OLLI 497: Ancient DNA

Session 5: October 26th **Summary and Observations**

Chapter 4: Humanity's Ghosts

The Discovery of the Ancient North Eurasians

A common metaphor used to describe the relationships among the evolved species on Earth is that of a tree. Species bud off from the common branch or trunk to find their own evolutionary path, a metaphor used by Darwin. But Reich notes: "If the tree metaphor is right, then any population today will have a **single ancestral population** at each point in the past. The significance of the tree is that once a population separates, it **does not remix**, as fusions of branches cannot occur."

For Reich: "The avalanche of new data that has become available in the wake of the genome revolution has shown just how **wrong** the tree metaphor is for summarizing the relationship among **modern human populations.**" Reich goes on to describe he Four Population Test (which I won't repeat here),.

He succinctly draws the point of the test: "The most natural way to test the tree model is to measure the **frequencies of mutations** in the genomes of two populations that we hypothesize have split from the same branch. If a tree model is **correct**, the frequencies of mutations in the two populations will have changed randomly since their separation from the other two more distantly related populations, and so the frequency differences between these two pairs of populations will be **statistically independent**. If a tree model is **wrong**, there will be **a correlation between the frequency differences,** pointing to the likelihood of **mixture** between the branches. The Four Population Test was central to our demonstration that Neanderthals are more closely related to non-Africans than to Africans, and thus that there was interbreeding between Neanderthals and non-Africans."

A further discovery using the Four Population test pointed he way to further discoveries: "My laboratory's first major discovery using the Four Population Test came when we tested the widely held view that Native Americans and East Asians are "sister populations" that descend from a common ancestral branch that separated earlier from the ancestors of Europeans and sub-Saharan Africans. To our surprise, we found that at mutations not shared with sub-Saharan Africans, **Europeans are more closely related to Native Americans than they are to East Asians**. It would be tempting to argue that this observation has a trivial explanation, such as Native Americans having some ancestry from European migrants over the last five hundred years. But we found the same pattern in every Native American population we studied, including those we could prove had no European admixture. The scenario of Native Americans and Europeans **descending from a common population** that split earlier from East Asians was also contradicted by the data. Something was deeply wrong with the standard tree model of population relationships."

In order to unravel this conundrum, Reich'e team devised another population test: "…the Three Population Test, which evaluates a "test" population for **evidence of mixture**. If the test population is a mixture of lineages related to the comparison populations in two different ways —as African Americans are a mixture of Europeans and West Africans—then the frequencies of the test population's mutations are expected to be intermediate between those of the two comparison populations. In contrast, if mixture did not occur, there is no reason to expect the

frequencies of mutations in the population to be intermediate. Thus the scenarios of mixture and no mixture yield two qualitatively very different patterns."

"When we applied the Three Population Test to diverse human populations, we detected negative statistics when the test population was northern European, proving that population mixture occurred in the ancestors of northern Europeans. We tried all possible pairs of comparison populations from more than fifty worldwide populations and found that the mixture evidence was strongest when one comparison population was southern European, especially Sardinians, and the other was Native Americans. It was clearly Native American populations that produced the most negative values, as we found that the statistic was more negative when we used Native Americans for the second comparison population than when we used East Asians, Siberians, or New Guineans. What we had found was evidence that people in northern Europe, such as the French, are descended from a mixture of populations, one of which shared more ancestry with present-day Native Americans than with any other population living today."

"How could we understand the results of both the Three Population Test and the Four Population Test? We proposed that more than fifteen thousand years ago, there was a population living in northern Eurasia that was **not the primary ancestral population** of the present-day inhabitants of the region. Some people from this population migrated east across Siberia and contributed to the population that crossed the Bering land bridge and gave rise to Native Americans. Others migrated west and contributed to Europeans. This would explain why today, the evidence of mixture in Europeans is strong when using **Native Americans as a surrogate for the ancestral population.…**"

"We called this proposed new population the "**Ancient North Eurasians**.… they were a "ghost"—a population that we can **infer** existed in the past based on statistical reconstruction but that no longer exists in unmixed form."

Reich notes that this ghost population was very successful: "All told, more than half the world's population derives between 5 percent and 40 percent of their genomes from the Ancient North Eurasians."

