surface. The helicopter, named Ingenuity, will test the first powered flight on another world. "It will truly be a Wright Brothers moment, but on another planet," says MiMi Aung, the helicopter's project manager at the JPL.

During Perseverance's first 3 months on the surface, team scientists and engineers are working on Mars time, in which a day is nearly 40 minutes longer than an Earth day. That means they often work through the night, their lives pushed into a sort of permanent jet lag. Working on Mars time, however, allows the team to be more efficient in planning daily operations, after checking in with the rover at the start of each Martian day.

Perseverance aims to travel quickly and efficiently, journeying at least 15 kilometres across Jezero and up onto its rim in one Mars year (which is nearly two years on Earth) – the time NASA allotted for the initial mission. The rover carries 43 tubes for collecting Martian rock and dirt; the goal for that initial mission is to fill and lay down 15–20 of them on the crater rim for future spacecraft to pick up.

Rock collector

If the rover is still working well after its first Mars year, it will head out from the crater rim onto the surrounding plains, called Nili Planum. This part of its journey will explore the most ancient terrain yet, including enormous blocks of jumbled-up rock that were blasted from deep inside Mars when another huge asteroid hit, nearly four billion years ago. These rocks could come not just from the Martian crust, but from a deeper layer of Mars known as the mantle – which scientists have never been able to look at directly before. "They're just sitting there, perhaps for more than three billion years, waiting for us to look at them," says Briony Horgan, a planetary geologist at Purdue University in West Lafayette, Indiana, and a member of the rover's science team.

Perseverance will drill and collect samples on Nili Planum until it runs out of tubes. The European Space Agency and NASA are working on plans for two missions needed to retrieve the samples. Launching no earlier than 2026, they would send a rover to retrieve the sample tubes laid down by Perseverance, as well as an orbiter to loop around Mars. The rover would put the tubes on a rocket and launch them into Mars orbit, where the orbiter would grab them and fly them back to Earth no earlier than 2031.

Perseverance, which launched in July 2020, cost US$2.4 billion to build and launch and another $300 million to land and operate, at least during its first year on Mars. It is the third mission to reach the red planet this month – following spacecraft from the United Arab Emirates and China, which are both now in orbit.

The Chinese mission, Tianwen-1, will try to land its own rover on the surface as early as May.

BETH ZAIKEN/CENTRE FOR PALAEOGENETICS

DNA from multiple mammoth species is illuminating a complex evolutionary picture.

MAMMOTH GENOMES SHATTER RECORD FOR OLDEST ANCIENT DNA

Permafrost-preserved teeth, up to 1.65 million years old, identify a new kind of mammoth in Siberia.

By Ewen Callaway

The million-year-old genome is here. Mammoth teeth preserved in eastern Siberian permafrost have produced the oldest ancient DNA on record, pushing the technology close to – but perhaps not past – its limits.

Genomic DNA extracted from a trio of tooth specimens excavated in the 1970s has identified a new kind of mammoth that gave rise to a later North American species. The findings were published in *Nature* on 17 February[1].

"I love the paper. I've been waiting for that paper for, what, eight years now," says Ludovic Orlando, an ancient-DNA specialist at the Centre for Anthropobiology and Genomics of Toulouse in France, who co-led a 2013 effort that sequenced the previous oldest ancient DNA – a genome from a 560,000–780,000-year-old horse leg bone[2]. "I'm pleased to lose this record, because it was a heavy one," he says.

Researchers had suspected that ancient DNA could survive beyond one million years, if the right sample could be found. Once an organism dies, its chromosomes shatter into pieces that get shorter over time. Eventually, the DNA strands become so small that – even if they can be extracted – they lose their information content.

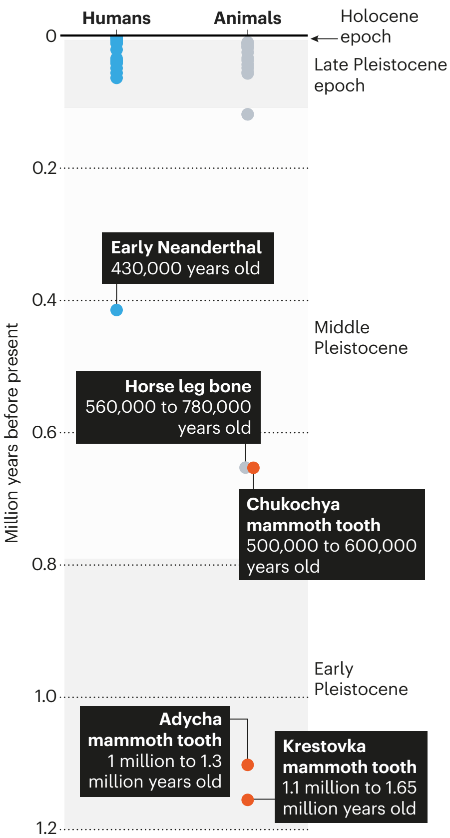
Orlando's team found that fragments as short as 25 DNA letters in their horse bone, from the Canadian Yukon Territory, could still be interpreted. They estimated that million-year-old remains preserved in the constant cold of permafrost – which slows DNA fragmentation – should also contain fragments of that length. "My only doubt: does such a sample exist?" Orlando says.

