"[Getz] provides an interesting new perspective," says Lotta Sundström, an evolutionary biologist at the University of Helsinki, Finland. However, she and West both caution that Getz has not captured the full picture. West in particular thinks the best model will be more inclusive and will factor in the value of sexual reproduction in ridding the genome of mutations and also in enabling organisms to deal with parasites.

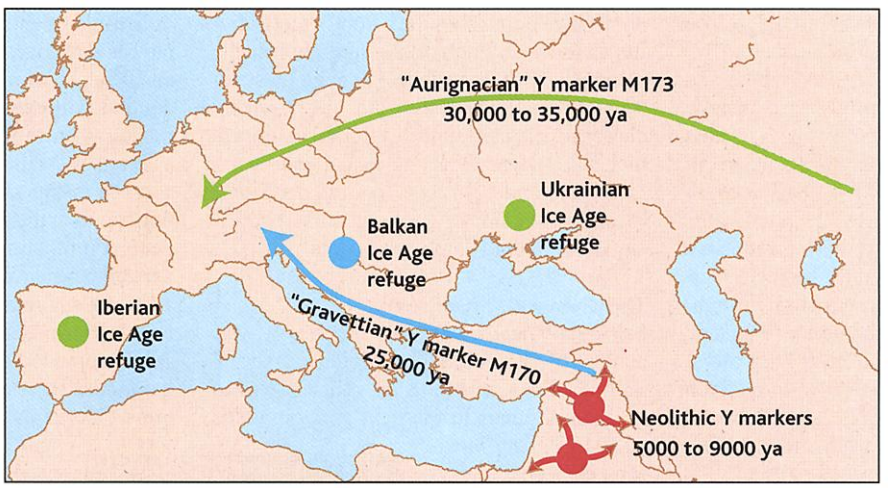
Getz takes their criticism in stride. Like Hamilton, he's open to considering a wide range of possibilities about how life works and gives serious thought even to farfetched ideas. Hamilton's career, he notes, demonstrated how such open-mindedness can have great rewards. "When we begin to think with a Hamiltonian frame of mind," Getz explains, "it allows us to consider astonishing kinds of phenomena"—and sometimes even figure them out. **–ELIZABETH PENNISI**

EVOLUTIONARY GENETICS

Europeans Trace Ancestry To Paleolithic People

Y chromosome data show that living Europeans have deep roots in the region—and researchers say genetic markers may be linked to archaeological cultures

About 8000 years ago, the people living in Franchthi Cave in southern Greece experienced a dramatic change of lifestyle. On the floor of the cave where hunter-gatherers had been dropping stone tools and fishbones for thousands of years, the remains of a new kind of feast appear: traces of wheat, barley, sheep, and goat, which can only be the result of farming and herding animals. Within the next 3000 years, the same abrupt transition ripples through archaeological sites along the shoreline of the Mediterranean, eventually reaching Europe, where settled villages of mud-brick houses appear. "The consequences of the transition were fundamental—village settlement, new beliefs, different social structure," says archaeologist Colin Renfrew of the University of Cambridge in England. "A behavioral revolution took place."



Men on the move. Y chromosome data reveal three major migrations into Europe, which researchers tie to known archaeological cultures. At 40,000 years ago (ya), the Aurignacian people moved in (green), followed by the Gravettians 25,000 years ago (blue), and finally the Neolithic farmers (red) 9000 years ago.

But which people made that revolutionary European transition? Did farmers move into Europe from the Fertile Crescent in the Middle East, or did local hunter-gatherers learn to trade and farm themselves? And if Neolithic newcomers brought farming technology, did they replace most of the locals, or did those Paleolithic locals survive and become the primary ancestors of modern Europeans?

Now, after years of debate, these questions are being answered not only by ancient remains but also by the genes of living Europeans. In a report on page 1155, an international team reports that a wealth of data from the Y chromosome show that it was the local hunter-gatherers who passed on more of their genes. More than 80% of European men have inherited their Y chromosomes—which are transmitted only from father to son—from Paleolithic ancestors who lived 25,000 to 40,000 years ago. Only 20% of Europeans trace their Y chromosome ancestry to Neolithic farmers. Thus, the genetic template for European men was set as early as 40,000 years ago, then modified—but not recast—by the Neolithic farmers about 10,000 years ago.

