PALEOANTHROPOLOGY

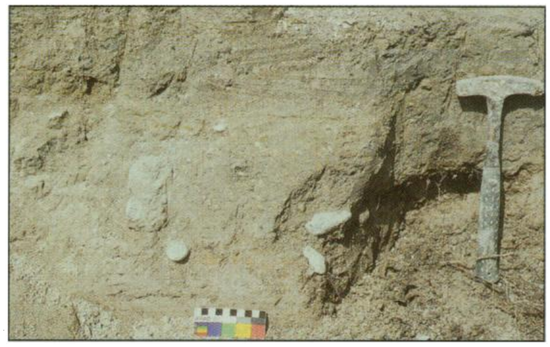
Ancient Island Tools Suggest *Homo erectus* Was a Seafarer

In 1968, a Dutch missionary living on the Indonesian island of Flores found stone tools alongside the bones of an extinct type of elephant called a *Stegodon*, known to have lived at least 750,000 years ago. If the tools were as old as the *Stegodon*, this was a spectacular discovery, for Flores lies beyond a deep-water strait that separates most Asian and Australian faunas. The tools meant that the only human species then living in Southeast Asia, *Homo erectus*, must have been able to cross this biological barrier, called Wallace's line.

But when the missionary, Theodor Verhoeven, reported his findings in the journal *Anthropos*, his claim was roundly dismissed. Although trained in classical archaeology, Verhoeven was an amateur, so researchers discounted his field work. And the accepted idea was that deep waters blocked human exploration until about 50,000 years ago. Although *H. erectus* was known from just 600 kilometers away on Java, most researchers were convinced that this early human lacked the social and linguistic skills needed to cross Wallace's line by piloting a raft over deep, fast-moving waters. Even after Dutch and Indonesian paleontologists backed Verhoeven's findings with new excavations and paleomagnetic dating in 1994, the claim was still considered dubious.

In this week's issue of *Nature*, however, an international team presents new dates for stone tools from Flores, based on a different and more reliable technique called fission-track dating, that confirm *H. erectus*'s presence there 800,000 years ago. The authors propose that the early humans who left behind these simple flakes and cobbles were "capable of repeated water crossings using watercraft" and may even have had language, needed to cooperate to build rafts. The "cognitive capabilities of *H. erectus* may be due for reappraisal," says archaeologist Mike Morwood of the University of New England in Armidale, Australia, lead author of the paper.

Most researchers accept the new dates for the artifacts, but they are sharply divided over what the findings reveal about the toolmaker. A few questions linger about whether the artifacts are really tools—and no *H. erectus* bones have been found on Flores to dispel these questions. Some researchers add that *H. erectus* might have accidentally drifted over to Flores on a raft or even walked on some previously unknown land bridge, says Colin Groves of Australian National University (ANU) in Canberra: "The Flores data



M. J. MORWOOD

Stonework. Stone tools found between layers of volcanic rock on the island of Flores show humans were there about 800,000 years ago.

do not seem convincing that *H. erectus* made boats." Nonetheless, he agrees with others that the tools "are quite remarkable evidence of the distributional extent and environmental flexibility of our perhaps underestimated cousin, *H. erectus*."

H. erectus in Asia has long been eclipsed by its relatives in Africa, where the species is thought to have arisen more than 1.8 million years ago. In the first known exodus of human beings from Africa, *H. erectus* then spread around the globe, settling in China and Java perhaps as early as 1.8 million years ago (*Science*, 25 February 1994, p. 1087). But although these early humans spread thousands of kilometers over land and across shallow straits, they seemed to have been incapable of deep-water crossings. In technical, social, and organizational skills—not to mention language—*H. erectus* was thought to lag far behind later humans.

H. erectus's limitations seemed especially severe in Asia. Starting 1.5 million years ago, the Africans made better tools—two-sided stone hand axes—while the Asian members of the species either left almost no tools, as in Java, or only simple cobblestone choppers and flakes. "This group of Eastern hominids has always been regarded as impoverished in technological or cultural capabilities, as compared to their contemporaries in Africa," says Philip Rightmire, a paleoanthropologist at the State University of New York, Binghamton.