So for humans, Reich thinks the tree metaphor is completely wrong. "The genome revolution has taught us that **great mixtures of highly divergent populations have occurred repeatedly.** Instead of a tree, a better metaphor may be a trellis, branching and remixing far back into the past."

The Ghost Is Found

The Ancient North Eurasians did not remain a ghost population for long: "At the end of 2013, Eske Willerslev and his colleagues published genome-wide data from the bones of a boy who had lived at the Mal'ta site in south-central Siberia around twenty-four thousand years ago. The Mal'ta genome had its **strongest genetic affinity to Europeans and Native Americans**, and far less affinity to the Siberians who live in the region today—just as we had predicted for the ghost population of the Ancient North Eurasians. The Mal'ta genome has now become the prototype sample for the Ancient North Eurasians."

"The analysis of the Mal'ta genome made it clear that Native Americans derive about a third of their ancestry from the Ancient North Eurasians, and the remainder from East Asians. It is this major mixture that explains why Europeans are genetically closer to Native Americans than they are to East Asians."

"The finding that several of the great populations outside of Africa today are **profoundly mixed** was at odds with what most scientists expected. Prior to the genome revolution, I, like most others, had assumed that the big genetic clusters of populations we see today reflect the deep splits of the past. But in fact the big clusters today are themselves the result of mixtures of very different populations that existed earlier. We have since detected similar patterns in every population we have analyzed: East Asians, South Asians, West Africans, southern Africans. There was never a single trunk population in the human past. It has been mixtures all the way down."

The Ghost of the Near East

In 2013, Iosif Lazaridis in Reich's laboratory was puzzled by "… a peculiar Four Population Test result showing that East Asians, present-day Europeans, and pre-farming European hunter-gatherers from around eight thousand years ago are not related to one another according to the tree model. Instead, his analysis showed that East Asians today are genetically more closely related on average to the ancestors of ancient European hunter-gatherers than they are to the ancestors of present Europeans. Ancient DNA studies prior to his work had already shown that present-day Europeans derive some of their ancestry from migrations of farmers from the Near East, who I had assumed were derived from the same ancestral population as European hunter-gatherers. Lazaridis now realized that the ancestry of the first European farmers was **distinct from** European hunter-gatherers in some way. Something more complicated was going on."

A solution was soon at hand: "With Mal'ta in hand, he carried out Four Population Tests among various sets of four populations. Mal'ta and the pre-farming European hunter-gatherers appeared to descend from a **common ancestral population** that arose after the separation from East Asians and sub-Saharan Africans. The data were consistent with a simple tree. But when Lazaridis replaced ancient European hunter-gatherers in this statistic with either present-day Europeans or with early European farmers, the tree metaphor could no longer describe the data. Present-day Europeans and Near Easterners are mixed: they carry within them ancestry from **a divergent Eurasian lineage** that branched from Mal'ta, European hunter-gatherers, and East Asians before those three lineages separated from one another."

"Lazaridis called this lineage "**Basal Eurasian**" to denote its position as the deepest split in the radiation of lineages contributing to non-Africans. The Basal Eurasians were **a new ghost population**, one as important as the Ancient North Eurasians, measured by the sheer number of descendant genomes they have left behind. The extent of the deviations of the Four Population Test away from the value of zero that would be expected if the populations were related by a simple tree indicates that this ghost population contributed about a quarter of the ancestry of present-day Europeans and Near Easterners. It also contributed comparable proportions of ancestry to Iranians and Indians."

In spite of the fact of not having a sample of Basal Eurasians to work with, Reich believes he can state some "facts" about them: "An extraordinary feature of the Basal Eurasians compared to all other lineages that have contributed to present-day people outside of Africa is that they harbored little or no Neanderthal ancestry…. Plotting the proportion of Basal Eurasian ancestry against the proportion of Neanderthal ancestry, we realized that the less Basal Eurasian ancestry a non-African person has, the more Neanderthal ancestry he or she has…. So wherever the Neanderthal admixture occurred, it seems to have largely happened after the other branches of the non-African family tree separated from Basal Eurasians."