These Y chromosome data are "strikingly similar" to new findings on mitochondrial DNA (mtDNA), which is inherited maternally, notes evolutionary geneticist Martin Richards of the University of Huddersfield in England, who led a mtDNA study published in the November issue of the *American Journal of Human Genetics*. "A consensus is emerging on what the genetic data are telling us," says Richards. "After all the debate, this is very exciting and encouraging."

The data from both genetic lineages not only enable researchers to trace the movements of the first farmers, they also paint a remarkably detailed picture of the identity and movements of ancient Europeans. The Y chromosome team, led by geneticists Ornella Semino of the University of Pavia in Italy and Giuseppe Passarino of Stanford University, also took the bold step of explicitly connecting genetic and archaeological data—a move that is already drawing some fire. The researchers link two early migrations recorded by the Y chromosome to two Paleolithic cultures, the Aurignacian and Gravettian, each famous for their spectacular art and artifacts (see map). "This paper shows us that molecular genetics is beginning to show us which genetic markers are coordinated with climatic events and population dispersals," says Renfrew.

The earliest glimpse of European genetic origins came from protein markers; more recently, researchers studied the mtDNA of European women. But the results were divided: One group of researchers that included Stanford geneticist L. Luca Cavalli-Sforza, a co-author of the new Y chromosome study, found similar markers in Europeans and Middle Easterners, which declined from east to west and looked like the signature of the Neolithic expansion. But other researchers proposed that several European genetic markers were too old to have been introduced with the Neolithic newcomers.

The obvious way to reconcile the sometimes heated debate was to look at men's genetic history as recorded on the Y chromosome. By comparing the variations, called polymorphisms or markers, at one site on the chromosome, and the frequency at which those variations occur in different populations, geneticists can sort out which populations are most closely related. They can then build a phylogenetic tree that traces

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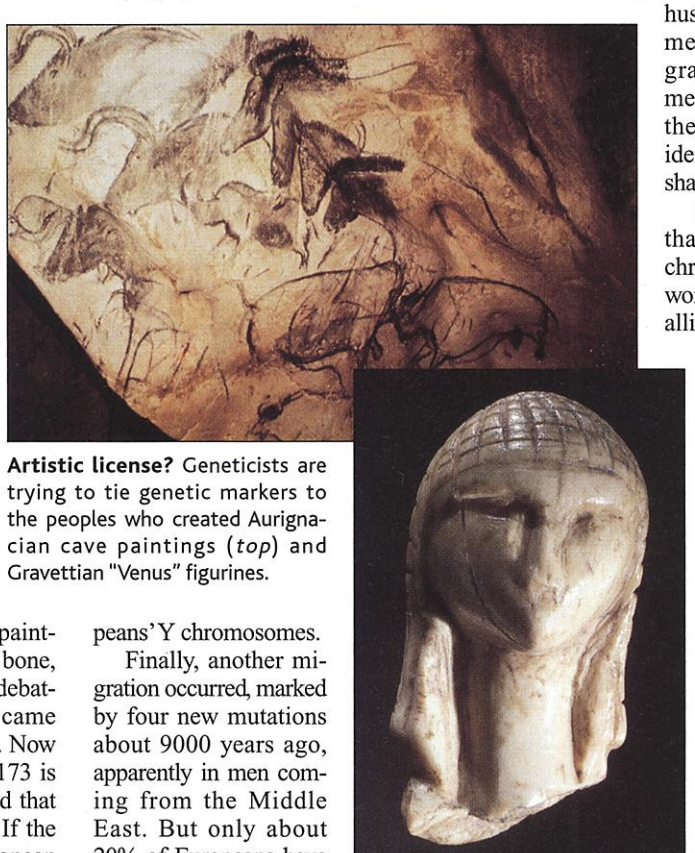
the inheritance of the Y chromosome markers in different populations. And by using average mutation rates, researchers can estimate how long ago particular mutations appeared, thus dating various population splits and movements.

Using samples from 1007 European men, the Y chromosome team got clear results: Most of the men could be sorted into 10 different Y chromosome variants or haplotypes. The researchers sorted those haplotypes on a phylogenetic tree and used the geographic distributions of modern markers to trace the evolution and spread of the ancient markers. For example, they found that four modern haplotypes, which account for 80% of European men's Y chromosomes, were descended from two now-vanished haplotypes. One, M173, arose more than 40,000 years ago from an even older marker called M45. Apparently M45 was present in men living in Asia, for other descendants of this haplotype are now seen in Siberians and Native Americans. Meanwhile, the descendants of the M173 marker are found at the highest frequency today in Europe. So the researchers conclude that M173 is an ancient Eurasiatic marker that moved into Europe about 35,000 to 40,000 years ago.