Love Dalén, an evolutionary geneticist at the Swedish Museum of Natural History (SMNH) in Stockholm, had been dallying with the idea of sequencing very old mammoth remains since he first encountered a collection of them, in 2007. The samples his team sequenced, one from an early woolly mammoth (*Mammuthus primigenius*) and two assigned to a precursor known as steppe mammoths (*Mammuthus trogontherii*), had been excavated by the Russian palaeontologist Andrei Sher.

Dalén hoped that DNA from the samples could capture the evolution of woolly mammoths and other species in action, but he was sceptical because of previous bad experiences with much younger remains found in permafrost. "It's not like everything found in the

ANCIENT GENOMES

Scientists have for the first time sequenced DNA that is more than one million years old — from mammoths. The oldest DNA sequenced previously dates from between 560,000 and 780,000 years ago.



The upper age bound for the mammoth teeth is based on a genetic dating method; the lower bound is based on the age of the sediments in which the teeth were found.

SOURCE: DAVID DÍEZ-DEL-MOLINO

permafrost always works," he says.

And, indeed, two of the three molars from Sher's excavations, retrieved from sediments more than one million years old, contained so little DNA that Dalén says he would have discarded them had they been younger.

But thanks to advances in sequencing technology and bioinformatics, his team managed to obtain 49 million base pairs of nuclear DNA from the oldest sample, found near a village called Krestovka, and 884 million base pairs from another tooth, called Adycha. Analysis of the DNA suggested that the Krestovka sample was 1.65 million years old, and the Adycha sample around 1.3 million (see 'Ancient genomes'). The third sample, a 600,000-year-old woolly mammoth tooth dubbed Chukochya, produced nearly 3.7 billion base pairs of DNA, more than the length of its 3.1-billion-base-pair genome.

From their shape, the two oldest teeth looked as if they belonged to steppe mammoths, a European species that researchers think pre-dated woolly mammoths and Columbian mammoths (*Mammuthus columbi*), a North American species. But their genomes painted a more complicated picture. The Adycha specimen was part of the lineage that gave rise to woolly mammoths, but the Krestovka specimen clearly was not.

Dalén's team found that it belonged to an entirely new lineage. "We can't say it's a different species, but it sure looks like it," he says. Although the Krestovka sample is from Russia, he suspects the lineage became isolated from other steppe mammoths in North America. The team found that Columbian mammoths trace half their ancestry to the Krestovka mammoth lineage, and the other half to woolly mammoths. Dalén estimates that the two lineages mixed more than 420,000 years ago.

The idea that new species can form through mixing — and not just splitting from a single parent species — is gaining currency. But this is the first evidence for 'hybrid speciation' from ancient DNA, says Orlando. "This is amazing."

Hendrik Poinar, an ancient-DNA specialist at McMaster University in Hamilton, Canada, says different mammoth species probably routinely hybridized when glacial expansion brought them together. His team has found evidence that later woolly and Columbian mammoths occasionally interbred.

Even though researchers have long been expecting a million-year-old genome, crossing that threshold is important, says Viviane Slon, a palaeogeneticist at Tel Aviv University in Israel. "There's a difference between what we think is possible and actually showing it."

Tom van der Valk, a bioinformatician at the University of Uppsala in Sweden who led the tooth work with evolutionary biologists Patrícia Pečnerová and David Díez-del-Molino at the SMNH, hopes it will encourage other labs. "It is a symbolic barrier that I hope can inspire and motivate other groups that have ideas about really deep-time sequencing."

By crossing the million-year threshold, ancient-DNA researchers might also access early histories of other mammals, says Dalén. Very old samples of musk oxen, moose and lemmings are now on his lab's radar.

The mammoth DNA does not represent the oldest biomolecular information from fossils. In 2016, researchers reported protein sequences from 3.8-million-year-old ostrich eggshells from Tanzania[3], and in 2019, another team decoded proteins from a 1.77-million-year-old rhinoceros tooth from Georgia[4]. Protein sequences tend to be much less informative about an organism's ancestry than DNA. But protein molecules are much hardier, so researchers can use them to glean insights from very old fossils found in places with no permafrost. The ostrich and rhino samples both come from archaeological sites famous for hominin remains.

The chances of finding million-year-old remains of ancient human relatives in the permafrost are very low, researchers say. But Dalén thinks the right environment, such as a deep cave, could yield samples that old. Neanderthal remains from a Spanish cave dated to 430,000 years ago represent the oldest DNA from an ancient human relative discovered so far[5]. "Finding a hominin in the sort of ideal context for preservation as permafrost would be would be a dream," says Slon.

As for the likely age limit of ancient DNA, Dalén says 2.6 million years is the limit in permafrost. "Before that, it was too warm."

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COVID VACCINES AND SAFETY: WHAT THE RESEARCH SAYS

As the vaccines are rolled out, researchers are learning about the extent and nature of side effects.

By Ariana Remmel

As people around the world receive COVID-19 vaccines, reports of temporary side effects such as headaches and fevers are rolling in. Much of this was expected — clinical-trial data for the vaccines authorized so far suggested as much. But now that millions of people have been vaccinated, compared with the thousands enrolled in early studies, reports of some rare, allergic reactions are surfacing, and questions are arising about whether any deaths are linked to the shots.

There is no question that the current vaccines are effective and safe. The risk of severe reaction to a COVID-19 jab, say researchers, is outweighed by the protection it offers against the deadly coronavirus. *Nature* looks at what scientists are learning about the frequency and nature of side effects as huge numbers of people report their reactions to physicians and