"The ancient presence of the Basal Eurasians in Eurasia becomes even clearer when one considers that peoples who lived ten thousand years ago or more in what are now Iran and Israel each had around 50 percent Basal Eurasian ancestry, despite the clear genetic evidence that these two populations had been isolated from one another for tens of thousands of years. This suggests the possibility that there were multiple highly divergent Basal Eurasian lineages coexisting in the ancient Near East, not exchanging many migrants until farming expanded. The Basal Eurasians were a major and distinctive source of human genetic variation, with multiple subpopulations persisting for a long period of time."

This leads Reich to ask: "Where could the Basal Eurasians have lived, isolated as they seem to have been for tens of thousands of years from other non-African lineages?"

He considers North Africa, especially the Nile Valley, but favors a different location: "A hint about the possible homeland of the Basal Eurasians comes from the Natufians, hunter-gatherers who lived after around fourteen thousand years ago in the southwestern parts of the Near East." He goes on to describe the Natufians, and the results of ancient DNA samples from them. Their DNA showed they have the highest proportion of Basal Eurasian ancestry in the Near East. But this analysis cannot determine where the ancestors of the Natufians lived. Back to square one. "… even if a genetic connection between Natufians and North Africa is established, it will not be the whole story, as it cannot explain the equally high proportions of Basal Eurasian ancestry in the ancient hunter-gatherers and farmers of Iran and the Caucasus."

The Ghosts of Early Europeans

Reich begins this section with a commentary on his method: "The discovery of one major ghost population after another—Ancient North Eurasians and Basal Eurasians—might make it seem as if ancient DNA is unnecessary, since the existence of ghosts can be predicted from modern populations. But **statistical reconstruction can only go so far**. With data from present-day people, it is difficult to probe further back in time than the most recent mixture event. Moreover, because humans are so mobile, it is impossible to determine with any confidence where ancestral populations lived based on analyses of the genomes of their descendants. With ancient DNA directly extracted from the ghosts, however, it is possible to project further back in time, revealing even more ancient ghosts than can be recovered from modern data alone. So it was when the Mal'ta genome was sequenced. We discovered the Mal'ta genome statistically, but once we had access to the sequence, we were able to discover the even more distant Basal Eurasians."

In 2016, a mob of ghosts appeared: "My laboratory assembled genome-wide data from fifty-one ancient modern humans in Eurasia, most of them from Europe, who lived between forty-five thousand and seven thousand years ago. These samples spanned the entire period of the Last Glacial Maximum—which occurred between twenty-five thousand and nineteen thousand years ago… with all our new data, we could show that repeated population transformations, replacements, migrations, and mixtures had taken place over this vast stretch of time."

Qiaomei Fu, working in Reich's lab, began comparing ancient individuals to each other. "She grouped them in four clusters that contained many samples that were similar both genetically and with respect to their archaeologically determined dates. Now she only needed to understand the relationships among the clusters."

"With her samples organized in this way, Fu was able to break down the story of the first thirty-five thousand years of modern humans in West Eurasia into at least five key events."

"**Event One** was the spread of modern humans into western Eurasia." There were two samples from 45,000 and 40,000 YA. The analysis "… showed that they were members of pioneer modern human populations that initially flourished but whose descendants largely disappeared." But this spread into western Eurasia was jolted by a huge catastrophe: "Around thirty-nine thousand years ago, a **supervolcano** near present-day Naples in Italy dropped an estimated three hundred cubic kilometers of ash across Europe, separating archaeological layers preceding it from those that succeeded it. Almost no Neanderthal remains or tools are found above this layer, suggesting that the climate disruption produced by the volcano, which could have produced multiyear winters, may have compounded competition with modern humans to create a crisis that **drove Neanderthals to extinction**. But the Neanderthals were not the only ones in crisis. Most modern human archaeological cultures that left remains below the ash layer left none above it. **Many modern humans disappeared** as dramatically as their Neanderthal contemporaries."

