news and views

Shu et al. model into question, and a roughly million-year time difference between chondrule and CAI formation seems to have been confirmed by recent lead-isotope data.

But these arguments against the Shu et al. model would be greatly weakened if it were shown that chondrules and CAIs formed contemporaneously. Although rare, CAI fragments have been found within chondrules, and this is consistent with chondrules forming either in the same period as or after CAIs. Finding a chondrule fragment poor in short-lived radionuclides inside a CAI rich in short-lived radionuclides would be unambiguous evidence in support of the Shu et al. model. Itoh and Yurimoto have found what they believe is just such an object.

In a section of the meteorite Y-81020, held at the National Institute of Polar Research, Tokyo, Itoh and Yurimoto have found what appears to be a CAI made up of three components: a chondrule fragment; a melilitite (silicate) crystal that is probably a fragment of an earlier CAI; and a porous, fine-grained calcium–aluminium-rich silicate that cements the object together, the ‘mesostasis’ (Fig. 1). The mesostasis probably formed during the final melting that produced the object. Itoh and Yurimoto do not present any short-lived-radionuclide data, but would not have been stable under the conditions of CAI formation. So it is surprising that it has survived.

Could this object be a chondrule whose precursors were dominated by much older CAI material, rather than a chondrule within a CAI? Arguments will certainly be made for both interpretations. Ultimately, the issue may only be resolved if the abundances of one or more of the short-lived radionuclides in the mesostasis can be determined. Much will be riding on these measurements.

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Human evolution

Out of Ethiopia

Chris Stringer

Newly discovered fossils from Ethiopia provide fresh evidence for the ‘out of Africa’ model for the origin of modern humans, and raise new questions about the precise pattern of human evolution.

The idea that modern humans originated in Africa, with populations subsequently spreading outwards from there, has continued to gain support lately. But much of that support has come from analyses of genetic variation in people today, and from fossil and archaeological discoveries dated to within the past 120,000 years — after our species evolved. Hard evidence for the inferred African origin of modern humans has remained somewhat elusive, with relevant material being fragmentary, morphologically ambiguous or uncertainly dated. So the fossilized partial skulls from Ethiopia that are described on pages 742 and 747 of this issue are probably some of the most significant discoveries of early Homo sapiens so far, owing to their completeness and well-established antiquity of about 160,000 years.

There are two broad theories about the origins of Homo sapiens. A few researchers still support a version of the ‘multiregional’ hypothesis, arguing that the anatomical features of modern humans arose in geographically widespread hominid populations throughout the Pleistocene epoch (which lasted from around 1.8 million to some 12,000 years ago). But most now espouse a version of the ‘out of Africa’ model, although there are differences of opinion over the complexity of the processes of origin and dispersal, and over the amount of mixing that might subsequently have occurred with archaic (non-modern) humans outside of Africa. Within Africa, uncertainties still surround the mode of modern human evolution — whether it proceeded in a gradual and steady manner or in fits and starts (punctuational evolution). Other questions concern the relationship between genetic, morphological and behavioural change, and the precise region, or regions, of origin.

For instance, possible early Homo sapiens fossils, dating from about 260,000 to 130,000 years ago, are scattered across Africa at sites such as Florisbad (South Africa), Ngaloba (Tanzania), Elyie Springs and Guomde (Kenya), Omo Kibish (Ethiopia), Singa (Sudan) and Jebel Irhoud (Morocco). But the best dated of these finds, from Florisbad and Singa, are problematic because of incompleteness and, in the latter case, evidence of disease. Meanwhile, the more complete or diagnostically modern specimens suffer from chronological uncertainties. So the most securely dated and complete early fossils that unequivocally share an anatomical pattern with today’s H. sapiens are actually from Israel, rather than Africa. These are the partial skeletons from Skhul and Qafzeh, dating from around 115,000 years ago. Their presence in the Levant is usually explained by a range expansion from ancestral African populations, such as those sampled at Omo Kibish or Jebel Irhoud, around 125,000 years ago.