For the past 4 years, however, Dutch and Indonesian paleontologists have been coming up with support for Verhoeven's 1968 claim—and for a more flattering picture of Asian *H. erectus*. A Dutch and Indonesian group led by Paul Sondaar of the Natural History Museum in Rotterdam, the Netherlands, applied paleomagnetic dating, which is based on well-known reversals in Earth's magnetic field recorded in volcanic rock, to a rock layer just below 14 stone artifacts they had found in volcanic ash beds at a site called Mata Menge. The dates, about 750,000 years old, nicely matched Verhoeven's. But the results, published in 1994 and 1997 in French and Australian journals, were considered suspect. That was partly because of the lack of human bones and the uncertainties of this type of dating at the site, and also because the initial publication was in conference proceedings and was missed by many researchers, says Iain Davidson, an archaeologist at the University of New England in Armidale, Australia.

Now new dating of ash layers from Mata

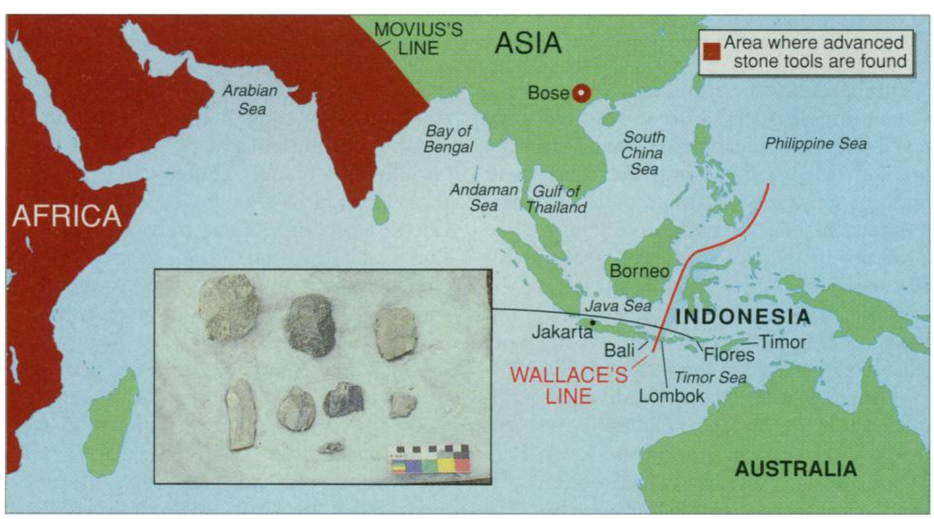


PHOTO: M. J. MORWOOD

Crossing the line. Early dates for stone tools *(inset)* show that *H. erectus* may have somehow crossed the rough seas that mark Wallace's line and so entered the world of Australian fauna.

In China, a Handier *Homo Erectus*

More than 50 years ago, Harvard University anthropologist Hallam Movius divided the peoples of the Early Stone Age into two cultures: those who could make sophisticated, two-sided stone hand axes, known as Acheulean or mode 2 technology, and those who could not. This invisible technological barrier, which came to be known as Movius's line, separated handy *H. erectus* in Africa, the Middle East, and Europe from their less adept cousins in Asia, who left only mode 1 technology—simple stone flakes and cobbles used for chopping (see map). Movius therefore wrote off the entire Asian continent as "a marginal region of cultural retardation." Because the climate and terrain in the forests of Asia remained stable for the past 2 million years, Movius wrote, humans there didn't advance in culture but stayed backward for eons.

Now, says Smithsonian Institution paleoanthropologist Rick Potts, "the Movius line is breached." New international excavations in China reveal that at least a few early Asians were also making two-sided, or bifacial, stone tools as much as 730,000 years ago. Other researchers aren't convinced that these tools indicate mode 2 sophistication. But they agree that Stone Age Asians were probably engaged in more complex activities than Movius gave them credit for, abilities also suggested by signs that *H. erectus* somehow reached a far-flung island in Southeast Asia (see main text).