"**Event Two** was the spread of the lineage that gave rise to all later hunter-gatherers in Europe." There were two samples from 37,000 and 35,000 YA. The analysis showed that they "… were part of a population that contributed to all later Europeans, including today's." The analysis also showed that "… during the entire period from around thirty-seven thousand to around fourteen thousand years ago, almost all the individuals she analyzed from Europe could be rather well described as descending from a single common ancestral population that had not experienced mixture with non-European populations. Archaeologists have shown that after the volcanic eruption around thirty-nine thousand years ago, a modern human culture spread across Europe making stone tools of a type known as Aurignacian, and that this replaced the diverse stone toolmaking styles that existed before. Thus genetic and archaeological evidence both point to multiple independent migrations of early modern human pioneers into Europe, some of which went extinct and were replaced by a more homogeneous population and culture."

"**Event Three** was the coming of the people who made Gravettian tools, who dominated most of Europe between around thirty-three thousand and twenty-two thousand years ago. The material remains they left behind include voluptuous female statuettes, as well as musical instruments and dazzling cave art. Compared to the people who made Aurignacian tools who came before them, the people who made Gravettian tools were much more deliberate about burying their dead, and as a result we have many more skeletons from this period than we do from the Aurignacian period. We extracted DNA from Gravettian-era individuals buried in present-day Belgium, Italy, France, Germany, and the Czech Republic. They were all genetically very similar despite their extraordinary geographic dispersal. Fu's analysis indicated that most of their ancestry derived from the same sublineage of European hunter-gatherers as the thirty-seven-thousand-year-old individual from far eastern Europe, and that they then spread west, **displacing** the sublineage associated with Aurignacian tools and represented in the thirty-five-thousand-year-old Belgian individual. The changes in artifact styles associated with the rise of the Gravettian culture were thus driven by the spread of new people."

"**Event Four** was heralded by a skeleton from present-day Spain dating to around nineteen thousand years ago—one of the first individuals known to be associated with the Magdalenian culture, whose members over the next five thousand years migrated to the northeast out of their warm-weather refuge, chasing the retreating ice sheets into present-day France and Germany. The data once again showed a correspondence between the archaeological culture and genetic discoveries, documenting the spread of people into central Europe who were not directly descended from the Gravettians who had preceded them. There was also a surprise: most of the ancestry of individuals associated with the Magdalenian culture came from the sublineage represented by the thirty-five-thousand-year-old individual from Belgium who was

associated with Aurignacian tools but who was later succeeded at the same site by people who used Gravettian tools and carried DNA similar to others in Europe associated with that culture of eastern European origin. Here was yet another ghost population that contributed to later groups in mixed form. The Aurignacian lineage had not died out, but instead had persisted in some geographic pocket, possibly in western Europe, before its resurgence at the end of the ice age."

"**Event Five** happened around fourteen thousand years ago, during the first strong warming period after the last ice age, a major climatic change known as the Bølling-Allerød. Geological reconstructions reveal that at this time, the Alpine glacial wall that extended down to the Mediterranean Sea near present-day Nice finally melted after about ten thousand years of dividing the west and east of Europe. Plants and animals from southeastern Europe (the Italian and Balkan peninsulas) migrated in abundance into southwestern Europe. Our Four Population Tests on our ancient DNA data showed that something similar happened with humans. After around fourteen thousand years ago, a group of hunter-gatherers spread across Europe with ancestry quite different from that of the people associated with the preceding Magdalenian culture, whom they largely **displaced**. Individuals living in Europe between thirty-seven thousand and fourteen thousand years ago were all plausibly descended from a common ancestral population that separated earlier from the ancestors of lineages represented in the Near East today. But after around fourteen thousand years ago, western European hunter-gatherers became much more closely related to present-day Near Easterners. This proved that new migration occurred between the Near East and Europe around this time."

Reich concludes: "The people who had waited out the ice age in southern Europe became dominant across the entire European continent following the melting of the Alpine glacial wall. Perhaps these same people also expanded east into Anatolia, and their descendants spread farther to the Near East, bringing together the genetic heritages of Europe and the Near East more than five thousand years before farmers spread Near Eastern ancestry back into Europe by migrating in the opposite direction."

The Genetic Formation of Present-Day West Eurasians

"Today, the peoples of West Eurasia—the vast region spanning Europe, the Near East, and much of central Asia—are genetically highly similar."