The new cranial material from Herto, Ethiopia — described by White and colleagues — adds significantly to our understanding of early H. sapiens evolution in Africa. The fossils are complete enough to show a suite of modern human characters, and are well constrained by argon-isotope dating to about 160,000 years ago. Three individuals are represented by separate fossils: a nearly complete adult cranium (skull parts excluding the lower jaw), a less complete juvenile cranium, and a somewhat cranial fragments from another adult. All display evidence of human modification, such as cut marks, considered to represent mortuary practices rather than cannibalism. Associated layers of sediment produced evidence of the butchery of large mammals such as hippopotamuses and bovines, as well as assemblages of artefacts showing an interesting combination of Middle Stone Age and late Acheulean technology.

The morphology of the most complete of these three fossils helps to clarify the pattern of early H. sapiens evolution in Africa, as it shows an interesting combination of features from archaic, early modern and recent humans. The cranium is very large, but once the size is standardized, it shares with ancient African crania a wide interorbital breadth (the distance between the orbits of the eyes), anteriorly placed teeth, and a short occipital (the bone at the rear of the braincase). It also has a wide upper face and moderately domed forehead, as do the ancient African crania. Within Africa, uncertainties still surround the mode of modern human evolution — whether it proceeded in a gradual and steady manner or in fits and starts (punctuational evolution). Other questions concern the relationship between genetic, morphological and behavioural change, and the precise region, or regions, of origin.

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Figure 1. Origin of our species. The figure shows the geographical and temporal distribution of hominin populations, based on fossil finds, using different taxonomic schemes. The new finds from Herto (H) represent early Homo sapiens. a. This reflects the view that both Neanderthals and modern humans derived from a widespread ancestral species called H. heidelbergensis. b. However, evidence is growing that Neanderthal features have deep roots in Europe, so H. neanderthalensis might extend back over 400,000 years. The roots of H. sapiens might be similarly deep in Africa, but this figure represents the alternative view that the ancestor was a separate African species called H. rhodesiensis. Different views of early human evolution are also shown. Some workers prefer to lump the earlier records together and recognize only one widespread species, H. erectus (shown in a). Others recognize several species, with H. ergaster and H. antecessor (or H. mauritanicus) in the West, and H. erectus only in the Far East (shown in b). Adapted with permission from refs 8, 11.

characteristics, such as its globular brain-case, are typically modern. In the angulation and transverse ridge of the occipital, there is also an intriguing resemblance to fossils from sites such as ElaNsfontan (South Africa) and Broken Hill (Zambia) that are often assigned to H. heidelbergensis or H. rhodesiensis. This may provide a clue to the individual's ancestors (Fig. 1). But overall, the fossil seems closest in morphology to particular crania from Jebel Irhoud, Omo Kibish and Qafzeh.

So White and colleagues' findings provide a plausible link back to more ancient African fossils, and forward to Levantine samples. They also raise questions about the overall pattern of modern human origins in Africa. Because of Africa's great area and still limited fossil record, it is uncertain whether the pattern of H. sapiens evolution there was essentially continent-wide, or was a more localized — and perhaps punctuation — process. The Herto finds shift the focus once again to East Africa. It seems from these crania and from possibly contemporaneous fossils, such as those at Ngaloba, Singa and Elibye Springs, that human populations of this era showed a great deal of anatomical variation. So, did the early modern morphology spread outwards from East Africa, perhaps gradually more archaic forms? Or could there have been an African version of multiregionalism, with modern morphology coalescing from various populations across the continent? Only better samples and better dating of the African fossil record will help resolve these questions.

And what of the taxonomic status of the new finds? White and colleagues propose that, although measurements of the most complete fossil differentiate it from geologically 'recent' (that is, post-Pleistocene) H. sapiens, there is sufficient evidence to assign the material to this species overall, while naming a new subspecies, idaltu. However, in my opinion, the distinctive features described for H. sapiens idaltu might not be so unusual, and could probably be found in late Pleistocene samples from regions such as Australasia.

Do the Herto fossils represent 'modern' H. sapiens? There is an ongoing debate about the concept of modernity, in terms of both morphological and behavioural characteristics. Nevertheless, despite the presence of some primitive features, there seems to be enough morphological evidence to regard the Herto material as the oldest definite record of what we currently think of as modern H. sapiens. The fact that the geological age of these fossils is close to some estimates...

Juan Maldacena

High-energy physics

Into the fifth dimension
J. Maldacena

Particles such as the proton can be imagined as vibrating strings. We also know that protons contain smaller, point-like particles, going against the string theory. But in five dimensions, the contradiction disappears.