Since Movius's time, bifacial tools have been found at almost a dozen sites in eastern Asia. But the dating of the sites is unreliable, and they appear to be less than 200,000 years old—long after the time of *H. erectus* and into the era of our own species, *H. sapiens*, says Indiana University, Bloomington, archaeologist Kathy Schick. And although researchers realized that early Asians might have used perishable tools made of wood or bamboo, the lack of advanced stone tools in Asia was still puzzling.

Now firmer—and much earlier—dates may be emerging from the 800-square-kilometer Bose Basin in southern China. In the red dirt of this hilly, rural area along the Youjiang River, Huang Weiwen, an archaeologist at the Institute of Vertebrate Paleontology and Paleoanthropology in Beijing, found thousands of stone tools, including bifacial hand axes. Since 1994, Huang and Potts have systematically excavated and dated basin sites in the same stratigraphic layer, using fission-track and paleomagnetic dating, to show that bifacial hand axes from the center of the basin were made between 700,000 and 800,000 years ago.

These hand axes don't look exactly like the classic Acheulean technology, but their shape suggests that they were manufactured systematically and, therefore, that the toolmakers shared technological traditions, says Potts. He argues that this elevates them above mode 1 technology and that it's time to redefine "mode 2" technologies in Asia: "For so long, we've equated mode 2 with the Acheulean."

But no one knows whether this group of axmakers was a band of failed immigrants from the west or whether the toolmaking tradition was born and refined in Asia. To answer that question, archaeologists need to discover and date such tools elsewhere in Asia. "You can't just rely on one basin to tell the whole story," says Potts. "There's so much to do in China."

–A.G.

Menge confirms these findings. The ash contains minerals such as zircon that are ideal for fission-track dating. Over time, atoms of uranium-238 in a zircon grain in volcanic rock undergo spontaneous fission, producing fragments that streak across the crystal lattice like a meteor in the sky and leave tracks about 10 micrometers long. By chemically etching the crystals, geochronologists can see and count the tracks; the more tracks they see, the more time has passed since the rock crystallized.

Using this method on 50 individual grains of zircon from ash layers just above and below the tool-bearing sandstone layer, Paul O'Sullivan and Asaf Raza at La Trobe University in Bundoora, Australia, where the technique was pioneered, came up with ages of 800,000 to 880,000 years for almost all of the grains. Although it's easy to undercount the tracks, fission-track dating is considered reliable in the right hands, such as those of O'Sullivan's team. "The research group is tops, as good as they come," says Andrew Carter, a geochronologist at the London Fission Track Research Group. "I can't find any faults with it at all. They've gone out of their way to undertake more grain analysis than is conventional."

But some researchers still wonder exactly what's being dated on Flores—human artifacts or just shattered rock. Smithsonian Institution paleoanthropologist Rick Potts notes that the ratio of 14 artifacts to 45 stone pieces recovered at the site in 1994 is only 31%, and he thinks at least 50% of stones at a site should be tools. "If this were a site in Africa, the fact that most of the rocks are not artifacts would make us doubt it as a lithics site," he says.

However, Morwood, an archaeologist invited to work with the Dutch and the Indonesians to check the authenticity of the tools and the stratigraphy at the site, insists that there is "absolutely no doubt about them being artifacts." Other experts who have seen these artifacts agree that they're the real thing. "I think yes, having seen a few," says Peter Bellwood, an archaeologist at ANU. Furthermore, some of the flakes are made of chert, a rock not found at the site, suggesting that the tools were made elsewhere.

Other hints of *H. erectus*'s presence on Flores come from the creatures that lived there, say Morwood and Sondaar. Sometime after 900,000 years ago, Flores's pygmy stegodons, giant tortoises, and giant Komodo dragons all suddenly went extinct. They were replaced by large stegodons, which apparently swam there in herds. Human hunters may have arrived and driven the pygmy stegodon and other animals to extinction, says Sondaar—making this the earliest extinction to be blamed on humans.