The authors note that this is just the time of the advent of the Aurignacian, an advanced culture that reached its height in Western Europe about 35,000 years ago and is well-known for its sophisticated rock-art paintings and finely crafted tools of antler, bone, and ivory. Archaeologists have hotly debated whether these people originally came from Europe, Asia, or the Middle East. Now the authors propose that haplotype M173 is the "signature of the Aurignacian," and that these people came from central Asia. If the team is right, then half of modern European men still carry the genetic signature of these ancient artists.

Using similar reasoning, the researchers report that the next wave of migration into Europe, marked by a mutation known as M170, occurred about 22,000 years ago from the Middle East. The authors link this wave to the so-called Gravettian culture, known for its Venus figurines and small, delicate blades, which first appeared in the area that is now Austria, the Czech Republic, and the northern Balkans. But archaeologist Alison Brooks of George Washington University in Washington, D.C., warns that there were many cultures in Europe at these times, such as the Solutrean from Iberia, and that it's risky to link genes to a particular culture.

Once in Europe, the timing and geographical distribution of markers suggests that Aurignacian people dominated Western and southern Europe, while the Gravettian people thrived in Eastern and Central Europe. But when the climate worsened during the Last Glacial Maximum 24,000 to 16,000 years ago, people carrying the "Aurignacian" marker apparently concentrated in refuges in the Iberian peninsula and the Ukraine. Meanwhile, the Gravettian people apparently moved to the Balkans. After the glaciers retreated, the geneticists say that these people moved out of the refuges and their populations expanded rapidly. That fast expansion is why these markers now account for such a large proportion—80%—of modern Europeans' Y chromosomes.



Artistic license? Geneticists are trying to tie genetic markers to the peoples who created Aurignacian cave paintings (*top*) and Gravettian "Venus" figurines.

Finally, another migration occurred, marked by four new mutations about 9000 years ago, apparently in men coming from the Middle East. But only about 20% of Europeans have these Neolithic markers. The authors tie this migration to the spread of farming out of the Fertile Crescent, as seen in the archaeological record. The distribution of markers even suggests something about the route the ancient farmers took: "There's more Paleolithic [markers] in the north of Europe than the south and more Neolithic in the south," says Cavalli-Sforza. "I believe at least part of the Neolithic people went by boat along the coast."

The new mtDNA data tell much the same tale, says Richards, with 80% of European women having the older Paleolithic markers and 20% having Neolithic markers—although in women, the Neolithic haplotypes are not concentrated along the Mediterranean coastline, a finding that could reflect the different movements of the sexes. But the mtDNA data also suggest the presence of ice age refuges in Iberia and, to a lesser extent, southern Europe. "This fits completely with the mitochondrial data that show an expansion out of Iberia," says Antonio Torroni, a geneticist at the University of Urbino in Italy who proposed the idea of an Iberian refuge in 1998.

The new Y chromosome data enhance the existing picture, says Renfrew. "The mitochondrial work showed us the way, but the Y is making it even more clear," as the Y chromosome data reveal geographical sources of origin more clearly. This is probably because in many societies women move to join their husband's families, while related men cluster more closely geographically. And because some men have many, many children, they leave more offspring with identical Y chromosomes—and a sharp geographical signal.

But those features also mean that there is less diversity in Y chromosome lineages around the world than in mtDNA, notes Cavalli-Sforza. That lack of diversity makes dating the Y chromosome mutations more difficult: In their calculations, researchers assume that low genetic diversity means that less time has passed—but instead, men's mating habits might be creating a pool of very similar DNA and swamping the data. That would cause researchers to underestimate the age of genetic and population events.

Some researchers are particularly wary of connecting these roughly dated markers to cultures known from the archaeological record. Although he praises the basic Y chromosome results, "I don't like attaching genetics to archaeological evidence," says Mark Jobling, a geneticist at the University of Leicester in England who also studies the Y chromosome in Europeans. "It appeals to the imagination, but the mutation rates on the Y [and therefore the dating of genetic events] have wide confidence margins."

Cavalli-Sforza agrees that genetic dates have large margins of error. But because even these preliminary dates from different genetic lineages correspond well with each other and with major migrations suggested by the archaeological record, it is hard to resist making the connections. "Genetic dating is in its infancy," says Cavalli-Sforza. "We have to start somewhere. The future will bring new evidence."

–ANN GIBBONS

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