In fundamental physics, our description of nature involves four forces: gravitational, electromagnetic, weak and strong. The strong force is responsible for binding protons and neutrons inside the atomic nucleus. Two different theoretical approaches have been taken in describing the workings of the strong force and the structure of particles such as the proton and neutron. The theories are seemingly odd with each other, but steps are gradually being taken to reconcile the two. Writing in the Journal of High Energy Physics, Polchinski and Strassler1 now dispel worries over an apparent contradiction between the theories, by showing that it is not a contradiction at all.

In the 1960s, experimenters high-energy collisions between protons revealed a plethora of other short-lived, strongly interacting particles. Shortly afterwards, a theory emerged that proposed that all of these different particles were particular excitation modes of a string: as a violin string can vibrate with different frequencies, these could oscillate in different ways, corresponding to the ‘zoo’ of particles that was observed. This ‘string theory’ proved useful in explaining some aspects of the masses and spins of the particles.

But further experiments carried out through the 1970s showed that protons are not fundamental particles. In the same way that, much earlier in the century, Rutherford had shown that the atomic nucleus was much smaller than an atom, experimenters showed that protons, and neutrons, have small point-like constituents. This didn’t fit with the theory of protons as strings, which are extended objects. In fact, these experiments led to a new description of the strong interaction in terms of point-like quarks and gluons, through a theory called quantum chromodynamics (QCD).

As the electron carries an electric charge, quarks and gluons carry a new type of charge, called ‘colour’ (hence ‘chromodynamics’). The gluons transmit the strong force between quarks in much the same way that the photon transmits the electromagnetic force between electrons and other charged particles. To describe the strong force we need three ‘colours’ — three different types of charges, usually designated ‘red’, ‘green’ and ‘blue’. The validity of QCD has been spectacularly confirmed by experiments at high energies in particle colliders. But, despite this success, it is still remarkably hard to do theoretical calculations with QCD at low energies. And that’s exactly where things should get interesting: at low energies, the colour flux lines form bundles of energy that should behave like a string — a tantalizing connection from QCD to string theory. These strings, made of gluons, bind the quarks together.

In fact, in the 1970s, Gerard ’t Hooft2 showed that QCD becomes a theory of free (non-interacting) strings if the number of colours is infinite. This simplifies the theory considerably. Strings still exist in the three-colour version of QCD, but in this case the strings are interacting. No way has yet been found to simplify QCD into a free-string theory, but it could be key to understanding many low-energy properties of particles that interact through the strong force, and in particular for deriving a curious property of QCD, called confinement. No one has ever observed a free quark, because colour-charge-bearing objects such as quarks and gluons are subject to confinement: in other words, as two quarks are gradually separated, the attractive force between them due to their colour charges remains constant; this contrasts with the more familiar forces in electromagnetism and gravity that fall off with the square of increasing distance.

The way forward has been signalled by work on strings in ‘QCD-like’ theories3–5. A surprising and counterintuitive feature of these strings is that they move in more than the familiar four dimensions of everyday life — three spatial dimensions and one of time. Even though the gluons that make up the strings move in four dimensions, the string itself moves in five dimensions. Polchinski and Strassler3 now show that this is a crucial element in reconciling the string picture and the point-like behaviour seen in high-energy collisions.

The strings move in a five-dimensional curved space-time with a boundary. The boundary corresponds to the usual four dimensions, and the fifth dimension describes the motion away from this boundary into the interior of the curved space-time. In this five-dimensional space-time, there is a strong gravitational field pulling objects away from the boundary, and as a result time flows more slowly far away from the boundary than close to it. This also implies that an object that has a fixed proper size in the interior can appear to have different size when viewed from the boundary (Fig. 1). Strings existing in the five-dimensional space-time can even look point-like when they are close to the boundary. Polchinski and Strassler3 show that when an energetic four-dimensional particle (such as an electron) is scattered from these strings (describing protons), the main contribution comes from a string that is close to the boundary and it is therefore seen as a point-like object. So a string-like interpretation of a proton is not at odds with the observation that there are point-like objects inside it.

Because the theory that describes the interior of the five-dimensional space-time