All this has convinced those who have worked at Mata Menge that *H. erectus* was there—and that they arrived by raft or other watercraft. Even when the sea level was at its lowest, these humans would have had to cross 19 kilometers of water to get to Flores from the closest island of Sumbawa—after a 25-kilometer crossing over treacherous waters between Bali and Sumbawa. And an even longer crossing would be needed if they came from Sulawesi to the north, says Morwood. "You've got to be talking about watercraft," he says. That has broad implications for *H. erectus* in Asia and beyond: "They were intelligent, thinking animals. Once you take into account the use of watercraft and their rapid radiation out of Africa, you have to rethink *H. erectus*. They must have had language for the collective effort needed to achieve this sea travel." He speculates that the species reached the southern Indonesian island of Timor, where undated tools have also been found—and from there, perhaps even Australia.

Few others are willing to go so far. "Australia would have been out of sight, whereas the island-hopping route to Flores was marked by huge volcanoes visible from afar," says Bellwood. And Groves points out that the tectonics of these volcanic islands is so unstable that there may even have been a land bridge briefly connecting them. "Let's be cautious about what conclusions we draw about the navigational skills of *H. erectus*," says Groves.

Even if *H. erectus* did float to Flores, it could have been by accident, on a primitive raft, adds Davidson. Monkeys have been seen floating on makeshift rafts of mangrove tree limbs and vegetation in Indonesia, he says. Still, says Rightmire, this "does help to dispel the notion that *H. erectus* in general, and Eastern *H. erectus* in particular, were relatively slow to react to challenges posed by the environment," because they not only navigated deep-water straits but adapted to life on an island, where the environment is thought to have been far different from the forest habitat of the mainland.

The new findings also fit well with other work showing that Asian *H. erectus* has been underrated. Controversial new dates from sites in Java suggest that *H. erectus* persisted there from as early as 1.8 million years ago until as recently as 30,000 years ago, implying that they were able to adapt to varied terrain and climate. Other new studies suggest that *H. erectus* left behind sophisticated hand axes in southern China (see sidebar on page 1636). For those who have worked on Flores and long believed in *H. erectus*'s presence there, the new results are vindication. Says Sondaar: "I am happy that the finds of Verhoeven are finally recognized."

–**Ann Gibbons**

MATHEMATICS

Polyhedra Can Bend But Not Breathe

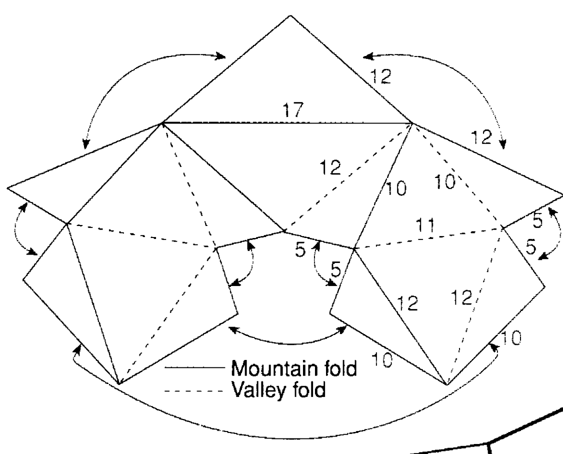
Anyone who has made an origami crane knows the delight and wonderment of conjuring a moving creature from the static geometry of lines and triangles. Although the flexibility of the paper is what allows the crane's wings to flap, mathematicians showed 20 years ago that a geometric equivalent could be constructed: a closed, three-dimensional figure made of rigid triangles, which can be squeezed or stretched into a new shape without distorting the faces. The finding upset what had been an article of faith for geometers and engineers—that a structure whose surfaces are made of triangles must be rigid. But a new proof shows that flexible polyhedra still face constraints: They have to keep their volume constant as they move. As Robert Connelly of Cornell University puts it, "You cannot build a mathematical bellows."

