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[3] 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 melilite (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, and so we must rely on inferences made from various physical and chemical features of the object to determine if it is what they claim. The inferred peak temperature (above 1,823 K) and cooling rate (between tens and hundreds of degrees per hour) experienced by the object are broadly consistent with those of chondrules and CAIs. The oxygen-isotope compositions of the chondrule fragment and mesostasis are typical of chondrules and CAIs, respectively. But there are two puzzling features of the chondrule fragment. Its edges seem quite angular, suggesting that, unlike the melilite crystal, it was unaffected by melting of the mesostasis. It also contains the iron-sulphide mineral troilite. This volatile mineral is present in chondrules, 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[1], and from fossil and archaeological discoveries dated to within the past 120,000 years[2,3] — 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[4,5] 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 *H. 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)[6]. 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[2,7]. 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 changes, and the precise region, or regions, of origin.

For instance, possible early *H. 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), Eliye 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[2,7,8], around 125,000 years ago.

The new cranial material from Herto, Ethiopia — described by White and colleagues[4,5] — 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 some robust cranial fragments from another adult[4]. 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[5].

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 Skhul and Qafzeh fossils. Its low nose and face and flat midface are more widely shared early *H. sapiens* features, whereas other

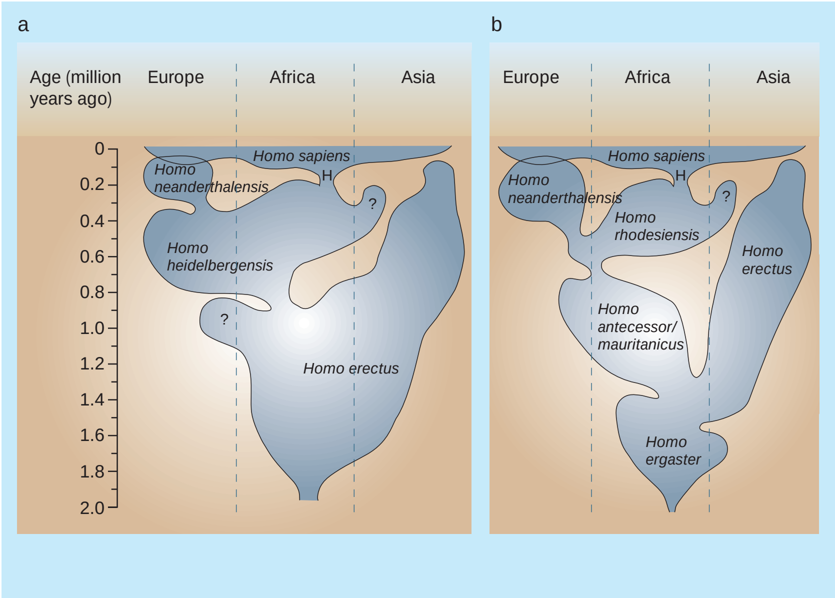

Figure 1 **Origin of our species. The figure shows the geographical and temporal distribution of hominid populations, based on fossil finds, using different taxonomic schemes. The new finds from Herto[4,5] (H) represent early *Homo sapiens*.** a, **This reflects the view that both Neanderthals and modern humans derived from a widespread ancestral species called *H. heidelbergensis*[2].** b, **However, evidence is growing that Neanderthal features have deep roots in Europe[2,8], 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*[2] (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[8] (shown in** b**). Adapted with permission from refs 8, 11.**

characteristics, such as its globular braincase, are typically modern. In the angulation and transverse ridge of the occipital, there is also an intriguing resemblance to fossils from sites such as Elandsfontein (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[4,5] 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 punctuational — 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 Eliye 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[2,7,8]? 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[9].

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[2,3,7,8,10]. 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

NATURE

100 YEARS AGO

It is reported that a young Austrian doctor named Sachs has fallen a victim to his scientific zeal having accidentally inoculated himself with plague, from the effects of which he died after a short illness. Such regrettable incidents will occur while scientific research is pursued, and cannot be avoided even by the greatest foresight. There is no likelihood that other cases will develop, as under good hygienic conditions plague is not particularly infectious from man to man, and European doctors and nurses tending the sick seldom contract the disease.

ALSO...

In the course of a recent article published in the *Recueil de l'Institut botanique de Bruxelles*, Prof. Errera comes to the conclusion that it is not possible for organisms to exist of a size very appreciably smaller than those which can be observed with the highest powers of the microscope now in use. An estimation is made of the number of molecules of certain bodies, such as albuminoids, which are present in a bacterium of given size: the number is of such an order of magnitude that only a few molecules could be present in an organism having a diameter 0.01μ, and thus a minimum limit to the possible size is obtained.

From *Nature* 11 June 1903.

50 YEARS AGO

***Meeting on "Preservation of Normal Tissues for Transplantation".* In opening the scientific proceedings, Prof. P. B. Medawar (University College London) said that living skin, when transplanted into positions formerly occupied by skin, was probably the most exacting of all tissues… Under the heading [of modifying host reactions] Prof. Medawar outlined experiments done in collaboration with R. E. Billingham and L. Brent which showed that if an animal were presented with living foreign cells in foetal life, its power to react against those cells in later life was reduced or wholly abolished. This was not due, as had been widely assumed, to an adaptation of the grafted cells, but to an adaptation of the host, for 'actively acquired tolerance', once established by inoculation of the foetus, extended to cells freshly transplanted in later life — cells which therefore had had no opportunity to adapt themselves to alien soil.**

From *Nature* 13 June 1953.

obtained by genetic analyses for the origin of modern human variation[1] only heightens their importance. ■

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High-energy physics

Into the fifth dimension

Juan 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 at odds with each other, but steps are gradually being taken to reconcile the two. Writing in the *Journal of High Energy Physics*, Polchinski and Strassler[1] now dispel worries over an apparent contradiction between the theories, by showing that it isn't necessarily a contradiction at all.

In the 1960s, experiments on 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 strings 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.

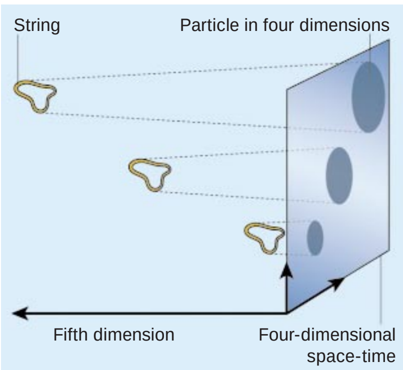

Figure 1 **Strings, particles and extra dimensions. Strings moving in the fifth dimension are represented in the everyday world by their projection onto the four-dimensional boundary of the five-dimensional space-time. The same string located at different positions along the fifth dimension corresponds to particles of different sizes in four dimensions: the further away the string, the larger the particle. The projection of a string that is very close to the boundary of the four-dimensional world can appear to be a point-like particle.**

In fact, in the 1970s, Gerard 't Hooft[2] 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 the 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' theories[3–5]. 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 Strassler[1] now show that this fact 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 a 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 Strassler[1] 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