"The most common way to measure the genetic similarity between two populations is by taking the square of the difference in mutation frequencies between them, and then averaging across thousands of independent mutations across the genome to get a precisely determined number. Measured in this way, populations within West Eurasia are typically around **seven times** more similar to one another than West Eurasians are to East Asians. When frequencies of mutations are plotted on a map, West Eurasia appears homogeneous, from the Atlantic façade of Europe to the steppes of central Asia. There is a sharp gradient of change in central Asia before another region of homogeneity is reached in East Asia."

"How did the present-day population structure emerge from the one that existed in the deep past? We and other ancient DNA laboratories found in 2016 that the formation of the present-day West Eurasian population was propelled by the **spread of food producers**."

After describing the spread of farming, Reich detours into a technical discovery that proved very beneficial: "Until 2016, getting genome-wide ancient DNA from the Near East to assess the extent to which these changes in the archaeological record were propelled by movements

of people had failed, as the warm climate of the Near East quickens chemical reactions, accelerating the rate of breakdown of DNA. However, two technical breakthroughs changed this. One came from a method developed by Matthias Meyer, which involved enriching DNA extracted from ancient bones for human sequences of interest. This approach makes ancient DNA analysis up to one thousand times more cost-effective and gives access to samples that would otherwise provide too little DNA to study. Working together with Meyer, we adapted this method to make possible genome-wide analysis of large numbers of samples. The second breakthrough was the recognition that the inner-ear part of the skull—known as the **petrous bone**—preserves a far higher density of DNA than most other skeletal parts, up to one hundred times more for each milligram of bone powder. Within the petrous bone, the anthropologist Ron Pinhasi, working in Dublin, showed that the mother lode of DNA is found in the **cochlea**, the snail-shaped organ of hearing. Ancient DNA analysis of petrous bones in 2015 and 2016 broke through one barrier after another and made it possible for the first time to get ancient DNA from the warm Near East."

The DNA gathered from this discovery showed that "… the degree of **genetic differentiation** between the first farmers of the western part of the Near East (the Fertile Crescent, including Anatolia and the Levant) and the first farmers of the eastern part (Iran) was about as great as the differentiation between Europeans and East Asians today. In the Near East, the expansion of farming was accomplished not just by the movement of people, as happened in Europe, but also by the **spread of common ideas** across genetically very different groups."

This genetic differentiation was originally widespread. Iosif Lazaridis in Reich's laboratory discovered the broader pattern: "Analyzing our data, he found that about ten thousand years ago there were **at least four major populations in West Eurasia**—the farmers of the Fertile Crescent, the farmers of Iran, the hunter-gatherers of central and western Europe, and the hunter-gatherers of eastern Europe. All these populations differed from one another as much as Europeans differ from East Asians today."

"Spurred by the revolutionary technology of plant and animal domestication, which could support much higher population densities than hunting and gathering, the farmers of the Near East began **migrating and mixing** with their neighbors. But instead of one group displacing all the others and pushing them to extinction, as had occurred in some of the previous spreads of hunter-gatherers in Europe, in the Near East all the expanding groups contributed to later populations. The farmers in present-day Turkey expanded into Europe. The farmers in present-day Israel and Jordan expanded into East Africa, and their genetic legacy is greatest in present-day Ethiopia. Farmers related to those in present-day Iran expanded into India as well as the steppe north of the Black and Caspian seas. They mixed with local populations there and established new economies based on herding that allowed the agricultural revolution to spread into parts of the world inhospitable to domesticated crops. The different food-producing populations also mixed with one another, a process that was accelerated by technological developments in the Bronze Age after around five thousand years ago. This meant that the high genetic substructure that had previously characterized West Eurasia collapsed into the present-day **very low level of genetic differentiation** by the Bronze Age."

"By demonstrating that the genetic fault lines in West Eurasia between ten thousand and four thousand years ago were entirely different from today's, the ancient DNA revolution has shown that today's classifications do not reflect fundamental "pure" units of biology. Instead, today's divisions are recent phenomena, with their origin in repeating mixtures and migrations. The findings of the ancient DNA revolution suggest that the mixtures will continue. **Mixture is fundamental** to who we are, and we need to embrace it, not deny that it occurred."