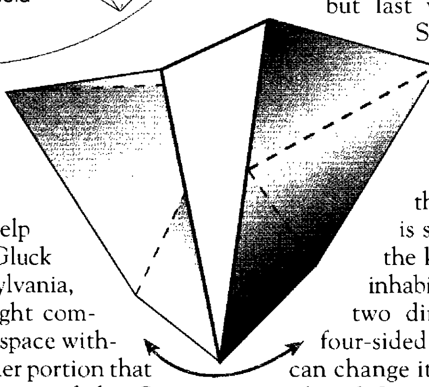
The discovery of flexible polyhedra, with their infinitely changeable angles, had blown a hole in the long-standing belief that a given set of edge lengths can yield only a finite number of shapes. But the new result, published jointly in the German journal *Beiträge zur Algebra und Geometrie* by Connelly, Idzhad Sabitov of Moscow State University, and Connelly's student Anke Walz, implies that edge lengths do narrow down one of the most important aspects of shape—the volume—to a finite number of possibilities.

In 1813, the French mathematician Augustin Louis Cauchy had proved that convex polyhedra—structures with flat faces, straight edges, and most important, no indentations—are always rigid. But that left open the question of whether polyhedra with indentations could flex. Around the turn of the century, a French engineer named Raoul Bricard found they could, if the faces were allowed to pass through each other. However, in the strictest sense Bricard's example, a flexible surface with eight faces, was not a polyhedron. For example, such a shape cannot be made into a physical object.

However, Bricard turned out to be on the right track. In the 1970s, Connelly managed to build a true flexible surface by elaborately altering Bricard's example, eliminating certain faces and allowing certain edges to detour around others. Later, Klaus Steffen of the University of Düsseldorf discovered a flexible polyhedron with only nine vertices and 14 triangular faces, which is believed to be the simplest one possible (see illustration).

As soon as these first models were built, mathematicians began playing around with them. "You could not help noticing," says Herman Gluck of the University of Pennsylvania, "that ... though they might compress some portion of the space within, there was always another portion that expanded." Dennis Sullivan of the City University of New York blew smoke into a model and observed that none came out when the model was moved back and forth—suggesting again that it was not acting as a bellows.





Flexible figure. This crease pattern, with the dimensions shown, yields what may be the simplest flexible polyhedron *(right)*.

SOURCE: PETER CROMWELL, *POLYHEDRA*

The key to proving what Connelly called the Bellows Conjecture was a vast generalization of a formula discovered by an ancient Greek mathematician, Heron of Alexandria. Heron's formula says that the area, x, of a triangle with side lengths (a, b, c) must solve the following polynomial: $16x^2 + a^4 + b^4 + c^4 - 2a^2b^2 - 2a^2c^2 - 2b^2c^2 = 0$. The volume of a tetrahedron has to satisfy a similar—but more complicated—polynomial. Connelly and, independently, Sabitov came up with the idea that the volume of any polyhedron might also solve some version of Heron's polynomial. If so, then the volume of a polyhedron with fixed side lengths could only change by jumping from one solution of the polynomial to another. But if the motion of the polyhedron is gradual, the volume cannot change suddenly. "It has no choice but to remain constant," says Gluck.

To prove that such polynomials exist for more complex polyhedra, Connelly and Sabitov found a way to divide these figures into tetrahedra, eliminate the edges of component tetrahedra that aren't actually edges of the final figure, and merge the known polynomials for the tetrahedra into a single polynomial for the entire shape. Even for a simple figure like an octahedron, the resulting polynomial involves 16th powers of the volume. Sabitov, in 1996, was the first to produce an algorithm that yields a polynomial for a general polyhedron, but last year's joint paper by Sabitov, Connelly, and Walz greatly simplifies the proof.

The proof still leaves plenty of mysteries. For one thing, the Bellows Conjecture is surprisingly sensitive to the kind of space the figure inhabits. It does not hold in two dimensions: A flexible four-sided figure, for example, can change its area without changing the side lengths. Connelly and Walz believe they can prove the Bellows Conjecture in four dimensions, but in higher dimensions, Connelly admits, "we're stuck."

Sabitov remains optimistic that in three dimensions, at least, mathematicians will soon have a complete understanding of how edge lengths determine the shape of polyhedra—not just their volume but also whether they can flex, and by how much. In the future, he says, "there will be a chapter of geometry titled 'The solution of polyhedra' as we now have 'The solution of triangles.' "

–**Dana Mackenzie**

Dana Mackenzie is a mathematics and science writer in Santa Cruz, California.