humans left Africa by crossing the Bab al-Mandab Strait, and moved along the southern margin of Arabia to reach Jebel Faya 125,000 years ago. During dry periods, the population would have moved eastwards, along river routes that are now submerged in the Gulf. The Jebel Faya population could have eventually reached India, where they might have interacted with extant archaic *Homo*[7]. Alternatively, humans may have entered Arabia from East Africa (green arrow) or from the Sahara (red arrow), eventually reaching the Es Skhul and Qafzeh caves in Israel, where human fossils have been found. During wet periods, Arabia had a network of rivers and lakes[8] that would have then facilitated human dispersal across the peninsula in southward and eastward movements (broken red arrows). Interbreeding may have occurred with Neanderthals who lived to the north of the Arabian peninsula.

The authors go on to suggest[4] that the Jebel Faya population was cut off during hyper-arid periods, as vegetated landscapes withered away and freshwater resources dried up in the regions between Jebel Faya and other populations. The inhabitants of Jebel Faya were therefore drawn to more favourable environments near the rivers whose routes now lie under the Gulf (Fig. 1), and eventually created their own cultural traditions.

The authors' theory suggests that the three Palaeolithic assemblages are remnants of a single population that survived continuously across the periods indicated by the sedimentary dating. But the separation of the assemblages in the sediments indicates significant temporal hiatuses in occupations at Jebel Faya. Is it possible that the earlier and later populations were unrelated? With the current archaeological data, and the small amount of dating information, answers remain elusive.

What is clear is that long-term population survival at Jebel Faya is difficult to reconcile in the light of present genetic findings. Genetics-based age estimates for human migrations across Arabia do not correspond with the early ages of the Jebel Faya occupation; moreover, genetic information indicates the importance of later influxes of groups into Arabia as opposed to long-term population continuity[6]. This suggests that we should expect population contractions to have occurred in refugium areas of Arabia — the areas inhabited by isolated populations — during hyper-arid phases, along with genetic bottlenecks, and population extinctions and replacements. Clearly, human fossils and more information from archaeological sites are needed to address the question of when humans first entered Arabia and how they overcame climatic and environmental fluctuations in the region. Nevertheless, Armitage and colleagues' findings[4] are an important demonstration that Arabia should take its rightful place centre-stage in out-of-Africa debates. ■

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